2011 Annual Report
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General Information

1.a General Information

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1.b Biographical Information for New Faculty by Institution

Assistant Professor of the University of Minnesota, Duluth, joined NCED as an affiliate PI February 1, 2010. Biographical information for Gran may be found in Appendix A: Biographical Information of New PIs.

1.c Annual Report Contact Person

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I. Context

“In making war with nature, there was risk of loss in winning,”
John McPhee, The Control of Nature

Civilization, by its very nature, has involved reshaping the natural environment to fit human needs. We have altered landscapes and ecosystems to enhance food supplies, reduce exposure to natural dangers, and promote commerce. We have converted approximately fifty percent of the world’s surface to grazed or cultivated cropland. We have built dams to control rivers for hydropower, irrigation, and flood mitigation. Nearly six times more water is now held in storage than occurs in free-flowing rivers. Climate change and a growing imbalance among freshwater supply, consumption, and population have dramatically altered the hydrologic cycle, a situation that will only intensify over the next century.

During its nine-year tenure, NCED has ushered in a new investigational paradigm in understanding landscape dynamics and their response to change. Through the integration of geomorphology, ecology, hydrology, sedimentary geology, engineering, social sciences, and geochemistry and the synergistic combination of field investigations, physical experiments, and computational models, NCED has facilitated the development of a quantitative, predictive Earth-surface science. It is a paradigm shift that will enable us to address the challenges of the future and provide science-based solutions for adaptation and mitigation of environmental change.

Our mission: to understand the dynamics of the coupled processes that shape the Earth’s surface—physical, biological, geochemical, and anthropogenic—and how they will respond to climate, land-use, and management change. To use this knowledge to deliver the science-based solutions necessary for addressing environmental change.

NCED Research

Our research is unified by a focus on a fundamental component of the Earth-surface system—channel networks and their surroundings—that recurs in varying but fundamentally related forms across a wide range of environments and scales. Our three research initiatives (“Integrated Programs” or “IPs”) approach channel networks from a source-to-sink perspective, looking at watersheds (Watersheds), individual stream reaches (Streams), and depositional systems (Deltas).

Watersheds

In our Watersheds Integrated Program, we work to develop quantitative expressions for the fundamental processes and dynamic interactions of water, sediment, and biota that are involved in landscape evolution. Our central theme in this program is the use of high-resolution digital topography to advance hypotheses, guide fieldwork, and test theories. We combine digital environmental data with transport laws to make explicit predictions about watershed attributes (e.g., riverbed grain size, landslide locations, algal abundance, food web interactions, and surface-subsurface exchanges) in order to further our scientific understanding of and inform management decisions about ecosystem protection and restoration.

Our Watersheds projects have led to new discoveries about the coupled dynamics of water, sediment, and biota and how the integrated system responds to change. We have advanced geomorphic transport laws, discovered thresholds in biogeochemistry and primary productivity in riverine ecosystems, developed theories for predicting size and location of shallow landslides, and challenged old theories of river incision into bedrock.

Streams

Historically, stream restoration management decisions have relied heavily upon experientially-based knowledge and reasoning by analogy. The NCED

Watersheds - Discovering and advancing the fundamental relations needed to predict landscape evolution and to model the coupling of ecosystem, landscape, and land-use dynamics.

Streams - Advancing the science and practice of stream restoration by conducting and coordinating research and by working with agency and industry partners to identify information needs, develop improved tools, and transfer our knowledge into practice.

Deltas - Using information from modern systems, experiments, and stratigraphic records to develop a predictive understanding of delta evolution, and applying our understanding to delta restoration.
Streams Integrated Program works to move the practice of stream restoration beyond analogy and experiential anecdote toward multidisciplinary quantitative prediction. We seek to transfer our scientific knowledge to practice by fostering true collaboration between academic and agency partners.

At the core of NCED Streams research is the belief that a significant improvement in stream restoration science requires quantitative models and methods that integrate results across disciplines. Our research program involves biologists, civil engineers, ecologists, geochemists, geologists, hydrologists, and economists in a concerted effort to develop practical, predictive models of river systems that can guide stream and watershed restoration practice.

Our Streams projects are providing an understanding of where and when restoration actions will be most effective for sustained ecological recovery, projecting ecological and landscape consequences of restoration action, and developing predictive capabilities for water and sediment dynamics upstream and downstream of dams. Our social science research is determining the value that the public places on restoration and whether stream restoration projects are worth their costs.

Deltas

Our Deltas Integrated Program seeks to understand the processes of delta dynamics in support of restoration of the Mississippi River Delta. Our research uses the subsurface stratigraphy of modern deltas to infer rates, spatial patterns, and mechanisms of natural (pre-human) delta building processes. Simultaneously, we perform experiments and field studies to develop predictive models of the processes by which deltas build land and maintain themselves and their associated ecosystems against subsidence and sea-level rise.

We look at deltaic land-building as a biophysical process, and our work involves collaboration among ecologists, Earth scientists, and engineers. Our projects investigate vegetation-sedimentation interactions in island and marsh development and maintenance, integrate our land building model within an ecosystem forecasting framework; and uncover the social trade-offs involved in the Mississippi Delta restoration. Our goal is to develop a fully integrated, quantitative description of delta evolution that can benefit the sustainable restoration of coastal lowland systems.

NCED Broader Impacts

Our community engagement activities are led by our Education, Diversity, and Knowledge Transfer Integrated Programs. These three initiatives work in parallel with the research IPs to educate a diverse audience (K-12 students, teachers, and the public) about the importance of understanding and managing the Earth’s surface environment. We transfer our scientific knowledge to practice, work closely with government agencies, industry and stakeholders, and foster synergistic collaboration with other community initiatives. We have led, and brought to a successful and ever-growing intellectual exchange, the first large-scale collaboration between academia and a Science Museum (the Science Museum of Minnesota) with the purpose of bringing the wonder of landscapes to larger audiences and exploring questions of sustainability under human and climate pressures. Our traveling exhibits have reached millions of people worldwide and special meetings held in Museum settings have reached policy makers faced with increasing pressures to protect and restore streams and watersheds while assuring safety and promoting economic development.
With forty-four percent of our 3.5 million miles of rivers and streams degraded due to sedimentation and excess nutrients, stream restoration has become big business in the United States. Estimates show that over $1 billion has been spent on stream restoration projects in every year since 1990. Despite its growth, the field of stream restoration is arguably in its infancy, lacking certification, licensing guidelines, or continuing education requirements. Without such standard industry regulations, practitioners often gather in regional river restoration symposia to stay current in the field and learn from the work of colleagues. Until now however, the Upper Midwest region of the country has lacked such an organizing forum.

To address the need, NCED and the St. Anthony Falls Laboratory (SAFL) created the Partnership for River Restoration and Science in the Upper Midwest (PRRSUM, pronounced “prism”) with the goal of fostering intense interactions and collaboration between federal and local agencies, watershed managers, consultants, researchers, and educators.

In 2010, with NCED sponsorship, PRRSUM launched the inaugural Upper Midwest Stream Restoration Symposium (UMSRS). This now has become an annual event bringing together more than 100 participants and providing extensive networking opportunities in topics including sediment management, large river restoration, stream and river structures, organism-focused restoration, and restoration monitoring. Most importantly, the symposium offers stream restoration practitioners in the Upper Midwest the opportunity to gather as a community and integrate basic research discoveries with applied knowledge, techniques, and case histories. NCED has made a different in bringing science to practice.

**NCED as a Community Resource**

We have placed our graduates in academia, industry and government agencies around the world. We have equipped them with a broad perspective on Earth-surface research and education and have provided them with a network of mentoring and facility resources upon which to grow. We continue to make a difference in the careers of young scientists around the world via training opportunities such as the Summer Institute on Earth-surface Dynamics, the NCED visiting scientist program and the NCED Affiliate Scientist program, which is geared towards mentoring and facilitating the participation of young scientists in the NCED interdisciplinary approach to Earth-surface dynamics. We are proud to have helped create the first Hydrology and Water Resources degree program in a tribal college, which will foster the development of local capacity for managing tribal lands. As our trust with the Native American community grows, so do the opportunities for solid and sustained exchanges that make a difference for generations to come.

NCED’s research, its scientific discoveries, and its interactions with the community have been made possible through the development of an extensive array of research field sites and experimental facilities. Our sites, facilities, and institutions are located across the United States and give us valuable perspective on source-to-sink Earth-surface dynamics.

Our visitor programs and informal interactions provide the entire Earth-surface community with on-going access to these facilities. During the summer field season, synthesis projects conducted across our facility network provide graduate students and young researchers with unique opportunities to access our resources and be involved in interdisciplinary research.
The Challenge

At Year 9, the group of NCED PIs seems to have become a “biosoma” which operates in a seamlessly integrated fashion addressing problem-driven research across disciplines, across environments (from the Mediterranean landscapes of the West to the agricultural landscapes of the Midwest and the threatened Mississippi delta), across methodologies and approaches, across ages (young and seasoned researchers), and across cultures. It forms a core that offers a resource to the broader community and has mentored the next generation of Earth-surface scientists and created new thinking and tools for sustainable restoration.

Quoting from the 2011 External Advisory Board (EAB) report, we are very proud to be seen by the community as having made a difference: “…you have generated new basic scientific knowledge through discovery research, developed new ways of organizing scientific inquiry in Earth-surface studies, encouraged a new journal and professional associations, produced a new cadre of researchers and educators different in both outlook and approach from those of traditional graduate programs, and created new courses, new degree programs, and exciting public outreach to under-represented Americans and beyond.”

It is the hard work, belief in change, and pursuit of cutting-edge science and integrated knowledge in service to society that has made this possible within the NCED group and the extended NCED family of researchers and educators. However, we have realized over the past nine years that such changes are not possible without a sustained center-mode of operation. They take time and commitment (from funders, researchers, and the community) to be created and to be successful. Sustainability rests on the shoulders of all.

Director’s Highlights of Year 9

Innovative techniques reveal major shift in sediment sources in the Upper Mississippi River

Excessive loads of fine sediment—and the concomitant turbidity, eutrophication, and degradation of water quality—are common problems for rivers that drain agricultural lands. Identifying the causes of, and developing effective solutions for, the excess sediment is particularly challenging in large watersheds due to their scale and complexity. Adopting mitigation strategies without an understanding of watershed-scale sediment dynamics threatens to be wasteful at best and destructive at worst.

Lake Pepin, a naturally dammed lake on the Upper Mississippi River, is a local recreational icon that sits within the heart of upper Midwestern farm country (Fig. 1). Lake Pepin, the Upper Mississippi River (UMR) and its largest tributary, the Minnesota River are all listed as impaired for turbidity by the USEPA. Sediment delivery to the lake has increased by an order of magnitude within the last 150 years and there is consensus among stakeholders that one third of the lake will fill within 100 years. But several fundamental questions must be answered before the state invests $3.5 billion over the next 20 years to improve the health of its terrestrial and aquatic ecosystems. Specifically, where is the sediment produced in the landscape; how much is natural and how much anthropogenic; have sediment dynamics changed over time; and what mitigation actions can be taken to improve water quality?

Geologic history and human-induced perturbations have conspired to make the Minnesota River the primary source of sediment to Lake Pepin. Previous work has revealed that 80-90% of the sediment deposited in Lake Pepin derives from the Minnesota River Basin, despite the fact that it comprises only 37% of the drainage area. The fact that the Minnesota River has contributed
a disproportionate amount of sediment throughout the past 13,000 years indicates that geologic history has primed this landscape to erode rapidly.

Approximately 13,400 years ago, Glacial Lake Agassiz drained through the proto-Minnesota river and incised the valley by as much as 70 meters. As a result, the base level of Minnesota River tributaries dropped catastrophically. The resulting knickpoint has propagated approximately 40 km up each of the tributary networks, causing the lower reaches of the tributaries to be characterized by steep river gradients, actively eroding bluffs, and ravines that connect the uplands to the incised river.

Against the backdrop of rapid geomorphic change, evidence suggests that human activities have dramatically altered sediment dynamics in the Upper Mississippi River Basin. Within the last 150 years, land cover within the Minnesota River Basin has shifted from poorly drained prairies and wetlands to 78% row crop agriculture. During this time, sedimentation rates in Lake Pepin have increased ten-fold, from approximately ~80,000 Mg/yr in 1830, to as high as 850,000 Mg/yr between 1950 and 2008. Prior to NCED addressing the problem it was known that the vast majority of this sediment derived from the Minnesota River Basin. What was not known was where within the Minnesota River Basin the sediment was being produced. The sediment pollution problem had become a politically and socially divisive issue with environmental groups primarily blaming row crop agriculture and farmers primarily blaming natural processes (erosion of bluffs). The financial stakes were high, with tens of millions of dollars in conservation practices implemented in the past few decades causing no discernible improvement.

To identify the sources and mechanisms of erosion and sediment transport in the Minnesota River Basin, NCED researchers constructed a sediment budget for the Le Sueur River, a tributary and primary contributor of sediment to the Minnesota River. Based on similar topographic history and land use, the sediment dynamics of the Le Sueur are likely representative of other tributaries to the Minnesota River.

The researchers used aerial LiDAR, Optically Stimulated Luminescence and Carbon-14 dating, and sediment evacuation modeling to develop a pre-settlement Holocene sediment budget for the watershed. They determined that sediment yield was relatively steady over the Holocene, with approximately 60,000 Mg/yr of sediment produced, 80% of which came from near-channel sources: bluff erosion, bank erosion, and vertical river channel incision. Twenty-percent of the sediment was derived from ravine incision. A modern day, 2000-2010, sediment budget for the Le Sueur based upon multiple lines of evidence including gaging stations, sediment fingerprinting analysis, and air photo analysis suggests that bluff erosion, primarily within the incised zone of the river, dominates the modern-day Le Sueur sediment budget, with erosion rates more than double the Holocene average (Fig. 2).
Additionally, NCED researchers measured concentrations of two radionuclides, $^{210}\text{Pb}$ and $^{10}\text{Be}$, within Lake Pepin cores to determine the relative proportions of watershed sediment derived from farmlands (uplands) versus ravines and bluffs over the past 500 years (Fig. 3). Higher concentrations of the radionuclides in lake cores suggest greater farmland erosion since upland (farmland) sediment contains higher concentrations of both $^{210}\text{Pb}$ and $^{10}\text{Be}$.

Sediment apportionment using the radionuclide tracers suggests that upland soil erosion 500 years ago was low relative to bluff erosion. The sharp mid-20th century increases in $^{10}\text{Be}$ concentrations indicate a pulse of soil erosion from agricultural fields at that time. Within the past 30 years, however, a shift back toward non-field sources is indicated by low concentrations of both $^{10}\text{Be}$ and $^{210}\text{Pb}$, a finding in accordance with the 2000-2010 sediment budget developed for the Le Sueur River. The coordinated decrease in concentration of both nuclides suggests that the data present a real decrease in field sources relative to bluffs and ravines, rather than recent re-activation of legacy field sediment.

The surprising shift in sediment sources suggests that recent human-induced hydrologic changes—including increased frequency and magnitude of extreme precipitation events; extensive channel network modification through the installation of agricultural ditches and subsurface tile drains; and increased soybean cultivation and concomitant decreased evapotranspiration—have acted to amplify erosion of near-channel sediment sources, including bluffs and streambanks. The implications for landscape managers is clear: the strategy implemented for sediment reduction must first and foremost address the primary amplifier of erosion, the altered hydrology of the watershed.

**Physical threshold shifts sources of stream nutrients**

Physical characteristics of stream channels that strongly influence biological processes change longitudinally across a watershed. In particular, benthic sediment particle size decreases; channels widen and shading is reduced; light irradiating the water surface increases; and summer temperatures rise as surface heat transfer warms the water. What remains unclear, however, is how the aforementioned longitudinal environmental gradients influence biological processes.

Understanding the biological effects of variable environmental conditions is especially relevant for understanding and predicting the fate and transport of nutrients in stream networks and how the relative importance of internal stream processes versus external watershed characteristics shift across a longitudinal gradient. Such an understanding will, in turn, enable better predictive capabilities regarding nutrient cycling and biological activity in streams.

In an effort to foster such predictive capabilities, NCED researchers seek to mechanistically understand how physical attributes typical of those encountered within stream networks influence nutrient cycling, and whether strong transitions in environmental conditions shift process dynamics affecting stream water nutrient composition and flux.

Synthesis of several years of stream metabolism and carbon flux data by NCED researchers has revealed that rapid increases in primary production occur due to channel widening (which increases light), which shifts sources of dissolved and particulate organic carbon from terrestrial to in-channel production. Specifically, they found that at a threshold of approximately 100km$^2$ watershed area and 10m stream width, strong changes in the concentration and stoichiometry of dissolved nitrogen (N), phosphorous (P), dissolved silica (Si) and dissolved organic carbon (DOC) occurred (Fig. 4). Organic carbon and nitrogen concentrations increased strongly downstream while phosphorous and silica declined substantially. Measurements of concentration and flux of reactive elements measured were strongly correlated with light and primary production.

![Figure 4: Relationships between watershed area and (a) mean light intensity (lux = lumens/m$^2$), (b) gross primary production, (c) dissolved organic carbon, (d) total dissolved phosphorous, TDP (e) dissolved organic nitrogen, DON and (f) dissolved silica.](image)
The researchers were puzzled however by the increase in stream-water dissolved nitrogen concentrations across the threshold. The team reasoned that algal demand for nitrogen must have increased in tandem with the increases in autotroph production from small to large streams, but there was no evidence to suggest watershed supply of nitrogen increased to meet the demand. Where did the additional nitrogen come from?

The abundance of N-fixing algae increased at approximately the same point in the watershed as increased dissolved N, and NCED researchers hypothesize that increasing N levels are a result of increasing autotrophic N fixation. The researchers reason that the alleviation of light limitation mediated by channel widening at the 100km² physical threshold enabled N-limited primary producers to rapidly bring new nitrogen into stream systems to meet nutritional demands. Greater algal production resulted in the lower availability of phosphorous and dissolved silica and increased production and loss of dissolved organic carbon and nitrogen. Together, these processes substantially altered the flux and stoichiometry of transported nutrients in the watershed, and possibly caused a shift from N to P limitation within the stream network.

With this work, the researchers provided strong evidence for regulation of stream ecosystem functions via physical conditions that affect both the role of terrestrial ecosystems and that of biological processes within stream ecosystems at the Angelo Coast Range Reserve. Ongoing work seeks to develop models of light inputs to stream channels, which will be used to examine the hypothesis of light-mediated transitions in stream ecosystem dynamics in other pristine and human-dominated watersheds.

**Shear-guided swimming by green algae**

In the coastal ocean, thin layers of phytoplankton (“Thin Layers”) containing cell concentrations up to two orders of magnitude above ambient concentrations are important hot spots of ecological activity. Thin Layers range in size from microns to centimeters vertically and can extend for kilometers horizontally, persisting for hours to days. The layers enhance zooplankton growth rates within coastal oceans and are essential for the survival of some fish larvae. At the same time, many phytoplankton species found in the layers are toxic, and there is a potential for thin layers to enhance fish mortality and seed harmful algal blooms.

Given such ecological significance, it is important to be able to predict the onset, lifetime, and destruction of thin layers. A definitive explanation for the mechanisms behind their formation is lacking however. Since the layers are often found in oceanic regions where shear flows are prevalent, it has been suggested that hydrodynamic shear contributes to thin layer formation by disrupting the vertical migration of motile phytoplankton, a hypothesis called “gyrotactic trapping.” NCED researchers have discovered surprising swimming patterns in a unicellular motile alga, *Dunaliella*, which may give an additional support to the gyrotactic trapping mechanism.

The motility characteristics of microorganisms have been studied extensively in stagnant fluids, but few studies on motility within a moving fluid have been reported, despite the fact that fluid motion affects cell division and growth, cell aggregation, and the transport of nutrients to microorganisms. Understanding how the motility of microorganisms is affected by moving fluids is therefore essential to understanding their physiology under varying environmental conditions.

To understand microbial motility in moving fluid, NCED researchers used high speed digital holographic particle image velocimetry (H-PIV) to quantify *in situ* swimming signatures of motile algae in moving flows. What they found was truly surprising.
Their research revealed random diffusive swimming behavior from the algae in quiescent flow conditions. When they introduced the cells to shear rates above $10^5$ s$^{-1}$ however, they depicted active swimming by *Dunaliella* in a direction perpendicular to the main fluid flow in regions of high shear (Fig. 5). The microorganisms were directing their swimming in response to fluid flow. The researchers hypothesize that the shear-guided swimming minimizes the drag on the algal cell bodies and is a direct effort by the algae to minimize cell physiological stress. Mechanistically, the cross-stream swimming is propelled by local fluid flow vorticity where the algal cells utilize a “free surfing ride” by moving fluid.

The researchers also suggest that the shear flows and resultant shear-guided swimming have consequences for the dynamics of cell aggregation. At high shear rates, where directional swimming is observed, the algal cells aggregate into two dimensional thin slices (Figure 5, C and D), identical in form to thin layers in oceans. The study could therefore have important implications for the evolution, distribution, and growth dynamics of ecologically significant phytoplankton thin layers in lakes, deltas, and oceans.

**Shredding of Environmental Signals by Sediment Transport**

The response of landscapes to climate, tectonic motions, and changes in sea level is mediated by sediment transport. Understanding how sediment transmits environmental signals is therefore crucial for the prediction of landscape response to climate change or the interpretation of paleoclimate and tectonics from stratigraphy (Fig. 6).

Generally, it is assumed that landscape patterns and sedimentary rocks record—with some level of distortion and filtering—the sources and sinks of sediment created by uplift and subsidence or cyclic variations of precipitation, sediment supply, and sea level over geologic time. It is also assumed that even when external processes interact on timescales similar to those of internal, autogenic (self-organized), processes, the autogenic processes act as noise, obscuring but not obliterating the record of the external signal.

Autogenic behavior in sedimentary systems such as alluvial rivers, hillslopes and mountain catchments, river deltas, and dry granular flows is manifested as large-scale fluctuations in sediment transport rates. Work by NCED researchers suggests that autogenic sediment transport fluctuations can act as a nonlinear filter, completely destroying—“shredding”—high-frequency external, environmental signals. The researchers have found that this shredding results from ubiquitous thresholds—landsliding, bed load transport, and river avulsion—in sediment transport systems.

Currently, most landscape evolution models predict that environmental signals with period below equilibrium timescale are simply damped and lagged as they propagate through a transport system. This work, however, suggests that signals will be obliterated unless they are sufficiently large to overwhelm autogenic fluctuations. Thus, the nonlinear dynamics of sediment transport sets a hard lower limit on the ability of stochastic transport systems to pass and record physical environmental signals.

**Figure 6:** Deposition and landscape patterns may reflect external forcing or autogenic sediment transport dynamics. (a) Glacial varves (lake deposits) from Champlain Valley, New York. Scale bar markings are 1 cm. (b) Eroded river terraces. Scale Unknown. (c) Ancient river deposits from the Book Cliffs, Utah. (d) Sequences of cyclic sedimentary rock layers exposed in Arabia Terra, Mars. (e) Deposits from eXperimental EarthScape Facility of a laboratory river delta (inset) with signatures of both autogenic dynamics and externally–forced sea level cycles. Arrow indicates flow direction. How much of the landscape dynamics and forcing is recorded in the stratigraphic record?
New Thinking in Geomorphic Transport

In many geomorphic transport systems, the time and length scales of motion vary widely: particles can be trapped for both short and long periods of time and they can travel large or small distances in very short intervals of time. To model such systems we need fresh conceptual and mathematical formalisms.

Through the Stochastic Transport and Emergent Scaling on Earth’s Surface (STRESS) working group, NCED researchers have led an interdisciplinary group of scientists in the exploration and development of such fresh formalisms. This group has generated new ideas that challenged existing geomorphic transport laws by asking: (1) How can we reconcile observed patterns and organization (from sand dunes, to landslides, sedimentary deposits, hillslope profiles, and sediment transport in rivers) with theories and dynamical models that can reproduce these patterns? (2) Are geomorphic transport laws based on the notion of a locally derived flux limited in some fundamental sense, and is the notion of a nonlocal flux (flux determined by conditions at some distance from the point of interest) a physically viable alternative? (3) How can we relate microscale and macroscale dynamics in stochastic transport theories and in predictive models?

The research generated through the working group has presented new ideas for modeling transport on the Earth’s surface from tracer and bed load transport in rivers, to hillslope transport, to the complexities of mixed erosional/depositional systems, and to transport along the whole river network. Several open problems have emerged from the research generated through this working group, seeding fertile avenues of future research. A special collection of the Journal of Geophysical Research – Earth Surface containing the STRESS work was published by the American Geophysical Union.

Improving Ecosystem Management through Multidisciplinary Science

In 2010, NCED researchers edited a special issue of the Journal of Hydraulic Engineering focused on stream restoration. The issue contains a collection of papers that cover topics as diverse as in-stream structures and their potential effects on river ecology and morphodynamics; flow-through vegetation; hydrodynamics and nutrient uptake in streams; and combined field and numerical studies that employ computational fluid dynamical tools for modeling physical and biological processes in streams. The issue draws across disciplines, integrating geosciences, ecology, and engineering to promote the development of practical, predictive models of river systems that can guide stream and watershed restoration practice.

CYCLES: Teachers Discovering Climate Change from a Native Perspective

CYCLES is an innovative approach for understanding and teaching about Global Climate Change (GCC) following a native friendly, place-based, holistic, interdisciplinary, and technologically rich framework that incorporates satellite observations, regional and global models, and cultural experience into a seamless web of knowledge. ‘CYCLES’ reflects the similarities between Native American and scientific explanations of the natural world as interconnected processes that are cyclical. In native culture, the medicine wheel symbolizes the interconnectedness of the earth, air, water, and fire. This is recognized in science through an Earth Systems approach based on the interconnectedness of the geosphere, atmosphere, hydrosphere, and biosphere, with the energy flow of these systems derived from the “fire” of the Sun and the interior of the Earth.
CYCLES is a three-year program, facilitated by NCED researchers and currently co-funded by NASA, targeting middle and high school science teachers from reservation schools or schools with significant native student populations. A cohort of 20 CYCLES teachers will be selected in the summer of 2011 to prototype this new approach to learning and teaching about Global Climate Change.

During summer workshops teachers will be actively involved in doing GCC science, both in the field with local projects and with existing NCED and NASA data. Teachers will also learn how to use computational tools to visualize and model GCC to answer questions about local and global impacts of environmental change. During the academic year, teachers will attend five additional training days and will be expected to implement lessons and activities from the summer workshops in their classrooms with support from the CYCLES staff.

Summer Institute on Earth-surface Dynamics (SIESD)

The National Center for Earth-surface Dynamics has created a new teaching and mentoring forum, the Summer Institute on Earth-surface Dynamics (SIESD), designed to engage young scientists in a focused topic in Earth-surface dynamics. Drawing on NCED’s approach of integrating theory, laboratory experiments, numerical modeling, and fieldwork, this two-week institute combines lectures with practical experiences in the laboratory and the field, as well as exposing the students to the broader impacts of their research.

SIESD was initiated in 2009 and created a pulse of energy in the 40 graduate students and young researchers who attended from across the world. Based on their feedback and that of their advisors, their perspective on Earth-surface dynamics research broadened, they acquired new knowledge and appreciation of an integrated approach to prediction via laboratory experiments, field work and theory, and developed a life-long network of mentors and fellow young researchers. The theme of the institute changes every year: in 2009 it focused on complexity and predictability in Earth-surface dynamics; in 2010 it focused on rivers and vegetation. The 2011 SIESD will focus on the biophysical status and predictive evolution of deltas. We will investigate coupled models of erosion, deposition, and vegetation; responses to up- and downstream anthropogenic perturbations; and how predictive modeling can be used for restoration of these delicate ecosystems. Hands-on learning opportunities will include the exploration of physical experiments and theoretical models as well as an intensive unit on the use of delta modeling tools available through the Community Surface Dynamics Modeling System (CSDMS).

The Institute will also expose students to broader-impacts research via the Science Museum of Minnesota and other NCED education and diversity activities.

The Summer Institute is a stimulating environment for learning, bonding, mentoring and life-long academic partnerships.

International Partnerships

Deteriorating streams and threatened landscapes, flood and landslide hazard prediction and control, delta ecosystem restoration, and sustainable exploration of natural resources under environmental change, are all problems of global character. NCED, since its inception, has embraced an international perspective on Earth-surface dynamics and has fostered the exchange of students and researchers from around the world to engage in an integrative,
interdisciplinary approach to Earth-surface science and science-based solutions to environmental problems. NCED aspires to create a nexus of institutions committed to international collaboration in research, data exchange, and graduate education in Earth-surface dynamics. Although many international activities are currently in place, some informal and some formal and funded from multiple sources, NCED researchers are currently exploring mechanisms and organizational models to formalize these activities into a sustainable international research network on Earth-surface dynamics.

National Center for Earth-surface Dynamics

At NCED, our mission is to understand the dynamics of the coupled processes that shape the Earth’s surface—physical, biological, geochemical, and anthropogenic—and how they will respond to climate, land-use, and management change. We use this knowledge to deliver the science-based solutions necessary for addressing environmental change.

We are transforming the way researchers approach Earth-surface science by integrating across disciplines and focusing on quantitative, predictive investigations. We are transforming the way research is transferred into practice by organizing academic-government-industry forums to promote sustainable restoration of the surface environment. We are engaging a diverse body of students, teachers, and the broader community in science and engineering through the appeal of landscapes and their social, cultural, and economic importance.

NCED: Earth, Water, Life
IIa. Desktop Watersheds (Watersheds) Integrated Program

Lead PI: William E. Dietrich
Program Manager: Collin Bode
Contributing PIs: Jacques Finlay, Efi Foufoula-Georgiou, Miki Hondzo, Kimberly Hill, and Mary Power

Executive Summary

Goal: The goal of Desktop Watersheds (DW) Integrated Program (IP) is to discover and advance the fundamental relations needed to predict landscape evolution and to model the coupling of ecosystem, landscape, and land-use dynamics. We pursue this goal through mechanistic field and laboratory studies, scaling analysis, and numerical modeling.

One central theme in DW is to exploit high-resolution digital topographic data to advance hypotheses, guide field work, and test theories. Combining digital environmental data (topography, vegetation, precipitation, runoff, etc.) with research showing how local environmental properties are controlled by drainage basin structure, we propose, for example, that such data can be used to make spatially explicit predictions about resource attributes (landslide locations, riverbed grain size, algae abundance, food web interactions, etc.). Such predictions can then become null hypotheses to guide fieldwork, transforming it from simple data gathering or monitoring to hypothesis-testing.

Digital topographic data also offer the possibility of building watershed-scale numerical models of real landscapes to explore problems ranging from the long time-scale controls on landscape evolution to short time-scale response of aquatic ecosystems to land-use change. Such modeling efforts are inhibited, however, by a lack of knowledge and quantitative expressions for many of the fundamental geomorphic and biotic processes. NCED principal investigators (PIs) and collaborators are closing this knowledge gap and introducing new theories and approaches, leading to discoveries about landscape evolution and to the construction of practical numerical models that will revolutionize land-use management and environmental forecasting. NCED’s unique breadth of researchers, experimental facilities, and field programs has enabled it to assume this leadership role.

Approach: High-resolution digital topography provides a common template for DW research. To unlock the potential of digital topography, we introduce new theories, propose new analytical approaches, conduct innovative experimental studies, and perform intensive field studies to discover, parameterize, and evaluate the fundamental driving equations. Our findings are made available to others to improve watershed-scale numerical modeling being developed across the community. We use our current digital-terrain based models to guide prioritization of research and to maintain a tight coupling between modeling and observation. In their simplest form, in which the topography is used to estimate such features as biological productivity, probable landslide location, channel morphology, or bed grain size, DW models can provide a relatively parameter-free prediction of landscape attributes: These predictions are useful in guiding fieldwork and in applications, such as planning timber harvests and stream restoration projects. Advances from new research will eventually lead to the ability to model cumulative watershed effects and controls on total maximum daily load (TMDL) levels of sediment and to “game” management scenarios in order to optimize land-use activities for ecosystem protection and restoration.

Highlights: Research took place across all eleven DW projects. Our significant results include:

1) The channel extraction and channel network mapping methodology, GeoNet, has been successfully applied to flat areas where valleys are typically poorly defined.

2) We proposed the use of “directed distance from the divide” as the scale parameter (instead of Horton’s stream order or upstream contributing area) for performing detailed probabilistic analysis of landscapes over a broad range of scales. This scale parameter offers several advantages for applications in hydrology, geomorphology, and ecology. It can be directly related to length-scale dependent processes, it can be applied seamlessly across the hillslope and fluvial regimes, and it is a continuous parameter allowing accurate statistical characterization (higher order statistical moments) across scales.
3) In 2010 we developed a light model to predict solar radiation flux at high spatial and temporal resolution across a watershed. This model gives for the first time spatially integrated estimate of light inputs into channels that takes vegetative shading and subcanopy light into account. Since light is the primary driver of interactions, processes and community structure in streams; this information will provide powerful insights into stream network ecology.

4) We have successively driven a river morphodynamic model with a mixed grain size sediment transport model and predicted the emergence of surface grain size patchiness. Unexpectedly, the emergence of surface grain size patchiness effects the amplitude and wavelength of alternate bars.

5) Spectral analysis of the bed elevations along with the statistics of tracer travel distances in the large SAFL flume revealed a strong dependence of travel distances on the spectral slope of the bed topography. The results showed that the statistics of tracer travel distances depend on the complexity of the bedforms and that the larger particles move farther (once entrained) than the smaller particles for the same duration of time. The mean travel distances of smaller particles do not get much affected by bed topography as their dynamics are mainly dominated by particle hiding effects.

6) A new distinct element model for granular flow was developed that explicitly treats effects of fluid between the particles. Although simple, initial numerical runs reproduce velocity profiles observed in our experimental studies.

7) We showed that non-local linear transport and erosion laws successfully reproduce key topographic steady state statistics of both hillslopes and fluviually-cut landscapes. The results of our fractional derivative models for flux and erosion offer alternative explanations for fundamental landscape form and dynamics.

8) Based on the marginal and join statistics of space-time precipitation from new remote sensing sources, we have developed a robust methodology that permits optimal fusion of high resolution multi-sensor measurements (i.e., rain-gages and ground-based radars) with low-resolution space-borne rainfall data, to be used for hydrologic and hazard prediction applications in remote watersheds around the world.

9) We have applied dimensional analysis to develop a functional relationship predicting larvae density of the caddisfly Glossosoma. A power-law relationship was found based on dimensionless local hydraulic and larval density variables that was applicable to areas where Glossosoma were present. Glossosoma densities were negatively correlated with streambed relative roughness and positively correlated with the ratio of inertial to gravitational forces in the stream.

10) Our Eel River field studies have revealed that upland wetlands are the major sources of insects to terrestrial insectivores during winter, when the river experiences scouring, cold, turbid flow, but annual terrestrial insect fluxes from wetlands are dwarfed by insect fluxes from the river during summer low flow.

11) In Minnesota, we have found that tile drainage accelerates soluble losses of both dissolved organic and inorganic carbon relative to standard drainage. By incorporating solute losses, this work suggests that agricultural activities are accelerating carbon losses by a greater degree than previously recognized. This work may also help explain the long term increase in dissolved inorganic carbon export to the Mississippi River and in other modified landscapes.

Projects

The multi-year commitment to projects with DWIP brought dividends in Year 9 of NCED. Continued collaborations across disciplines, long-term experiments and field observations, and the maturing of research questions brought many new findings. Below we summarize findings for the 11 DW projects. An explanation and defined milestones for each project are provided in the Appendix E: Strategic and Implementation Plan of this document.

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<table>
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<th>Project</th>
<th>Project Name</th>
</tr>
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<tbody>
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<td>Sediment routing; coarse sediment transport in shallow flow; fine sediment interaction with coarse bed</td>
</tr>
<tr>
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<td>DW11</td>
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**► DW01: Numerical techniques for feature extraction**

High-resolution data obtained from airborne laser swath mapping continues to be an inspiration and challenge to quantitative landscape analysis. In DW01 our goal is to advance methods to extract features such as channels, roads, and other topographic attributes of importance to environmental prediction.

**Channel and geomorphic feature extraction in flat areas**

We use LiDAR data available for the Le Sueur River basin in Minnesota, and GeoNet, the channel network extraction algorithm discussed in last year’s report, to explore the challenges and opportunities encountered in the extraction of channels and geomorphic features in flat landscapes. We propose a technique for automated channel morphometric analysis including extraction of cross-sections, detection of bank locations, identification of geomorphic bankfull water surface elevation and measurement of bank and bluff heights, the latter three made possible using the slope computed along each channel-floodplain cross-section. GeoNet is able to extract natural and artificial features without adding any extra sinuosity, thus making it possible to distinguish them (see Figs. 1, 2, and 3).

**Plans**

We plan to further explore the application of the nonlinear diffusion/geodesic formalism for feature extraction over low relief regions which include a mix of natural and artificial features. We intend to explore the potential for automatic extraction of roads and trails from LiDAR data, and also develop a methodology for extraction of deltaic channels from satellite images. Using a scale parameter of distance from the divide, we will also look for the signature of deep-seated landslides.

**Figure 1:** Geometric curvature versus Laplacian curvature computed on channel (a), artificial ditch (b), and road (c) section of the Le Sueur tributary. The panels are about 60 m by 60 m and from left to right represent elevation, cross-section profile, geometric curvature and Laplacian. Notice that the gradient normalization operated in the geometric curvature makes the curvature values of the same order of magnitude in the three cases. The Laplacian, instead, distinguishes very well between natural and artificial features.

**Figure 2:** Analysis of a road crossing in an 800m by 800m focus area. Elevation data (a). The letters A and B indicate the horizontal extent of the road in the focus area. The skeleton of the likely channelized pixels (b) correctly detects a channel disruption in correspondence of the road. The extraction based on area threshold fails in correctly extracting the channel path through the road crossing. We can notice how the channel splits in two in correspondence of the road (c). Due to the global optimization performed in the geodesic tracing operation, GeoNet correctly traces the channel path through the road crossing.
The notion of dynamic river networks for environmental transport

The development of a systematic framework within which to study dynamical processes on river networks remains of considerable theoretical and practical interest in hydrology, geomorphology and river ecology. Motivated by this problem, we presented a new direction of studying dynamical processes operating on directed trees. Specifically, we introduced the concept of a “dynamic tree,” which describes the directed transport along the links of a “static tree” that has given topology and link-length distribution, as well as other space- and time-dependent attributes (Zaliapin et al., 2010). This approach paves the way to building minimal complexity models for dynamic transport of fluxes along river networks. We demonstrated that dynamic trees are self-similar, albeit with different self-similarity parameters than their corresponding static trees. We also reported an unexpected phase transition in the dynamics of river networks that appears to have some universal features. This phase transition depicts the characteristic length scale (or equivalently time) at which the network is most dynamically connected and thus it participates in the transport in a collective way. At that characteristic distance $d^*$ the distribution of clusters (branch magnitude) transits from exponential to power law.

The hierarchical structure of river networks is commonly described via a formulation based on the so-called Tokunaga self-similar trees. A Tokunaga self-similar tree (SST) is a two-parameter class of trees specified by the parameter pair $(a, c)$ (see Zaliapin et al., 2010); the parameter $c$ describes the ratio of two consecutive branching indices and the parameter $a$ is the proportionality constant. Any river network can, to a very good approximation, be described via this two-parameter model. The questions we posed are: (a) is the width function of a river network uniquely specified by the two parameters of the Tokunaga SST? (b) what is the relative contribution of random topology (branching) versus random geometry (link length distributions) in the network-to-network width function variability?, and (c) what are the properties of the width function of the dynamic trees resulting from the static trees?

The width function, $W(x)$, is defined as the number of streams at distance $x$, where $x$ is measured along the tree from the outlet. The width function reflects the distribution of travel distances to the outlet and as such it gives a measure of the catchment hydrologic response. It was found via simulations that the width functions of Tokunaga synthetic trees have a large variability, which is mainly due to the random number of side-branches (branching topology) even under the same model parameters $a$ and $c$. The implication of this result is that in mapping a real river network into the “Tokunaga space” of parameters, the unique shape of the hydrologic response function of that basin might not be recoverable. It was also observed that the link lengths and side-branch attachment order have a prominently weaker effect on the width function variability (see Fig. 4). The relative effect of random topology (red curves) versus random geometry for a fixed topology (blue curves), varies with the magnitude of the parameters $a$ and $c$, pointing to the varying ability of recovering a hydrologic response based on Tokunaga characterization. Further analysis of these results and the extension of the concept of width function to dynamic trees are a topic of current research.

Revisiting scaling laws in river basins

Increasing availability of high-resolution (1m) topography data and enhanced computational processing power present new opportunities to study landscape organization at a detail not possible before. Recently we proposed the use of “directed distance from the divide” as the scale parameter (instead of Horton’s stream order or upstream contributing area) for performing detailed probabilistic analysis of landscapes over a broad range of scales. This scale parameter offers several advantages for
applications in hydrology, geomorphology, and ecology in that it can be directly related to length-scale dependent processes, it can be applied seamlessly across the hillslope and fluvial regimes, and it is a continuous parameter allowing accurate statistical characterization (higher order statistical moments) across scales (Gangodagamage et al., 2011).

Application of this scaling formalism to three basins in California demonstrated the emergence of three distinct geomorphic regimes of divergent, highly convergent and moderately convergent fluvial pathways (see Fig. 5), with notable differences in their scaling relationships and in the variability, or spatial heterogeneity, of topographic attributes in each regime. We showed that topographic attributes, such as slopes and curvatures, conditional on directed distance from the divide exhibit less variability than those same attributes conditional on upstream contributing area (see Fig. 6), affording thus a sharper identification of regime transitions and increased accuracy in the scaling analysis.

**Plans**

We will continue to examine the concept of dynamic tree and the dynamically evolving width function for transporting fluxes along river networks in a minimal complexity, simple predictive framework. The conjecture that hillslope and fluvial transport are governed by different phase transition length and time scales will be further explored, and the phase transition scale will be related to characteristic attributes of the static river network and the dominant dynamic process.

**DW03: Predictive mapping of key biotic populations: relationships to habitats**

The goal of this research is to link the distribution and abundance of organisms and their influences on biogeochemical cycles to habitat state and availability in a spatially explicit channel network framework. We are using new field, laboratory, and modeling analyses to discover and explain how distributions and physiological performances of key organisms, and therefore their abundances and impacts in food webs and ecosystems, should change through drainage networks, along environmental...
Our approach is to conduct field studies of food webs (led by PI Mary Power), perform biogeochemical analyses that trace uptake and exchange processes (led by PI Jacques Finlay), and conduct local measurements in the field and apply advanced instrumentation and engineering analyses to identify physico-chemical controls on organisms and their interactions with the fluid environment (led by PI Miki Hondzo). These studies are focused on identifying how the landscape template affects environmental regimes that influence the performance and the interactions of river and watershed biota. Some results are reported in DW08 and DW09.

**Prediction of solar radiation to channels and mapping biotic response**

In 2010, we developed a light model to predict solar radiation flux at high spatial and temporal resolution across a watershed. This model gives for the first time a spatially integrated estimate of light inputs into channels. Since light is the primary driver of interactions, processes and community structure in streams, this information will provide powerful insights into stream network ecology. In Figure 7 we report the correlations found between light and various nutrient and biotic controlled processes. This suggests that our light model will enable us to scale up local measurements, on which this correlation was established, to the entire watershed.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Equation</th>
<th>$R^2$</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPP (g O$_2$/m$^2$·d$^{-1}$)</td>
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<td>0.75</td>
<td>&lt;0.0001</td>
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<tr>
<td>N fixation (mg N/m$^2$·hr$^{-1}$)</td>
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<td>DON (mg L$^{-1}$)</td>
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<td>SRP (mg L$^{-1}$)</td>
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<td>0.0008</td>
</tr>
<tr>
<td>Si (mg L$^{-1}$)</td>
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<td>0.0043</td>
</tr>
<tr>
<td>HCO$_3^-$ (mg C L$^{-1}$)</td>
<td>$17.20 - 6.59e^{-5}$*light</td>
<td>0.15</td>
<td>0.0924</td>
</tr>
</tbody>
</table>

**Plans**

Several field studies are planned at the Angelo Coast Range Reserve: 1) further testing of the light model, 2) parameterize subcanopy and shaded channel light flux with field data, 3) develop correlations between light input and distribution and dynamics of biota, and 4) document periphyton response to observed and manipulated light and flow conditions.

### DW04: Understanding linkages among solutes, soil production, and biota

The collaboration with the Berkeley Keck HydroWatch initiative has proven very fruitful regarding studies of these linkages. On an approximately 4000 m$^2$ hillslope near the mouth of Elder Creek, an intensive hydrologic monitoring program has been developed in order to document the linkages among climate, vegetation, hydrologic processes and ecosystems. Our experimental hillslope is heavily instrumented now with over 600 instruments, including 12 wells and four automated ISCO
samplers (to follow chemical evolution of waters) (Fig. 8). This is being done to improve model predictions of the co-evolution of California’s climate, vegetation and water supply in response to coming climate change. We are also exploring controls on the development of the weathering zone (Fig. 9).

**Plans**

We will be shifting from monitoring to experimental addition of tracers to quantify rates and pathways of subsurface movement and the role of rock moisture in providing summer dry period water for transpiration. Preliminary models have been developed that predict the shape of the weathered bedrock to bedrock transition across the landscape. Further model development and verification will be performed.

- **DW05: Controls on rate of landslide transport to channels**

This past year considerable effort was given to developing an efficient parallel program to calculate drainage area which, via subsurface flow pathways, strongly influences pore pressure evolution. To contribute to the US Geological Survey ArkStorm emergency preparedness study (of the consequences of a major storm system striking California) we used the new parallel program to calculate the relative slope stability across the entire state of California (Fig. 10).

**Plans**

Work continues on our landslide size model and will focus on improved model efficiency and will explore the use of a simple dynamic hydrologic model to predict the evolving spatial pattern of pore pressures.
Development of surface grain size patches

Nelson et al. (2010) used flume data collected in the large flume at SAFL and simple modeling of flow and boundary shear stresses to document and explain the mechanisms controlling grain size surface patchiness which are fixed in a channel relative to their position within bar-pool topography. Surprisingly, coarse patches did not correspond to areas of high boundary shear stress. Instead these patches occurred over bar tops where the divergence of boundary shear stress (i.e., a decrease in the downstream component of the boundary shear stress) led to size selective bedload transport and surface coarsening. The cross-stream component of the boundary shear stress transported sediment away from the zone of downstream decreasing boundary shear stress. By combining a flow model with the Parker surface-based bedload transport model, Nelson (2011) was also able to predict spatial patchiness of the bed surface driven by boundary shear stress divergence and sloping bed topography. He also predicted the co-evolution of bars and bed-surface sorting. Surprisingly, surface sorting strongly influences bar evolution.

Grain interactions

Venditti et al. (2010a) explored how the addition of bed material load in pulses (a contribution of increased load over a relatively short duration) affected bedload transport rates and surface texture. No sand was present. Fine sediment addition, at a size about 1/5 that of the median of surface grains, mobilized the coarse bed surface layer and greatly increased sediment transport rate. Venditti et al. (2010b) shows that the arrival of fine bedload sediment in these flume studies causes reduction of near bed turbulence, local slight increase in velocity and slight shallowing of the flow (Fig. 11). These observations strongly support the hypothesis that fine mobilization of coarse sediment arises from reduction in flow resistance due to burial of wake regions and increase in drag and lift on particles due to increased nearby velocity.

Tracer dispersal in rivers

Following previous work in the group where a new model was proposed to capture deviation of breakthrough curves from the Gaussian distribution and to explicitly incorporate long particle travel distances in the bedload transport law (Ganti et al., 2010), we initiated a set of experiments in the Main Channel with the purpose of understanding and quantifying tracer transport dynamics in a gravel-bedded river. Instantaneous, high-resolution bed elevations, velocity fluctuations and sediment transport rates along with travel distances of tracer particles (paramagnetic in nature) representing the grain size distribution of bed material were measured, for a range of discharges (Figs. 12 and 13).

Spectral analysis of the bed elevations along with the statistics of tracer travel distances revealed a strong dependence of travel distances on the spectral slope of the bed topography. The results showed that the statistics of tracer travel distances depend on the complexity of the bedforms and that the larger particles move farther (once entrained) than the smaller particles for the same duration of time. For the case of higher discharges with pronounced bed topography, the length of the bed form dominates tracer travel distances (Fig. 14). The results showed that mean travel distances of smaller particles do not get much affected by bed topography as their dynamics are mainly dominated by particle hiding effects. The implications of these results for predictive modeling of sediment transport are being explored.
Plans

Current results suggest a path for developing a quantitative model for explaining bed surface patchiness due to topographic and grain surface response to the boundary shear stress field. A key process in gravel bedded streams appears to be size selective cross-stream bedload transport. This will be explored through modeling. Research on the mobilization of the coarse fraction by the fine tail of bedload will be expanded to coarser sediment and an investigation of the controlling mechanisms will be conducted.

► DW07: Develop predictive models for channel incision

Channel incision occurs by sediment wear of bedrock due to fluvial flows, debris flow cutting, and knickpoint propagation. Progress was made on all three processes in the past year.

Episodic bedrock incision due to meander migration and cutoff

If rivers cut laterally as well as down as they carve their way through bedrock, an intrinsic instability may develop that leads to episodic strath terrace formation. Finnegan and Dietrich (2011) developed a model for incision and lateral shifting that predicts upstream propagating knickpoints after cutoff, leading to distinct, but unpaired strath terraces (Fig. 15). This finding adds another consideration, beyond climatic and tectonic effects, in the interpretation of strath terraces in the field.

Predictive models for channel incision by debris flows

In this research we addressed several questions: How do the local and global particle size distributions in a debris flow affect boundary pressure, shear stresses, and associated erosion of stress on the boundaries over which they flow? What is a suitable model that predicts both the variability of particle size distributions in a debris flow and subsequently local stresses that ultimately determine sediment flux, landscape evolution, and potential hazard in these systems?

Predicting the boundary stresses due to overland debris flows is critical to predicting landscape evolution and ultimately the associated sediment flux and related damage to property. We have developed simulations that produce salient features of dry mixed particle size model debris flows observed experimentally. We have previously shown that the most commonly used model to predict boundary stresses in debris flows proposed by Bagnold (1954) relating shear and pressure stresses $\sigma_0$ to shear rate $\dot{\gamma}$ and particle size $d$, $\sigma_0(\dot{\gamma}d)^2$, is not suitable for mixtures of different sized particles. In fact, we showed that in a typical debris flow, pressure is not directly related to any local measure of particle size. Instead, we showed that particle/boundary contact forces provide a more clear link to the particle size distribution and likely link to dynamics associated with

![Figure 11. Measured changes in hydraulics and the near-bed flow structure associated with passage of the pulse of sediment: (a) water and bed surface elevation $z$ and probe elevations (dashed lines), (b) observed $(U_m)$ and predicted $(U_2)$ mean velocities, (c) measured near-bed velocities, and (d) nearbed turbulent kinetic energy (TKE).](image)
erosive processes. The results suggest a power law relationship between local average particle size and metrics of the stress at the boundary including average pressure and standard deviation of the pressure.

This year, we developed a first order model on which to build an understanding of the relationship between particle size distribution and boundary forces. Specifically, we considered the importance of individual particle/wall collisions compared with the importance of multiple particle collisions. To do so, we queried the statistics of the maximum force for each individual particle/wall interaction. For a single isolated particle, this is dependent on their size and the initial velocity (Fig. 16a).

For a mixture under the boundary conditions, the importance of particle-particle interactions in determining the maximum force is not clear. For a measure of the relative importance of the two, we plotted the results for a mixture of 13.8 mm particles and a single 50 mm particle (Fig. 16b). Then we compare these results with those from a single 13.8 mm particle. We found that the largest events are associated with single particle-wall collisions and collective events appear relatively less important. A more complete model for the relative importance of the nature of the different types of collisions will require consideration of the minimum boundary force for bedrock wear. This work will carry into year 10 and include a mechanistic link to cut-off forces for bedrock erosion.

**Fluid/particle interactions in debris flow dynamics and associated sediment flux and channel erosion**

To develop a more broadly applicable model for debris flows, we have added to our Discrete Element Model (DEM) simulations a simple model to incorporate fluid/particle interactions, particularly relevant to dense granular-fluid flows typical of debris flows. When the pore spaces between the particles are entirely filled with liquid, the effect the liquid has on the interparticle interactions is linked to the effect of the variability of pore pressure. This can result in the interstitial liquid rather than interparticle contacts supporting the particles, resulting in pore pressure in excess of hydrostatic pressure. This leads to anomalous behaviors such as long run-out avalanches.

**Figure 12.** Measurements of tracer travel distances were made in the Main channel facility of St. Anthony Falls Laboratory at the University of Minnesota. For each discharge, the experiment was run until steady-state was achieved. Then the flow was shut down and the magnetic tracers were positioned in a row at the top of the flume; the flow was re-introduced for 5 minutes allowing for the tracers to move throughout the bed and their locations to be recorded. The Main Channel is 55m long, 2.75 m wide and 1.8 m deep.

**Figure 13.** Schematic of the experimental setup showing the locations of sonars (used for measuring temporal bed elevation $h(t)$), the ADV (used for measuring velocity fluctuations $v(t)$) and the pans (used for measuring bedload transport $s(t)$) at the downstream end of the channel. Fifteen tracer columns were installed in the bed for measuring the entrainment rate of the particles. The flow direction is from the left to the right of figure. The dash line at the upstream end of the channel represents the location of the paramagnetic tracers introduced at the end of the run.

**Figure 14.** (Right) Centerline transect of spatial bed elevation for the discharges of 600, 800, 950, 1150 and 1600 l/s (from top to bottom), and (Left) mean travel distances of tracer particles (para-magnetic) of three different sizes (8, 16, and 22 mm) as a function of discharge.
To develop a model that takes this into account, we consider the sketch in Figure 17, which illustrates the dynamics that can lead to increased pore pressure for a single particle approaching or departing from a group of other particles. A particle approaching a group of other particles needs to push out a pocket of interstitial fluid and thus that particle and the group of particles feels a mutually repellent force. Tracking the pore spaces in DEM models is computationally very intense.

We employ a simpler model to capture the essence of the effect of pore pressure without as much additional computational intensity. This model captures the “action at a distance” for particles moving relative to one another, as suggested by the sketches in Figure 17:

$$F_{12} = -k\frac{v_n}{r_{12}},$$

where, in suggesting this, we propose that $F_{12}$, the fluid-mitigated force associated with two nearby particles moving relative to one another, increases as their relative velocities increase and decreases with distance to one another. $v_n$ is their relative velocity in the direction connecting their two particle centers; $r_{12}$ is the distance between particle centers, and $k$ can be thought of as a “pore pressure coefficient” that varies with fines content and other details that influence the permeability of the particle network. The basic structure captures the reduction in velocity profile measured from large scale experiments at the Richmond field station (Fig. 18). The next step is to link the parameter $k$ to vary with physical system details such as fines content, a problem we plan to tackle in year 10.

**Figure 17.** Sketches illustrating the effect of a pore-filling liquid on damping relative particle motion. The liquid can either work to create a repulsive force between particles if they are approaching or to effectively attract them if they are moving away from one another.

**Figure 15.** A: Shaded relief image of Smith River, Oregon (United States) and surrounding topography from 1-m-resolution LIDAR data. B: Shaded relief image of 10-m-resolution numerical model output. In A and B, locations of bedrock meander cutoffs are identified with white dots, and outside edge of strath terrace treads are shown in red; river flow is from right to left. River elevation profile (blue) and strath terrace elevations (red) from A and B, respectively, projected onto east-west–striking plane. UTM—Universal Transverse Mercator.

**Figure 16.** Maximum force plotted against collision velocity. (a) Results for isolated particle-wall collisions. (b) Results for a model debris flow simulation in a drum. The line in (b) corresponds to the results from (a) for 13.8 mm particles.
Collaborative physical modeling experiments will be performed to collect data on the influence of fluids and pore pressure dynamics on boundary forces, grain segregation, and velocity profiles through debris flows. These data will be used to guide and motivate theory for accounting for fluid effects in distinct element model simulations.

**Plans**

Collaborative physical modeling experiments will be performed to collect data on the influence of fluids and pore pressure dynamics on boundary forces, grain segregation, and velocity profiles through debris flows. These data will be used to guide and motivate theory for accounting for fluid effects in distinct element model simulations.

**DW08: Upscaling transport laws and biotic processes**

**Local vs non-local geomorphic transport**

The notion of non-local flux, i.e., a flux which depends not only on local gradient but on gradients upstream of a point of interest, is a new concept in geomorphology. It is an expression of the fact that heterogeneities of all scales are present in the system and that the notion of a characteristic length scale over which mass balance is to be performed (or the notion of flux divergence converging as the volume shrinks to zero) loses its meaning. Instead, one has to consider mass balance over an infinite volume, or equivalently, to consider an integral or convolution Fickian flux (Foufoula-Georgiou and Stark, 2010). Under the assumption of a convolution kernel which takes a power-law form, this flux can be concisely expressed in terms of a fractional (non-integer) derivative. We continued this year to explore the theoretical and physical justification of employing non-local transport formulations for transport problems that involve a broad range of scales. Progress has been made on the following topics:

**Figure 18.** Velocity profiles from (a) experimental and (b)-(c) model debris flows. For the latter, the particle interactions are modelled as (a) dry, and (b) saturated, where the long range force is added to the dry DEM model.

**Figure 19.** (a) Probability density functions of the magnitudes of local slopes at three different scales (resolutions) computed from the hillslope pixels in the Coos Bay region. (b) Total computed nonlinear sediment flux from the hillslope pixels of the Coos Bay region as a function of scale. Note that the nonlinear flux law shows a considerable scale dependence (red circles), which is corrected for (at least for scales smaller than 20 m) by considering the proposed subgrid scale closure (black circles).
Scale-dependence of local laws and derivation of closures

Geomorphic transport laws express the sediment flux at a point as a function of topographic attributes of the system (such as slope, curvature, soil thickness, etc.) at that point only or at an appropriately defined vicinity of that point. Typically, topographic attributes are computed from DEMs and thus their estimates depend on the DEM resolution (1 m, 10 m, 90 m, etc.) rendering thus any sediment flux computation scale-dependent. Often calibration compensates for this scale-dependence resulting in effective parameterizations with limited physical meaning.

Motivated by the strong scale-dependence of the probability density functions of the magnitudes of local slope (see Fig. 19), we derived a sub-grid scale closure term for the typical nonlinear sediment flux law, using Reynolds averaging methods. The Taylors series expansion, after neglecting the higher order terms of the nonlinear flux, is given by:

$$q_i(x) = KS + \frac{K}{S_c^2} S^3$$

where $S$ is the magnitude of the local slope, $K$ is the diffusivity coefficient and $S_c$ is the so-called critical gradient. Expressing the magnitude of the slope as a summation of filtered slope at a given scale, $S_\Delta$ and its fluctuations at that scale, $S'_\Delta$, we can upscale the above equation to derive the flux law at any given scale as:

$$\tilde{q}_i(x) = K\left(S_\Delta + S'_\Delta\right) + \frac{K}{S_c^2}\left(S_\Delta + S'_\Delta\right)^3$$

Performing an averaging of the above equation and neglecting the higher order moments yields the upscaled nonlinear sediment flux law given by:

$$\tilde{q}_i(x) = Ks\Delta + \frac{K}{S_c^2} (S_\Delta)^3 + \frac{3K}{S_c^2} S_\Delta Var(S'_\Delta)$$

Figure 20. The subgrid-scale closure term of the nonlinear local flux law was shown to depend on the variance of the slope fluctuations at the resolved scale. Here we show that this variance is a power law function of scale for two different basins: Coos Bay region (left panel) and Eel river basin (right panel), enabling thus a parameterization of the subgrid scale fluxes knowing the variance at scales equal to or larger than the resolved scale.

The right hand side (RHS) of the above equation is the same as the original equation except for the third term of the RHS, which is the subgrid scale flux term. The subgrid scale term comprises of two essential attributes of the landscape: the local slope at a given scale (which is computable from the available data) and the variability of slope for scales smaller than the given scale (which needs to be parameterized). It was shown that the variance of slope fluctuations can be well approximated by a power-law relationship in scales (see Fig. 20 for the Coos Bay region and the Eel river basin), thus providing a concise way of parameterizing the subgrid scale closure term. More details can be found in Ganti et al. (2011).
Non-local models for landscape evolution

Landscapes are primarily shaped by the energy dissipated by stream flow. Stream power erosion models, which express the erosion rates as nonlinear powers of discharge and local slope, when coupled with the continuity equation present a class of simple Langevin type models for landscape evolution (Passalacqua et al., 2006). It has long been argued that the nonlinear dependence of erosion rates on discharge and local slope is essential in reproducing the steady-state statistics and scaling observed in real landscapes. The question we posed is whether a linear but non-local formulation of erosion rate on discharge and local slope can indeed reproduce dissected fluvial landscapes. The answer seems to be ‘yes’ and this poses further questions related to physical realism of this formulation as an attractive modeling framework that can capture concisely the effect of space-time variable rainfall, and thus runoff, on landscape evolution.

We developed a nonlocal, linear model that takes into account the extreme variability in stream discharges across weathering landscapes spatially and temporally. We have cast this model into a fractional derivative form via the concept of subordination (replacing the homogeneous time axis over which variable runoff occurs with a dynamically “stretched” time axis over which a uniform rate of runoff applies). Our model results show that a non-local, linear model for fluvial erosion reproduces the observed statistics of slope-area relationship (see Fig. 21), drainage area statistics and power spectral scaling of the steady-state elevation field. Our model presents a radical alternative in explaining the observed steady-state statistics of real landscapes (Passalacqua et al., in prep.) and awaits further verification and detailed comparison with standard local nonlinear models.

Precipitation downscaling and multi-sensor data fusion

Understanding the space-time variability of precipitation is of central importance for forecasting extreme storms, and for modeling landscape evolution and the movement of water, sediment and nutrient fluxes in river basins. The past decade has witnessed the remarkable emergence of new sources of multi-sensor precipitation datasets including high resolution local rain gages, regional ground-based weather surveillance radars, and global spaceborne active and passive sensors. The questions of interest in our research are the following: (a) how can spaceborne precipitation data be combined with other sources of rainfall measurements to increase the resolution of precipitation information from space, important for regions of limited ground data, such as over complex terrain? and (b) how can high resolution features, such as intense raincells and frontal lines, be recovered from the low-resolution precipitation satellite data for flood and hazard prediction applications? The existing methodologies for multi-scale multi-sensor data merging, e.g., based on the Scale Recursive Estimation (Chou et al., 1994 and Gorenburg et al., 2001), cannot deal effectively with the highly non-Gaussian statistics of rainfall fluctuations, resulting in high-resolution precipitation estimates that do not reproduce extremes. These extremes are important for accurate hydrologic modeling and must be preserved in any downscaling or fusion methodology. This aspect is at the heart of the developed methodology, as explained below.

Analysis of two hundred near-surface reflectivity images of independent storm events, coincidently observed by TRMM and NEXRAD precipitation radars over two TRMM-GV sites in Houston (HSTN) and Florida (MELB) (e.g., see Fig. 22 for one such storm), has revealed that the distributions of the wavelet coefficients (i.e. rainfall fluctuations) exhibit remarkably regular and universal shape with extended tails, significantly thicker than can be explained in the Gaussian domain (Fig. 23).
It is demonstrated that this heavy tail behavior can be well explained by a class of heavy tail density functions, the so-called Generalized Gaussian (GG) distribution

\[ f(x) = \alpha \exp\left(\frac{|x|^p}{\sigma}\right) \]

in which, in addition to the width parameter \( \sigma > 0 \), a shape parameter \( \alpha > 0 \) controls the thickness of the tail. For reflectivity images in the scale of 1 x 1 km, this shape parameter is typically in the range of 0.5 < \( \alpha < 1.0 \) and tends to larger values for coarser scales. Note that \( \alpha = 2 \) corresponds to Gaussian density, \( \alpha = 1 \) to Laplacian and \( \alpha < 1 \) to a thicker tailed distribution. Theoretical and experimental observations (Ebtehaj and Foufoula-Georgiou, 2011a,b) indicate that this distribution can be simulated via a mixture of Gaussian random variables, the so-called Gaussian Scale Mixture (GSM). Formally, a Gaussian Scale Mixture (GSM) random vector \( d \) is defined as the product of a zero mean Gaussian random vector \( u \) and a positive scalar multiplier random variable \( z \):

\[ d = \sqrt{z} \cdot u \]

where \( d \) denotes equality in distributions. Analyzing the aforementioned precipitation dataset by deconvolving the Gaussian vector \( u \) from the distribution of the wavelet coefficients, we demonstrated that by using a log-normal multiplier random variable \( z \sim \mathcal{LN}(\mu_z, \sigma_z) \) the marginal statistics of the rainfall images in the wavelet domain can be reproduced very well, using a GSM probability model (e.g., see Fig. 23). A very useful characteristic of this model is that while \( d \) is non-Gaussian, \( p(d | z) \) is a Gaussian density with covariance \( C_{d|z} = zC_u \), where \( C_u = \mathbb{E}[uu^T] \). It is theoretically proven that the orthogonal wavelet transformation can decorrelate dependent stochastic processes. Recent studies show that the wavelet coefficients of rainfall exhibit short range intra-scale correlation even though the rainfall fields are often strongly correlated with long range dependence (Ebtehaj and Foufoula-Georgiou, 2010 and 2011a). Indeed this decorrelation effect ensures that instead of the full covariance characterization in the real domain, which is typically computationally prohibitive (e.g., Kalman Filter), a local estimate of the covariance in the wavelet domain can sufficiently capture the full correlation structure of precipitation fields in the real domain. An additional important finding of our research is that the rainfall wavelet coefficients also exhibit higher order statistical dependence across scales in the sense that larger coefficients at one scale (parents) give rise to larger coefficients, and also larger variance, at next finer scale (children). These are important characteristics of rainfall variability that are explicitly preserved in the proposed downscaling and data merging framework. Application of the developed methodology to downscaling precipitation data from 10x10km down to 1x1 km resolution is encouraging (Ebtehaj and Foufoula-Georgiou, 2011a).

Based on the marginal (thick tails) and joint (scale-to-scale dependence) statistics of precipitation images as revealed in our recent research, a robust algorithm that permits optimal fusion of high resolution multi-sensor measurements (i.e. rain-gauges and ground-based radars) with low-resolution space-borne rainfall data, while respecting these marginal and joint statistics has been developed. The developed methodology shows significant advantages over previous methodologies in reproducing...
the localized extreme precipitation values, which are important for flood and landslide prediction. An application of the developed methodology in fusing low resolution microwave estimates from the TRMM satellite and ground-based radar from NEXRAD is shown in Figure 24.

Scaling *Glossosoma* density by abiotic variables in mountain streams

The stream-dwelling larvae of the caddisfly *Glossosoma* spp. are dominant grazers in lotic food webs and are capable of suppressing stream periphyton. We explored a method for developing a scaling relationship between macroinvertebrate density and local hydraulic variables. As an example of this method, we quantified habitat for larval stone-cased caddisflies, *Glossosoma califica* and *Glossosoma penitum* (Fig. 25), in three coastal mountain streams in northern California over 2 years (Morris et al., 2011). We applied dimensional analysis to develop a functional relationship from a power law based on dimensionless local hydraulic and larval density variables that was applicable to areas where *Glossosoma* were present. *Glossosoma* densities were negatively correlated with streambed relative roughness and positively correlated with the ratio of inertial to gravitational forces in the stream. The proposed scaling relationship

\[
\frac{G_{\text{mass}}}{\mu} = 10^{-1.5} \left( \frac{k_s}{H} \right)^{-0.57} \left( \frac{u_{\text{rms}}}{\sqrt{gH}} \right)^{0.97}
\]

described 51% of the variance in the spatial distribution of glossosomatid larvae. \(G_{\text{mass}}\) is the *Glossosoma* larval mass per unit bed area, \(u_{\text{rms}}\) is the depth-averaged root-mean-square velocity, \(k_s\) is the average bed roughness height, \(H\) is the local water depth, and \(U\) is the depth-averaged velocity. The proposed scaling relationship implies that the *Glossosoma* larval mass is mediated by stream local roughness \((k_s/H)\), Froude number \((U/\sqrt{gH})\) and local turbulence characteristics \((u_{\text{rms}})\). Although the proposed scaling analysis provides a simple prediction for \(G_{\text{mass}}\), two relevant and fundamental questions remain: a) do \(G_{\text{mass}}\) measurements depend on spatial sampling scale in reported streams?; and b) does an independent analysis demonstrate that indeed the proposed scaling variables determine \(G_{\text{mass}}\)? In order to answer the above questions, the distribution of *Glossosoma* was quantified at different sampling spatial scales with experimental and theoretical variograms. The spherical theoretical model depicted experimental variograms of *Glossosoma* density \((G_{\text{den}})\) with the overall highest goodness of fit (Morris et al., 2011). Graphical examples of theoretical and experimental variograms are shown for 3 representative sites (Figs. 26a-c). The nugget effect was apparent on variograms from each site, a result indicating variability at distances smaller than the minimum sampling-point separation distance. The range of variograms based on \(G_{\text{den}}\) varied from 0.19 m to 0.8 m with an average of 0.39 m. Beyond the range, variogram sills indicated constant variance of \(G_{\text{den}}\) regardless of the sampling scale. Prior to the estimated range values, the variograms showed that the mean and variance of \(G_{\text{den}}\) were scale dependent.
This analysis suggested that the mean and empirical variance of $G_{\text{den}}$ changed as a function of sampling-length scale up to 0.8 m. Variogram analysis of roughness height resulted in an average variogram range of 0.26 m. The spectral analysis of characteristic eddies in the turbulent flow at sampling sites suggests that large scale eddies (eddy length scale $> H$) control the aggregation of Glossosoma. The variogram analysis of Glossosoma spatial density and relative roughness revealed overlap in the variogram range and therefore justifies the variables selected in the proposed scaling relationship.

**Epiphyte interaction with moving fluid on filamentous algae**

Nitrogen fixation and transformation in aquatic environments has been a research focus over the past year. We hypothesized that under conditions of dissolved inorganic nitrogen (DIN) and mass transfer-limited stand productivity, epiphytic diatoms such as *Epithemia* spp., which contain an endosymbiotic nitrogen-fixing cyanobacteria, will dominate the epiphyte community on filamentous algae. In order to quantify nitrogen fixation by endosymbiotic nitrogen-fixing cyanobacteria, we investigated how epiphyte community on filamentous alga *Cladophora glomerata* influence fluid flow conditions and corresponding momentum and mass transfer in the proximity of filaments. Field measurements at five sites within the Eel River at Angelo Coast Range Reserve were conducted to assess the relationship between fluid flow conditions and epiphyte community. At each site, vertical profiles of three-dimensional velocity components were measured, extending from the water surface through the *Cladophora* stand (Figs. 27 and 28). Although the flow was turbulent above the *Cladophora* filaments ($y>h_c$), Reynolds stress distribution in the filaments indicated laminar flow conditions ($y<h_c$). The field measurements provided a physical basis for the laboratory measurements at SAFL.

A micro particle image velocimetry (uPIV) channel was constructed (Fig. 29) to study fluid flow interaction with epiphyte community on *C. glomerata*. The influence of the epiphyte community on momentum exchange was quantified with uPIV under a variety of flow rates past single filaments of *C. glomerata* tethered in a closed channel (1mm x 1 cm x 3 cm). A laser was used to illuminate small and neutrally buoyant particles that were suspended in the fluid. A high speed camera took pairs of images in rapid succession. These images were compared to determine distance travelled by each particle over the defined time interval. Surface velocity gradients were determined for each velocity profile normal to the surface. These were spatially averaged across the measurement window to provide a time-averaged, spatially-averaged velocity gradient for each sample at each flow rate. Velocity gradients were used to calculate the friction factor, $f$, from the definition:

$$f = \frac{8\mu(\partial u / \partial y)}{\rho U^2} \bigg|_{y=0}$$

For a closed channel, the dependency of $f$ on Reynolds number $Re = U L / u$ can be determined exactly from the conservation of momentum equation and a no-slip boundary condition at the wall surface.

For our channel geometry, the analytical solution showed that $f Re = 22$. For two parallel plates and wide plates, $f Re = 24$. Several *C. glomerata* filaments with variable coatings (mixed diatom community, E. coli bacteria, bare *C. glomerata*, bare *C. glomerata* fixed in formalin) and non-biological filaments (steel wire, surgical thread) were tested in the uPIV channel (Fig. 30). Stainless steel wire results agreed well with the analytical solution, thus validating our experimental setup. Of the algal filaments, only the preserved *C. glomerata* behaved as predicted by fluid flow theory. Friction factors for all other filaments are higher than predicted by theory. All filaments with primarily diatom communities exhibited similar behavior and collapsed onto one line. Bare filaments and filaments with primarily bacteria populations collapsed onto another line.
Our results indicate that live *C. glomerata* affects the local flow field in a way not predicted by fluid flow theory and the no-slip boundary condition. This effect is lessened by the presence of diatoms. If this were due to roughness, the bare *C. glomerata* results would fall below the epiphyte covered filaments on Fig. 30. Instead, the diatom communities are closer to the steel wire and the bare *C. glomerata* exhibits the largest deviation from theoretical predictions. Surface stresses on live *C. glomerata* filaments can only be accounted for by a “slip” surface boundary condition. Slip has been measured and accounted for by: surface roughness, surface hydrophobicity, surface gas layer; however, in our study surface roughness did not cause the slip. Ongoing experiments will determine if surface characteristics on preserved filaments were altered or if photosynthesis is creating a gas layer. Our results suggest that nutrient replenishment at filament surface experience higher shear stress and corresponding higher nutrient mass transfer velocity than based on the fundamental theory of mass transfer in a laminar flow. This finding implies more rapid nutrient mass transfer velocity in the proximity of filament than the nutrient mass transfer prediction that is based on the fundamental fluid flow theory in a laminar flow.

**Plans**

We will continue to explore non-local theories of geomorphic transport laws. This will include looking for evidence of non-locality in hillslope transport, developing more mechanistically the origin of non-locality in flux, and examining consequences for landscape evolution. We will fully explore the potential of satellite precipitation data over complex terrain for improving flood and hazard prediction.

We intend to formulate a model for nitrogen fixation in streams driven by abiotic variables and LiDAR generated topography. Furthermore, work will continue on grazer and periphyton distribution scaled by abiotic variables in streams.
**DW09: Link food webs and channel networks, including dynamic response**

In contrast to DW03, this project is directed at documenting and explaining seasonal and interannual dynamics linking stream biota and physico-chemical processes. A major goal is to build sufficient understanding to guide the development of dynamic versions of the Ripple type model and to expand it to other organisms (i.e., algae and frogs).

We have investigated controls determining drainage area thresholds for algal accrual and significant nitrogen loading to streams by cyanobacterial fixation (Power et al., 2009, Finlay et al., 2011, Welter et al., submitted NSF proposal), grazer control over algal biomass (McNeely and Power, 2007, McNeely et al., 2007) and insect grazer effects on and responses to successional changes in algal-epiphyte assemblages which occur at different rates in different habitats through the summer low flow season (Furey et al., submitted); changes in carbon sources fueling steelhead and other predators (Finlay et al., in press), and aquatic insect emergence (Power et al., 2004 and Power et al., Moreno-Mateos et al., in preparation). A mechanistic understanding of the relationship between environmental boundaries or gradients and regime change should help us forecast how spatial domains under one control regime or another should expand or contract, and how boundaries between regimes will relocate over landscapes, with changes in land use, climate, or biota (e.g., invasions, disease spread, or extinctions that weaken interactors or change food web membership).

**Long distance connections: landscape, stoichiometric, and food web controls of nutrient spiraling (cycling and transport)**

Identifying landscape thresholds, scaled to drainage area, where outcomes of such interactions change is a necessary step, but insufficient for forecasting basin-wide production or fluxes (of, for example, algal carbon, nitrogen, fish, or mosquitoes) needed for forecasting global change. Clearly, the “paint by numbers” approach (identifying, then re-mapping domains of regimes as they would be altered by external drivers) is insufficient because integrated basin-wide outputs are not simply additive. We are engaged in three investigations of long distance linkages to inform our attempts to scale up from knowledge of local processes and interactions. The first is an NSF funded study, with three young faculty who were PI Mary Power’s former graduate students (Jacques Finlay) or NCED postdocs (John Schade and Jill Welter). We have two manuscripts in press that are based on our 3-year NSF-funded study of nutrient spiraling (cycling and downstream advection) through different parts of the drainage network, comparing heterotroph-dominated headwaters to autotroph-dominated mainstem reaches. The nutrient spiraling project examines the interplay of food web interactions, landscape structure, and stoichiometrically constrained nutrient cycling as it influences N and P flux vs retention down the river drainage network (Finlay et al., 2011, Schade et al., 2011).

**Long distance connections: river-to-watershed fluxes mediated by insect emergence and nitrogen fixation.**

A second cross-ecosystem linkage project examines lateral (river—watershed exchanges), adding an explicit year-round seasonal dimension to our previous studies that link algal dynamics to watershed fluxes of insects that support ‘terrestrial’ insectivores like spiders, lizards, bats. Postdoc David Moreno-Mateos’ work with birds, and graduate student Kirsten Hill’s work with ground spiders compares upland wetland production and consumption of insects to riparian dynamics. Moreno-Mateos has found that upland wetlands are
the major sources of insects to terrestrial insectivores during winter, when the river experiences scouring, cold, turbid flow, but annual terrestrial insect fluxes from wetlands are dwarfed by insect fluxes from the river during summer low flow. We are analyzing the importance of ground-water versus precipitation in maintaining wetlands, which may maintain resident insectivores when rivers are flooding and too turbid and disturbed to support high rates of insect production.

We were first alerted by collaborator Rex Lowe of Bowling Green State Univ. to the ecological importance of a group of diatoms that contain nitrogen fixing cyanobacterial endosymbionts, and encrust large proliferations of the macro-alga *Cladophora* when it proliferates in sunny mainstem reaches (> 100 km² drainage area) in the Eel River. *Epithemia* and other nitrogen fixers increase nitrogen availability markedly when channels become wide enough to support abundant populations. NCED postdoc Paula Furey has examined seasonal patterns of epiphyte succession in the river, and also the effect of one of the most common macro-invertebrate grazers, larval midges (*Pseudochironomus richardsoni*, Diptera), on epiphyte assemblages.

There is a group of diatoms that contain nitrogen fixing cyanobacterial endosymbionts, and encrust large proliferations of the macro-alga *Cladophora* when it proliferates in sunny mainstem reaches (> 100 km² drainage area) in the Eel River. *Epithemia* and other nitrogen fixers increase nitrogen availability markedly when channels become wide enough to support abundant populations. Jill Welter (Asst. Prof. at St. Catherine’s University, Minneapolis) has, discovered that when *Cladophora* proliferations become covered with *Epithemia spp.*, they increase areal rates of nitrogen loading to the river ca. 6-fold. We are monitoring the spatial and seasonal variation in the algal proliferations that drive this loading, and are investigating its consequences for nitrogen limited river food webs, river-to-watershed fluxes of emerging insects (Power et al., 2009), and contributions by rivers to nearshore marine ecosystems.

**Long distance connections: river-to-ocean**

In a new collaboration, we are investigating algal-mediated river-ocean-atmosphere linkages. Algal proliferations (which graduate student Jack Sculley estimates to increase ecological surface area in mainstem channels in the Eel by ca. 200,000x) also increase rates of areal nitrogen loading to the river six-fold (Jill Welter et al., unpublished data, Fig. 31).

Riverine algae transported through the Eel to the Pacific are voraciously, and preferentially (over local seaweeds) consumed by intertidal amphipods that abound in the delta’s gravel sediments (Charlene Ng, dissertation). Algal mediated fluxes in carbon, nitrogen, Fe, Si, or other elements may enhance amphipod production consumed by fish and local shorebirds, and eventually may stimulate plankton blooms in near-shore marine waters off the mouth of the Eel, particularly during winter when...
coastal upwelling is suppressed. We are collaborating with atmospheric scientist Inez Fung, coastal oceanographer Zack Powell, marine chemist Jim Bishop, and coastal stratigrapher Chuck Nittrouer, to study how interannual variation in hydrologic regimes and spatial environmental variation down the entire 9500 km² Eel River basin influence annual basin-wide export of sediments, solutes, and particles, including algal-derived carbon and nitrogen, to the sea. This challenging task is usefully constrained by century-to-millenium scale records, some with annual resolution, from sedimentary cores taken from deep marine canyons off the mouth of the Eel River. These canyons typically collect about 30-50% of the sediment exported by the river during a given year. Cores collected for the ONR-STRATAFORM project (led by C. Nittrouer, Univ. Washington) have been carefully dated, and subjected to thorough analyses of sediment grain sizes, varve thickness, and chemistry. No scientist had previously looked at core diatoms, however. Jack Sculley (dissertation) has identified all of the Eel’s common epiphytic riverine diatoms in these deep cores, including several epiphytic taxa (Epithemia, Cocconeis, Rhoicosphenia, Gomphonema) that appear to indicate the magnitude of riverine macroalgal blooms. His analyses (Sculley et al., 2009) suggest that diatoms are a useful, and for this system new, paleoproductivity indicator (Fig. 32).

Sculley has also confirmed that the marine diatom Chaetoceros is a strong indicator of marine upwelling in Eel River cores, as it is elsewhere in the ocean. SeaWifs imagery that reveals annual chlorophyll bloom magnitudes of nearshore marine phytoplankton reveals a stronger relationship of marine productivity with riverine algal productivity (indicated by Epithemia) than with marine strong upwelling (indicated by Chaetoceros) (J. Sculley, dissertation). Because the Nittrouer cores were collected in 2001 and SeaWifs imagery began in 1997, data for this comparison are limited to four annual points, but we are investigating other imagery, and the possibility of collecting another core.

**Interactions regulating food web productivity and structure (nutrient and contaminant cycling, metabolism) in drainage networks**

Observations on the Eel River suggest that stream channels can be important sources of variation in mercury in stream food webs (Fig. 33). In year 9 we expanded this research to Minnesota streams, where surveys were conducted to understand mercury transport through river networks and into aquatic food webs, and the effects of agricultural modifications on carbon transport from soils to rivers. Land use gradients were used to consider the role of watershed and internal source of DOC sources in influencing mercury transfer to food webs.

In Minnesota we have hypothesized that tile drainage will influence carbon composition and flux to river. This work, led by Postdoc Brent Dalzell, shows that intensive tile drainage accelerates soluble losses of both dissolved organic and inorganic carbon relative to standard tile drainage. By incorporating solute losses, this work suggests that agricultural activities are accelerating carbon losses by a greater degree than previously recognized (Dalzell et al., in press). This work may also help explain the long term increase in dissolved inorganic carbon export by rivers observed for the Mississippi River, and in other modified landscapes. Interestingly,
preliminary results indicate strong effects of in-channel processes on DOC, much as we have observed at the ACRR (Fig. 34). We plan further work to understand how these processes lead to similar network influences on carbon transport in both the relatively pristine ACRR and heavily modified agricultural watershed.

**Plans**

We plan to focus on a two-pronged collaborative effort to model the spatial and temporal controls over the production and fate of algae in the Eel River as a model system for analyzing landscape-climate-ecosystem linkages. We will refine the dimensionless analyses of Warnaars et al. (2007) and Barnes et al. (2007) to include seasonality and more realistic and spatially resolved light and flow information to model algae with an empirical approach. An alternative approach will be to parameterize and refine a deterministic differential equation model that tracks major sources and sinks for algal production through the seasons (winter rainy, spring growth, and summer senescence) and down the river network, from dark but stable headwaters to more productive but unstable mainstems. The latter project has four goals: 1) define seasonal and spatial production rates as limited by light, time since disturbances (chiefly bed movement), nutrients, temperature, and algal biomass; 2) link all major sinks (or fates) for algae, which include grazing, export, and decomposition to site-specific and seasonal landscape controls; 3) predict the expected biomass and taxonomic dominance of algae at different times and river network positions that result from these interactions and 4) derive windows of space and time where we expect algal-mediated food web transfers (to fish) and landscape transfers (to watershed via insect emergence and to marine coastal zones via algal export) to be important.

We will also continue to do research on mercury cycling, with a particular emphasis on analyzing mercury stable isotopes in food webs of the SF Eel to determine sources and sinks of toxic methylmercury in the watershed. Hypotheses will be tested to understand the dominance of heterotrophic and autotrophic organisms in river network nutrient cycles.

**► DW10: Desktop Watersheds model code development**

**Plans**

This marks a transition year for the Ripple model, our model for doing limiting factors analysis based on digital terrain data and a populations dynamic model for salmon. The user interface we built is based on Visual Basic and, unfortunately, this software is being abandoned. We have also initiated a contract with Google that will eventually lead to a Google-based system for determining the channel network and the slope and drainage area attributes of the network. Consequently, we have halted further development of Ripple built on the ArcMap interface (with Visual Basic). Our plan is to shift to a web-based system instead.

Through NCED support our collaborator, Stillwater Sciences, did develop versions of Ripple for Chinook and steelhead. We will implement this on the web-based system.

**► DW11: Use of Desktop Watersheds models in land-use management decisions**

In collaboration with Stillwater Sciences, the Ripple model is being fully parameterized for application to Pescadero Creek with support from the San Francisco Regional Water Control Board.

**Plans**

With successful development of the Google-based channel network quantification, we anticipate releasing Ripple as an application working in the Google Earth Engine. This will require obtaining further funds beyond NCED support.
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<thead>
<tr>
<th>Project</th>
<th>Milestone/Deliverable</th>
<th>Progress</th>
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<tr>
<td>DW01</td>
<td>Numerical technique for feature extraction</td>
<td>The channel extraction and channel network mapping methodology, GeoNet, has been successfully applied to flat areas where valleys are typically poorly defined.</td>
</tr>
<tr>
<td>DW02</td>
<td>Topographic signatures of properties and processes</td>
<td>The use of “directed distance from the divide” as the scale parameter (instead of Horton’s stream order or upstream contributing area) was introduced for performing detailed probabilistic analysis of landscapes over a broad range of scales. This scale parameter offers several advantages for applications in hydrology, geomorphology, and ecology in that it can be directly related to length-scale dependent processes, it can be applied seamlessly across the hillslope and fluvial regimes, and it is a continuous parameter allowing accurate statistical characterization (higher order statistical moments) across scales. Further analysis of routing in river networks using the “dynamic tree” concept was completed. This describes the directed transport along the links of a “static tree” that has given topology and link-length distribution, as well as other space- and time-dependent attributes.</td>
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<tr>
<td>DW03</td>
<td>Predictive mapping of key biotic populations: relationships to habitats</td>
<td>A light model to predict solar radiation flux at high spatial and temporal resolution across a watershed is under development. This model gives for the first time spatially integrated estimate of light inputs into channels.</td>
</tr>
<tr>
<td>DW04</td>
<td>Understanding linkages among solutes, soil production and biota</td>
<td>At the Angelo Coast Range Reserve a hillslope is intensively instrumented to explore the coupling between hydrology, vegetation, and geochemical evolution of waters. A theory for prediction of the depth of the weathering zone under the hillslope is being developed.</td>
</tr>
<tr>
<td>DW05</td>
<td>Controls on rate of landslide transport to channels</td>
<td>Considerable effort was given to developing an efficient parallel program to calculate drainage area (which, via subsurface flow pathways) strongly influences pore pressure evolution. This has contributed to the US Geological Survey ArkStorm emergency preparedness study of the consequences of a major storm system striking California.</td>
</tr>
<tr>
<td>DW06</td>
<td>Sediment routing: coarse sediment transport in shallow flow; fine sediment interaction with coarse bed</td>
<td>A river morphodynamic model has been coupled with a mixed grain size sediment transport model which predicts the emergence of surface grain size patchiness. Unexpectedly the emergence of surface grain size patchiness effects the amplitude and wavelength of alternate bars. Spectral analysis of the bed elevations along with the statistics of tracer travel distances in the large SAFL flume revealed a strong dependence of travel distances on the spectral slope of the bed topography. The results showed that the statistics of tracer travel distances depend on the complexity of the bedforms and that the larger particles move farther (once entrained) than the smaller particles for the same duration of time. The mean travel distances of smaller particles do not get much affected by bed topography as their dynamics are mainly dominated by particle hiding effects.</td>
</tr>
<tr>
<td>DW07</td>
<td>Predictive models for channel incision</td>
<td>A coupled meandering and bedrock incision model predicts upstream propagating knickpoints after cutoff, leading to distinct, but unpaired strath terraces. A first order model was developed to predict for granular flows the relationship between particle size distribution and boundary forces. In addition, a new distinct element model for granular flow was developed that explicitly treats effects of fluid between the particles. Although simple, initial numerical runs reproduces velocity profiles observed in our experimental studies.</td>
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### Project Milestone/Deliverable Progress

<table>
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<th>Milestone/Deliverable</th>
<th>Progress</th>
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<tr>
<td>DW08</td>
<td>Upscaling transport laws and biotic processes</td>
<td>Non-local linear transport and erosion laws were found to successfully reproduce key topographic steady state statistics of both hillslopes and fluvially-cut landscapes. The results of these fractional derivative models for flux and erosion offers alternative explanations for fundamental landscape from and dynamics.</td>
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<td>We applied dimensional analysis to develop a functional relationship predicting larvae density of the caddisfly <em>Glossoma</em>. A power law was found based on dimensionless local hydraulic and larval density variables that was applicable to areas where <em>Glossosoma</em> were present. <em>Glossosoma</em> densities were negatively correlated with streambed relative roughness and positively correlated with the ratio of inertial to gravitational forces in the stream.</td>
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<tr>
<td>DW09</td>
<td>Link food webs and channel networks, including dynamic response</td>
<td>Our Eel River field studies have revealed that upland wetlands are the major sources of insects to terrestrial insectivores during winter, when the river experiences scouring, cold, turbid flow, but annual terrestrial insect fluxes from wetlands are dwarfed by insect fluxes from the river during summer low flow.</td>
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<td>Based on the marginal and join statistics of space-time precipitation from new remote sensing sources, we have developed a robust methodology that permits optimal fusion of high resolution multi-sensor measurements (i.e., rain-gages and ground-based radars) with low-resolution space-borne rainfall data, to be used for hydrologic and hazard prediction applications in remote watersheds around the world.</td>
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<tr>
<td>DW10</td>
<td>DW model code development</td>
<td>In Minnesota, we have found that tile drainage accelerates soluble losses of both dissolved organic and inorganic carbon relative to standard tile drainage. By incorporating solute losses, this work suggests that agricultural activities are accelerating carbon losses by a greater degree than previously recognized. This work may also help explain the long term increase in dissolved inorganic carbon export by rivers observed for the Mississippi River, and in other modified landscapes.</td>
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<tr>
<td>DW11</td>
<td>Use of Desktop Watershed models in landuse management decisions</td>
<td>We have initiated a contract with Google.org to use their application programming interface on Earth Engine to make Desktop Watershed programs broadly available.</td>
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<td>Ripple is being fully parameterized in application to a watershed south of San Francisco.</td>
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### References Cited (non-NCED)


IIb. Subsurface Architecture (Deltas) Integrated Program

**Lead PI:** David Mohrig

**Program Manager:** James Buttles

**Contributing PIs:** Chris Paola, Gary Parker, Robert Twilley, Vaughan Voller, Benjamin Hobbs, Efi Foufoula-Georgiou, Rina Schumer

**Executive Summary**

**Goal:** The Subsurface Architecture (SA) Integrated Program (IP) focuses on developing methods for predicting delta evolution in support of sustainable restoration of the Mississippi River Delta (MRD). This IP emphasizes the development and use of predictive models to integrate information from modern field studies of channel network self-organization and delta ecology, as well as from subsurface and experimental studies of delta lobe development. We are focusing on building connections between often disparate models and research efforts aimed at describing the geomorphic, ecologic, and social tradeoffs of delta evolution and maintenance. We are also developing methods to use subsurface records to understand how the delta maintained itself naturally (i.e., before human influence), with the aim of using these natural self-maintenance processes to guide the design of a sustainable delta-restoration program. Our goal is to develop a fully integrated, quantitative description of delta evolution that can benefit sustainable restoration of these coastal lowland systems.

**Approach:** NCED’s transdisciplinary approach, with emphasis on prediction, together with its status as an independent national research center, make it ideally suited to provide understanding and tools that support restoration of the MRD, an issue long recognized as fundamental to protecting New Orleans and the Gulf Coast infrastructure from devastation by hurricanes. NCED’s delta land-building field site, the Wax Lake Delta (WLD), has significantly contributed to our understanding of natural delta systems.

**Highlights:** During the past year, the researchers involved with the SAIP have continued to gather data and advance discoveries relevant to delta construction. These achievements are summarized in the following descriptions within each of the 10 IP subprojects. During the past year, program participants also took the first steps in organizing a “Deltas” manual that, when finished, will be made available to all parties interested in the maintenance and management of coastal river systems.

**Projects**

SAIP has thrived because of substantial interactions among a group of researchers who have different backgrounds: ecology, economics, engineering, mathematics, and sedimentary geology. All of these researchers are working toward modeling efforts on the Mississippi River Delta that are designed to couple natural and social science. Below we summarize findings for the 10 SA projects.

<table>
<thead>
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<th>Project</th>
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<td>Current sediment budget and subsidence distribution in Mississippi Delta</td>
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<td>SA02</td>
<td>Behavior and deposition of cohesive sediment</td>
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<td>SA03</td>
<td>Vegetation-sedimentation interaction in island and marsh development and maintenance</td>
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<td>SA04</td>
<td>Reconstructing delta dynamics from seismic records</td>
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<td>SA05</td>
<td>Reconstructing delta dynamics from cores and other records</td>
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<td>SA06</td>
<td>Modeling land building: integration with Louisiana State University’s Coastal Louisiana Ecosystem Assessment and Restoration project</td>
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<td>SA09</td>
<td>Coastal system response to rising relative sea level</td>
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<td>SA10</td>
<td>Social tradeoffs in Mississippi Delta restoration</td>
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SA01: Current sediment budget and subsidence distribution in Mississippi delta

Sediment transport and river discharge in the lowermost Mississippi River

Using a large data set of cross-channel transects (n=2650) for the lower Mississippi River, graduate student Jeff Nittrouer and PI David Mohrig have determined its cross-sectional area as a function of water discharge and downstream position (Figs. 1, 2). These data define a high discharge and low discharge trend for the river. During low-water discharge the cross-sectional flow area increases downstream, while during high-water discharge the cross-sectional flow area decreases downstream (Fig. 2). The mean flow velocity associated with these trends can be estimated from water discharge divided by the local measure for cross-sectional area (Fig. 3). Mean velocity is calculated to decelerate while approaching the coast during low-flow conditions and very weakly accelerate to the coast at the highest water discharges. These calculated trends are consistent with measurements of velocity collected at some gaging stations and by Nittrouer aboard the UT-Austin, R/V Itasca. The velocity data have been used to estimate values for skin-friction shear velocity so that bed-material load can be calculated using appropriate sediment-transport algorithms. Once again, these estimates of bed-material load (Fig. 4) are consistent with those measured by Nittrouer aboard the R/V Itasca. Changes in bed elevation associated with these spatial and temporal changes in bed-material load have been estimated by using the Exner equation and results show a tendency for the upper reaches of the backwater segment (200-600 km above the Mississippi outlet) to be a site of aggradation, while the lower 200 km of the Mississippi River is defined by a tendency for the channel bed to degrade. From this analysis it is clear that accurate prediction for the evolution of the Mississippi River channel requires sophisticated treatment of the time varying, non-uniform flow associated with the coastal river.

This research has demonstrated that flow and sediment-transport dynamics in the backwater zone of the Mississippi River not only modulate the timing and magnitude of sand flux to the river delta and neighboring marine environment, they also affect the development of important channel properties including: the extent of alluvial cover on the river bed, the rates of lateral channel migration, and the location of nodal channel avulsions. The mixed bedrock-alluvial segment measured for the river, described in last year’s annual report, coincides with a river reach that is prone to bed erosion. Measurements by Hudson and Kesel (2000) have defined a change in lateral migration rate for the Mississippi River with distance downstream and the position of this change coinciding with: the predicted zones of bed aggradation and erosion; high rates of lateral movement in the region where the channel bed has a tendency to aggrade (i.e., 200-600 km above the outlet); and minimal movement where the channel bed has a tendency to erode (river km 200 to the outlet). Finally, the location of the first distributary channel on the Mississippi River, the Atchafalaya River, as well as early points of channel avulsion for the Mississippi River system, coincides with a position of predicted channel-bed aggradation.

Plans

NCED-sponsored field work defining the sediment transport in the lowermost Mississippi River is now complete. Results of this work are presented in Nittrouer’s completed Ph.D. dissertation and summarized in three submitted manuscripts that are currently now under review.
SA02: Behavior and deposition of cohesive sediment

Investigating interactions among sediment transport and biota in deltaic wetlands

With graduate student Ryan Littlewood in the lead, PI’s Paola and Voller are investigating interactions among sediment transport and biota in deltaic wetlands. Observations and common presumption suggest that wetland vegetation can act as a sieve, increasing sediment deposition by baffling flow or by some other method. A lack of predictive understanding of this phenomenon limits the accuracy of mass-balance predictions for growth of deltas. In particular, in the Wax Lake Delta study site, while it might be assumed that all coarse material conveyed to the delta is retained, the same cannot be said for the fine fraction, and so an arbitrary proportion must be assumed. Further, if parameters that optimize deposition of fines can be identified, managers may be able to increase the usable sediment budget of diversion projects throughout the Mississippi River Delta.

Their initial flume experiments demonstrated that arrays of vertical cylinders (Fig. 5), a common laboratory surrogate for plant stems, did not promote deposition of suspended sediment but were instead associated with net scour due to vortices and added turbulence generated by the cylinders. When the cylinders were replaced by artificial vegetation, the chief result was deposition of the sediment, chemically flocculated kaolinite, onto the plastic vegetation surfaces (Fig. 6). Using filamentous green algae, results suggested, though not conclusively, that algal biomass in a section of the flume was positively related to the amount of deposition that occurred there (Fig. 7). Littlewood, Paola and Voller are now focusing their work on mechanisms for sediment trapping along two separate but complementary experimental tracks.

The first track is mechanical, focusing on the hypothesis that flow baffling is an important means by which patches of marsh biota retain sediment. This mechanism presumably requires that a patch of plants or periphyton reduces near-bed shear stress for a sediment-laden flow in such a way that deposition is increased relative to the no-vegetation case, even after accounting for two mechanisms that reduce deposition—scour around obstacles and routing of the flow around the patch. Their studies with dowels have been ineffective due to the production of turbulent eddies that increase scour enough to offset any bulk reduction in flow velocity.

A recent experiment involving bedload transport through and around a patch of thin fins oriented parallel to the flow did demonstrate increased deposition, however (Fig. 8). Follow-up experiments will investigate the hypothesis that enhancement of deposition from obstacles can be predicted as a function of drag production (favoring deposition) and turbulent eddy generation (favoring scour and reducing net deposition).

The second track of research focuses on the adhesion of sediment particles to surfaces. As a depositional mechanism, surface adhesion is hypothesized to be controlled by adhesiveness of surfaces; boundary layer shear that delivers and removes particles; production of new usable surface area by the ecosystem; and the conveyance of accumulated sediment to the bed, either through settling of dead vegetable matter or sloughing of aggregated sediment to the bed. Field observations of sediment flocs adhering to filamentous green algae and stems of marsh grasses suggest that adhesion may be an important control on deposition. Chemical and physical processes may be responsible for such effects. In order to explore the role of surface properties, Littlewood, Paola and Voller are measuring fine particle adhesion to smooth surfaces for
surfaces with varying properties—initially, plastic films with hydrophobic and hydrophilic coatings. Extracellular polymeric substances, sticky microbial polysaccharides that make up biofilms, may also be relevant to such adhesion in that they coat many plant and periphyton surfaces.

**Experimental delta-front dynamics**

With graduate student Antoinette Abeyta in the lead, PIs Paola and Voller have been studying delta front dynamics experimentally to determine how sediment cohesion affects the mechanics, rate, and size distribution of delta-front failures. As ongoing work by the UT group is demonstrating, sediment transport on the delta front can feed back strongly to the dynamics of the delta-top channel system by controlling sediment mass balance on the delta top and influencing channel initiation.

The evolution of river deltas depends on how sediment is transferred to and along the delta foreset. Typically sediment transport along the delta foreset involves mass failures; however the initiation mechanisms and statistics of these failures are poorly understood. Previous studies have generated these mass failures experimentally by injecting a mixture of sediment and water into ambient water. These types of studies provide information about the behaviors of the flows, and how the deposits form. However, one of the limitations of these studies is that the slurries are premixed and are injected into the water column, thus artificially generating the flow. It is uncertain where these slurries come from and what sets the initial flow conditions (e.g., density, composition, sediment concentration). Consequently, there is a gap in our understanding of these flows. We do not know the driving factors that influence the occurrence of these flows or how they initiate. Thus, we have devised an experimental system that allows a variety of delta-front failures to self generate.

Abeyta, Paola and Voller have developed a sediment mix that, instead of producing uniform small grain flows on the foreset, as sand does, might self-organize to create larger and more complex flows that would shed light on mass-flow processes on natural delta foresets, which typically include substantial amounts of clay. They built a clinoform using a cohesive mixture of crushed walnut shells and kaolinite, which leads to episodic stick-slip failures, generating spontaneous sediment gravity flows of a much greater variety of sizes and failure modes than the grain flows that occur in typical laboratory deltas. In these experiments, it was observed that slopes undergo a series of morphological changes prior to failure, leaving the slope in a metastable state. The slope develops a concave shape which becomes exaggerated as deposition continues (Fig. 9). There are two mechanisms that trigger the destabilization of the slope, slumping and bed load transport. Once the slope is destabilized, failure is initiated in modes ranging from large, high-energy movements to slow-creeping flows. Also, in this study, they investigated the role of delta progradation rates and their influence on failure size and frequency. Abeyta conducted experiments over a range of water and sediment discharge rates (7.1 to 36.6 cubic centimeters of water per second, 0.5 to 1.3 grams of sediment per second). Neither failure size nor failure frequency changes with discharge rate (Figs. 10 and 11); instead, increases in the progradation rate appear to be taken up by changes in the partitioning of sediment between the steep upper foreset and the more gradual delta-front apron below (Fig. 12). A significant amount of sediment deposition occurs via
slow, creeping-type of mass flows, a mode not generally recognized in the submarine transport literature. Increased sediment supply rates are shown to dampen the influence of failure events by increasing the rate of slow, creeping motion of the sediment.

**Plans**

Develop quantitative measures and theory for predicting the effect of obstacle form and aerial density on trapping of bedload and suspended sediment.

Investigate critical surface properties for adhesion of fine sediment, including flocs, onto subaqueous biotic and abiotic surfaces.

Investigate the applicability of conventional sediment transport laws to predicting the flux of flocculated fine sediment.

In 2010, Abeyta, Paola and Voller moved the delta front experiments to a larger facility, allowing them to conduct experiments at a larger scale and in deeper water. They hypothesize that with more depth, the flows will have more space to self organize into larger, more complex flows, and perhaps to generate turbidity currents. The latter would be a significant breakthrough: to date no one has documented spontaneous evolution of mass failures to turbidity currents at laboratory scales.

**SA03: Vegetation-sedimentation interaction in island and marsh development and maintenance**

**Nitrogen diagenesis model within the Wax Lake Delta**

LSU graduate student Ben Branoff and PI Robert Twilley have begun development of a numerical model to simulate nitrogen diagenesis within the WLD. To successfully simulate diagenesis, each step of the cycle must be quantified based on the immediately surrounding soil characteristics. These include but are not limited to temperature, pH, saturation and vegetation coverage. The first step is development of the unit model. The unit model is a representation of all possible pathways for nitrogen. It is a mass balance of incoming, transformed and outgoing nitrogen. Once all of these pathways are properly represented, the model will simulate nitrogen cycling within a “unit” of unique environmental characteristics. Such a unit may be taken as a given area of the delta. The actual nitrogen cycle within multiple units for WLD has already been measured in core samples as part of ongoing experiments by the Louisiana State University (LSU) research group led by Twilley and LSU Asst. Professor Victor H. Rivera-Monroy. Modifying the model so that it accurately simulates these experiments is a crucial goal before scaling up.

Once the unit model has been calibrated, it may be replicated and applied to a given area in the form of a communicating grid of cells. Within the grid, each unit model fills one cell and performs based on its unique inputs of elevation, temperature, vegetation coverage, etc.
It then passes on its output to its surrounding cells. In this way, water flowing through the delta will be subject to the nitrogen cycle within each cell, until it flows outside the bounds of the model. Ideally, if the model is applied correctly, it will accurately simulate the measured values of various nitrogenous compounds throughout the delta.

A conceptual representation of the various levels of the model is shown in Figure 13. Visual Basic and Microsoft Visual Studio will be used to build an application in which the user may enter preferred values for initial conditions and rate constants. A screen shot of the user-interface is shown in Figure 14.

**Nitrogen cycling within Wax Lake Delta**

Simulations of the hydrodynamic interactions within the delta will be necessary to accurately represent nitrogen diagenesis. To do so, two strategies have been explored. The first is the acquisition of model outputs from previous hydrodynamic simulations of the delta. As of yet, sufficient outputs have not been acquired. The second is by direct measurements of flow velocities along transects of Mike Island in WLD (Fig. 15). By correlating flow velocities with elevation, a delta-wide hydrodynamic representation may be possible.

During the spring and summer of 2010 the LSU group continued work investigating nitrogen cycling within WLD. This work is done in conjunction with a Louisiana Sea Grant funded research proposal to investigate nitrogen cycling in WLD marshes through PI Twilley and LSU Researcher Rivera-Monroy and Bevington. Initial sampling of flow velocity and direction in marsh/mudflat habitats at Wax Lake was completed in spring and summer of 2010; the maximum flow velocity measured was 7.5 cm/s; see representative flow fields from April 14, 2010 sampling in Figure 15. These results indicated that the planned experimental design, which utilized a flume setup to determine sediment-water column flux rates would not be sufficient. A velocity of greater than 10 cm/s is required based on the planned flume design. We re-designed our experimental setup and will now utilize in situ sampling and mesocosms to measure nitrogen flux rates.

During the fall of 2010 the LSU group began measurements of inorganic nutrient fluxes using intact sediment cores. The results of this work can be seen in Figure 16. These results show a significant flux of inorganic nitrate moving from the surface water into the sediments at both sampling locations and support the hypothesis that diffusion and microbial processing are removing nitrate from the surface water as it moves through the marsh/mudflat habitat. However these results are preliminary and measurements of inorganic nutrient fluxes, as well as gas fluxes and nutrient pools in pore water, sediment, surface water and vegetation will continue throughout the spring and summer of 2011.
Organic-clastic interaction—Applications of geometric models

To this point in time the modeling of the growth of ocean deltas has been essentially based on treatments of the transport and deposition of mineral sediments. It is suspected, however, that biochemical processes, in particular the accumulation and decay of organic matter (peat), could have a significant role in controlling the nature of delta growth. Graduate student Jorge Lorenzo-Trueba, working with PIs Voller, Paola, and Twilley, is working on a novel geometric model that takes into account the role of peat production and decay in delta growth dynamics. The domain of this model, a long profile cross-section through the delta deposit, is shown in Figure 17. The objective of the model is to track the dynamics of the delta deposit by tracking the movements of the Alluvial-Bedrock Transition (ABT)—where the sediment first deposits on the bedrock—and the Shoreline (SH)—where the sediment enters the ocean. These moving boundaries are controlled by the sediment input to the system, the change in base-level, and the subsidence of the basement bed-rock. Accounting for peat production and decay is achieved through the specification of a source term that is tuned to act with different rates in the fresh and saline regions of the delta. The model assumes that peat accumulation is much higher in fresh than in saline environments and that the bedrock is subject to a hinge-style pattern of subsidence. Preliminary results from this model were presented at the AGU fall meeting in 2010. A paper is currently in preparation.

A standard behavior for the model is for the shoreline to undergo an initial progradation (advance) followed by a shoreline transgression (retreat). In this system the onset of the transgression is controlled by the rate at which accommodation space is created by the subsidence and sea-level change. Figure 18 shows the predicted time to transgression with increasing accommodation rate $K$. Three possible behaviors can be observed. At low $K$ values (region A), transgression is never achieved, i.e., in both the pure mineral delta (dashed line) and delta with organics (solid line) the shoreline advances continuously. At medium values of $K$ (region B), transgression (retreat) of the shoreline is achieved. Interestingly, at these medium values, even though the organic delta shoreline initially advances more rapidly than its mineral only counterpart, it also undergoes transgression at an earlier time. Essentially as the delta gets too long, the creation of organic material and supply of sediment is insufficient to keep up with the increasing rate of the accommodation space. On the other hand, larger values of $K$ (region C) quench the initial rapid advance of the organic delta and, although transgression occurs for all deltas at these high values of $K$, it now occurs first in the mineral only delta. The model presented above is based on a diffusion treatment of the sediment transport and deposition. Numerical and analytical treatments of this model were reported in two papers last year, (Lorenzo-Truba and Voller, 2010, and Voller, 2010a).

**Plans**

The nitrogen diagenesis unit model is well underway and is expected it to be completed this summer, at which point scaling up may begin.

We will further develop our simple time stepping geometric model for delta growth dynamics and make this a contribution to the planned NCED handbook on delta restoration management.

Since May 2011, Bevington has taken over a large share of the completion of the sediment deposition/erosion analyses initiated by LSU researcher Guerry Holm. This includes completion of the 2008 flood,
storm, cold front sediment budget which will result in the following manuscript: “Patterns of sediment deposition and erosion following spring flood, tropical storms and cold front passage in 2008,” with planned submission spring 2011 to *Estuaries and Coasts*.

The LSU group is working to complete the analysis of the vegetation community composition data that were collected along the previously established transects at WLD. They will determine trends in community composition and change as a result of environmental factors including inundation frequency. This analysis will be completed in Fall 2012, with manuscript submission in early 2012.

Work will continue with NCED ecology colleagues to integrate delta morphologic models with ecological prediction.

A paper will be submitted on the role of organic production/decay in delta growth dynamics.

▶ **SA04: Reconstructing delta dynamics from seismic records**

There was minimal work completed on this project during the past year. Time was spent writing up results from the previous two years and rebuilding the seismic project used to study sedimentation and subsidence patterns associated with land in southern Louisiana adjacent to the Mississippi River.

**Plans**

Results from previous NCED-related studies will be submitted for publication in refereed journals. MS student Chris Armstrong at UT-Austin will finish study of the control of growth faulting and spatially varying subsidence on pre-anthropogenic patterns of sedimentation associated with delta channels and wetlands.

▶ **SA05: Reconstructing delta dynamics from cores and other records**

During the past year, UT graduate student John Shaw working with Mohrig has collected the first set of high resolution bathymetric data defining the distal ends of distributary channels on the WLD (Fig. 19). The data and resulting maps are intended to illustrate how these channels grow seaward over time. The surveys show that completely subaqueous extensions of the distributary channels persist for distances up to 2 km seaward of last subaerial levee. The subaqueous channels lose definition at their distal ends through a combination of channel-bed shoaling and loss of bank relief. Channels bifurcate in this region, although the number and symmetry of the bifurcations changes from channel to channel. Very little bathymetric relief is observed at the tips of the subaqueous channels, calling into question the role of channel-mouth bars in generating the bifurcations observed in this delta-channel network.

Figure 20A shows the trends in channel bed and bank depth as a function of downstream distance on Gadwall Pass (Fig. 19). These data lead to a conceptual model for delta-front progradation where channel extension is driven by the combination of channel-bed erosion and channel-bank sedimentation (Fig. 20b).

**Plans**

The channel network for the sub-aerial delta is stable over tens of years, so it is very likely that the dynamics of channel initiation at the distal ends of the channels set the long term morphology for the distributary system. Future work involves
measuring fluid and sediment fluxes through the subaqueous channels during the annual flood event of 2011 (between March and May). This campaign will provide NCED with the necessary information on patterns of erosion and deposition to guide development of a numerical model describing growth at the tips of subaqueous distributary channels.

► SA06: Modeling land building; integration with Louisiana State University’s CLEAR project

**Fish population models and delta growth**

LSU post-doctoral research associate Paul Venturelli and Twilley are working on a mathematical model for exploring how land building affects fish productivity. The model describes how fish productivity on an evolving delta changes in both time and space, and the extent to which these patterns vary with food web structure. By linking fish productivity to delta morphology, this work is improving our ability to predict the effects of a given land building strategy on coastal fisheries.

The working model is comprised of five layers: bathymetry, water levels, habitat, basal prey, and fish. In partnership with NCED collaborator Doug Edmonds (Boston College), we used the numerical flow and transport model Delft3D (version 3.28) to generate three static bathymetric maps (Layer 1); one from each of early, middle, and late in the simulated development of a coastal delta. Each map is made up of 3750 x 2500 cells, each 2 x 2 m. WLD serves as the calibration template for distributing habitat types on all three grids (e.g., Fig. 21). Water (Layer 2) is added to each of these maps by obtaining gauge data from a station on Atchafalaya Delta, Louisiana. Because these water levels fluctuate over an uneven bathymetry, some cells are inundated for more hours of the year than others. Using rules that are based on empirical data from WLD during summer 2007 (Guerry Holm, unpublished data), the model converts each cell’s inundation time to one of 6 habitat types (Layer 3): deep, open water; submerged aquatic vegetation; deep emergent plants; shallow emergent plants; woody plants; and shallow, unvegetated substrate. Each cell also contains dynamic, independent populations of five invertebrate prey types (two size classes of zooplankton and three size classes of benthos; Layer 4). The equilibrium densities of each of these prey types depends on habitat type. The fifth and final layer is a 5-species individual-based fish model that simulates 50 years of fish population and community dynamics on each of the 3 spatial grids. Two of these species prefer vegetated marsh habitat and two prefer channels and open water. The fifth species is a general predator. An individual-based approach is used because it allows for movement, which is essential to generating realistic patterns of productivity in both space and time. Individuals in the model move in response to fluctuating water levels, habitat type, prey availability, and predator density. Individuals also consume prey and grow, experience mortality (natural, starvation, predator, and stranding), and reproduce. Fish productivity on a given delta is an emergent property of all of these processes.

![Figure 21. The distribution of 6 habitat types during the early stages of delta formation. The map is made up of 3750 x 2500 cells, each 2 x 2 m. A habitat type was assigned to a cell based on the number of hours in a year that it was inundated.](image)

**Inundation model**

One of our central efforts in regard to restoration of the Mississippi Delta has been an inundation model that can be coupled to our existing macroscale land-building model (Kim et al., 2009). The inundation model allows the prediction of vegetation succession on newly-built land as a delta builds out.
The geometry of the delta is represented in Figure 22. The coarse structure, Figure 22a, is predicted with the land-building model (Kim et al., 2009). The delta is assumed to be axially symmetric with a specified angle $\Theta$ and the radial coordinate from the delta vertex is denoted with $r$. The distance between the vertex and the shoreline is denoted as $r_s$. The width of the fan-delta, $B_f$, in each transect is equal to $r \Theta$. The fine structure of the delta in each transect, Figure 29b, is characterized in terms of local bed elevation, $\eta$, mean bed elevation, $\eta_{av}$, width of inundation $B_i$, average water surface elevation, $\xi$, and probability density of bed elevation, $p_e$ that corresponds to the portion of the transect at distance $r$ from the vertex with elevation between $\eta$ and $\eta + d\eta$.

For the definition of probability density function,
\[
\int_{-\infty}^{+\infty} p_e(\eta, r) \, d\eta = 1
\]
where $-\infty$ and $+\infty$ respectively denotes points that are very deep in the bed deposit and very high in the water column.

For any value of average water surface elevation $\xi$, the inundated and emergent fractions, $F_i(r, \xi)$ and $F_e(r, \xi)$ respectively, of the transect are, with the aid of Eq. (1), respectively defined as
\[
F_i(r, \xi) = \int_{-\infty}^{\xi} p_e(\eta, r) \, d\eta \\
F_e(r, \xi) = 1 - F_i(r, \xi)
\]

The width, $B_i$, and the mean depth, $H_i$, of inundation are thus computed as
\[
B_i(r, \xi) = B_f(r) F_i(r, \xi) \\
H_i(r, \xi) = \xi - \int_{-\infty}^{\xi} \eta p_e(\eta, r) \, d\eta
\]

The average water elevation in each transect, $\xi$, is computed for given values of water discharge, $Q$, and sea level, $\xi_{\text{sea}}$, solving the backwater equation expressed in terms of specific energy $E$
\[
\frac{dE}{dr} = -S_f
\]
where the specific energy is defined as
\[
E = \xi + \frac{U_{\text{flow}}^2}{2g}
\]
Here $U_{\text{flow}}$ denotes the mean flow velocity computed as
\[
U_{\text{flow}} = \frac{Q}{B_{\text{flow}} H_{\text{flow}}}
\]
with $B_{\text{flow}}$ and $H_{\text{flow}}$ defined as effective width and mean depth of the flow over a surface that typically only partially inundated. The term on the right hand side of Eq. (4), $S_f$, represents the losses of specific energy per unit length, i.e. the friction slope; it is computed as
\[
S_f = C_f \frac{U_{\text{flow}}^2}{g H_{\text{flow}}}
\]
where $C_f$ is a non-dimensional friction coefficient. Rearranging the above four equations arrives at:
\[
\frac{d}{dr} \left[ \xi + \frac{Q^2}{2g B_{\text{flow}}^2 H_{\text{flow}}^2} \right] = -C_f \frac{Q^2}{g B_{\text{flow}}^2 H_{\text{flow}}^2}
\]
In seeking a solution of this equation, the effective width and the mean depth of the flow are related to the width and mean depth of inundation as $B_{\text{flow}} = \Gamma_B B_i$ and $H_{\text{flow}} = \Gamma_H H_i$, within the current calculations $\Gamma_B$ and $\Gamma_H$ are set equal to 1. The equation is solved iteratively stepwise upstream from $r = r_s$, where $\xi = \xi_d$, because on a low-gradient delta the flow is most likely Froude-subcritical. Having in mind that the average water elevation computed is not only a function of the radial coordinate $r$, but also depends on the water discharge and the sea level, the submerged fraction of the delta, $F_i$, is thus also a function of the water discharge and sea level. As a result, the inundated fraction can be rewritten as:

$$F_i(r, Q, \xi_d) = \int_{-\infty}^{\xi_d} p_i(\eta, r) \, d\eta$$

The interannual variability of water discharge and sea level in the present version of the model is accounted for with 365 user-specified daily values and the mean annual frequency of inundation is defined as arithmetic mean value of the $F_i$.

**The first application to the Wax Lake Delta**

The probability functions of bed elevation are represented in Figure 23. They have been obtained combining the LIDAR data of 2006 for the emergent fraction of the delta, with transects measured by the USACE in 1999. The non-dimensional elevation $\eta_{\text{ned}}$, defined as $\eta_{\text{ned}} = (\eta - \eta_{\text{av}})/\sigma_\eta$, where $\eta_{\text{av}}$ and $\sigma_\eta$, respectively, denote the average elevation and the standard deviation of delta elevation along an axial transect, is introduced to compare probability functions relative to different transects. We assume similarity relationships such that the non-dimensional probability functions expressed in terms of dimensionless downdelta coordinate $r/r_s$, are time-invariant, even as $r_s$ increases in time due to delta progradation.

Daily values of water discharge and sea level have been recorded at the USGS stations of Calumet and Vermilion Bay, respectively, operating since October 1, 1995 and October 23, 1997. Measurements of sea level at the Vermillion Bay are relative to the NADV88. A series of 365 consecutive daily values of water discharge and sea level is recorded from September 7, 1999. This series is assumed to be representative of the average climate of the area, and is thus cyclically repeated in the inundation model.

**Prediction of the type of vegetation**

The prediction of the ecological succession on the delta top is based on unpublished data of Holm, Bevington and LSU Professor Charles E. Sasser, reported in Tables 1 and 2 below. In Table 2, the percent of transect covered by a certain vegetation community, PC, is given as a function of mean elevation, $\eta_{\text{veg}}$, expressed in centimeters above mean sea level.

**Table 1:** Criterion to determine the type of vegetation.

<table>
<thead>
<tr>
<th>Vegetation Community Type (dominant species)</th>
<th>Annual frequency of inundation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Woody (<em>Salix nigra</em>)</td>
<td>&lt; 44%</td>
</tr>
<tr>
<td>High Emergent (<em>Colocasia esculenta, Polygonum punctatum, Vigna luteola</em>)</td>
<td>13 to 62%</td>
</tr>
<tr>
<td>Intermediate Emergent (<em>Schoenoplectus americanus, Alternanthera philoxeroides, Leersia oryzoides</em>)</td>
<td>27 to 86%</td>
</tr>
<tr>
<td>Low Emergent (<em>Sagittaria platyphylla, Nelumbo lutea</em>)</td>
<td>68 to 97%</td>
</tr>
<tr>
<td>Submerged Aquatic (<em>Potamogeton nodosus</em>)</td>
<td>86 to 100%</td>
</tr>
</tbody>
</table>
Table 2: Percent cover as a function of mean elevation above sea level.

<table>
<thead>
<tr>
<th>High Woody</th>
<th>High Emergent</th>
<th>Intermediate Emergent</th>
<th>Low Emergent</th>
<th>Submerged Aquatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_{\text{veg}}$</td>
<td>PC</td>
<td>$\eta_{\text{veg}}$</td>
<td>PC</td>
<td>$\eta_{\text{veg}}$</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>-20</td>
</tr>
<tr>
<td>15</td>
<td>30</td>
<td>7</td>
<td>35</td>
<td>-10</td>
</tr>
<tr>
<td>20</td>
<td>40</td>
<td>15</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>25</td>
<td>50</td>
<td>22</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>30</td>
<td>60</td>
<td>30</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>35</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The data reported in Table 1 are used for an overall prediction of the ecological succession on the delta. The information reported in Table 2, on the other hand, is crucial for determining the fractions of the delta covered with a certain vegetation community.

Model results

Model results are presented in Figures 24 and 25. The computed mean annual frequency of inundation on the WLD since 1976 is plotted along with the overall prediction of the vegetation community using the criteria reported in Table 1. Submerged aquatic vegetation develops near the shoreline only. As we move landward, the mean annual frequency of inundation decreases and other vegetation communities colonize the top of the delta. Low and intermediate emergent communities dominate the central part of the delta, while high and intermediate emergent vegetation types characterize the upstream portion of the topset. The growth of high woody vegetation has started only recently in the very upstream part of the delta, where the mean annual frequency of inundation dropped below ~ 44% of the time. Figure 24 illustrates the predicted vegetal succession as the delta builds outward over 30 years. The predictions of the portion of delta that is covered by a certain type of vegetation for the present WLD is shown in Figure 25; the arrows denote the overall prediction of the type of vegetation, as plotted in Figure 24.

Adaptive environmental multi-stage multi-attribute decision analytic framework

PI Ben Hobbs and NCED post-doc Melissa Kenney have built a two-stage decision model that uses predictions from CLEAR (led by Twilley), for the Louisiana Coastal Assessment (LCA) study. This study quantifies a number of environmental benefits of coastal restoration projects including land building, water quality (N removal), and habitat suitability index (HSI) for 12 different freshwater, brackish, and saltwater fisheries. In addition to the environmental benefits, we quantified the costs of nine LCA projects (three each of reduce, maintain, and enhance project portfolios) and a no action alternative for Province 1.

Because these attributes all have different measures, we used a linear utility function to “normalize” the measured values into a 0-1 index of desirability (0 least desirable, 1 most desirable). We then use these utility values for the environmental benefits and cost in the multi-stage multi-attribute utility model. Currently, we are using values inferred from the CLEAR report for the LCA.
As an example of model inputs, Figure 26 shows tradeoffs between the amounts of land built in Province 1 of the MRD and water quality (indicated by tons of N diverted to the wetlands) and cost. Some projects are inferior (dominated) by others in terms of these three objectives (that is, there exist other projects that are as good or better in all objectives), yet because combinations of projects can be chosen, such projects may be still part of an optimal portfolio. Furthermore, these are expected values; projects that are seemingly dominated by others may have advantages in terms of risks.

**Plans**

Graduate student Kate Shepard is in the process of developing and testing an additional fish movement sub-model based on game theory. Further testing of the sub-models with dynamic grids, and evaluation of the sub-models that are successful in this testing phase by embedding them in a large-scale marsh community model will be conducted.

Currently, we are calibrating model output to field data from the WLD and other coastal marshes. We expect to begin generating useable output in a month’s time and should have a draft of the first of two papers by the start of the summer. This paper will show how fish productivity 1) is distributed on the simulated delta, and 2) changes over time (i.e., early, middle, and late in the delta’s development). We are also planning a second version of the model as part of a NSF Frontiers in Earth System Dynamics proposal. This version will include dynamic bathymetric maps with simulated water levels that will allow modeling of vegetation in a more dynamic way. The goal is to compare fish productivity among different delta formations so that restoration decisions regarding sediment mixtures, discharge pulses, etc., can be optimized to biology.

Implement the new distribution of bed elevation.

Application of the inundation model to engineered diversions of the Mississippi River.

Development of a more advanced version of the inundation model that accounts for: the effects of vegetation on the flow, sediment transport and deposition; salinity variations; the formation and consumption of organic soil; and probability functions of water discharge and sea level derived from a longer series of field observations.

We are testing the inundation model on the WLD and then we hope to apply it for prediction of the ecological succession on the land built with controlled diversions of the Mississippi River.

We are currently finalizing the model and inputs and plan to submit a paper for publication in Decision Analysis in the late spring of 2011.

Analysis of alternative land building measures in the Mississippi River Delta, incorporating public valuations of alternative objectives and accounting for the multidecadal and multistage nature of these decisions, in which previous resource commitments can be modified based on new knowledge.

► SA07: Self-organization of distributary systems including elevation statistics

**Development of Delta Metrics**

As we move toward modeling the fine scale of delta top channel networks and wetlands, we need better methods to quantify their morphology so that we can compare models and observations quantitatively. Toward this end, NCED post-doc Doug Edmonds and PI Paola have developed a set of delta metrics that describe delta morphology and can be used to quantitatively determine similarities and differences among deltas. To first order, delta networks can be thought of as inverse tributary networks and in that spirit our metrics for deltas are partly inspired by those developed for tributary networks. The delta metrics are: 1) the fractal dimension, 2) the distribution of island sizes, 3) the walking distance, 4) synthetic distribution of sediment fluxes at the shoreline, and 5) the nourishment area. The walking distance is the shortest distance to water from a given location on the delta and is analogous to the inverse of drainage density in tributary networks. The nourishment area is the downstream delta area nourished by sediment coming through a given channel cross-section and is analogous to drainage area. As a first
step, we measured these metrics on the WLD (Louisiana), the Mossy Delta (Saskatchewan), a numerically created delta, and an experimentally created one (Fig. 27). All these deltas have dominantly distributary networks, mixed cohesive-noncohesive sediment supply, and are largely free of the complicating influences of waves, tides, or other external factors.

Among the four deltas the metrics are generally similar, indicating that the numerical and experimental deltas accurately reproduce the geometry of deltas in the field. For all deltas, the average walking distances are also remarkably consistent moving down delta suggesting that the network organizes itself to maintain a consistent distance to nearest channel (Fig. 28). Nourishment area distributions (Fig. 29) are consistent with a river mouth bar model of delta growth and also scale with the width of the channel, and with the length of the longest channel, analogously to Hack’s Law for drainage basins. The channel network is fractal but apart from this none of the distributions of the metrics are clearly power-law. Power laws and scale invariance appear to be much less pervasive in deltaic distributary networks than in erosional tributary networks. Deltas may occupy an advantageous middle ground between complete similarity and complete dissimilarity, where differences in morphologic metrics can be used to understand delta behavior. This work has been led by Edmonds, now an Assistant Professor at Boston College, and is in review in *Journal of Geophysical Research--Earth Surface*.

**Growth of weakly cohesive deltas with wave and tidal effects**

Although all fluvially-fed deltas share similarities in basic structure and formation, they present a wide variety of shapes in plan view. In most deltas, sediment is transported not only by the river that supplies it, but also by waves and tides. To date, however, deltas created in the laboratory form under no such influences. In order to explore these processes, we have constructed (in collaboration with colleagues at ExxonMobil Upstream Research) a wave generator and a tide generation system in a delta basin at SAFL in early 2010. The design was led by SAFL Engineers Jim Mullin and Chris Ellis. The wave generator is a large paddle connected to a motor, the tide generator a pair of pumps which pump water back and forth between the delta basin and an auxiliary basin. Both generators can be adjusted to produce a range of periods and amplitudes.

The new setup will allow us to create deltas under a variety of wave and tide regimes for comparison with field examples and with deltas created without these influences. This will help us to explore the effects of tides and waves on the morphology of the shoreline and channel network of a delta. We began these experiments in 2010 with two experiments, each allowed to grow first under no tidal influence, then with the wave generator and tidal pumps active (both separately and together). An example of tidal variation using a period of approximately 120 s is shown in Figure 30. The effects of the tidal input are qualitatively similar to what is observed at field scales: channels are more numerous and less prone to migrate laterally; and the topographic profile is convex. PI Paola and students are working, as described above, to develop metrics by which these effects can be evaluated quantitatively and related to the relative strength of the tidal and wave forcing.

![Figure 27. Planview images of (A) Wax Lake Delta, (B) Mossy Delta, (C) a numerical delta created with Delft3D modeling system, and (D) an experimental delta.](image)

![Figure 28. Downstream variation in normalized walking distance, a relative measure of distance to the nearest channel. Delta channel networks appear to organize themselves so that this distance is relatively consistent.](image)

![Figure 29. Relation between nourishment area (AN, normalized to delta total area) and channel segment length (L, normalized to the maximum channel length) for the four deltas listed above.](image)
Plans

Work with Edmonds and personnel from DELTARES to integrate synthetic (rule-based) approaches to modeling delta growth and morphology.

Finish, analyze and write up results from the first experimental study of wave and tide influence on a laboratory-scale delta, focusing on quantifying the effect of waves and tides on channel and shoreline geometry.

Continue work on developing quantitative metrics for deltas that provide information relevant to the relative influences of rivers, waves, tides, and sediment type on delta form, as well as to the delta-top ecosystem, working with former NCED post doc Paola Passalacqua (now a faculty member at the University of Texas) and Paul Venturelli (UM Fisheries).

SA08: Upscaling short-term rates and small-scale geometries

Effects of nonlocal transport in erosional and depositional systems

Voller and Paola have continued to investigate how non-local descriptions of sediment transport, based on fractional diffusion models, may be able to better describe field and experimental observations of fluvial profile shapes. This work has involved a degree of general investigations of fractional diffusion models. One investigation was directed at understanding how fractional diffusion treatments could modify moving boundary phenomena—a critical component in our delta building models. This resulted in two publications. Voller (2010) developed an analytical solution of a fractional diffusion limit case Stefan melting model (a model that was the basis for our early delta modeling work). This solution clearly illustrated how a fractional time derivative would lead to sub-diffusion behavior, whereas a fractional space derivative in the flux term leads to super-diffusion behavior. Related to the work, Voller (2011) also developed a solution for a fractional version of the green-Ampt infiltration model. This work showed that under a given set of conditions, a fractional Green-Ampt model could predict a non-monotonic infiltration rate—consistent with field observations for infiltration into heterogeneous soils. In addition to these theoretical studies Paola and Voller with graduate student Dan Zielinski, have developed a control volume based numerical solution approach (Voller, Paola, and Zielinski, 2011). This was a critical piece of work for us because not only did it result in a flexible, easy to use numerical solution for a wide class of fractional diffusion problems, it also provided a novel description of how the fractional derivative in the flux term might be related to non-local behavior of sediment transport via surface channels. This later work enabled us to develop, along with Liz Hajek (former NCED post-doc now a faculty member at Penn State), a model that could predict the shape of the fluvial profile under different subsidence styles; this paper was an oral presentation at the 2010 AGU meeting. A subsequent exciting development of this work—currently in investigation with PI Efi Foufoula-Georgiou and Graduate Student Vamsi Ganti—shows that the style of subsidence might control the direction of the non-locality. A preliminary analysis of the mathematics and physical feasibility of the predictions suggests that in an uplift system the non-locality is controlled by up-stream processes, whereas in a subsiding system the non-locality is from the down-stream.

Statistical stratigraphy

Stratigraphy contains important information for reconstructing past environmental conditions via inversion methodologies. Paola and Voller, along with Foufoula-Georgiou and Graduate Student Vamsi Ganti, NCED PI Rina Schumer and former NCED postdoc Kyle Straub, now a faculty member at Tulane University, are quantifying how the probabilistic structure of the processes that govern the evolution of depositional systems relates to the probability distribution of the preserved bed thicknesses. They have demonstrated that the extreme variability previously documented in the magnitude of erosional and depositional events wipes itself out in the resulting stratigraphy. Specifically, bed thickness is well described by an exponential distribution even if the erosional and depositional events characterizing the surface evolution exhibit a heavy tail distribution, with a small but finite chance for extremely large events. The team attributes this finding to the symmetric nature of the distribution of elevation fluctuations (both erosional and depositional events) and has shown that the variance of this distribution directly relates to the mean and variance of the bed thickness distribution (Ganti et al., 2011 in press; Straub et al., 2011, in review) (Fig. 31).
Analytical stochastic models

Effects of power-law distributed segments of the stratigraphic record combined with measurement bias is one explanation for observed increases in deposition rates with time (Schumer and Jerolmack, 2009). The same may also be true of measured changes in rates of a variety of geologic processes including the subsidence of deltas (Meckel, 2009) where we observe that there is a near one-to-one correspondence between measurement interval and age.

In collaboration with former NCED postdoc Douglas Jerolmack, now a faculty member at UPenn, and PI Schumer proposed the development of more sophisticated stochastic models of growth for the stratigraphic record. The model previously used to describe the Sadler effect simply assumed constant deposition rates with random hiatuses drawn from a single probability density. In reality, the rates of deposition, compaction, and subsidence exhibit fluctuations. Further, hiatus length is affected by forcings that operate on a variety of timescales (transport fluctuations versus Milankovich-scale sea level change). We proposed the development of stochastic models that accurately reflect our conceptual understanding of deposition, incision, and subsidence and learned how to estimate true geologic rates from an incomplete record.

We describe a stochastic process to represent the stratigraphic filter (Schumer et al., in review). The “reversed ascending ladder” \( d(t) = \min\{S(k) : k \geq t\} \) (Stam, 1977) converts Earth surface evolution \( S_n(t) \) into the sedimentary record \( d(t) \) by recording the lowest surface elevation that occurs after the present time. This process mathematically summarizes the geological intuition that each stratum is a record of the most recent interval during which the surface occupied the corresponding stratigraphic position. Preserved portions of the depositional history, recorded in \( d(t) \), are characterized by random hiatus lengths \( J_i \) with distribution \( G \) and random jumps \( Y_i \) corresponding with bed thickness (Fig. 32). We relate the distribution governing deposition/erosional jumps \( F \) with the distribution of stratigraphic hiatuses \( G \). For example, if the deposition process that gave rise to the fractional exponent \( \gamma \) were (fractional) Brownian motion, then \( \gamma \) can be used to estimate the Hurst coefficient \( H \) that describes the nature of correlations in deposition increments. Preservation of heavy-tail magnitudes of deposition is likely limited to avalanching-type processes like landslides and turbidity currents that deliver large pulses of sediment to locations where it is unlikely to be re-eroded. Although such a process would affect the distribution of bed thickness, it should not yield a power-law hiatus distribution. Available depositional data suggest that most sedimentary systems are either governed by Brownian motion or a fractional Brownian motion with negative correlations, across timescales up to \( 10^6 \) yr. Negative correlation means that a location experiencing deposition in one increment is less likely to experience deposition in the next increment. This concept is consistent with the notion of “compensational stacking,” the tendency for sediment transport systems to preferentially fill topographic lows through deposition (Straub et al., 2009). This analysis has important implications for interpreting stratigraphy.

The Earth’s surface is continually reworked by bed forms, river channel migration, landslides, debris flows and turbidity currents, and a host of other physical, chemical, and biological processes. Because kinematic rates of surface evolution typically can be orders of magnitude greater than the long-term rate of generation of accommodation space (e.g., subsidence), only a small fraction of Earth surface evolution is permanently preserved in the geologic record. This is the stratigraphic filter. Since virtually all depositional and erosional processes contain some degree of randomness, a natural framework for describing the stratigraphic filter is that of stochastic processes. With knowledge of the statistics of surface fluctuations, we may pass through the filter to predict bias in measurement rates and potentially correct for it.

**Plans**

We will work toward fully developing our concept of the relationship between the direction locality and geomorphic environments.

Our longer term plan is to identify experimental systems that can isolate, confirm and quantify non-local effects in sediment transport systems.
Analyze the correlation structure between erosional and depositional events and the sequencing of periods of inactivity and the following erosional/depositional events.

Develop an analytical framework to derive avulsion timescales under varying erosional-depositional environments.

Test for dynamic scaling of depositional system from the experimental data and check for the consistency of numerical models with the observed scaling behavior and statistics documented.

Further analysis of the stratigraphic filter, including application of the so-called reverse ladder method and quantitative study of the influence of stochastic subsidence (e.g., earthquake clusters) on stratal preservation.

Completion of a manuscript focused on the stratigraphic filter and bed thickness distributions which describe the relationship between the statistics of deposition/erosion and the resulting distribution of bed thickness.

**SA09: Coastal system response to rising relative sea level**

**Interactive Mississippi delta land building**

Graduate student Man Liang with Voller and Paola continue to work toward developing models that can predict not only the overall growth of the delta but also predict the formation of channels. The overall approach is to develop hybrid models that blend appropriate amounts of deterministic and rule based predictions. Towards this end the team has been exploring the possible use of pattern producing models from other fields, in particular crystal growth processes.

One very exciting development in these research efforts has been a new collaboration with the Science Museum of Minnesota to use the “TacTile Table” facility to build an exhibit that can be used to inform the public on the consequences of Mississippi delta restoration proposals.

The main goal of the exhibit is to show this land building process on a touch table. Visitors to the museum can interact by touching the screen to initiate diversions at multiple locations, to observe the growth of new land, with the options of controlling sea-level-rise rate and fluctuations in sediment supply. Ongoing research supporting the development will include two goals: 1) to develop a numerical land-building model, including the formation of channel networks and 2) to develop a method to couple dynamic cartoon demonstrations with the land-building model. Figure 33 shows the desired user interface.

The exhibit requires the land-building model to run fast (maximum 2-3 seconds to generate a new frame), so its not possible to use traditional flow-sediment hydrodynamic models like Delft3D or other existing models. Here, a structured-random-walk method is developed to route sediment along pre-calculated channel patterns to create fast yet realistic-looking images. The basic idea can be found in the Monte Carlo scheme previously developed by Voller for tracking filling fronts.

The land-building model runs as follows:

- Once the location breaking point (the starting point of a new delta) is received from the user, a sub-routine calculates a channel network pattern according to local water and sediment supply.

- Another sub-routine routes sediment particles following the channels and deposits them in the surrounding areas with certain probabilities. Each particle releases part of its volume on hitting an “unfilled” node, and the routing starts over when a particle is completely consumed.

---

**Figure 32.**

a) The time series of surface location represented by discrete random walk with random jump sizes over constant intervals. b) Bed preservation by the stratigraphic filter, a reversed ascending ladder process. Shaded area represents time not represented in the stratigraphic record. c) If the random walk runs backwards in time, the reversed ascending ladder process of (b) becomes an ascending ladder process, recording running maxima.
- There is a piece of code “watching” the sea-level and change in sediment supply controlled by the users. Whenever changes happen, it adjusts related parameters, such as particle volume, channel width, etc. Figure 34 shows a sequence of results at different running times.

**Plans**

The “TacTile Table” model is only a preliminary version. The following will be improved before the exhibit is installed: 1) the sub-routine for generating channel patterns, 2) background bathymetry - detailed data of the birdfoot area will be obtained, and 3) the black-white display will be replaced by color contour plots with finer elevation details.

For the research alone, we see a great potential in this Monte Carlo scheme, to develop a reduced-complexity model for delta formation with channel networks. The next step is to explore how to connect this method with existing sediment transport models.

**SA10: Social tradeoffs in Mississippi delta restoration**

PI David Mohrig and former NCED postdoc Wonsuck Kim are retrofitting the land building model (Kim et al., 2009) given their new understanding of the carrying capacity and the vertical distribution of sediment in the Mississippi River water column. Using recently obtained data from the Mississippi River, they will be creating new equations for these two parameters that will provide the information necessary to modify the model so that it can predict land building given different diversion sizes. Using common diversion sizes that have been built or proposed for either freshwater introduction and/or land building, PI Mohrig will calculate a tapping depth (i.e., the depth of the Mississippi River that will be diverted given the flow (cfs) from the diversion). This result will illuminate whether the assumption that land building is a linear function of diversion size is correct, or whether there are important nonlinearities such that, in order to build a critical mass of land, the diversion needs to be a larger size.

A simple version of the model formulated by Hobbs and Kenney is as follows: Choose the number $n$ of projects and amount of sediment $s_{tot}$ to divert in order to maximize the following objective function subject to the following constraints:
where the notation is:

**Design variables:**

n = Number of projects

w = Width of diversion aperture [m]

d = Depth of diversion aperture [m]

**Outputs:**

z(t) = Depth of diversion discharge (< d) [m]

s(t) = Sand diversion rate from one project [t/s] \( (s_{tot} = \text{Total annual sand diverted} \ [t/yr]) \)

q(t) = Water diversion rate from a single project \([m^3/s]\) \( (q_{tot} = \text{Total annual water diverted} \ [m^3/yr]) \)

\( \lambda (y) \) = Cumulative land created by end of year y [km]

**Functions:**

PW(n,w,d) = PW of cost of n projects, each with width w and depth d

L1(s_{tot},y) = Land build from a single project diverting \( s_{tot} \)

S(•) = Sand discharge as \( f(z,w,q,H...) \)

**Indices and constants:**

t = time (within year), y = time [years]

H(t) = Depth of river, time t [m]

\( H_o \) = Height of diversion structure above river bed [m]

C(t) = Mean river concentration of sand, time t [t/m^3]

In words, the weighted (over time) sum of land built is maximized subject to limits on project budget, sediment that can be diverted, the relationship between sand diversions and land building over time, and relationships between opening (aperture) of the avulsion and the amount of water and sand diverted. Projects are assumed to be identical and implemented at the same time. More sophisticated formulations would consider staggering projects, budget limitations over time, and the possibility of projects of differing sizes.

Our statistical analysis of past land building projects has resulted in an initial estimation of the relationship between opening (aperture) depth (as fraction of the river depth) and width (in meters) of diversion projects as follows (in 2008 dollars):

\[
\text{Cost} = 19.1d^{0.933}w^{0.609} \quad R^2 = 0.97
\]

This exhibits slight scale economies in depth and strong scale economies in width. For instance, if we interpret this equation for the Bonnet Carre diversion, the following conclusions would be made:
A narrowing of the project’s width from its original 2330 m to 100 m would lower cost by 85%, and an increasing of depth (as a fraction of the river depth) from its actual 0.223 to 0.5 would increase cost by 210%.

Given that important coastal restoration decisions are currently based on what we believe is an incorrect understanding of the relationship between the predicted land building and cost given the size of the diversion, this research has the potential to make an extremely important contribution to the environmental management literature and hopefully will cause decision makers in the MRD to reconsider the influence of scientific predictions on their decisions.

**Plans**

The economic analysis is headed by Hobbs and Kenney. We have identified potential land building projects and are collaborating with Mohrig and Kim to choose the final projects. Given the final project list, we will finalize the actual or projected costs of approved state and federal coastal restoration projects. This cost information will be used to develop and confirm the cost function for coastal restoration projects.

**Progress on Deliverables**

<table>
<thead>
<tr>
<th>Project</th>
<th>Milestone/Deliverable</th>
<th>Progress</th>
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<tbody>
<tr>
<td>SA01</td>
<td>Identified two different trends for area of water flow: during low-water discharge, cross-sectional area of flow increases downstream, and during high-water discharge, cross-sectional area of flow decreases downstream.</td>
<td>Backwater flow and sediment transport dynamics in the lower Mississippi River not only modulate the timing and magnitude of sand flux to the river delta and neighboring marine environment, but also affect the development of channel properties; examples include the evolution of the channel-bed long profile, and kinematic properties such as lateral mobility and location of avulsion nodes that form distributary channels.</td>
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<tr>
<td>SA02</td>
<td>Experimental cylinders were replaced by artificial vegetation, resulting in deposition of the sediment, chemically flocculated kaolinite, onto the plastic vegetation surfaces. We have devised an experimental system that allows a variety of delta-front failures to self generate.</td>
<td>Using filamentous green algae, results suggest, though not conclusively, that algal biomass in a section of the flume was positively related to the amount of deposition that occurred there. In these experiments, we observed that slopes undergo a series of morphological changes prior to failure, leaving the slope in a metastable state.</td>
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<tr>
<td>SA03</td>
<td>Development of a numerical model to simulate nitrogen diagenesis within WLD. Work is ongoing with a novel geometric model that takes into account the role of peat production and decay in delta growth dynamics. Initial sampling of flow velocity and direction in marsh/mudflat habitats at Wax Lake was completed in spring and summer of 2010.</td>
<td>We are in the process of deploying a set of instruments, at Mike Island located near the apex of the WLD, to monitor inflow of nutrients and sediment into marshes and downstream through the system. A standard behavior for the model is for the shoreline to undergo an initial progradation (advance) followed by a shoreline transgression (retreat). These results indicated that the planned experimental design, which utilized a flume setup to determine sediment-water column flux rates, would not be sufficient; we re-designed our experimental setup and will now utilize in situ sampling and mesocosms to measure nitrogen flux rates.</td>
</tr>
<tr>
<td>SA04</td>
<td>Rebuilding of seismic project used to quantify pre-anthropogenic sedimentation styles associated with the southernmost portion of the Mississippi River Delta.</td>
<td>Rebuild is now complete and final analysis of sedimentation and subsidence patterns is beginning.</td>
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<td>Project</td>
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<td>SA05</td>
<td>Have carried out the first high resolution mapping of the distributary channels of the WLD using swath bathymetry.</td>
<td>The surveys show that the distributary channels extend up to 2 km seaward of their subaerial portions. These channels lose definition at their distal ends through a combination of channel-bed shoaling and loss of bank relief. Little bathymetric relief is observed at the tips of the subaqueous channels. Observations call into question the role of channel-mouth bars in generating the bifurcations observed in the delta-channel network.</td>
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<tr>
<td>SA06</td>
<td>Tests of genetic algorithms (GAs) to calibrate different fish movement sub-models; these sub-models can ultimately be embedded in a broader model of a marsh community on a prograding delta.</td>
<td>Movement sub-models successfully aggregated individuals in areas of low predator density and high prey density. Continued development of an inundation model that can be coupled to our existing macroscale land-building model. The inundation model allows the prediction of vegetation succession on newly-build land as a delta builds out. Model results show that as we move landward, the mean annual frequency of inundation decreases and other vegetation communities colonize the top of the delta. Low and intermediate emergent communities dominate the central part of the delta, while high and intermediate emergent vegetation types characterize the upstream portion of the topset.</td>
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<tr>
<td>SA07</td>
<td>Developed a set of delta metrics that describe delta morphology and can be used to quantitatively determine similarities and differences among deltas. We have constructed (in collaboration with colleagues at ExxonMobil Upstream Research) a wave generator and a tide generation system in a delta basin.</td>
<td>The delta metrics are: 1) the fractal dimension, 2) the distribution of island sizes, 3) the walking distance, 4) synthetic distribution of sediment fluxes at the shoreline, and 5) the nourishment area. The effects of the tidal input are qualitatively similar to what is observed at field scales: channels are more numerous and less prone to migrate laterally; and the topographic profile is convex.</td>
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<td>SA08</td>
<td>Continued to investigate how non-local descriptions of sediment transport, based on fractional diffusion models, may be able to better describe field and experimental observations of fluvial profile shapes. Through the use of physical and numerical experiments, the forward problem, that is, we quantify how the probabilistic structure of the processes that govern the evolution of depositional systems relates to the probability distribution of the preserved bed thicknesses. We demonstrate that the extreme variability previously documented in the magnitude of erosional and depositional events wipes itself out in the resulting stratigraphy, and that the bed thickness is well described by an exponential distribution even if the erosional and depositional events characterizing the surface evolution exhibit a heavy tail distribution, with a small but finite chance for extremely large events. Proposed development of more sophisticated stochastic models of growth for stratigraphic record.</td>
<td>This work shows that under a given set for conditions a fractional Green-Ampt model could predict a non-monotonic infiltration rate—consistent with field observations for infiltration into heterogeneous soils. This analysis has important implications for interpreting stratigraphy. The Earth’s surface is continually reworked by bed forms; river channel migration; landslides; debris flows and turbidity currents; and a host of other physical, chemical, and biological processes. Because kinematic rates of surface evolution typically can be orders of magnitude greater than the long-term rate of generation of accommodation space (e.g., subsidence), only a small fraction of Earth surface evolution is permanently preserved in the geologic record.</td>
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**Deltas** 59
### Project Milestone/Deliverable Progress

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<th>Project</th>
<th>Milestone/Deliverable</th>
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<tr>
<td>SA09</td>
<td>Continued work toward developing models that can predict not only the overall growth of the Delta but also predict the formation of channels. The overall approach is to develop hybrid models that blend appropriate amounts of deterministic and rule based predictions.</td>
<td>A very exciting development in this research effort has been a new collaboration with the Science Museum of Minnesota to use the “TacTile Table” facility to build an exhibit that can be used to inform the public on the consequences of Mississippi delta restoration proposals, including the initiation of diversions at multiple locations, to observe the growth of new land, with the options of controlling sea-level-rise rate and fluctuations in sediment supply.</td>
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<td>SA10</td>
<td>Using common diversion sizes that have been built or proposed for either freshwater introduction and/or land building, a tapping depth with be determined (i.e., the depth of the Mississippi River that will be diverted given the flow from the diversion).</td>
<td>Result will illuminate whether the assumption that land building is a linear function of diversion size is correct, or whether there are important nonlinearities such that in order to build a critical mass of land the diversion needs to be a larger size.</td>
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<td>Statistical analysis of past land building projects has resulted in an initial estimation of the relationship between opening (aperture) depth (as fraction of the river depth) and width (in meters) of diversion projects.</td>
<td>The statistical analysis exhibits slight scale economies in depth and strong scale economies in width. Given that important coastal restoration decisions are currently based on what we believe is an incorrect understanding of the relationship between the predicted land building and cost given the size of the diversion, this research has the potential to make an extremely important contribution to the environmental management literature and hopefully will cause decision makers in the MRD to reconsider the influence of scientific predictions on their decisions.</td>
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IIc. Stream Restoration (Streams) Integrated Program

Lead PI: Peter Wilcock

Program Manager: Daniel Baker

Contributing PIs: Bill Dietrich, Jacques Finlay, Efi Foufoula-Georgiou, Benjamin Hobbs, Miki Hondzo, Chris Paola, Gary Parker, Mary Power, Fotis Sotiropoulos, Vaughan Voller, Greg Wilkerson

Executive Summary

Goal: The goal of the Stream Restoration (SR) Integrated Program (IP) is to advance the science and practice of SR by conducting and coordinating research and by working with agency and industry partners to identify information needs, develop improved tools, and transfer this knowledge into practice. We aim to promote a transition in restoration practice from an approach based on single-discipline analogy to one based on multidisciplinary quantitative prediction. We implement this transformation by defining and promoting an objectives-driven approach to restoration, emphasizing quantitative objectives and predictive design and supporting explicit trade-off evaluation and decision analysis.

Approach: NCED research addresses three key areas of SR practice: 1) watershed context for evaluating and locating restoration alternatives, 2) predictive relations for the physical and ecological response of stream channels to project actions, and 3) decision making methods incorporating improved information, predictive methods, and uncertainty. To define watershed context, we use Desktop Watersheds (DW) methods to focus on mechanisms connecting a project site to its watershed via the supply of water, sediment, and nutrients. Project planning and design requires predictive relations for stream composition and configuration. NCED research focuses on the physical components of streambed and channel geometry and their interaction with the fluvial ecosystem. Better understanding and tools are not sufficient on their own, we must also anticipate the challenges to putting these tools to work. Our goal is a transformed, professional practice in which project goals are predictive targets quantitatively linked to public preference, regulatory and policy guidelines, and management actions. This focus leads to the development of an assessment and design system based on a decision analysis framework and active participation in professional training.

Highlights: As NCED approaches Year 10, SRIP accomplishments are increasingly focused within three legacy efforts. With StreamLabs, NCED has championed a new standard of experiments in river ecogeomorphology, operated at full scale while maintaining experimental control and using instrumentation that can resolve both local and full-scale processes. We have developed a successful virtual StreamLab: full-scale, turbulence-resolving, predictive numerical models of flow-bed and flow-organism interactions. We have conducted multiple successful seasons in the Outdoor StreamLab, evaluating response of channel geometry and biogeochemical processing to in-stream rock structures and changes in water and sediment supply. In the Le Sueur Watershed, we have established the history of sediment supply over annual to millennial time scales and identified an important shift in sediment source from agricultural fields to near-channel erosion. The growing problem is water runoff from agricultural drainage systems, rather than soil erosion, forcing a major change in perspective for attempts to reduce turbidity in the Minnesota River. In stream restoration practice, we have established the Stream Project, a collaboration among NCED, the US Army Corps of Engineers, and the Intermountain Center for River Rehabilitation and Restoration. The goal of the project is to develop a stream restoration decision analysis and design guidance document and software that define and implement a rational, objectives-driven approach to evaluating and designing stream restoration projects.

Projects

Our report on Year 9 research efforts is organized by the seven projects detailed in the NCED Strategic and Implementation Plan (the SIP, in Appendix E, contains an explanation and defined milestones for each project).

<table>
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<tr>
<th>Project</th>
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<tr>
<td>SR01</td>
<td>Watershed context for stream restoration</td>
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<tr>
<td>SR02</td>
<td>Improved models for sediment source, routing, storage, and yield</td>
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<tr>
<td>SR03</td>
<td>Dynamics of mixed-size sediment</td>
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Three efforts are broader and integrative and, by design, cut across several of the SRIP projects. To provide a clear statement of their purpose and organization, we describe these cross-cutting projects first and then cite connections to the seven SRIP projects.

► Cross-cutting Project 1: An Integrated Sediment Budget for the Le Sueur River Basin, Minnesota

The Le Sueur River is a large (2,800 km$^2$) agricultural watershed in southern Minnesota. Postglacial river incision, agricultural practice, and location conspire to make the Le Sueur one of the primary sources of sediment to the Minnesota River and to Lake Pepin on the Mississippi River (Fig. 1). Much of the Le Sueur and Minnesota Rivers are listed as impaired for turbidity under the Clean Water Act, and the Minnesota River contributes 85-90% of the suspended sediment delivered to the Mississippi River’s Lake Pepin, which is also impaired for turbidity and eutrophication.

The Le Sueur River project contributes to SRIP projects SR01, SR02, SR04, and SR06. The Le Sueur River project and broader Minnesota River collaboration involves NCED PIs (Hobbs, Parker, Wilcock, Gran), postdoctoral research associates (Utley, Viparelli), current NCED students (S. Cho, S. Day, L. Giangola, and A. Johnson), partners from Florida International University (students Ashley Thomas, Luam Azmera, and Fukhrudin Khalif and Professor Assefa Melesse), and NCED partners (C. Jennings, Minnesota Geological Survey; NCED PhD graduate W. Lauer, Seattle University; P. Belmont, Utah State University). External partners include the St. Croix Watershed Research Station (Science Museum of Minnesota) and the University of Minnesota (UMN), Department of Soil, Water, and Climate. Work on the Le Sueur project has been supported by NCED and leveraged by a major contract from Minnesota Pollution Control Agency and additional grants from the Minnesota Department of Agriculture.

We have completed development of an integrated sediment budget and sediment routing model for the Le Sueur Watershed and 11 papers are published or currently in review. Using leveraged support from the Minnesota Pollution Control Agency (MPCA) and Minnesota Department of Agriculture (MDA), the Le Sueur River project is a test bed for integrating advances in watershed modeling, sediment routing, and environmental decision analysis. Data contributing to these models include sediment
flux at eight stream gages (Fig. 1), ground-based lidar measurements of bluff erosion, water and sediment monitoring of five ravines, measurements of bank cohesion and modeling of bank stability, and over 140 measurements of grain size in banks and floodplains. We completed our analysis of Holocene river incision, dating a total of 17 strath terraces using Optically Stimulated Luminescence and \(^{14}\text{C}\) and collected over 80 meteoric \(^{10}\text{Be}\) samples from suspended sediment during high-flow events. NCED is using leveraged support from MPCA and MDA to advance the application of radiogenic sediment fingerprinting by comparing the concentration of meteoric \(^{10}\text{Be}\) in sediment source areas as well as suspended sediment during high flow events.

Desktop Watersheds analysis in the Le Sueur combines aerial lidar, surface dating, and multi-scale modeling to document evolution of the channel and valley network through the Holocene. Belmont (2011) used a floodplain inundation tool developed jointly between Barr Engineering and NCED to document floodplain development in response to incision of the Le Sueur channel network. Lidar was used to map the full suite of strath terraces in the watershed. Combined with terrace dating, Gran et al. (in review) developed a history of valley evacuation of the Holocene and Finnegan et al. (2010) used a 1D numerical model to show that declining incision rate has been balanced by increasing valley width in producing a steady sediment export over the Holocene. The average Holocene sediment load is a factor of 4-5 smaller than the modern load on the Le Sueur River, providing exceptional baseline information for evaluating the effect of modern agricultural practice on sediment loads. NCED post-doc Viparelli et al. (in review) developed a reduced complexity sediment routing model that includes channel migration, valley bottom storage, and mass balance for radiogenic tracers.

We have developed a geochemical fingerprinting technique, using \(^{210}\text{Pb}\) and \(^{10}\text{Be}\) to identify sediment sources. This work builds on recent advances in cosmogenic nuclide (specifically meteoric \(^{10}\text{Be}\)) systematics and measurement capacity (Willenbring and Von Blanckenburg, 2010) and radionuclide transport theory (Lauer and Willenbring, 2011). Measuring concentrations of these two tracers in suspended sediment collected during storm events has allowed us to determine the amount of sediment derived from agricultural sediment versus near-channel sources during individual storm events.

Using multiple lines of evidence, we have demonstrated that, under current conditions, the largest sediment sources are near-channel (erosion of bluffs, channel widening and incision) within the incised portion, or knick zone, of the Le Sueur watershed. Current erosion rates from bluffs appear to be three to four times larger than the background erosion rates prior to European settlement (Fig. 2). The likely cause of these elevated erosion rates is increased river flow, driven by changing precipitation patterns and pervasive changes to upland hydrology including historic draining of wetlands, connection of previously closed basins to the main channel network, and installed networks of tiles and ditches. Because of the geologic history and setting, these near-channel areas are vulnerable to accelerated erosion, and hydrologic changes in the upper watershed have had large impacts on sediment loading. Predicted increases in heavy rainfall over the next century in the upper Midwest are likely to further accelerate sediment supply through this hydrologic amplification.

A broader conclusion can be reached when combining our sediment budget with independent evidence from mainstem sampling on the Minnesota River and from Lake Pepin sediment cores. Although the rate of sediment supply to the Mississippi River has remained very large through the past 40-50 years (approaching an order of magnitude larger than pre-settlement background), the source of the sediment has shifted from predominantly field to predominantly near-channel sources through a combination of accelerated toe erosion and channel widening (Fig. 3). This calls for a significant shift in efforts to reduce sediment supply and indicates that management efforts must expand from soil erosion to factors contributing to increased water runoff.
Plans

Major field work for assembling the Le Sueur sediment budget is complete. Field work during Year 10 of NCED will consist of continued water and sediment gaging in collaboration with the Water Resources Center at Minnesota State University and MPCA, and continued sediment sampling for isotopic tracer investigations using meteoric $^{10}$Be and $^{210}$Pb. In our sediment budget, we have demonstrated that a combination of stream gaging and sediment fingerprinting provide reliable, corroborating evidence of sediment dynamics and system response to management actions.

Our principal focus on the Le Sueur Project is now shifting to couple our understanding of sediment dynamics with policy and management decisions (SR06). NCED PIs Wilcock, Hobbs, and Gran, and affiliate scientist Belmont have collaborated on a proposal to extrapolate what has been learned in the Le Sueur to develop a sediment budget and decision analysis framework for the Greater Blue Earth River, of which the Le Sueur comprises 40%. The sediment budget developed for the Le Sueur will be used to develop a simulation model for the larger watershed to evaluate the effect on sediment reduction of different management actions. The modeling will incorporate uncertainty and be developed and applied with a stakeholder group to recommend management actions. Multiple NCED PIs have teamed with external collaborators to develop a pending proposal to the NSF Coupled Natural and Human Systems Program. The focus of that work is to understand the history and motivation for individual decisions made by farmers and to estimate the cumulative impact of those decisions on runoff and accelerated erosion in the Minnesota River Basin.

► Cross-cutting Project 2: StreamLabs

Experimental studies are a key component of NCED investigations, but essential features of river systems are difficult if not impossible to scale to laboratory dimensions. These features include processes involving aquatic organisms and their interactions with their physical surroundings, as well as features, such as channel-scale bedforms and habitat, that arise from interactions among processes operating across a range of spatial scales. Improved prediction in river science—a central NCED objective—will require models that can reliably represent organism and grain scale processes at larger scales, and the development of these models will be supported by consistent observations of local mechanisms and their broader interactions. This combination has been difficult to achieve under laboratory conditions. Therefore, we have worked toward a new standard of performing experiments at full scale while maintaining experimental control and using instrumentation that can resolve both local and full-scale processes. Although such experiments impose considerable conceptual, technical, and organizational challenges, automated measurement technology and sustained center-mode support have made the approach feasible.

To lead the research transformation made possible by full-scale, high resolution experiments, NCED and SAFL have invested in the creation of physical and virtual research facilities, known collectively as StreamLabs. The essential features of the StreamLabs are an explicit multi-disciplinary focus, experimental control at the field scale, and the use of advanced technology to support detailed observations and predictions typical of small-scale lab experiments. The major investment in StreamLabs is based on our conviction that prediction of physical and biological interactions across scales is essential in developing and testing predictive models of the integrative dynamics of streams. True prediction of the response of streambed composition, stream morphology, nutrient flux, and biotic community to changes in watershed condition or intentional management actions is not possible without developing and testing such models.

StreamLabs include three facilities: Indoor StreamLab (ISL), Outdoor StreamLab (OSL), and Virtual StreamLab (VSL). ISL uses flumes within the SAFL laboratory. In 2006, we initiated collaborative, cross-disciplinary ecogeomorphologic research as a proof-of-concept for combining high-resolution observation with field-scale, controlled experiments on the interaction between physical and biological systems. In Years 6 and 7, NCED and SAFL collaborated in the construction of the Riparian Basin of OSL, which takes the StreamLab approach outside. OSL will eventually include a second basin, the Riverine Corridor. VSL extends the StreamLab concept to full-scale, turbulence-resolving, predictive numerical models of flow-bed and flow-organism interactions.
interactions. The different components of StreamLabs have an essential symbiosis. ISL and OSL provide the high-resolution, field-scale observations needed to validate VSL. VSL provides the capability to extrapolate detailed flow information beyond regions of direct observation, supporting testing of reach-scale hypotheses and models. VSL also expands our experimental capacity, supporting virtual experiments in a number and range much broader than could be accomplished in a physical flume. This interaction among the different components of StreamLabs is essential in developing a new approach to modeling the ecogeomorphology of streams. We combine active collaboration among a wide range of investigators with the development of new facilities, equipment, and models, all of which requires the sustained support and collaboration made possible by a center.

**Progress and plans: ISL**

The primary Year 9 ISL activities were flow and transport experiments in the SAFL main channel to investigate bar response and tracer motion in response to increased sediment supply and detailed measurements of flow around bluff objects to validate VSL application. Building on 2006 experiments on the response of gravel bars to a reduction in sediment supply, Wilcock and NCED student Podolak examined bar response to an increase in sediment supply (SR02). This work provides detailed observation of the interaction among flow, transport, sorting, and topography to support development of a model linking local sediment storage to long-distance sediment routing. The model will be tested on the Sandy, Trinity, and Provo Rivers (SR07). NCED PIs Foufoula-Georgiou and Wilcock and NCED student Singh continued large-scale laboratory experiments on the effects of increasing discharge on multiscale statistics of bed topography, velocity fluctuations, and sediment transport and the coupled dynamics of flow and bedforms above the sediment-water interface (SR03). Additionally Foufoula-Georgiou’s group initiated a set of experiments in the Main Channel with the purpose of understanding and quantifying tracer transport dynamics in a gravel-bedded river. Instantaneous, high-resolution bed elevations, velocity fluctuations and sediment transport rates, along with travel distances of tracer particles (paramagnetic in nature) representing the grain size distribution of bed material, were measured for a range of discharges.

Year 10 will include additional gravel tracer experiments in the ISL. Tracer dispersal in gravel bed rivers is important for understanding pollutant transport and for developing sediment transport routing models. Statistical theories for predictability of transport in the presence of bedforms will be extended to the sand-bed experiments conducted in 2006.

**Experimental data from the ISL were used to validate the bed-morphodynamics module of the VSL for local scour processes around bridge piers.** Analysis of three different bridge pier shapes was carried out in a 7.0 m long, 1.2 m wide, and 0.45 m deep flume at SAFL. Non-cohesive bed sediment (median size 0.525 mm) was used at a thickness of 20 cm. For each run, the flatbed elevation was recorded at the beginning and the water flow was allowed to flow through the flume until an equilibrium scour depth was reached. A high-definition camera installed within the pier structure was used to observe the time evolution of scour and to determine the final equilibrium scour depth. When equilibrium was reached the incoming flow was stopped for

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**Figure 4.** Computed (up) and measured (down) bed topography around cylindrical (a), square (b), bridge piers at equilibrium condition (in cm) with the flow direction from left to right.
measuring the final equilibrium bed topography at sub-mm accuracy with a laser range finder. When the computed and measured equilibrium bed topography were compared, the predicted values for maximum scour depth and maximum deposition agreed well with those observed in the laboratory experiment (Fig. 4).

**Progress and plans: OSL**

Experiments in the OSL during summer 2010 focused on flow and transport in the presence of different in-stream rock structures (Fig. 5). This work is supported with leveraged funding from the National Cooperative Highway Research Program (NCHRP) to PI Sotiropoulos. In-stream rock structures are widely used in stream restoration but their impact on flow, transport, and the in-stream and hyporheic ecosystem is poorly understood. The NCHRP experiments are intended to develop a design methodology for the stability and impact of in-stream structures.

OSL experiments in 2011 will complete the investigation of in-stream rock structures, which will be followed by VSL runs covering a wider range of conditions. Design charts developed from this work will play a key role in supporting SR04 and SR05 and the overall SR IP goal of developing predictive relations for stream composition and configuration.

The OSL experiments also provide the basis for testing of VSL at field scale. A high-resolution robotic cart provides the necessary topography and turbulence data.

In 2010, NCED leveraged these experiments with coupled experiments examining the effect of structures on both in-channel and subsurface ecogeomorphic function. NCED PI Hondzo investigated the interactions among velocity, temperature, dissolved oxygen (DO) and nitrate concentration (SR05). PIs Hondzo, Finlay, Wilcock, and Sotiropoulos will continue investigating nitrogen transformation and transport in streams, utilizing the OSL to verify ISL models for temperature and denitrification.

**Figure 5.** Flow visualizations using confetti (from top): no structures, rock vanes, J-hook vanes, and bendway weirs. Flow is from right to left.

**Progress and plans: VSL**

VSL is the first computational framework for simulating turbulent flow and sediment transport processes, including coupled turbulence/aquatic biota interactions in natural streams with real-life in-stream structures at full scale Reynolds numbers. VSL supports NCED’s science-based stream restoration vision by 1) developing, validating, and disseminating to the stream restoration community an advanced computational fluid dynamics (CFD) software enabling virtual design of stream restoration projects; 2) guiding, along with input from ISL and OSL, the development of the first physics-based set of guidelines for designing, installing, and operating in-stream structures in real-life streams; and 3) providing a cyber-platform for integrating physical and ecological observations with state-of-the-art computational and visualization techniques to develop predictive tools for evaluating the quality of aquatic habitats and simulating the distribution of nutrients, grazers and biomass.
The flow simulation module

During the last year, we made major progress by further expanding the capabilities of the VSL, validating the model, and applying it to carry out high-resolution, reach-scale, roughness resolving simulations of turbulence in a natural stream with and without in-stream structures. Using velocity and topography data from the 2009 St. Anthony Falls Laboratory (SAFL) Outdoor StreamLab (OSL) summer research season, the VSL with LES (large eddy simulation) was used to solve the bankfull flow (280 LPS) condition with and without a single rock vane. High resolution bed topography (Fig. 6a) was obtained by utilizing the laser topography scanner and was used as the input data for the numerical simulation. Scour around the rock vane and aggradation of sediment along the outer bank were observed.

The presence of a rock vane significantly altered the instantaneous flow field; the flow field around the rock vane was highly complex and three-dimensional. High velocities were observed in the VSL near the tip of the rocks, which suggests the formation of the shear layer along the tip of the rock vane. A high speed jet entered the pool from the first riffle, and it impinged upon the rock vane installed near the apex of the bend (Fig. 6b). A high velocity region was observed at the location above the rock vane due to the contracted flow area, but it quickly dissipated as the flow moved downstream. Such flow patterns indicated that the rock vane effectively dissipated the mean flow energy of the jet. At the water surface, the rock vane deflected the flow direction of the jet to the center of the channel and prevented it from impinging upon the outer bank. This indicates the ability to suppress erosion from occurring at the outer bank of the bend.

Modeling sediment transport and scour

The three-dimensional numerical URANS model coupled with the bed-morphodynamics module has been employed to simulate the flow and the ensuing sediment transport process near the stream restoration structures for the indoor experiments (Fig. 7). The presented model could capture most of the scour pattern characteristics including the maximum scour depth, maximum deposition height and scour hole pattern and position with an acceptable accuracy; however, because of the inherent complexity of the flow field in the quiescent area of the wake zone directly downstream of the rock-vane, the resultant scour pattern accuracy is lower.

The ultimate objective of the VSL project is to develop an integrated software package that can be used for simulating SR flows in an accurate and efficient manner. The envisioned software, which will be called VSL 2.0, will be capable of accounting for all major complexities of such flows so that it can be used by stream restoration engineers as a powerful design tool for site-specific optimization of stream restoration projects.


Through continued collaboration with the Intermountain Center for River Rehabilitation and Restoration (ICRRR) and the US Army Corps of Engineers (USACE) we are developing a stream restoration decision analysis and design guidance document and accompanying software that will define and implement a rational, objectives-driven approach to evaluating and designing stream restoration projects. The Stream Project will be a major legacy of the NCED Stream Restoration IP, fulfilling our goal to promote a transition in restoration practice from an approach based on single-discipline analogy to one based on multidisciplinary quantitative prediction. The project is guided by two themes: a predictive link between restoration objectives and actions and an explicit coupling between restoration science and decision analysis.

The Stream Project is led by Wilcock and managed by the SRIP project manager, Baker. PI Hobbs leads the decision analysis development. PIs Parker, Sotiropoulos, Belmont, Hondzo, and Finlay will contribute. ICRRR participants include NCED post doc Utley, NCED Affiliate Scientist Belmont, and Profs. Budy, Schmidt, and Wheaton from Utah State University. Participants
from the US Army Corps of Engineers Engineer Research and Development Center, DC Environmental Laboratory are Jock Conyngham, Richard Fischer, Craig Fischenich, and Meg Jonas. The project has a two-year schedule (completion Summer 2012) and will include four working meetings to support development and testing of methods, software, decision techniques, and case studies.

The decision analysis and design manual is intended to be a complete realization of a new approach. To address this challenge in a two-year project, we will not be able to address all possible objectives that could be defined for a restoration project. Our intent is to include a sufficient suite of objectives to be able to completely address a range of common restoration situations. The objectives list includes channel stability, infrastructure protection, water quality improvement, including nutrient and sediment loading, fish passage, aquatic species recovery, and aesthetic/recreation enhancements. Case studies will have a central role in the project, serving not only as illustrations of the method, but as a basis for the dialog between science, design, and decision analysis. It is by combining our efforts on realistic case studies that we will define actionable objectives, relevant tools, and feasible design approaches.

SR01: Watershed context for stream restoration

Watershed context plays a key role in SR by defining favorable locations for restoration actions as well as effective and sustainable actions at designated project sites. We focus on a key mechanism controlling watershed context: the flux and storage of water, sediment, and nutrients. This includes topics in SR02 on sediment routing models incorporating storage and transformations and fingerprinting methods for identifying source and, in SR06, on using watershed location as a key factor in sediment source reduction management decisions.

SR01 strongly interacts with Desktop Watersheds. The principal research watershed within SRIP is the Le Sueur (discussed above). The Le Sueur provides a nicely defined target—sediment yield at the watershed mouth—for watershed scale research. The effort to extract watershed characteristics from high-resolution topographic datasets for the purpose of making better-informed resource management decisions is a primary focus of DWIP and has a direct application in the SRIP. A first step in using high-resolution topography is determination of channel networks. The GeoNet toolbox (discussed in DWIP) has been tested for the low-gradient landscape of the Le Sueur River (Passalacqua et al.) and a GIS-based floodplain inundation tool was jointly developed by Barr Engineering and NCED and was applied by Belmont (2011) to analyze valley bottom development within the incised portion of the Le Sueur watershed.

Many DWIP projects at ACRR are closely aligned with SR01. Ongoing work by PIs Finlay and Hondzo on the cause and consequences of thresholds in biological processes in river networks play an important role in defining appropriate locations for restoration activities in watersheds. In contrast to smooth gradients in rates of change in ecological processes with stream size and geometry, PIs Finlay, Power, and Hondzo have observed abrupt changes in conditions at ACRR.
A focus of this work on thresholds in ecological processes involves development and testing of a model of light inputs. NCED post doc Mike Limm and DW program manager Colin Bode are leading efforts to model light inputs, one of the most critical variables regulating ecological properties in streams, including nutrient removal. This model is essential to prediction of nutrient removal capacity; we will need to build in effects of turbidity on light transmission through water for sites (e.g., wetland influenced or human dominated) where attenuation is significant.

NCED PIs Finlay and Power, along with former NCED post docs Schade and Welter, have completed 3-year NSF-funded study of nutrient spiraling (cycling and downstream advection) through different parts of the drainage network. The nutrient spiraling project examines the interplay of food web interactions, landscape structure, and stoichiometrically constrained nutrient cycling as it influences N and P flux vs retention down the river drainage network. This work allows a fuller understanding of where stream restoration for nutrient retention may best be located in a catchment.

**Plans**

We will use airborne LIDAR to extrapolate field-measured bluff and ravine erosion rates from the Le Sueur watershed to the Blue Earth watershed. Together, these two watersheds provide the majority of sediment to the Minnesota River Basin (MRB). Foufoula-Georgiou and Belmont will use new leveraged National Science Foundation (NSF) support to extract information on land use practices and ephemeral gully erosion. We are collaborating with the MPCA to apply sediment source analysis and decision making tools from the Le Sueur to other sub-watersheds in the MRB, with the goal of scaling up to apply our sediment budget results and models to the basin turbidity TMDL.

**SR02: Improved models for sediment source, routing, storage, and yield**

Routing of sediment through drainage networks is a core area of investigation for NCED and has direct implications for restoration management decisions. In a stream restoration context, routing is needed to link target channels to their watershed, setting upstream boundary conditions for project sites, and contributing to the identification of the most effective sites for reducing basin sediment yield. NCED sediment routing projects span the range of composition, physiographic location, and management context: from gravel routing through boulders in steep mountain torrents to transport of sand through the Mississippi Delta to the delivery of mud and associated nutrients in agricultural lowlands. A key focus of this work is developing predictive methods for routing sediment—developing approaches that take advantage of new technology for high-resolution topography while preserving interpretability through reduced-complexity models. SR02 efforts are closely aligned with work in DW06 and SA01.

A code for the routing of sediment and cosmogenic nuclides in the Le Sueur River system has been completed by NCED postdoc Viparelli (in review), in association with NCED PIs Parker and Wilcock, former NCED student Lauer (now at Seattle University), and NCED affiliate Belmont. The one-dimensional sediment routing model provides the numerical framework to make predictions regarding (a) the production, transport, and storage of sediment and tracers in the channel and floodplain, (b) the morphodynamic responses to changes in the magnitude and distribution of sediment sources, and (c) the rate of sand and mud transport through the system, which will inform our understanding of the time lag that could be expected between implementation of mitigation strategies and resulting improvements in water quality.

PI Wilcock and NCED student Podolak have completed a sediment budget for the Sandy River, OR in response to removal of Marmot Dam (Major et al., in review). This provides the basis for testing a sand and gravel routing model over approximately 40 km of a steep, energetic mountain river. A key element of this work is to explore the interaction between nonuniform water and sediment flux and local adjustments of topography and sorting. To explore this further, Wilcock and Podolak investigated the response of gravel bars to an increase in sediment supply using experiments in the SAFL main channel. A mixture of sand and gravel was fed into a large flume containing alternate gravel bars, and the evolution of the transport, topography, and grain size were monitored using the NCED/SAFL precision cart. The experimental results are being used to validate a 2D multi-fraction morphodynamic model (discussed in SR07). These measurements will help to develop a better understanding of sediment routing and storage.
Plans

Year 10 will see the completion of the wide range of sediment routing projects underway at NCED. The sediment and tracer routing model developed by NCED post-doc Viparelli will be developed for multiple tracers and tested against other rivers in the Minnesota River Basin. This contributes to the goal of testing the model’s capabilities under a range of conditions and to develop a stronger basis for evaluating management options for reducing turbidity in the Minnesota River. A 1D sediment routing with coupled sediment storage functions will be developed by Podolak and Wilcock and tested against observations of channel response and transport on the Sandy River.

► SR03: Dynamics of mixed-size sediment

The transport of streambed material has direct impact on surface and subsurface bed composition, the morphology of the channel, and surface and subsurface fluid flow. The details of the channel planform, the composition of the bed surface, and hyporheic flow constitute the essential, organism-scale template for the stream ecosystem. This project focuses on developing our understanding of the transport and sorting of coarse bed material. Our goal is the development of predictive relations for sediment entrainment, sorting, and transport and to extract essential mechanisms and controls for application to reach and network scales.

NCED PI Foufoula-Georgiou and NCED student Singh’s flume experiments resulted in the observation of a “spectral gap” in turbulence velocity fluctuations collected above a river bed with evolving bedforms. Verified by simultaneous velocity and bed elevation observations, it was concluded that the spectrum of turbulence carries information about the evolving multi-scale nature of the bed topography, and can thus form a useful tool for non-invasive and economical/robust field monitoring in real rivers. Year 9 experiments included simultaneous high-resolution measurements of velocity fluctuations, bed elevations and sediment flux sampled at the downstream end of the channel for a range of discharges. Resulting probability density functions (pdfs) of the bed elevation fluctuations and the instantaneous Reynolds stress reveal heavy-tailed pdfs and a strong feedback between the co-evolution of bedforms and the near-bed turbulence (Fig. 8).

Parker and NCED post-doc Viparelli completed development of a mixed-size morphodynamic model that includes creation and consumption of stratigraphy in gravel-bed rivers by bed aggradation and degradation (Viparelli et al., 2011a, b). They are also extending a broad record of experiment and modeling on alongstream sorting with experiments on downstream “lightening” in an aggrading deposit consisting of a mixture of sediment, all with the same grain size, but with different specific gravities.

Hill, Paola and Wilcock, along with NCED student Sara Baumgardner, are extending experiments begun by NCED student John Gaffney to examine the effect of fine sediment on the transport of gravel beds. This work extends previous results indicating a strong increase in gravel transport rate with the addition of fines. When the fine sediment is smaller than approximately 1/20 the gravel size, the influence of fines on gravel transport begins to decline, providing the first experimental demonstration of the wash load/bed material load boundary.

PI Hill has been investigating the dynamics of grain displacement in mixed-size sediment. Work within the last year focused on the effect of an abrupt change in particle size distribution and associated bed roughness on certain parameters of bedload transport. In particular, this work investigates the variable turbulence statistics as they relate to particle entrainment events. We simultaneously measure instantaneous fluid velocities at certain heights above the bed and correlated particle entrainments (Fig 9). Additional mixed-size sediment experiments by PI Dietrich and NCED student P. Nelson are described in DW.

Figure 8. (Left panel) Semilog pdfs of bed elevation fluctuations (top) and instantaneous Reynolds stress (bottom), and (Right panel) their third statistical moment counterparts (x3pdfs) which further highlight the asymmetric nature of the pdfs. The three curves are for the discharges of 1500 l/s, 2000 l/s and 2800 l/s and demonstrate that the asymmetry increases with increasing discharge.
Plans

The NCED focus on mixed-size sediment transport will reach culmination in Year 10 with a range of publications and a summary monograph distilling the overall work. Hill will complete work on the response of streambed slope to the addition of fines with the goal of developing a general definition of the wash load / bed-material load boundary in terms of the transport capacity of sediments of different sizes. Parker and Viparelli are converting routing and mixed-size morphodynamic models to Community Surface Dynamics Modeling System (CSDMS) standards (see Knowledge Transfer section). Podolak and Wilcock will implement mixed-size morphodynamic code for a 2D modeling environment (USGS Multidimensional Surface-Water Modeling System). DeTemple will complete publications that present a complete theoretical framework for vertical sorting and armor development in a mixed-size sediment channel, and the new experimental data recently collected to support the theory. Dietrich, Nelson and other students will submit papers related to river bed patchiness and sediment transport dynamics in steep channels.

Figure 9. Simultaneous fluid velocity and particle entrainment measurements. (a) shows experimental schematic. (b) and (c) show velocity statistics as they correlate with particle entrainment (at t = 0 in both plots). Our results show only correlation between downstream velocity bursts and particle entrainment with little correlation between Reynolds stress and velocity entrainment.

► SR04: Predictive relations for channel and floodplain geometry

Once the boundary conditions of water and sediment supply are specified (with uncertainty), predictive stream restoration requires an ability to forecast the dynamics of channel and floodplain geometry. Work in this project focuses on both the influence of channel and floodplain storage on the movement of sediment through the drainage network and the response of local geomorphic elements to specified water and sediment supply.

Focusing on river meander migration, Parker and NCED student Ester Eke have completed the implementation of a nonlinear 2D depth-averaged numerical model of flow in a meandering channel with a freely erodible bed. The numerical model has been specifically designed to allow independent laws for eroding and depositing bank migration, thus it allows the co-evolution of width with meander migration. They have published one manuscript on this work and Eke is nearing completion of her PhD thesis. In addition, they are working with Hokkaido University on implementation of aspects of the model. Dietrich and NCED student Braudrick have completed work at Richmond field station on the relationship between sediment supply and river morphodynamics in fixed-wall and freely meandering experimental channels.

NCED students Susannah Erwin and Christian Braudrick, under the guidance of PI Wilcock, conducted experiments in fall 2009 to investigate the relations between sediment supply and bar growth in the OSL. Beginning with a meander point bar developed under a modest sediment supply rate, sediment feed was then increased and the point bar grew in volume, height, and area. When sediment feed was reduced to its previous level, the point bar returned to its previous size and configuration. This well-defined adjustment, coupled with detailed observations of topography, flow, and grain size, provides an exceptional data set for testing of both the morphodynamic code developed for the VSL and the mixed-size morphodynamic code recently incorporated into MD-SWMS.

Wilkerson and Parker brought a study of the hydraulic geometry of sand-bed channels to completion and a resulting paper has been published. This study used observations of bankfull channel hydraulics and geometry (i.e., discharge, width, depth, and slope) to back-calculate parameters for the physical relationships that underlie channel formation. The underlying physical relationships are based upon a Manning-Strickler resistance relation, the channel-forming Shield’s number, and sand yield at bankfull flow. This completes a redefinition for hydraulic geometry for both gravel- and sand-bed rivers.
PI Wilkerson and NCED student Mathew Hagene worked to develop a new model for predicting depth-averaged velocity distributions in channels with rigid cylindrical vegetation. This model is significantly different from the existing models in that it is being derived using momentum balance rather than the continuity equation. This study was able to develop a new velocity defect model using the momentum equation and compare the new model to the previous continuity based model. Hagene defended his thesis in March 2011 and will submit a manuscript related to the work this summer.

**Plans**

Year 10 will see the conclusion of the NCHRP study of the interaction between in-stream rock structures and flow, bed topography and sorting under baseflow, bankfull, and flood discharges. Detailed observations of flow and transport will be used to test VSL and to develop design guidance for in-stream structures. Work in Year 10 will continue to move toward development of design tools for restoration practice. Wilkerson will lead an effort to develop channel design guidelines for restored gravel- and sand-bed channels using hydraulic geometry relations. This will build on the physically based relations developed for gravel-bed rivers ($D_{50} > 25.0$ mm) and sand-bed rivers ($0.062$ mm < $D_{50}$ ≤ $0.50$ mm). Variability in the relations will be addressed by presenting lookup tables that will facilitate quantification of confidence bounds and prediction intervals for the relations. Parker will develop tools for routing coarse sediment through meander bends. Wilcock will add multiple discharges and their duration to the channel design tool iSURF.

► **SR05: Predictive relations for the effect of physical channel structure and disturbance regime on primary productivity, nutrient transport, and species recovery**

Restoration projects commonly have ecological or water quality objectives. Predictive relations for addressing water quality, habitat, and species recovery are at or beyond not only current practice, but also our general knowledge of stream ecosystems. This project focuses on developing knowledge to guide planning and design of stream projects for the ecological purposes of water quality and habitat improvement as well as for species recovery. Predictive understanding of stream ecosystem function is needed in a number of key areas, including linkages between physical channel conditions and nutrient cycling, in particular between surface geomorphology and nutrient processing. Fluid flux between surface water and ground water mediates important naturally occurring biogeochemical and ecological processes.

In OSL during the summer 2010, NCED PI Hondzo made micro-scale observations of metabolic activity of denitrifying bacteria and local turbulence and dissolved oxygen (DO) characteristics at the sediment-water interface and this year with the added complexity of studying the effects of common in-stream hydraulic structures, including rock vanes, J-hooks, and bendway weirs (Fig.10). The experiments demonstrated a removal of nitrate from the bulk fluid over short distances. Nitrate concentrations were generally smaller near the sediment in comparison to concentrations in the water column above the sediment bed. Shear stress velocities at the sediment bed and spatial heterogeneities of nitrate concentrations mediated removal of nitrate at the stream bed. The estimated nitrate flux assumes a linear relationship for change in nitrate concentrations in the streamwise direction. During the summer of 2011, additional measurements will be conducted in the OSL in order to a) test the proposed linear assumption, b) quantify the activity of denitrifying bacteria in the stream bed, and d) finalize functional relationship among nitrate, turbulence characteristics above the stream bed, and organic material concentration in the stream bed.

**Plans**

In 2011, we will continue to take advantage of the NCHRP project to evaluate the effect of in-stream structures on in-channel ecogeomorphic function. PI Hondzo will formulate three scaling relationships that form the basis for a predictive model for denitrification in streams. The scaling relationships include 1) activity of denitrifying bacteria versus turbulence characteristics and bed topography; 2) activity of denitrifying bacteria versus carbon content in the sediment; 3) activity of denitrifying bacteria and soil moisture. In collaboration with PIs Power and Wilcock, Hondzo will also develop scaling relationships for epiphyte attachment and detachment on filamentous algae. Together with a model for nitrogen mass transfer in the proximity of algae filaments, the scaling relationships will be integrated into a reach-scale model of periphyton biomass. With the biomass and denitrification models and a temperature component in VSL, metabolism and uptake predictions can be tested against OSL observations. These will provide the basis for design criteria or charts for predictive denitrification in streams.
NR06: Linking public preference, objectives, and stream restoration alternatives

As we move toward a predictive science of stream restoration, we must address the challenges to putting this knowledge to work. Stream restoration objectives are diverse, including infrastructure protection, water quality, aesthetics, habitat, and species recovery. In addition, there are large uncertainties regarding the physical and biological outcomes of projects, and there is limited information on public preference and economic valuation. This situation raises a host of challenges: How can restoration objectives be more effectively identified and combined with physical and biological models in predictive restoration design? How do we most effectively incorporate improved ecosystem information in stream management? How do we characterize uncertainty in landscape prediction and use this information effectively in management decisions? Our goal is a professional practice in which project goals are predictive targets quantitatively linked to public preference, regulatory and policy guidelines, and management actions. Under the direction of PIs Hobbs and Wilcock, this project plays the lead role in synthesizing advances in science and prediction and placing them in a consistent and transparent decision framework.

A key emphasis of the NCED approach to stream restoration is to combine balance explicit objectives against their cost. A group including PIs Wilcock, Hobbs, former post doc Kenney, and NCED student Martinez have developed a basis for evaluating the balance of benefits and costs for urban stream restoration (Kenney et al., in review). This work provides a starting point for developing decision analysis tools as part of the Stream Project.

NCED student Cho, along with PIs Hobbs and Wilcock are building on the work of former NCED students Jacobi and Zheng in developing methods to evaluate sediment control options for the Le Sueur watershed. They are evaluating high-resolution topography and soil loss data to develop a GIS tool for estimating the effect of topography on sediment delivery ratio (SDR). They are working to streamline the framework developed by former NCED student Jacobi to evaluate research actions and an optimization model that can be used to recommend appropriate research actions and restoration efforts as a part of an adaptive management program for reducing water impairments in a watershed. The goal is to adapt the Jacobi framework so that it is practical for use in larger watersheds, while still considering uncertainties (and their correlations) in sediment sources, SDR, and BMP effectiveness.

Plans

In Year 10, SR06 will play a key role in both the Le Sueur/Minnesota River project and the Stream Project. In the Minnesota River Basin, we will work with local stakeholders and state agencies to establish a decision-making context for the greater Blue Earth Watershed (which includes the Le Sueur Watershed). Using the Le Sueur sediment budget as a starting point, we will develop a simulation model for sediment sources within a decision analytic framework that allows stakeholders to consistently evaluate different restoration options. This work represents the intersection of many NCED goals—improved prediction using reduced complexity models, watershed context using topographically driven prediction, and the explicit integration of science and engineering predictions in a decision analysis framework supporting improved environmental management.

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Figure 10. Field measurements in the OSL during summer 2010. Time-averaged streamwise velocity contours (m/s) and shear stress velocities (m/s) at the bed are displayed on 10 cm resolution topographic data (A). Time-averaged nitrate (NO3) contours (mg/L) and concentrations (mg/L) near bed sediments (B).
The Stream Project: Decision Analysis and Design Guidance project for stream restoration uses a decision analysis as its underlying framework. Objective setting, alternatives evaluation, and design/learning feedback all play a central, integrating role in defining and implementing a new approach to restoration. In collaboration with the other Stream Project team members, Hobbs, Baker, and Wilcock will implement this framework for the Stream project and develop computational tools to facilitate tradeoff analysis and transparent decisions-making.

**SR07: Dam reoperation and removal for ecosystem restoration**

Large dams present a significant opportunity for ecosystem restoration as well as an opportunity for exploring river response to large-scale perturbations and restoration efforts. This project includes 1) the influence of dam operation or removal on the movement of water and sediment through downstream reaches and 2) the response of local bed composition and configuration to changes in sediment routing, and 3) the use of channel reconfiguration, gravel augmentation, and reservoir releases as restoration experiments.

We have established an active collaboration, informally termed Bar Flies, among those working on SR07 projects. This group has focused on investigating mechanisms of bar response to changes in sediment supply using flume experiments, field studies, and hydraulic models. In the laboratory, NCED student Christian Braudrick, with PI Dietrich, investigated bar response to decreased supply in two experiments, one with fixed bars and one with translating bars. Braudrick also collaborated with NCED student Susannah Erwin to study the response to increasing the sediment supply in a meandering channel in the OSL.

The field component of the Bar Flies collaborative efforts involves measurements of morphologic change and sediment flux in three rivers in the western United States. The studies examine changes to bar morphology associated with sediment supply changes due to gravel augmentation, stream restoration, and dam removal. PI Wilcock and NCED student Andreas Krause are working on the Trinity River, CA, where dam releases, gravel augmentation, and channel restructuring provide the opportunity to investigate channel response to a range of sediment supply conditions. They are developing a suite of metrics to characterize channel complexity for use in the context of stream restoration and rehabilitation.

On the Sandy River, Oregon, removal of the Marmot Dam released several years’ worth of sediment load to an energetic mountain river with existing bed topography. PI Wilcock and NCED student Podolak have been measuring changes in the grain size and topography downstream of the former Marmot Dam as well as making sediment transport measurements on the river. By teaming together with partners from the USGS, the Marmot Dam has been one of the most intensely monitored dam removals and the fate of both the bed and the released sediment have been well documented.

In collaboration with NCED partner Jack Schmidt at Utah State University, PI Wilcock and PhD student Susannah Erwin are examining changes in channel morphology resulting from an influx of gravel into a recently reconfigured reach of the Provo River (UT). The study site is 16 km long and is located downstream from Jordanelle Dam. The same restoration design was used immediately below the dam and further downstream where a local source provides a supply of gravel. The migration of gravel through the downstream reach and comparison with the sediment starved reach provide a field experiment incorporating flow control, sediment supply, and channel re-engineering. A sediment transport measurement campaign was conducted during a controlled flood in summer 2009. Highly detailed channel surveys were completed before and after the controlled flood event, with the goal of explicitly linking sediment flux with changes in channel morphology in this actively aggrading system.

The Bar Flies are using MD_SWMS, a quasi 3-D hydrodynamic model developed by the USGS, to evaluate bar and patch response to changes in sediment supply. NCED student Podolak is working with the USGS to incorporate mixed-size morphodynamics and variable sediment supply in MD-SWMS. Model development will be tested against the lab and field observations and the updated model will be used to generalize the results and develop design guidance for channel change and stream restoration.

**Plans**

In year 10, the four Bar Fly projects will reach completion, providing a testbed for mixed-size transport, 2D flow, and reduced complexity routing models that accommodate topographic variability and fluctuations in sediment supply.
## Progress on Deliverables

The SIP organization developed in year 4 aligns well with the general goals of SRIP, but does not fully capture the focus leading to our primary legacy targets. For completeness, progress on these deliverables is summarized here.

<table>
<thead>
<tr>
<th>Project</th>
<th>Milestone/Deliverable</th>
<th>Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SR01</strong></td>
<td>Specify location and type of restoration action for reduced sediment loading in a large (2,800 km²) watershed (Yr 9)</td>
<td>A sediment budget has been completed for the Le Sueur watershed.</td>
</tr>
<tr>
<td></td>
<td>Demonstrate application of lidar topographic analysis tools for evaluating restoration options in different landscapes (Yr 10)</td>
<td>Airborne lidar used to 1) identify Le Sueur terraces and document sediment evacuation over the Holocene and 2) upscale local observations of bluff erosion. NCED-Barr floodplain tool used to analyze valley bottom development in the incised portion of the Le Sueur watershed.</td>
</tr>
<tr>
<td><strong>SR02</strong></td>
<td>Test improved reach-averaged sediment routing models with explicit storage functions for both sand and gravel rivers (Yr 7).</td>
<td>Reduced-complexity models developed for routing sand and mud in Le Sueur River and gravel and sand on the Sandy River. 2D models to be applied in Year 10 to develop in-channel storage functions in gravel-bed rivers.</td>
</tr>
<tr>
<td></td>
<td>Establish sediment fingerprinting methods for sediment source and history (Yr 8)</td>
<td>An innovative mix of fallout and cosmogenic radionuclides used to develop sediment source estimates in the Le Sueur and Minnesota River watersheds. Combination effectively demonstrates a key shift in sediment source over recent decades.</td>
</tr>
<tr>
<td><strong>SR02</strong></td>
<td>Complete sediment budget for 2,800 km² watershed combining geochemical fingerprinting and flux/storage estimates with valley bottom sediment storage and steambank erosion in a network routing model (Yr 9).</td>
<td>A sediment budget has been completed for the Le Sueur watershed.</td>
</tr>
<tr>
<td><strong>SR03</strong></td>
<td>Complete initial model for vertical sorting and morphodynamics in spatially homogeneous beds (Yr 7).</td>
<td>Theoretical development of a vertical sorting model is complete and tested against stratigraphy and tracer flume data. Complete theory of mixed-sediment mass conservation to be finished in Year 10.</td>
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<td></td>
<td>Management guidelines for gravel augmentation and sand infiltration (Yr 7)</td>
<td>Management guidelines for gravel augmentation and sand infiltration have been developed by NCED partner Stillwater Science.</td>
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<tr>
<td></td>
<td>Strategy for scaling up lateral variability in reach to network modeling (Yr 7)</td>
<td>VSL has been successfully developed for field-scale flows and tested against OSL observations and flows around different blunt objects.</td>
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<tr>
<td></td>
<td>Tested model of sorting and morphodynamics for field data sets (Yr 8)</td>
<td>Routing model incorporating mixed-size stratigraphy published and model posted on NCED Toolbox website. Testing of these models is underway on Trinity River, Sandy River, Provo River, and OSL.</td>
</tr>
<tr>
<td><strong>SR04</strong></td>
<td>Develop sand-bed and universal hydraulic geometry relations and design guidelines incorporating variability (Yr 7)</td>
<td>Hydraulic geometry development for both sand and gravel rivers complete. Design guidelines under development.</td>
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<tr>
<td></td>
<td>Integrate hydraulic geometry and dimensional analysis to upscale nutrient concentrations in terms of stream reach length and drainage area (Yr 8)</td>
<td>Dimensionless relations for stream metabolism developed. Relation between channel width, light, metabolism, and nutrient uptake established. Upscaling to reach to be completed in year 10 using VSL and OSL/field observations.</td>
</tr>
<tr>
<td></td>
<td>Basis for scaling laboratory bank strength and vegetation effects to the field (Yr 7)</td>
<td>A dynamic, vegetation-controlled meandering stream has been successfully developed at the UCB Richmond lab. Studies of the effect of sediment supply on bar and meander growth are underway.</td>
</tr>
<tr>
<td></td>
<td>Numerical StreamLab for testing effect of channel geometry and in-stream structures on channel stability and habitat (Yr 7)</td>
<td>Field testing at ACRR, initial observations in OSL, and VSL development provide basis for upscaling nutrient processing using StreamLabs research in Yr 8.</td>
</tr>
<tr>
<td>Project</td>
<td>Milestone/Deliverable</td>
<td>Progress</td>
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<tr>
<td>SR05</td>
<td>Initiate Outdoor StreamLab, bringing experimental control and high resolution measurement to field-scale ecogeomorphology studies (Yr 7)</td>
<td>OSL successfully operated for three years.</td>
</tr>
<tr>
<td></td>
<td>Quantify relations among channel attributes, fluid mechanics, nutrient transport/transformation, ecosystem metabolism, and species habitat (Yr 7)</td>
<td>Effect of channel roughness on nutrient uptake established. Work now focused on using VSL to upscale local processes to reach scale.</td>
</tr>
<tr>
<td></td>
<td>Use hydraulic geometry to establish framework for upscaling local biotic and metabolic processes in terms of stream reach length (Yr 8)</td>
<td>Effect of channel width on light availability, primary production, and nutrient uptake established. Work now focused on design guidance.</td>
</tr>
<tr>
<td></td>
<td>Dimensionless groups of biotic and abiotic variables to describe functional relations (Yr 10)</td>
<td>Field observations at ACRR demonstrate local relations among physical and biogeochemical function and the existence of larger scale gradients in the controls of nutrient processing. Testing on rural stream in Minnesota in Year 10.</td>
</tr>
<tr>
<td></td>
<td>Model impact of fine sediments on carrying capacity and fish habitat productivity (Yr 7)</td>
<td>Impact of fine sediment on spawning and rearing established.</td>
</tr>
<tr>
<td>SR06</td>
<td>Demonstrate survey method for measuring public preference, considering uncertainty (Yr 7)</td>
<td>Public preference for stream restoration action established using WTP survey, demonstrating the benefits/costs of urban stream restoration.</td>
</tr>
<tr>
<td></td>
<td>Demonstrate watershed framework for optimizing water quality improvement under risk (Yr 7)</td>
<td>Initial model demonstrates effectiveness. Continued work will be based on reduced complexity sediment model and stakeholder-based shared vision modeling.</td>
</tr>
<tr>
<td></td>
<td>Implement Bayesian methods for estimating the value of reduced uncertainty (Yr 8)</td>
<td>Initial model completed; developing streamlined model for practical application in Year 10.</td>
</tr>
<tr>
<td></td>
<td>Assess value of improved models vs. improved data in SR decision making (Yr 10)</td>
<td>Le Sueur sediment budget to be tested to expansion to larger watershed, supporting a collaborative decision analysis exercise with stakeholders.</td>
</tr>
<tr>
<td>SR07</td>
<td>Develop field data sets on the effects of injected and dam-released sediments on downstream channel geometry and habitat (Yr 8)</td>
<td>Extensive data sets have been developed for the Sandy and Trinity rivers in response to dam release and gravel augmentation, respectively. Channel response to varying sediment supply has been established on Provo River and in OSL and Richmond Field Station.</td>
</tr>
<tr>
<td></td>
<td>Predictive relations for the control and management of reservoir erosion (Yr 8)</td>
<td>NCED contributed to development of decision guidance for dam removal and reservoir control.</td>
</tr>
<tr>
<td></td>
<td>Tested application of reach-scale models for sediment routing and channel change (Yr 8)</td>
<td>Initial test of 1D routing model on Sandy River complete. Modifications accounting for local topography to be completed in Year 10.</td>
</tr>
</tbody>
</table>
IId. Facilities

Introduction

Over the course of NCED’s nine year tenure, the center’s research, its associated scientific discoveries, and its interactions with the community have been made possible through the development of an extensive array of field research stations, experimental facilities, and educational exhibits. The development of this “hardware” has enabled NCED to not only make significant advances in predicting the coupled dynamics of landscapes and their ecosystems, but also to communicate this knowledge to partners outside of NCED, helping us transform the management and restoration of the Earth-surface environment.

In our research, we focus on a fundamental component of the Earth-surface system – channel networks and their surroundings – that recurs in varying, but fundamentally related forms across a wide range of environments and scales. To investigate these channel networks, NCED has invested in three major field observatories: the Angelo Coast Range Reserve (ACRR), Minnesota River Basin (MRB), and Wax Lake Delta (WLD). Through these three research sites, we place landscape and ecosystem dynamics in a watershed context and investigate the erosional and depositional processes that drive source to sink landscape evolution in North America. Work at ACRR primarily investigates watershed context, while research in the MRB focuses on erosional processes like those that eventually come to bear on the depositionally-focused research site of WLD.

As a complement to its field research stations, NCED has also invested in designing state-of-the-art experimental facilities for environmental research. These facilities include a wide array of equipment at Saint Anthony Falls Laboratory, among which are “Jurassic Tank,” a specialized basin used to study fluvial geomorphology on a geologic time scale; and the Outdoor StreamLab (OSL), the first meso-scale integrated earth observatory that provides for laboratory-quality monitoring in a natural scale and setting. These investments have produced major new discoveries and laid the foundation for future work by the broader Earth sciences community.

What follows in this section is a description of each of our major research stations and facilities.
Summary

The Angelo Coast Range Reserve continues to be the center of Desktop Watershed (DW) IP field efforts. The research activities are discussed in the DW section. Cyberinfrastructure is fully operational and in maintenance mode.

Field Site, Setting and Natural History

The Angelo Coast Range Reserve, one of 35 natural history research reserves in the University of California Natural Reserve System, (UCNRS) is one of the largest tracts of coastal Douglas fir-coastal redwood forest remaining in California. The Reserve itself is 9,142 acres. The South Fork Eel River runs north through the nearly parallel reserve, to the Pacific coastline for most of its length. Recent studies suggest that the river’s downstream reach may be uplifting as much as ten times faster than the headwaters area near the reserve. Continued uplift and incision by the Eel River and its tributaries created the Reserve’s steep topography. Terraces create the only level land in an otherwise rugged terrain of narrow ridges and steep valleys. Surrounding slopes may exceed 50 percent. Elevations range from 378 meters (1,240 feet) near headquarters to 1,290 meters (4,231 feet) at Cahto Peak. Underlying most of the Reserve are greywacke sandstones and mudstones of the Franciscan Complex, with derivative soils from the Josephine and Hugo series.

The region has a Mediterranean climate, having heavy rains in the winter (Oct-Apr) then summer drought with no rain. Annual precipitation is 80 inches (203 cm). Being one of the few undammed rivers in California, the South Fork Eel River floods during the rainy season (>120 cubic meters per second). Five km of the South Fork of the Eel River and the entire watersheds of three of its perennial tributaries are contained in the Reserve. One of these, the Elder Creek watershed, is considered the largest pristine watershed remaining in the state of California, and has been continuously monitored since 1967 by the U.S. Geological Survey as a benchmark for purity of natural waters.

The Reserve itself has a long tradition of environmental monitoring, which started under The Nature Conservancy and has continued as part of the UCNRS. Meteorological and stream runoff monitoring data, including a 36 year record from Elder Creek, as a USGS Benchmark Station, is available. There are over twenty-five years of research on biological, ecological, geomorphological, and human cultural aspects of the Angelo Reserve ecosystem. The favorable location with relatively simple underlying geology and no major upwind sources of urban or agricultural pollution facilitates the study of atmospheric inputs from the Pacific Ocean. The reserve has a $1.2M Environmental Science Center, gifted by the Goldman Fund, completed in 2002. The complex includes laboratory, computer, library, and meeting spaces that have been used for several workshops and multi-university scientific collaborations.

Angelo Coast Range Reserve Activities

The ACCR Sensor Observatory has been operational since 2009 and is in maintenance mode. The Berkeley Sensor Database now has 70 million observations from 1229 datastreams. Current efforts are focused on improving researcher alertness to outages or issues with the sensors and improving the interface to facilitate the interaction.

Algal Biomass and Distribution Model

NCED is developing, as one of the last Desktop Watershed IP initiatives, an algal biomass model at the watershed scale. This effort builds on the Ripple Coho salmon population model. This effort will use the geomorphic characteristics of the river channel, light levels using subcanopy lidar solar radiation modeling, hydraulic characteristics, and in-field characterization at ACRR as inputs to the model. The goal is to predict algal biomass both spatially and temporally in the South Fork Eel river, then upscale to the entire Eel River system.
Prop 84 Project

California Proposition 84 provides public funding for parks and education facilities to provide 100% matching funds for facilities improvements. ACRR has raised $650K of funding as a match for the Prop 84 grant proposal which, if successful, would provide a total of $1.3 million dollars for new housing facilities adjacent to the ACRR’s Science Center. The old severely sub-standard HQ House would be replaced as a dining hall/kitchen/bath/laundry facility, and three bunk houses and a small two bedroom apartment would provide a total of 24-30 beds for visiting researchers and classes.

CyberInfrastructure Improvements

UCNRS has been awarded stimulus funding to upgrade the cyberinfrastructure of its field stations. ACRR will replace all the wireless radios in the reserve that NCED originally installed. The funds are timely, since the radios are near obsolescence. New equipment will be considerably faster (11mbps to 54mbps), but will have a higher power demand requiring additional solar panels.

Weather Station Grant

UCNRS has also been awarded an environmental monitoring grant to place a weather station at each of the field stations in the system. ACRR will gain another weather station in South Meadow as a result.

RFFI

ACRR and NCED are continuing their collaboration with the Redwood Forest Foundation Initiative (RFFI) in a grant proposal for an education center on the RFFI Usal forest lands. The center would be a combined Redwood ecology and Native American center. NCED is providing both the scientific expertise and the technological expertise to the project, which may include a small educational sensor observatory, a rain table, and a geowall.

Kurok Tribe

We have been in discussions with the Kurok Tribe who live north of the Reserve in the Klamath river basin about opportunities for collaboration. We submitted a proposal to replicate the Rivendell study site at Happy Camp on Kurok lands and are looking for further ways to collaborate in their initiatives in forest and river restoration.
Wax Lake Delta Research Field Site

WLD Field Site: Research Activities

Distal Wax Lake Delta distributary channel network: Understanding the morphodynamics of the modern Wax Lake Delta distributary channels is essential for reconstructing delta dynamics—from interpreting ancient deltaic successions to forecasting the morphology of proposed Mississippi river diversions.

Very little is known about the WLD’s distributary channels—one outstanding question regarding the distributary channels of the WLD is how they lose definition at their distal ends. Over the past year, UT graduate student John Shaw has carried out the first high resolution mapping of the distributary channels of the WLD using swath bathymetry (Fig. 1). The surveys show that the distributary channels extend up to 2 km seaward of their subaerial portions. These channels lose definition at their distal ends through a combination of channel-bed shoaling and loss of bank relief. Channels bifurcate in this region, although the number and symmetry of the bifurcations changes from channel to channel. Little bathymetric relief is observed at the tips of the subaqueous channels, calling into question the role of channel-mouth bars in generating the bifurcations observed in this delta-channel network. Figure 1 shows the trends in channel and bank depth as a function of distance downstream on Gadwall Pass. We hypothesize a conceptual model of delta front progradation, where the channel banks and region in front of the channels aggrades while the channel degrades. Taken together, these processes force progradation of the delta as well as extension of the channel (Fig. 2).

Nitrogen cycling within Wax Lake Delta: During the fall of 2010 the LSU group began measurements of inorganic nutrient fluxes using intact sediment cores. The results of this work can be seen in Figure 3. These results show a significant flux of inorganic nitrate moving from the surface water into the sediments in both sampling locations and support the hypothesis that diffusion and microbial processing are removing nitrate from the surface water as it moves through the marsh/mudflat habitat. However these results are preliminary and measurements of inorganic nutrient fluxes as well as gas fluxes and nutrient pools in pore water, sediment, surface water and vegetation will continue throughout the spring and summer of 2011.

Development of delta metrics: We have developed a set of delta metrics that describe delta morphology and can be used to quantitatively determine similarities and differences among deltas. The delta metrics are: (1) the fractal dimension, (2) the distribution of island sizes, (3) the walking distance, (4) synthetic distribution of sediment fluxes at the shoreline, and (5) the nourishment area. The walking distance is the shortest distance to water from a given location on the delta and is analogous to the inverse of drainage density in tributary networks. The nourishment area is the downstream delta area nourished by sediment coming through a given channel cross-section and is analogous to drainage area. As a first
step, we measured these metrics on the Wax Lake Delta, the Mossy delta (Saskatchewan), a numerically created delta, and an experimentally created one (Figure 4). All these deltas have dominantly distributary networks, mixed cohesive-noncohesive sediment supply, and are largely free of the complicating influences of waves, tides, or other external factors.

Among the four deltas the metrics are generally similar indicating that the numerical and experimental deltas accurately reproduce the geometry of deltas in the field. For all deltas, the average walking distances are also remarkably consistent moving down delta suggesting that the network organizes itself to maintain a consistent distance to nearest channel (Figure 5). Nourishment area distributions (Figure 6) are consistent with a river mouth bar model of delta growth and also scale with the width of the channel, and with the length of the longest channel, analogously to Hack’s Law for drainage basins. The channel network is fractal but apart from this none of the distributions of the metrics are clearly power-law. This work has been led by Doug Edmonds, now an Assistant Professor at Boston College, and is in review in *Journal of Geophysical Research--Earth Surface*.

**Figure 3:** Sediment-water column nutrient and oxygen fluxes from two sampling sites within Wax Lake delta. Creek Mouth (CM) and Island Edge (IE) stations were measured in October 2010. Nitrate uptake was higher in the IE station (-273.6 ±62.0 µmol m-2 h-1) compared to the CM (-206.6 ± 23.8 µmol m-2 h-1) station. Negative fluxes indicate diffusion of nitrate into sediment.

**Figure 4:** Planview images of (A) Wax Lake Delta, (B) Mossy Delta, (C) a numerical delta created with Delft3D modeling system, and (D) an experimental delta.
Figure 5: Downstream variation in normalized walking distance, a relative measure of distance to the nearest channel. Delta channel networks appear to organize themselves so that this distance is relatively consistent.

Figure 6: Relation between nourishment area ($A_N$, normalized to delta total area) and channel segment length ($L$, normalized to the maximum channel length) for the four deltas listed above.
**Le Sueur River Watershed Research Site**

**Summary**

The Le Sueur River Watershed (LSRW) field site, located in southern Minnesota, was chosen by NCED in 2008 in an effort to study sediment dynamics on a watershed scale with direct implications for sustainable watershed management and policy. The sediment budget being developed for the LSRW integrates several state-of-the-art approaches to quantifying erosion rates, geochemical sediment fingerprinting, analysis of high-resolution topography, and numerical modeling, coupled with traditional approaches of river gaging, field-based surveys, and geological mapping. Social science efforts in the LSRW involve development of competing Bayesian and deterministic economic decision-making models that incorporate scientific understanding and multiple restoration alternatives, as well as a cost-benefit analysis for placement of Best Management Practices (BMPs) throughout the watershed.

**Field Site Setting and Background**

The LSRW has been implicated as a primary source of sediment to the Minnesota River and Lake Pepin, a naturally dammed lake on the Mississippi River (Fig. 5). Gaging records indicate that the LSRW contributes as much as 30-40% of the suspended sediment load to the Minnesota River, despite the fact that it makes up a mere 7% of the Minnesota River watershed area. Subsequently, the Minnesota River accounts for a mere 38% of the Lake Pepin watershed, yet contributes 85-90% of the sediment load to Lake Pepin (Kelley and Nater, 2000; see Fig. 1). Sedimentation rates in Lake Pepin have increased approximately ten fold in the past 170 years since the onset of extensive agricultural land use in the area (Engstrom et al., 2000). The Le Sueur River, Minnesota River, and Lake Pepin are all impaired for turbidity under Environmental Protection Agency standards in the Clean Water Act Section 303d.

The Le Sueur watershed represents a rare opportunity to study fundamental processes in landscape evolution as well as the effects of pervasive, and mostly uniform, human modifications. The relatively flat landscape was initially formed by the Wisconsinian ice sheet 12,000 years ago. Then, 11,500 years ago, glacial Lake Agassiz catastrophically drained through the Minnesota River resulting in nearly instantaneous vertical incision of the Minnesota River by 65 meters, causing a steep gradient, or knickpoint, at the mouth of the Le Sueur. The knickpoint that was created from this baselevel fall has rapidly propagated 35 km upstream in the Le Sueur River and its two primary tributaries, the Maple and Cobb Rivers (Fig. 2).

In the wake of the knickpoint, steep bluffs and ravines have developed, connecting the flat uplands with the incised river. The record of incision has been preserved in the strath terraces that are ubiquitous within the incised valley. The landscape evolution history of the Le Sueur has left a strong imprint on the landscape, which we can exploit to study processes of knickpoint propagation, bedrock incision, strath terrace formation, floodplain development and channel morphodynamics in such a way that is typically only possible on a smaller scale in physical experiments in a laboratory. Recent human modifications to the ecology, geomorphology, and hydrology of the system present new opportunities to study this evolution in an anthropogenic context.
Research Activities

Summary of current understanding of sediment sources

Multiple lines of evidence indicate that most of the sediment entering Lake Pepin comes from the Minnesota River Basin and that the rate of sediment supply has increased by approximately an order of magnitude over the past 150 years. Widespread agricultural development over that time clearly plays a dominant role in this history, although changes in climate may have also contributed. The geological history of the Minnesota River valley leaves it primed to produce large amounts of sediment. Floods from glacial meltwater lowered the Minnesota River valley bottom by as much as 70 m about 12,000 years ago and the tributaries draining into the mainstem have been adjusting to this downcutting by carving their own valleys ever since. An extensive series of stream gages documents that the tributaries that contribute the most sediment to the Minnesota River Basin are those with a deep incised drainage, a large drainage area, and readily eroded soil and sediment. Actions to reduce sediment loading require identification of not only the subwatershed from which the largest amounts of sediment derive, but the specific location and mechanism of large sediment supply. Sediment sources can be grouped into four categories: field, ravine, bluff, and streambank (Fig. 3). Stream gages located above and below the incised zone in seven watersheds show that these portions of the tributary watersheds produce a large fraction of the sediment supply, indicating that the bluffs and ravines that predominate in these regions are important sources of sediment.

Further resolution of the location and mechanism of erosion is not a simple task: erosion is generally episodic and locally intense, making direct observation uncertain and extrapolation to large areas difficult. We develop confidence in our estimates by using different methods to develop multiple lines of evidence. Comparison among the different estimates is guided by the strong constraint of mass balance (e.g., the erosion and change in sediment storage in a watershed must equal the total sediment leaving the watershed) and corroboration between multiple lines of evidence (e.g., the proportion of field-derived sediment estimated by sediment fingerprinting should be consistent with the rates used to estimate a sediment budget; the sum of the estimates from individual mechanisms should be consistent with the total load measured at stream gages). Research has focused in the Blue Earth and Le Sueur watersheds, which together may contribute as much as half of the sediment to the Minnesota River, even though they account for only one-fifth of its drainage area (Fig. 4). These watersheds contain the majority of the bluffs in the basin as well as many large ravines. Sediment derived from bluffs and ravines may be the largest source of sediment in these watersheds although local observations have not been fully reconciled. In watersheds with fewer bluffs and ravines, the contribution of sediment from non-field sources will be smaller.

Based on stream gaging results, more sediment is delivered to the Minnesota River from its tributaries than is discharged to the Mississippi and Lake Pepin, indicating that sediment storage occurs along the Minnesota River and its wide valley bottom. This is significant because reductions in loading in the tributaries will be reduced by the proportion stored along the Minnesota River and because factors that influence changes in sediment storage along the Minnesota River valley bottom may also play a role in determining sediment supply to Lake Pepin.
Saint Anthony Falls Research Facilities

Summary

The St. Anthony Falls Laboratory (SAFL), located on the Mississippi River in Minneapolis, Minnesota, is NCED’s major experimental research facility. The laboratory houses faculty, graduate students, and staff from the University of Minnesota’s departments of Civil Engineering and Geology and Geophysics. Its island location provides an ideal site for a variety of experimental flumes and channels, as river water can be routed directly through the building. Experimental facilities at SAFL include a large wind tunnel, four basins devoted to experimental stratigraphy (one with a subsiding floor), the 275-foot long “main channel” flume, and weighing and volumetric tanks for large scale flow rate calibration.

During the years of NCED operation, SAFL’s Experimental Earthscapes basin (“Jurassic Tank”) has seen major improvements in its functionality and measurement capability. In addition, two basins having similar purpose but simpler design have been added to SAFL’s experimental facility repertoire. SAFL/NCED personnel have developed new three-dimensional automated positioning and measurement platforms (“Magic Carts”), one of which has been installed in the Outdoor StreamLab (OSL). We are initiating an effort to create a “virtual lab,” instrumenting our facilities with live data streaming from measurement carts, sensors, and video cameras. The OSL, in addition to its primary purpose of conducting field scale hydraulic and ecological research, has provided us with an environment for the development of novel field measurement devices and techniques. Field deployable, high precision measurement platforms using wireless data systems, robotic data acquisition devices, and in situ holographic and PIV fluid and organism measurement systems are either currently in use or scheduled for development in the OSL.

Facilities

Delta Basins: Using NCED and Oil Consortium resources, two SAFL basins have been built, instrumented, and nearly constantly used (Figure 14). Unlike Jurassic Tank, these basins have fixed floors but experiments can still simulate uniform tectonic uplift or subsidence. Like Jurassic Tank, changes in sea level as well as water and sediment fluxes are experimentally controlled and modeled. The basins’ functionality has recently been expanded with the inclusion of tidal effects. Wave effects will be added soon.

Three-dimensional automated positioning and measurement platforms: During the past year, several magic carts have been developed for outside research institutions. Data collection abilities of the carts include: subaqueous topography, water surface & wave height, subaerial topography, photographic mosaics, and auxiliary equipment positioning.

VirtualLabs: In order to make NCED research facilities accessible to a larger audience and to foster collaborative activities, we need to find ways to put the facilities online. To this end, we have begun setting up a VirtualLab environment for many of our facilities. One of the SAFL flumes is the first experimental facility to be instrumented. It is currently outfitted with live data streaming from a measurement cart and sensors in the flume. We have also attached cameras to monitor the experiment remotely.

StreamLabs

The SAFL/NCED StreamLabs represent a three-pronged approach to predictive stream restoration. Consisting of the Indoor StreamLab (ISL), Outdoor StreamLab (OSL), and Virtual StreamLab (VSL), StreamLabs represent a large, multidisciplinary, experimental effort to study reach-scale issues of sediment transport, geomorphology, and ecohydraulics under controlled laboratory conditions. Together, the StreamLabs support full-scale, high-resolution experiments of complex riverine processes using the latest in advanced technologies.
The ISL concept was established in 2005 and used in a series of experiments in 2006, 2008, and 2010. The 3m wide, 60 m long Main Channel in SAFL can recirculate large gravel particles and sand and is outfitted with equipment for high-precision laser topographic surveys of water surface and bed surface, along with other important data collection capabilities. The VSL consists of in computational infrastructure and personnel focused on developing numerical tools and models for free-surface modeling of turbulence, sediment transport and fluid-sediment-biotic interactions. OSL takes the StreamLab approach outside, designed to a unique field-scale experimental facility devoted to stream restoration.

The three components of StreamLabs complement on another. ISL and OSL provide the high-resolution, field-scale observations needed to validate VSL. VSL provides the capability to extrapolate detailed flow information beyond regions of direct observation, supporting testing of reach-scale hypotheses and models. VSL also expands our experimental capacity, supporting virtual experiments in a number and range much broader than could be accomplished in a physical flume. This interaction among the different components of StreamLabs is essential in developing a new approach to modeling the ecogeomorphology of streams.

OSL: The Outdoor StreamLab at SAFL is located on Hennepin Island in the heart of Minneapolis. Two abandoned spillways, located on the north (river left) bank of the Mississippi River adjacent to the existing indoor research facilities at SAFL, have been transformed into a new outdoor laboratory for ecogeomorphology and river restoration. (Fig. 2)

This facility is unique in that:

- Discharge, velocity, and water surface elevations can be imposed, considerably reducing the length of time necessary for data collection when compared to field work.
- Measurements can be obtained within a nearly full-scale sinuous channel with a mobile bed, which is not possible with laboratory models.
- Steady and unsteady inlet hydrographs, including artificial floods, can be imposed and, if desired, repeated.
- Velocity distribution and bed elevation can be measured along the entire channel-floodplain system, and the site is easily accessible for biological measurements.
- Pollution impacts to a stream reach can be studied without polluting a pristine site.
- Outdoor location allows experimental study of processes influenced by riparian vegetation, periphyton, and other organisms dependent on natural precipitation and sunlight.

The OSL allows unprecedented control and measurement under near-field-scale channel depths and widths. Testing in the Outdoor StreamLab can be supplemented by detailed investigations using SAFL’s indoor flume facilities, advanced numerical modeling capabilities, and extensive field monitoring experience.

ISL: Indoor StreamLab research takes place in the Main Channel facility at the St. Anthony Falls Laboratory. The channel has a rectangular cross-section that measures 2.74 m in width and 1.8 m in depth. Water for the channel is diverted from the Mississippi River through SAFL’s intake structure. The maximum discharge in the channel is 8.5 m$^3$/s. Approximately 55 meters downstream from the entrance of the channel is the Sediment Monitoring and Recirculation System (SMRS) and 15 meters downstream of the SMRS is a sharp crested weir with the dual purpose of controlling tail water elevation and instrumented monitoring of water discharge. The facility has the ability to recirculate large quantities and large sizes of sediment 55 meters upstream of the SMRS; allowing long duration sediment transport research. The recirculation system is capable of moving particles up to 75mm (3 in) in diameter.

VSL: While not a physical research facility, The Virtual StreamLab (VSL), serves as the third arm of our StreamLab research approach. The VSL is the first multi-scale computational framework for simulating abiotically- and biotically-generated turbulence and it interaction with biota in real-life aquatic environments and at ecologically relevant scales. The VSL employs sophisticated numerical algorithms that can handle the arbitrarily complex geometry of natural waterways, features advanced
turbulence models, and utilizes the latest advances in massively parallel supercomputers. The VSL is capable of simulating turbulent flow and transport process in real-life aquatic ecosystems while accounting for the coupled interactions of flow with fish and organisms across a range of scales. The first simulation of a real body of water, the OSL (Fig. 3), was unveiled for the first time at the 2009 American Physical Society Division of Fluid Dynamics meeting in Minneapolis. More than 90 million data points were mapped into the VSL computer mode for the simulation, resulting in the most accurate model of a real stream to date.

Figure 3. Results of a simulation of flow and transport in the OSL.
III. Education Initiative

Project team

Education Director: Karen Campbell
Contributing Principal Investigators: All

Executive summary

Goal: The overall goal of NCED’s Education Initiative is to bring Earth-surface dynamics to life for a broad spectrum of learners in order to educate future leaders in NCED’s key mission areas of land, resource, and ecosystem management.

Approach: NCED’s approach to education emphasizes informal as well as formal learners with strong connections between its research and education programs. Therefore, our Education Initiative includes the following key elements:

ED01. Work intensively with SMM and other science museums to develop engaging new methods for informal education centered on Earth-surface dynamics and environmental awareness.
   1.1. Work with SMM to develop engaging new methods and experiences for delivering NCED-related science to the museum’s annual audience of 800,000 visitors.
   1.2. Work with SMM and the American Museum of Natural History (AMNH) to incorporate both new and existing NCED-related science exhibit components into a major new national and international traveling exhibition about water.
   1.3. Work with SMM and five other geoscience-oriented, National Science Foundation (NSF)-supported STCs to develop collaborative means by which the research and science of all six STCs can reach larger, informal science education audiences.
   1.4 Work with SMM and the University of Illinois’ Electronic Visualization Laboratory (EVL) to advance the use of scientific visualization technologies to communicate NCED-related science to both formal and informal science education audiences.

ED02. Enhance the education of NCED student participants by providing unique opportunities and an extended, cross-disciplinary peer and mentor network.

ED03. Develop a new, practice-oriented program in stream restoration that will help advance training in restoration as well as attract a broader student population into NCED areas, including students who are not intent on research careers.

ED04. Adapt research tools such as 3D visualization, wireless sensors, and laboratory experiments to provide novel K-16 educational tools.

ED05. Design programs to engage science teachers in NCED research that allows them to bring this knowledge to their students in practical ways and then share the products of this work via the NCED website.

Highlights: NCED’s Year 9 Education activities focused in three areas: continued participation in strong existing programs, pursuit of new funding streams to carry us past NCED’s STC funding sunset and development of publications related to NCED Education programs. This year in particular saw a strengthened collaboration with two local STEM education centers and a renewed NCED push to strengthen STEM teacher education. Finally, our three most notable achievements are 1) full involvement of Dr. Gillian Roehrig, co-director of the UMN STEM Education Center as an NCED PI, 2) successful completion of a second Summer Institute in Earth Surface Dynamics (SIESD), which is now well established as an annual offering, and 3) successful launch of our new monthly public science happy hour series, “A Sip of Science”.

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▶ ED01: Work with SMM to bring Earth-surface dynamics to informal education audiences

**EarthScapes**

NCED’s Earthscapes Programming at the Science Museum of Minnesota (SMM) has led to an ever-expanding array of programs and exhibits which amplify the impact of this transformative partnership. Year 9 saw the award of a National Oceanic and Atmospheric Administration (NOAA) grant to further our ability to reach public audiences with innovative programming and exhibits about surface process science and global change.

**Big Back Yard**

The Big Back Yard (BBY) continues as a popular seasonal destination for 45,000 SMM visitors each year. Today, the 1.75-acre BBY offers many educational and fun visitor experiences, including:

- EarthScapes Mini Golf, a 30,000 square-foot nine-hole miniature golf course that reveals the role of water in shaping landscapes.
- Several large interactive exhibits that invite visitors to examine a 3D map of the world, play in a giant braided stream, and explore how river deltas form;
- Hands-on exhibits that reveal the properties of groundwater through the use of water from a real artesian well;
- The Eye Pod, a walk-through pin-hole camera that projects an image of the outdoor world onto a blank wall to illustrate basic optics properties;
- Two gardens that demonstrate Native traditions of working with the Earth: A Turtle Effigy Medicinal Garden that features medicinal plants, and a Three Sisters Garden (beans, squash, and corn);
- A chance to pan for gems, using running water to separate sediment from treasure;
- A 17,000 square foot prairie maze, featuring plants, grasses, and flowering plants native to Minnesota’s prairies;
- A chance to play paleontologist and uncover real fossil remains; and
- Science House, an award winning solar powered building, home of the SMM’s Teacher Resource Center.

Each fall, the BBY is open during the month of September exclusively for school field trips, in which students across a variety of grade levels use the BBY as a giant outdoor laboratory.

We also continuously look for opportunities to bring NCED content inside SMM for year-round viewing. Some BBY components, such as Dam Removal and Artesian Well are moved into indoor galleries during the nine months the BBY is closed. Other non-BBY components, such as Science on a Sphere and the TacTile table, are year round venues for NCED content. In Year 9 we also shared the TacTile Table with visitors to the USA Science and Engineering Festival on the National Mall in Washington DC, as a part of NSF’s presence at that event.

**Big Back Yard: Teacher Resource Center**

The Teacher Resource Center (TRC) in the BBY is the home of SMM’s teacher professional development programs. A resource for school districts throughout Minnesota, it provides summer and school year professional development experiences for K-16 teachers, with an emphasis on teaching STEM content in a culturally responsive context. NCED is proud that its Elwha...
Dam Removal models, which expose students to river science and engineering as well as the issues around making land-use decisions that affect fragile ecosystems and diverse human populations, including Native people, continue to be an integral piece of this work, used as both a resource members can check out to bring to their classroom and as a focal point for much of the culturally responsive workshop work of the TRC.

**Big Back Yard: Park Crew**

The BBY Park Crew is composed of a team of high-school-aged youth from inner city schools who work all year to learn more about concepts illustrated in the BBY and then share those concepts with park visitors and the wider community. In Year 9 they taught over 5000 museum visitors in the Big Back Yard. They reached 513 youth and adults through one-time community events outside the museum and taught 140 elementary students in St. Paul Public School and Park & Recreation after school programs.

In Year 9 the crew was treated to two immersive summer experiences related to NCED concepts. In the first, led by three researchers at the St. Croix Watershed Research Station (an NCED collaborator) and funded by the National Park Service, the crew traveled to the research station three days in a row and participated in an in-depth hands-on research experience. They learned about the St. Croix River from the three researchers’ perspectives – water chemistry, diatoms & core sampling, and aquatic macroinvertebrates. Youth got to canoe on the river to collect water samples, work in the lab to analyze the samples, and go back out in the field to assess stream water quality by sampling aquatic macroinvertebrates. Then, the crew connected with NCED’s six undergraduate summer interns twice in July. They invited the interns to the museum and shared their work with them. They led several team builder activities, shared their Big Back Yard activities, and explored the Big Back Yard together. The crew then visited the interns’ research site – the St. Anthony Falls Laboratory. They got a tour of the research facility and saw the interns’ research projects. They also learned how each intern transitioned from high school to college and ultimately ended up at NCED for the summer.

**River Restoration Residency**

The River Restoration Residency, developed in 2004 by Campbell, ESTREAM interns and SMM School Programs staff from the research of NCED visitor Chris Bromley, continues to be an SMM fee-based program. While the SMM Teacher Resource Center and colleagues at the UMN STEM Center have found new innovative ways to use our models of removal of the Elwha River’s Glines Canyon Dam, the River Restoration Residency remains a directly research-related experience for students in understanding how dam removal affects the incision of a river into the delta in the reservoir behind the dam. In the process, they learn important lessons in how scientists and engineers use data and experiments to make decisions, ways in which they must work together, and some basic information about “how rivers work”. So far in the Year 9 school year, the fee-based residency was presented only once; however several spring 2011 bookings are in place. In summer 2010, we also provided a residency, for the first time, to children in a public library summer program, in Faribault, Minnesota.

**Science on a Sphere**

SMM’s leadership role in development of programming for NOAA’s Science on a Sphere (SOS) spherical projection system grew in Year 9. Of the over 60 SOS institutions in the U.S. and around the world, SMM is one of the few producing new shows for this increasingly international visualization platform. Early in Year 9, SMM and NCED received a $500,000 NOAA award entitled “Science Decision Theater”. This award will enable development of a new, facilitated film for the SOS system on the Anthropocene, as well as new visualizations for SMM/NCED’s interactive “TacTile Table”. The award makes possible development of interactive programming using “clickers” to involve the audience in the information being presented on the Sphere and gauge their comprehension. Among the TacTile table visualizations to be developed is one allowing visitors to try their hand at land building in the Mississippi Delta, based on NCED’s ongoing delta restoration research. NCED PIs Vaughan Voller, Chris Paola and graduate student Man Liang worked on developing this visualization in Year 9.
Wider audiences

“Water” Exhibition

The Water Exhibition, developed in partnership with the American Museum of Natural History (AMNH), continued its North American and World tours in Year 9. Several components in the exhibition were developed by NCED PIs and staff, including Dam Removal, the SOS film, Blue Planet, the Mississippi Delta, and Porous Rocks. Each year, 1,000,000 visitors experience the Water Exhibition. As NCED’s Year 9 ended, the exhibition was on display at the Royal Ontario Museum, Toronto, Canada and in Assisi, Italy. The international copy of the exhibition will spend the rest of 2011 in Abu Dhabi.

Work performed under a small companion grant from the McKnight Foundation to SMM, NCED, and the local chapter of NEMO (Nonpoint Education for Municipal Officials), awarded in 2008, was extended into Years 9/10. Based on three previous events, two new workshops will be held in spring 2011. At these workshops, stakeholders from local watersheds are immersed in an interactive session on sustainable land-use planning using 3D maps, presentations and an innovative watershed card deck developed by the St. Paul Riverfront Corporation. While the stakeholders are involved in the workshop, their family members are treated to a free day at the museum.

“Future Earth Initiative”

In Year 9, substantial progress was made toward the fall 2011 opening of the NSF-funded Future Earth Exhibit. A short movie explaining scientific models to public audiences has been produced, specific exhibit components are being constructed and a portable sustainability exhibit focused on land-use was installed on the UMN campus, evaluated and moved back to SMM for inclusion in the exhibition. Two new visualizations are under development for the TacTile Table, to be located within the Future Earth Exhibit: the aforementioned delta land building model and a visualization of sea-level rise, to be shared with the Maryland Science Center. The Future Earth Initiative includes “Earth Buzz” kiosks and content, based upon SMM’s popular science blog, Science Buzz. Kiosk content is developed by a Science and Technology Center or similar center while kiosks themselves are installed in public locations of the center’s choice, usually museums. A leveraged NASA Climate Change Education grant to SMM has enabled us to expand the kiosk content and deployment to additional research center/public location teams. The table below summarizes Year 9 kiosk progress:

<table>
<thead>
<tr>
<th>Research Partner</th>
<th>Kiosk Location</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center for Multiscale Modeling of Atmospheric Processes (CMMAP)</td>
<td>Discovery Science Center, Fort Collins, Colorado</td>
<td>Initial content developed  Kiosk installed</td>
</tr>
<tr>
<td>Center for Coastal Margin Observation &amp; Prediction (CMOP)</td>
<td>1. Hatfield Marine Sciences Center</td>
<td>Initial content developed  Both kiosks installed</td>
</tr>
<tr>
<td></td>
<td>2. Oregon Museum of Science and Industry</td>
<td>Graduate students trained to blog</td>
</tr>
<tr>
<td>Center for Microbial Oceanography: Research and Education (C-MORE)</td>
<td>Bishop Museum</td>
<td>Initial content developed  Kiosk installed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Active blogging</td>
</tr>
<tr>
<td>Center for Remote Sensing of Ice Sheets (CReSIS)</td>
<td>Natural History Museum at Kansas University - Lawrence</td>
<td>Initial content developed, blogging during</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Antarctic field season</td>
</tr>
<tr>
<td>National Center for Earth-surface Dynamics (NCED)</td>
<td>Mill City Museum, Minneapolis, Minnesota</td>
<td>Content developed  Active blogging</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kiosk installed</td>
</tr>
<tr>
<td>Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA)</td>
<td>Flandreau Science Center</td>
<td>Content developed  Active blogging</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kiosk installed</td>
</tr>
<tr>
<td>Cooperative Institute for Meteorological Satellite Studies (CIMSS)</td>
<td>Dane County, Wisconsin Regional Airport</td>
<td>Content developed  Kiosk installed</td>
</tr>
</tbody>
</table>
In Year 9, NCED’s star Earth Buzz blogger, graduate student Kelsi Anderson, attended the STC Educators’ meeting in Washington, DC. There she spoke with Education and Diversity Directors from many centers about her blogging experience. This led to an invitation to train graduate student bloggers at CMOP.

**University of Minnesota’s Institute on the Environment**

As we look toward NCED’s legacy, we continue to actively pursue opportunities to collaborate with the UMN Institute on the Environment (IonE). In the area of Education, this has taken two primary forms: Campbell meets regularly with IonE staff in the outreach area and also serves as a coordinator between SMM and IonE, much as she has done for NCED. In Year 9, Campbell worked with IonE staff to organize a Broader Impacts in the Environmental Sciences fair and directory to increase UMN faculty awareness of Broader Impacts opportunities through centers.

**Wider audiences: TacTile Table (a.k.a “Rain Table”) and Meander Model**

The “RainTable” touch screen exhibit component (now known as the TacTile Table) continues to be a focus of development effort at SMM, NCED and with partners at the Electronic Visualization Laboratory at the University of Illinois, Chicago (EVL). While the multi-panel “Lambda Table” continues to tour with both copies of the Water Exhibition, the TacTile Table resides at SMM and is likely to be the favored development platform going forward. In Year 9, several significant developments were realized in our development of this component: work began on two new visualizations: land building in the Mississippi Delta and sea-level rise on the Eastern Seaboard, a new table and visualization was developed for the Arkansas Museum of Discovery and the TacTile Table was selected to be a part of NSF’s October 2010 booth on the National Mall as a part of the USA Science and Engineering Festival.

In Year 8, SMM revived a popular component of the Mississippi River Gallery, the Meander Model. This “stream table under glass” is an ever changing low-slope meandering stream, reset once daily, engaging visitors in what an un-engineered Mississippi River might look like. It is a nearly impossible task to accomplish meandering (as opposed to braiding) in a stream table with simply water and sediment. The original meander model was designed with NCED assistance but was retired from the gallery for a few years due to space constraints. In that time, the carefully researched materials, ranging from recycled eyeglass plastic to particular clay from a particular seam in a Georgia quarry, had become unavailable. Long hours of experimentation finally led to a new mixture that performs well. SMM has made a video of the model available on YouTube with the result that several university faculty have requested “the secret recipe”, which we make available, with a request to credit SMM, NCED and NSF in any resultant publications.
**Wider audiences: public lectures**

In Year 9, NCED launched “A Sip of Science”. This “science happy hour”, based on the popular “Café Scientifique” model, was launched with a talk on the Mississippi Delta on a September evening. The UMN Bell Museum of Natural History joined NCED in hosting PI Robert Twilley for this popular event. We then moved to a restaurant near St. Anthony Falls Laboratory for two talks in October and November, on Patterns in the Landscape (PI Chris Paola) and “Out damned Dam, Out I Say!” (Partner Gordon Grant). Sip of Science has now settled at a café across Main Street from St. Anthony Falls Laboratory, with talks, often accompanied by music, on climate, weather, natural disasters, road salt, diamond exploration in the midcontinent, and the delta, revisited. These events are well attended by Laboratory neighbors, local college and university students and the press. We intend to continue this popular series well beyond Year 9.

**Progress toward milestones/deliverables**

<table>
<thead>
<tr>
<th>Project name</th>
<th>Milestones</th>
<th>Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ED01</strong></td>
<td>Bring surface dynamics to informal education with SMM</td>
<td>BBY exhibits fully functioning, at least one new component added, and functioning YSC–NCED docent program for the BBY; BBY visitor target of 150,000 reached or surpassed; initial NCED components of the “Water” exhibition and SOS developed; 3D film outline developed with SMM</td>
</tr>
<tr>
<td><strong>ED01.1</strong></td>
<td>Deliver NCED-related science to the SMM’s annual audience of 800,000 visitors.</td>
<td>BBY and associated YSC-NCED docent up and running since June 2004; at least one new component added each season; BBY visitor target of 150,000 reached or surpassed</td>
</tr>
<tr>
<td><strong>ED01.2</strong></td>
<td>Incorporate both new and existing NCED-related science exhibit components into a national and international travelling exhibition about water.</td>
<td>Open exhibition at AMNH in November 2007; replicate the exhibition so that two copies are available for the national and international tours beginning in May 2008</td>
</tr>
<tr>
<td><strong>ED01.3</strong></td>
<td>Develop collaborative means such that the research and science of six STCs can reach larger, informal science education audiences.</td>
<td>Through SMM FEI, fabricate and distribute SMM’s SCIENCE BUZZ kiosks to all STCs in 2008; SMM and all six STCs collaborate in creating online science content</td>
</tr>
</tbody>
</table>
### Project name

**ED01.4**

Advance the use of scientific visualization technologies to communicate NCED-related science to both formal and informal science education audiences.

### Milestones

Develop new scientific visualization programs, especially for GeoWall and Science On a Sphere; distribute programs to educational institutions throughout the US that use these visualization systems.

### Progress

We secured a NOAA award which will lead to further SOS film development (Anthropocene content) as well as development of two new TacTile table visualizations. Other museums are beginning to purchase TacTile tables, while all SMM developed content remains freely available to any member of the SOS network.

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**Plans**

1. Continue to carry NCED research to national and international audiences through NCED-developed components in the “Water” exhibition.
2. Continue collaboration with SMM and other partners on development of Earth Buzz kiosks and content.
3. Continue to develop visualization components for use “on the floor” at SMM.
4. Continue to develop NCED-related programming for the YSC youth and the public.
5. Continue using the TRC to promote the use of river science to improve teaching and learning at the K-16 level.
6. Seek additional avenues over the next several years by which IonE, NCED, and SMM can collaborate for their mutual benefit and for the ultimate benefit of the many and diverse audiences that each of them serves.
7. Work with SAFL colleagues to develop more opportunities for public education about environmental restoration and renewable energy at both SAFL and SMM.
8. Continue to promote NCED’s transformational partnership with a leading science museum, through pursuit of new funding opportunities, such as Climate Change Education Partnerships.
9. Continue our popular Sip of Science series.

**ED02: Enhance the education of NCED student participants**

NCED continued its tradition of co-advised graduate students and synthesis post-doctoral fellows in Year 9. NCED/UMN graduate student Antionette Abeyta assumed the role of chair of the NCED Student Council, after the June Site Visit. During the Site Visit, former chair Stephanie Day organized a “preparing future faculty” professional development day, led by geology faculty from the University of St. Thomas who have been instructors in the NSF funded On the Cutting Edge faculty preparation workshops (http://serc.carleton.edu/NAGTWorkshops/index.html). Abeyta attended the annual STC Directors’ event, which this year included a special

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**Figure 2.** Summer Institute students on “Flume Day” at the St. Anthony Falls Laboratory.
meeting for graduate students only. She organized a graduate student dinner at AGU, attended NCED’s January PI retreat, and developed a series of UMN NCED student monthly get togethers. NCED “web seminars” continued in Year 9, with the coordination of this series, as well as the majority of the seminar presenting being done by graduate students. In Year 9 we moved from the proprietary platform we have used for these seminars to a more accessible web-based format available through UMN. NCED’s Graduate Museum Assistantship continued with Man Liang working to develop a delta land building model for the TacTile table at SMM. The GMA concept was shared with UMN Institute on the Environment, where a graduate student continues to develop IONE kiosk and blog content for Earth Buzz kiosks. NCED continued to support selected alumni and other young colleagues through its affiliates program. Affiliates participate in NCED research and short courses, attend retreats, collaborate on proposals and, most importantly, ensure NCED’s research legacy as they bring “the NCED approach” to their own institutions, teaching and research. Finally, progress was made on establishing joint degree programs with universities in other countries in Year 9, with the Institut De Physique Du Globe, Paris, agreeing to co-lead NCED’s Summer Institute in Earth-surface Dynamics in 2011.

In Year 9 NCED once again hosted the NCED Summer Institute in Earth Surface Dynamics (SIESD). This innovation institute is designed to engage young scientists in a focused topic in Earth-surface dynamics. Drawing on NCED’s approach of integrating theory, laboratory experiments, numerical modeling, and fieldwork, the two-week institute combines lectures with practical experiences in the laboratory and the field. SIESD 2010 focused on rivers and vegetation. The curriculum of the SIESD is based on a quantitative, cross-disciplinary approach to the study of the Earth’s surface through exploration of the dynamic linkages between ecology, hydrology, and geomorphology within a watershed context. Over the course of two weeks, students attend lectures on modeling, are introduced to simple physical models, and visit the SMM to learn more about Broader Impacts. In addition to sessions and workshops, students also have the opportunity to participate in experimental work conducted in the Outdoor StreamLab. Summer 2011 SIESD will focus on Coastal Processes and the Dynamics of Deltaic Systems and include participants from the Institut De Physique Du Globe, Paris, as well as a training module in use of the Community System Dynamics Modeling System.

**Progress toward milestones/deliverables**

<table>
<thead>
<tr>
<th>Project</th>
<th>Project name</th>
<th>Milestones</th>
<th>Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>ED02</td>
<td>Enhance the education of NCED student participants by providing unique opportunities and an extended, cross-disciplinary peer and mentor network.</td>
<td>Strong graduate student participation in cross-disciplinary research and seminars, GSC, videoconferences, NCED retreats, site visits, partner research, internships; thriving Graduate Museum Assistantship program</td>
<td>With the exception of the Graduate Museum Assistantship, all of these programs continued to have strong participation in Year 9.</td>
</tr>
</tbody>
</table>

**Plans**

We will continue to encourage all NCED students to be involved in the GSC and in web seminars. We will continue to encourage them to seek NCED coadvisors from outside their own department or institution. We will strengthen the Affiliates program and continue to seek international opportunities for our graduate students. We will continue to find opportunities for Graduate Museum Interns through the FEI and Earth Buzz programs. Year 10 will see the third NCED SIESD with plans for additional SIESDs to continue through NCED’s tenure and beyond.

**ED03: Establish stream restoration certificate program**

The NCED-sponsored UMN post baccalaureate Certificate in Stream Restoration Science and Engineering (SRSE), a one-year graduate program leading to a post baccalaureate certificate in the science and engineering of stream restoration, is now approaching the end of its fifth year of operation. The certificate comprises an interdisciplinary curriculum that is a blend of engineering, ecology, biology, geology, and social science. Its objective is to produce graduates who will understand how to blend engineering, physical, biological, and social sciences in order to contribute to the process of prioritizing, designing, implementing, and evaluating stream restoration projects. Successful SRSE graduates are able to design stream restorations that:
1. Integrate across disciplines;
2. Incorporate natural variability and uncertainty;
3. Aim for prediction by analysis, not analogy;
4. Account for the range of space and time scales; and
5. Optimize within the constraints of the science and engineering objectives economic and social use.

To date 31 students have enrolled in the program and 17 students have graduated with the certificate. The upper-level graduate class CE/EEB/GEO 8601 Introduction to Stream Restoration, specifically developed for the program, and taught every fall, is proving to be a popular course. Its last offering in fall 2010 attracted 12 students across a wide range of disciplines, from civil engineering to ecology and landscape architecture.

In Year 9 we were successful in getting the program approved as a full-fledged masters offering through the UMN. However we still need to secure seed funding to actually enroll masters candidates. An NSF Science Master’s Program proposal was unsuccessfully reviewed in Year 9; new funding avenues are being pursued. PI Voller (with Pls Paola, Karen Gran. Education Director Campbell and Knowledge Transfer Director Deborah Hudleston) submitted an invited paper describing the certificate program to the 2011 World Environmental & Water Resources Congress. The paper will be included in a publication resulting from the meeting.

Progress toward milestones/deliverables

<table>
<thead>
<tr>
<th>Project name</th>
<th>Milestones</th>
<th>Progress</th>
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</thead>
<tbody>
<tr>
<td>ED03: SRSE Certificate Program</td>
<td>Functioning certificate program in stream restoration</td>
<td>31 students have enrolled in the program; 17 students have graduated with the certificate</td>
</tr>
</tbody>
</table>

Plans

NCED PI Vaughan Voller will continue to direct the SRSE Certificate and present our program at the 2011 World Environmental & Water Resources Congress. We will continue to seek funding to make the program and full Master’s degree offering.

► ED04: Adapt NCED research tools and approaches to provide novel K-16 educational tools

Visualization

The main progress in this area in Year 9 was continued development of the Tac’Tile Table exhibit component with SMM. The table appeared on the National Mall as part of the October 2010 USA Science and Engineering Festival, at NSF’s invitation. Two new visualizations, on delta land-building and sea-level rise, are in near-final development, and software to adapt the “RainTable” application (in which visitors touch the screen to “rain” on a topographic landscape) is being adapted to portray individual U.S. states.

Models and experiments

NCED continues to bring its two copies of the Elwha River Restoration table-top model to a wide variety of formal and informal education settings each year. In Year 9, these included a public library, a nearby history museum, the University of Minnesota at Duluth and the Minnesota State Fair. The models are also regularly borrowed by other units within UMN, such as the Department of Civil Engineering and the Institute on the Environment, for events ranging from “Family Fun Fest” to New Student Days. In most cases, those presenting the model are NCED graduate students, giving them an in-depth experience of Broader Impacts.

In summer 2010, Campbell redesigned NCED’s smaller “do-it-yourself” stream tables, constructed from simple building supply store components. Table design was revised to enable more quantitative data collection for elementary classrooms. These tables were tested with the St. Catherine University Montessori STEM summer institute and at the Minnesota Minerals Education Workshop in August 2010 and will again be used by the St. Catherine program in summer 2011. Possible commercial prototyping is being explored.
Instruction & Course Design

Internships: Research Experience for Undergraduates on River and Coastal Restoration

In Year 9, this program again sent five mostly minority undergraduate students to the Wax Lake Delta. As field work at the Marmot Dam removal site in Oregon has concluded, our second team remained at St. Anthony Falls Laboratory to work on flume experiments related to river restoration. After initial orientation to physical and numerical modeling and experiments, the REU students worked in the field with NCED researchers at the Wax Lake Delta or on three flume experiments at the lab before final paper and poster presentations at SAFL and on the UMN campus. (See the Diversity Section of this report for further details.)

A renewal of this REU program was submitted to NSF in August 2010 and received one year of funding. Interns for summer 2011 are being recruited to work on landscape restoration projects at the Fond du Lac and Salish Kootnenai communities in Minnesota and Montana.

STEM Programs at St. Catherine University (http://stem.stkate.edu/)

In Year 9, Campbell continued as an active member of the STEM development team at St. Catherine University’s National Center for STEM Elementary Education, along with EAB member emeritus Tony Murphy and NCED alumna Jill Welter. The foundation of the program is a minor for elementary education majors, open to all St. Kate’s students, regardless of major. This innovative program, developed and taught by teams of science division and education department faculty, explores science, mathematics and engineering from an Earth System Science perspective, incorporating materials from the GLOBE (www.globe.gov) program as well as from NCED. The minor consists of five courses, two of which make use of the Elwha Dam Removal model and visits to St. Anthony Falls Laboratory. The capstone course, in which Campbell participates, combines Earth science, Engineering/Computer Science and science literacy, using NCED materials and the Earth Science Literacy Principles, among other resources. The final capstone project requires students to construct an Earth Science museum exhibit and accompanying signage. In Year 9, Campbell worked with co-instructors to revise and teach the curriculum of this course in J-Term 2011. In addition, Campbell collaborated with colleagues to design and deliver a one week summer institute on the Mathematics of Earth Science and Engineering to elementary Montessori teachers. Following the successful completion of this institute, she is assisting the program in reworking this material into a two summer sequence on Earth Science and Engineering, with an emphasis on mathematics for elementary Montessori teachers, to be offered nationally. Finally, Campbell is teaching an undergraduate course in Environmental Geology at another local college in Spring 2011, with the goal of experiencing first hand how NCED developed materials can be incorporated into the undergraduate curriculum. NCED graduate students Fuller and Day are co-teaching a parallel course at the same institution; the three meet regularly to share ideas and plan field trips for both class with NCED themes.

Figure 3. Elementary teachers explore velocity in straight and meandering channels in the redesigned NCED stream table.
### Progress toward milestones/deliverables

<table>
<thead>
<tr>
<th>Project name</th>
<th>Milestones</th>
<th>Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>ED04 NCED enhancements to K-16 education</td>
<td>Non-NCED participation in summer research surpasses 20 total participants (shared with Diversity); NCED research-based materials made available to undergraduate instructors through textbooks, 3D maps, web-based and physical materials, and field trips, with documented use at local and national scales</td>
<td>In the 9 years NCED has been in existence, we have far exceeded this milestone. We also continue to distribute 3D maps and glasses at national and local meetings for teachers and the public.</td>
</tr>
</tbody>
</table>

#### Plans

We will continue to promote the use of our table-top models and 3D maps and to facilitate the use of SAFL, SMM, and other NCED facilities in undergraduate education and well as continuing to participate in teacher professional development (see next section).

▶ **ED05: Professional development, involving NCED research, for teachers of grades K-16**

**SMM-based EarthScapes programs**

While the NCED-funded teacher institutes at SMM concluded in 2006, much of the material developed for the EarthScapes Teacher Institutes has been incorporated into ongoing institutes and programming at SMM’s TRC (see section ED01), as well as into other teacher development programs in which NCED is now involved.

**ESTREAM teacher interns**

While NCED has formally suspended this program, we continue to work with ESTREAM alums. In Year 9, former interns Kate (Poulter) Rosok (high school science teacher, Minneapolis Edison High School and Knowles Foundation Fellow) and Jill Baumtrog (Wayzata, MN middle school Earth Science teacher) collaborated with Campbell on delivering one day geology inquiry activities at the Mississippi and St. Croix Teacher Institutes offered each year by the Center for Global Environmental Education at Hamline University. Rosok also presented on behalf of NCED two workshops at the Minnesota Minerals Education Workshop. Finally, in 2011, she was awarded the NAGT Minnesota Outstanding Earth Science Teacher of the Year.

**Teacher workshops**

In 2010, Campbell and St. Catherine University colleagues Katherine Ibes and Yvonne Ng developed and taught a one week (with year-long follow-up) workshop on the Mathematics of Earth Science and Engineering for elementary Montessori teachers. This was the third in a three year pilot series on Montessori STEM workshops which will begin to be offered nationally in 2011.

In July 2010, Campbell and Dalbotten developed and partially funded, in partnership with the Center for Compact and Efficient Fluid Power (an NSF Engineering Research Center at UMN), and SMM, an additional year of programming for the TRIBES cohort. This group of approximately 25 teachers of Native American children across several Ojibwe reservations in northern Minnesota, has been working to strengthen teachers’ understanding of STEM concepts, particularly in the area of Earth Science, within a culturally-responsive context. The program is overseen by Dwight A. Gourneau. (Turtle Mountain Chippewa), a retired IBM computer development engineer with an extensive background in Indian STEM education. In summer 2010, we delivered TRIBES-E, in which we explored the ways in which teachers with existing Earth Science knowledge can form a strong foundation for the two new challenges of teaching Climate Change Science and Engineering in K-12 settings.

Finally, the team of Campbell, Dalbotten and Roehrig, along with Ojibwe colleagues in Minnesota, submitted three proposals to climate change education solicitations in 2010/11. Our Climate Change Education Partnership Phase I (a planning grant) to NSF was well enough received to be finalist, and we were encouraged to continue planning toward the Phase 2 award. We secured an award from NASA to develop the CYCLES program for developing culturally responsive climate change education material to teachers of Native American middle school children in Minnesota. We have worked with the STEM
Education Center at UMN throughout Year 9 to prepare for this three year program, which will begin with an institute in July 2011. Finally, we were invited to propose to a NOAA solicitation for climate change education. The Northern Climates, Native Voices program, if awarded would enable us to continue developing similar material, but aimed at elementary school teachers and children from Native communities. Throughout this activity, we continue to plan toward a submission to the Climate Change Education Partnership Phase 2 NSF solicitation to be announced in late 2011.

**Progress toward milestones/deliverables**

<table>
<thead>
<tr>
<th>Project name</th>
<th>Milestones</th>
<th>Progress</th>
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</thead>
<tbody>
<tr>
<td>ED05 K-12 teacher development</td>
<td>Materials developed and made available online, through the TRC at SMM, and promoted at local and national conferences</td>
<td>In Year 9, we developed several new opportunities to deliver teacher education which build on our past experiences and materials.</td>
</tr>
</tbody>
</table>

**Plans**

In Year 9, we will continue to promote and support the use of our table top models by educators across the country for use in teacher education and undergraduate settings. With SMM TRC, we will continue to look for opportunities to distribute NCED-related material to teachers through this venue. We will continue to develop our ability to design and deliver high quality Earth science education with a climate change focus to Native communities. Most importantly, we will continue to work with the UMN STEM Center, St. Catherine’s National Center for STEM Elementary Education and the CGEE Rivers Institutes as well as our TRIBES-E partners in developing ways to incorporate Earth Science and Climate Literacy into K-12 and teacher education and finding funding to sustain this activity past NCED’s STC sunset.

**Additional, significant broader impacts activities**

**Community Surface Dynamics Modeling System**

In Year 9, Campbell continued to serve as the Education and Knowledge Transfer Working Group Chair (and member of the Executive Committee) for the Community Surface Dynamics Modeling System. This work continues to emphasize promoting use of CSDMS modeling tools and animations in the undergraduate curriculum, to develop the quantitative skills of future graduate students. Her keynote address at the October 2010 CSDMS All-Hands meeting, “Taking it to the Streets: The Case for Modeling in the Undergraduate Classroom,” has recently been submitted for publication in a special CSDMS issue of the journal *Computers and GeoSciences*.

**STC Educators Meeting**

Campbell and Dalbotten served on the organizing committee for the 2010 STC Educators’ meeting, this year held in conjunction with the STC Directors’ meeting, in Washington, DC. NCED assisted in particular in organizing Day One of the event, which included behind the scenes visits for the entire group to the Koshland Museum and the Smithsonian Natural History Museum. Graduate student Kelsi Anderson presented to the educators about Science Buzz blogging as an educational opportunity for graduate students in any area of science. Day Two of the event offered an opportunity for STC Educators old and new to hear from NSF HER representatives, as well as for directors from senior centers, including Campbell and Dalbotten, to present lessons learned and best practices to new center directors.

**Professional Meetings**

Campbell presented at a very productive half-day session at the annual meeting of the Geological Society of America on communicating Earth Science to Museum audiences. Much of the day’s discussion focused on implementation of the Earth and Climate Science Literacy Principles and the event proved fertile ground for discussion across the boundaries of Natural History and Sci-Tech museums. Campbell also presented at the Broader Impacts poster session, sponsored by the Centers for Ocean Science Education Excellence at the Fall Meeting of the American Geophysical Union. Finally, Campbell is serving on the local organizing committee for the annual meeting of the Geological Society of America, to be held in Minneapolis in October 2011. The theme of the meeting is “Archean to Anthropocene: the Past is the Key to the Future” and NCED has agreed to sponsor a myriad array of field trips, short courses, sessions and public events focusing on our science and our Broader Impacts.
Dam Conference

NCED had the unique opportunity in Year 9 to host the two-day international conference, Experiments on Rivers: The Consequences of Dams, An Interdisciplinary Conference, Thursday and Friday, November 11-12, 2010. This event, organized by the UMN Institute for Advanced Study (IAS), was a part of the University Symposium on Abundance and Scarcity. The conference brought together diverse experts from a range of academic practices and disciplines to examine the phenomena of dams and the consequences, intended and unintended, that accrue from their construction. The sessions offered examples focusing on global as well as more localized frames of reference, critical and theoretical perspectives as well as immanent and pragmatic views, and understandings derived from biological and physical sciences as well as social science disciplines. There was a strong focus on indigenous voices from around the world. NCED participants included Karen Campbell, Efi Foufoula and Partner Gordon Grant. The event was held at St. Anthony Falls Laboratory, overlooking the dam at St. Anthony Falls, and was free and open to the public. Full coverage of the event, including videotaped presentation and discussion, is available at: http://www.ias.umn.edu/Initiatives/ExperimentsOnRivers.php.

Executive summary – plans

In Year 10, NCED’s Education Initiatives will continue to strive for the following goals:

• Focus heavily on innovative development and distribution of NCED research through the “Water” exhibition FEI, and other SMM initiatives, especially in the area of visualization products for education and knowledge transfer.
• Support the unique, Center-based activities of our graduate students, through the GSC, and those of our alumni and close collaborators, through the Affiliate Scientists Program and SIESD.
• Support the ongoing development of the SRSE Certificate Program and efforts to develop this program into a full-fledged master’s program.
• Expand our impact on K-16 education locally, nationally, and internationally, through new proposal opportunities, focusing especially on teacher education on the topics of Earth science and climate change education.
• Complete another successful REU on River and Coastal Restoration program.
• Focus, in particular, in documenting successful NCED Education Initiatives to ensure their sustainability.
### Table 1: Performance indicators

<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NCED Students</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Graduate student participation in NCED center-wide</td>
<td>Number of participating students</td>
<td>Year 9</td>
</tr>
<tr>
<td>activities</td>
<td></td>
<td></td>
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<tr>
<td>2. Graduate student application and</td>
<td>Number of students graduated</td>
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</tr>
<tr>
<td>graduation rates and job placement.</td>
<td>Number of students placed:</td>
<td>14</td>
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<tr>
<td>(note that this figure includes students placed in a</td>
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<td></td>
</tr>
<tr>
<td>higher degree program or post-doc as well as those</td>
<td></td>
<td></td>
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<tr>
<td>placed in a faculty position or outside academia)</td>
<td></td>
<td></td>
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<tr>
<td>in academic positions</td>
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<td>12</td>
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<tr>
<td>(note that this figure includes students placed in a</td>
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<td></td>
</tr>
<tr>
<td>higher degree program or post-doc as well as those</td>
<td></td>
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<tr>
<td>placed in a faculty position)</td>
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<td></td>
</tr>
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<td>in government/industry</td>
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<td>2</td>
</tr>
<tr>
<td>in other</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>3. New seminars and course materials developed for</td>
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<td>3</td>
</tr>
<tr>
<td>undergraduate education</td>
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<td></td>
</tr>
<tr>
<td><strong>Earth Science Teachers and Students</strong></td>
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<td>1. Participation in NCED programs.</td>
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<tr>
<td>Number of Students</td>
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<td>2. Classroom tools developed and used.</td>
<td>Number of tools developed</td>
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<tr>
<td>Number of web hits</td>
<td>Due to Year 9 move to a new web platform, some of which remains incomplete,</td>
<td></td>
</tr>
<tr>
<td>(Maps, ESTREAM and SERC resources)</td>
<td>web statistics for Education resources will be resumed in Year 9</td>
<td></td>
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<tr>
<td>Data downloaded (same)</td>
<td>Due to Year 9 move to a new web platform, some of which remains incomplete,</td>
<td></td>
</tr>
<tr>
<td>(same)</td>
<td>web statistics for Education resources will be resumed in Year 9</td>
<td></td>
</tr>
<tr>
<td><strong>Public</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Attendance statistics and feedback from the BBY.</td>
<td>Attendance</td>
<td>45,000 (2010)</td>
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<tr>
<td>Feedback</td>
<td>300,000 (cumulative)</td>
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</tr>
<tr>
<td></td>
<td>Nothing new in Year 9</td>
<td></td>
</tr>
</tbody>
</table>
IV. Knowledge Transfer Initiative

Project team

Staff: Collin Bode, James Buttles, Craig Hill, Sara Johnson
Contributing PIs: All

Executive Summary

Approach: In Year 6 NCED developed a new model, focused on the establishment of Research Cooperatives (RCs), for knowledge exchange with industry and agency partners. Based upon published National Science Foundation (NSF)-funded work by Gray and Walters (2008), RCs consist of small multi-disciplinary, multi-institutional teams working on critical areas of research. The hallmarks of the RC model of knowledge exchange include the following features:

- Small numbers of participants with multidisciplinary expertise. Participants represent academia, industry, and government.
- Focus on a specific research topic.
- Regular meetings aimed at fulfilling publicly stated goals.
- Eventual self-sustaining capabilities after establishment by a founding center like NCED.

Year 9 saw the continuation of this model with a focus on setting the foundation for partnership continuation beyond the years of NCED funding. In support of that goal, the formal and informal Science Partner Groups (Table 1) that have been established for each of the three IPs were strengthened over the course of the year.

Highlights: Over the past nine years, NCED has developed an extensive array of unique and pioneering research approaches, facilities, cognitive paradigms, training methodologies, and community partnerships. These products of NCED activities have had and will continue to have a significant impact on the Earth-surface dynamics research community and on the application of Earth-surface sciences to practice and training. Our Knowledge Transfer Program seeks to disseminate NCED’s groundbreaking science to stakeholders, the interested public, and our applied partners. We accomplish our goals through the development of educational programs, partnerships, working groups, and strategic communications.

Goal: To establish and foster collaboration and communication among NCED researchers and participants, our applied science partners, and the broader research community. Such interactions are intended to ensure that NCED research is informed by the most pressing societal concerns and that the tools and insights gleaned through the work of NCED are disseminated throughout the broader community.

Table 1: Knowledge Transfer Science Partner Groups. A comprehensive listing of Science Partner Groups active in each of the three IPs – Desktop Watersheds (DW), Stream Restoration (SR), and Subsurface Architecture (SA). A full description of the activities of each group is available in the Knowledge Transfer project descriptions below.
In addition to the establishment and promotion of RC activities, each of the three IPs promotes knowledge exchange with the wider community through the following activities:

- Developing website content for each Integrated Program (IP), including making research products available online.
- Teaching short courses focused on science applications.
- Conducting workshops and lectures for targeted groups within the community to communicate research ideas to the public.

Finally, Year 9 saw continued success of major initiatives within NCED’s Knowledge Transfer program, including the Visitor Program, the Working Groups Program, and the Summer Institute for Earth-surface Dynamics (SIESD) to promote collaboration with researchers outside of NCED.

**Major initiatives**

As part of its Knowledge Transfer Initiative, NCED has developed several unique programs designed to facilitate interaction and collaboration between NCED researchers and researchers outside of the NCED community. Among such programs are the Visitor Program, the Working Groups Program, CSDMS, and SIESD. The activities of these programs in Year 9 are summarized below:

**Visitor Program**

Year 9 Visitor Program activities are summarized within the Visitor Program Report, please refer to the Visitor Program section of this report for details.

**Working Groups Program**

Another major NCED Knowledge Transfer initiative that cuts across all three IPs is the Working Groups Program. First convened in November 2007, the Stochastic Transport and Emergent Scaling on Earth’s Surface (STRESS) Working Group, led by Director Efi Foufoula-Georgiou, investigates the use of heavy-tailed stochastic models and fractional probability density equations (PDEs) to describe processes and transport laws that take place on Earth’s surface, from the hillslope to the whole river network. The group is cosponsored by NCED, the University of Illinois Hydrologic Synthesis Activities, and the Desert Research Institute and was organized by Foufoula-Georgiou.

The group’s second workshop, STRESS II, convened experts in Earth-surface processes and mathematicians and scientists who have successfully applied heavy-tailed stochastic theory and fractional differential equations in both Earth-surface...
science other disciplines. STRESS II was organized by PIs Foufoula-Georgiou and Rina Schumer. NCED graduate students Singh, and Ganti; PIs Voller and Hill; NCED Affiliate PIs Jerolmack and Passalacqua, and NCED alum McElroy, and researchers from *École Polytechnique Fédérale de Lausanne* Station 18 in Switzerland, the Colorado School of Mines, the Desert Research Institute, the University of Pennsylvania, the University of Illinois -Urbana/Champaign, Michigan State University, the University of Colorado-Boulder, the University of Otago, Purdue University, Northwestern University, Arizona State University, and Columbia University attended the workshop. The 3-day workshop consisted of presentations, group discussion, and breakout groups. The group’s collaborative work has yielded an AGU special collection publication. Work by Foufoula-Georgiou, Ganti, Dietrich, Viparelli, Parker, Hill, McElroy, Mohrig, Jerolmack, Schumer, Voller, and Paola, originally published in the *Journal of Geophysical Research*, were included in the special collection.

A second NCED working group, the Mathematics of Geomorphology group, furthered plans for a 2011 meeting.

**Community Surface Dynamics Modeling System**

CSDMS is an NSF-funded project that promotes the modeling of Earth-surface processes by developing, supporting, and disseminating integrated software modules. The software predicts the movement of fluids and the flux of sediment and solutes in landscapes and sediment basins. NCED is supporting this work by transferring models and data to CSDMS. In Year 9, NCED Postdoc Enrica Viparelli completed converting the codes of PI Gary Parker’s ebook and toolbox into the programming platform supported by CSDMS. Additionally, Education Director Karen Campbell is chairperson of the Education and Knowledge Transfer CSDMS Working Group, PI Chris Paola is on the Stirling Committee, and NCED researchers are working in the CSDMS terrestrial, marine, coastal, and hydrology working groups. The outcomes of CSDMS’ October 2010 all-hands meeting is being compiled in a special issue of *Computers and Geoscience*, to which Campbell and other NCED members contributed.

**Summer institute and education initiatives**

In Year 9, NCED’s initiative, the Summer Institute on Earth-surface Dynamics (SIESD) continued. Aimed at late-stage graduate students and young faculty, the program engaged participants in interdisciplinary research on Earth-surface processes based on integration of theory, physical experiments, fieldwork, and numerical modeling. The curriculum of the SIESD is based on a quantitative, cross-disciplinary approach to the study of the Earth’s surface. Year 9’s focus was on vegetation and geomorphic dynamics. The program promotes the dissemination of NCED knowledge to emerging researchers.

In addition to the SIESD initiative, NCED has formed strategic partnerships with the Institute on the Environment (IonE) and the Institute for Mathematics and its Applications (IMA). The partnership includes knowledge exchange via staff and postdoctoral research associate site visits, as well as formal meetings between postdoctoral research associates and students. The goals of the strategic partnerships are to exchange ideas about basic science and community engagement activities that will bring our scientific advances to the public.

**Website**

NCED unveiled its new website in June of 2009 followed by a second iteration in June 2010. The site features increased accessibility and improved content.

**Plans**

**Visitor Program**

In 2011, the Visitor Program will fund four small, multidisciplinary research efforts that involve a strong collaboration between academia and federal agencies. The research will focus on experimental and field work related to stream restoration science or the ecohydrology of deltas.

**Faculty-to-Faculty Program**

In Year 10 NCED will continue to develop its Faculty-to-Faculty collaboration with Antony Berthelote, a hydrologist from Salish Kootenai Tribal College (SKC), in Montana focused on establishing a four-year hydrology degree program at SKC.
Working Groups Program

The NCED Mathematics of Geomorphology Working Group will meet again in June 2011. Working group members and NCED PIs Voller and Paola anticipate publishing an algorithm for the mapping of complex coasts that they developed while participating in the group. NCED PIs are in the process of forming a Delta Working Group. The group, outlined in project KT09, will hold stakeholder meetings and workshops additional to those held in New Orleans in October 2010.

Community Surface Dynamics Modeling System

The Coho salmon population model Ripple, along with other NCED-developed models, will be made CSDMS-compatible during Year 10.

Summer Institute and educational initiatives

NCED will continue to offer the Summer Institute on Earth-surface Dynamics in Year 10. SIESD 2010 will focus on coastal processes and the dynamics of deltaic systems. Attending students will investigate coupled models of erosion, deposition, and vegetation; responses to up- and downstream anthropogenic perturbations; and how predictive modeling can be used for restoration of these delicate ecosystems. Hands-on learning opportunities will include the exploration of physical experiments and theoretical models as well as an intensive unit on the use of delta modeling tools available through CSDMS. The SIESD will also expose students to broader-impacts research via the Science Museum of Minnesota (SMM) and other NCED educational and diversity activities.

NCED is also developing several new venues for dissemination of its science. The Minneapolis-based NCED 2011 Symposium will play host to academic, industry, and governmental partners and will showcase NCED’s breakthrough Earth-surface science. Less formal seminars on NCED science for a general audience will continue to emerge through our new “Sip of Science” lecture series. Through strategic partnership with local organizations, restaurants and night spots, NCED researchers will continue to present their science to engaged, socially conscious young adult audiences.

Another exciting program that will bring NCED science to new audiences is our VirtualLabs initiative. Through this program, NCED is instrumenting many of its experimental facilities—including flumes and delta basins at SAFL, the Le Sueur River field site, and the Wax Lake Delta field site—with web-accessible data streams, instrument control, and video surveillance. As part of this program, we will also bring the existing environmental sensors from the Angelo Coast Range Reserve online. VirtualLabs will offer researchers from around the world direct access to NCED experiments and data.

Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Project Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>KT01</td>
<td>Interactions with DW Science Partner Group</td>
</tr>
<tr>
<td>KT02</td>
<td>Collaborative DW research with stakeholders and partners</td>
</tr>
<tr>
<td>KT03</td>
<td>Disseminate DW knowledge, approaches, and tools outside of NCED</td>
</tr>
<tr>
<td>KT04</td>
<td>Interactions with SR Science Partners Group</td>
</tr>
<tr>
<td>KT05</td>
<td>Collaborative SR research with stakeholders and partners</td>
</tr>
<tr>
<td>KT06</td>
<td>Disseminate SR knowledge, approaches, and tools outside of NCED</td>
</tr>
<tr>
<td>KT07</td>
<td>Promote and develop education and training programs in SR</td>
</tr>
<tr>
<td>KT08</td>
<td>Interactions with SA Science Partner Group</td>
</tr>
<tr>
<td>KT09</td>
<td>Collaborative SA research with stakeholders and partners</td>
</tr>
<tr>
<td>KT10</td>
<td>Disseminate SA knowledge, approaches, and tools outside of NCED</td>
</tr>
</tbody>
</table>

KT01: Interactions with Desktop Watersheds Science Partner Groups

Desktop Watersheds (DW) Science Partner Groups have been formed to direct DW IP research towards the areas of knowledge most needed by industry partners as well as to provide a community outlet for the research products. Towards those goals, five DW Science Partner Groups had been formed in previous years: 1) the Coho Fish Population Model Development Group,
2) the Debris Flow Erosion Partner Group, 3) the Keck HydroWatch Project, 4) the Wireless Observatory Development Partner Group, and 5) the Sensor Observatory Cyberinfrastructure Partners Group. In Year 8, an additional Science Partner Group has been established, the Le Sueur River Basin/Minnesota River Group on Sediment Budgeting and Routing.

Plans

Future work of the DW Science Partner Groups will include maintaining the established productive avenues of communication and fostering additional collaborations for Year 10. Specifically, we expect the Sensor Observatory Cyberinfrastructure Partners Group to grow to include new members, as the University of California Natural Reserve System (UCNRS) becomes more involved with wireless data collection.

► **KT02: Collaborative Desktop Watersheds research with stakeholders and partners**

**Coho fish population model development**

NCED researchers have worked in close collaboration with Stillwater Sciences to produce a fish population model for Coho salmon. Dubbed “Ripple,” the digital terrain-based model provides estimations of fish populations throughout a watershed channel network. Ripple was released to the public in July 2008. Since then, the model has been downloaded by graduate student classes and provides a rapid, spatially explicit assessment of possible factors limiting salmon populations from a minimum of data. Thus far, NCED partner Stillwater Sciences has applied Ripple to investigate the effects of stream temperature and large woody debris on Coho populations in Rock Creek, Oregon. Stillwater Sciences has also used Ripple in Lagunitas Creek, California, and in the Tonsina River of Alaska to guide field investigations.

**Debris Flow Erosion Partner Group**

The Debris Flow Erosion Partner Group has been especially active in research over the past two years, driven in large part by the creation of the 4m-diameter vertically rotating drum debris flow facility. Partner group activities in Year 9 include collaboration with Brian McArdell (a researcher with the Swiss Federal Institute for Forest, Snow, and Landscape Research (WSL) in Zurich, Switzerland) to conduct an on-going debris flow field monitoring campaign. Bellugi and Taylor Perron are collaborating with Jim McKean of the US Forest Service to further the development of a model that efficiently identifies least stable slope areas, and therefore gives insight into potential landslide size. Bellugi is also collaborating with the US Geological Survey on their ARkstorm project to predict landslide potential from major storm events in California.

**Keck HydroWatch Project, Wireless Observatory Development Partners, and the Cyberinfrastructure Partners Group**

As ecological monitoring and data retrieval are achieved through the work of all three of these partner groups, the activities of the three groups will be described together.

These partner groups have made significant progress at Angelo Coast Range Reserve (ACRR). Considerable effort has been given to installing an extensive array of root and trunk sap flow monitors, developing automated pump sampling systems to document groundwater and streamflow chemistry, and water sampling for isotope tracing studies. Data are collected, relayed, and archived from these new instruments through data retrieval and storage architecture provided through partnership with the Hydrologic Information Systems (HIS) project of the Consortium of Universities for the Advancement of Hydrological Science (CUAHSI), the California Biodiversity Center (CBC), the Berkeley Natural History Museums. With the infrastructure in place, ACRR has developed collaborative partnerships with the USFS sediment-monitoring program, and a collaborative NSF-funded Nutrient Spiraling study by former John Schade and Jill Welter (now faculty at the College of St. Olaf and St. Catherine University, respectively), Steve Thomas (University of Nebraska), and Finlay and Power.

**Le Sueur River Basin Watershed Group**

The Le Sueur River Basin Watershed Group is a collaboration focused on addressing the role of watershed context in river restoration research and implementation. Watershed location is a central theme of the Le Sueur River project because the location of sediment sources, as well as the erosion mechanism and rate, play a key role in developing a sediment budget and guiding management actions. Details on the research activities of this group can be found in the SR IP section of the report. The collaborative group of the project involves NCED PIs (Flores, Gran, Hobbs, Parker, Wilcock), an Affiliate Scientist (Belmont), postdoctoral research associates (Kenney, Viparelli), graduate students (Day, Jacobi, Johnson, Meyer, Shafran,
Zheng, Zuerndorfer), and NCED affiliates (Jennings, Minnesota Geological Survey; NCED PhD graduate Lauer, Seattle University). External partners include the St. Croix Watershed Research Station (SMM) and the Department of Soil, Water, and Climate (UMN). Much of the work on this project is made possible using leveraged support from the Minnesota Pollution Control Agency (MPCA). The group interacts regularly in support of the goal of evaluating water quality models for the Le Sueur and the larger Minnesota River basin and developing a total maximum daily load (TMDL) for the Minnesota River.

In June 2009, Wilcock collaborated with the MPCA to release a report that connects NCED research on sediment sources in the Minnesota River with studies complete or in progress by other Minnesota River turbidity stakeholders. The report synthesizes and clarifies the current body of knowledge on the issue and will help guide future TMDL and management decisions for the watershed. Wilcock, Belmont, Gran, and collaborators are steadily publishing project findings.

**Plans**

**Ripple: A Coho Salmon Population Model**

NCED researchers are currently working to make several improvements to the first release of Ripple: 1) add ability to include the effects of barriers (dams, road crossings, etc.), 2) enable the user to use field data for individual reaches when such data are available, and 3) include effects of off-channel habitat on rearing (especially winter rearing) on juveniles. Work is also underway to expand Ripple for application to other salmon (Chinook and Steelhead). We will continue to test Ripple in a collaborative project (with Stillwater Sciences and Leonard Sklar (San Francisco State University) on a TMDL analysis of Pescadero Creek (south of San Francisco). In this application we are using Ripple to guide field data collection and to develop hypotheses on limiting factors. We also will explore an improved sediment model component. In the next year we plan to announce and advertise the application potential of Ripple through papers and meetings with stream restoration and landscape management practitioners.

**Debris Flow Dynamics Partner Group**

Collaborative debris flow work with Swiss partners will continue. Roland Kaitna, a postdoctoral fellow visiting from Universität für Bodenkultur Wien in Austria will collaborate with NCED graduate student Johannes to document boundary forces, pore pressure dynamics, and velocity profiles through granular flows using the NCED-built 4m-diameter rotating drum. This group also plans to continue to work with Brian Mc Ardell on field landslide monitoring.

**Keck HydroWatch Project, Wireless Observatory Development Partners, and the Cyberinfrastructure Partners Group**

Collaboration with the Keck HydroWatch group at UCB will continue. Plans for this group include an intensive field hydrological investigation in the Elder Creek Watershed of the ACRR. The goal of this work is to document how flow in near-surface fractured rock works and how it possibly controls the rest of the hydrologic system (evapotranspiration, atmospheric boundary layer conditions, storm flow, and summer baseflow).

**Le Sueur River Basin/Minnesota River Group on Sediment Budgeting and Routing**

The Le Sueur project is publishing its findings and working to develop a strategy for up-scaling the constructed models to the entire Minnesota River Basin. Social issues become fully enmeshed at this largest scale and this work must incorporate public preference, willingness to pay for water quality improvement, and the need for incentives to promote conservation and restoration measures. The basin-scale model will be developed in coordination with MPCA and stakeholders in the Minnesota River Basin.

► **KT03: Dissemination of Desktop Watersheds knowledge, approaches, and tools outside of NCED**

Highlights of the dissemination of DW knowledge, methods, and products include:

**Desktop Watersheds tools**

- NCED PI Dietrich gave a series of lectures, including a presentation to Google executives, on the use of the model Ripple. The tool is available for download on the NCED website (http://software.nced.umn.edu/ripple/index.html).
• Meteorological and network quality data have been added to the ACRR website (http://angelo.berkeley.edu/sensors/met, http://angelo.berkeley.edu/sensors/net) courtesy of NCED.
• A Cyberinfrastructure Development website has been updated and expanded (http://sensor.berkeley.edu).

**Invited lectures**

• April 2010, PI Dietrich gave a series of lectures on the future of shallow landsliding at INTERPRAEVENT 2010 in Taipei, Taiwan.
• June 2010, PI Dietrich gave a lecture on “Bedrock Matters” at the Goldschmidt Conference in Knoxville, Tennessee.
• September 2010, PI Dietrich gave a lecture on “Eberswalde Crater: learning to read the fluvial system” at the Fourth Mars Science Landing Site Meeting in Monrovia, California.
• October 2010, Foufoula-Georgiou gave a lecture on “Delta around the world: Finding common ground” to the Wetlands Foundation in New Orleans, Louisiana.
• November 2010, Finlay gave a lecture on “Natural abundance stable isotopes as recorders of dominant biogeochemical processes in river ecosystems” in Kyoto University in Japan.
• November 2010, Power gave a lecture on “Towards predictive mapping and sustainable forestry in the California Redwood belt” to the Ecological Society of America, Millenium Conference on Drought, Water Ecosystem Services, and Social Justice in Athens Georgia.
• December 2010, Dietrich gave a lecture on “Shallow bedrock storm-flow, rock moisture, and consequences for geomorphic, ecologic and, possibly, climatic processes” at the American Geophysical Union, San Francisco, California.
• January 2011, Dietrich gave a lecture on “Sediment supply to rivers” at the Chapman Conference Source to Sink in Oxnard, California.
• February 2011, Foufoula-Georgiou gave a lecture on “Stream restoration in a watershed context” in Buenos Aires
• February 2011, Power gave a lecture on “Cross ecosystem fluxes and River to ocean linkages” at the University of British Columbia, in Vancouver BC.
• March 2011, Foufoula-Georgiou gave a lecture on “Hydrologic changes in the Upper Midwest and potential effects on groundwater biofuel transport” to the U.S. Environmental Protection Agency in Texas.
• March 2011, Hill gave a lecture on “Bedload Transport: Particle Mixtures, Turbulence statistics, and Heavy Tails” to the University of Michigan, Ann Arbor.
• March 2011, Power gave three lectures and one departmental seminar on “Sustainability and Resilience in river ecosystems at the University of Puerto Rico, Rio Piedras in San Juan Puerto Rico.

**Media coverage**

• See the media section of this report.

**Plans**

Success in disseminating DW knowledge, approaches, and tools outside of NCED in Year 9 has resulted largely from the community interest generated with the production of groundbreaking research. We would like to continue to be highly productive in the transfer of DW knowledge over coming years. To that end, all six DW Science Partner Groups will continue with their fruitful collaborative work. Major plans include the modification of the Ripple model to make it more reflective of field conditions and applicable to a wider range of species. Likewise, work will continue on the GeoNet tool to broaden its applicability. NCED PIs will continue to disseminate these tools throughout the community by providing short courses and seminars that discuss their utility.

► **KT04: Interactions with the Stream Restoration Science Partner Groups**

Five active SR Science Partner Groups have been established: 1) Training and Education Partners, 2) Sediment Monitoring Partners, 3) Rivers and Dams Partners, 4) PRRSUM, and 5) SRDADG. These partnerships are critical to informing NCED researchers about knowledge gaps within the community as well as to providing the community with the tools and information to fill those gaps.
Plans

In Year 9, PRRSUM brought to fruition the third annual Upper Midwest Stream Restoration Symposium (UMSRS). The SRDADG Partner Group is a new collaborative effort between NCED researchers and the US Army Corps of Engineers (USACE). This group will also be especially active in Year 10. Details of both the UMSRS and the work of the SRDADG are described below.

KT05: Collaborative stream restoration research with stakeholders and partners

Sediment monitoring partners

PI Hill is collaborating with Barr Engineering to determine size dependent statistics for bedload transport for mixed size grains. Collaborative research on sediment in the Minnesota River Basin is underway in two projects. NCED researchers continue to work with the MPCA; Minnesota State University, Mankato; the UMN Department of Soil, Water, and Climate; Seattle University; UMN, Duluth; the St. Croix Watershed Research Station; Barr Engineering, and the Minnesota Geological Survey to develop an integrated sediment budget for the Le Sueur River basin. In support of that goal, PI Wilcock worked with the MPCA to release a report that connects NCED research on sediment sources in the Minnesota River with studies complete or in progress by other Minnesota River turbidity stakeholders. The report synthesizes and clarifies the current body of knowledge on the issue and will help guide future TMDL and management decisions for the watershed.

A second project, which began in April 2009, has linked erosion to the hydrograph of the Minnesota River by tracing sediment sources with $^{10}$Be amd $^{210}$Pb. Work on the project will continue through this year and will contribute to the knowledge base used for decision-making by the Minnesota Department of Agriculture.

River and dam partners

During the summer and fall of 2007, NCED collaborated with the Oregon Watershed Enhancement Board (OWEB), the US Geological Survey (USGS), Graham Matthews and Associates (GMA), and the USFS to monitor and investigate ecological and hydrological repercussions of the removal of the Marmot Dam from the Sandy River in Oregon. In Year 9, data from the project continued to be added by all partners to NCED’s FTP (or file transfer protocol) site where it is freely available to the public.

Plans

Research into the sediment budget of the Le Sueur River basin will continue in Year 10. The strong, extensive partnership network will continue to produce research knowledge that will inform policy decisions made by the MPCA on sediment loads and management in the Minnesota River Basin. Collaboration with the Minnesota Department of Agriculture is just beginning. The project will promote the transfer of NCED research knowledge on sediment flux to the government agency where it is most needed and will be applied.

The activities of the SRDADG Partner Group will be a major focus of SR knowledge transfer activities in Year 10. The group will combine the expertise of NCED researchers with the applied experience of the USACE to develop a decision analysis framework for SR projects that assesses the environmental drivers of the system, the restoration objectives, proposed management actions, and subsequent assessment. The design guide will put each project into its watershed context, establishing the locations and restoration actions available for accomplishing particular objectives, assessing the water and sediment supplies of a given target site, and determining the biological components of the system, such as nutrient supply and organism populations. Once the watershed context is established, the partner group will address issues relating to channel design, such as how channel dynamics relate to water and sediment supply or to biogeochemical processing, or how in-channel structures influence these processes. Finally, the partner group will provide a tool that helps restoration practitioners weigh the benefits and costs of a project before deciding on proper actions.
 KT06: Dissemination of stream restoration knowledge, approaches, and tools outside of NCED

Stream restoration toolbox
- The Barr-NCED Floodplain Mapper was added to the NCED website. The tool performs inundation mapping on series of cross sections and corresponding water surface elevation polygons. This tool allows the user to map multiple events at once.

Lectures and presentations
- Parker gave invited lectures at: the XVIII International Conference on Computational Methods in Water Resources in Barcelona, Spain; Earth Flows, the 23rd Kongsberg Seminar in Kongsburg, Norway; the CSDMS 2010 Meeting on Modeling for Environmental Change in San Antonio Texas; the PIRE Conference in Louvain-la-Neuve Belgium; the Annual Meeting of the American Geophysical Union in San Francisco California; and the Chapman Source to Sink Conference in Oxnard California.
- Hobbs and Kenney gave talks on “Model-based Identification and Correction of Cognitive Biases in Subjective Probability Assessments” to the Maryland State Water Quality Advisory Committee and the INFORMS National Meeting.
- Parker gave invited lectures at: the Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling in Las Vegas Nevada; the 7th Gravel-bed Rivers Conference in Tadoussac Quebec, Canada; the Annual Meeting of the American Geophysical Union in Sanfrancisco, California.
- Gran gave an invited lecture on “Impact of Holocene valley evolution on modern sediment loading in the Le Sueur River, Minnesota” to the Minnesota Geological Survey in Minneapolis, MN.

Media coverage
- Please see the media section of this report.

Plans
Stream restoration toolbox
- Parker and Viparelli, in cooperation with Wilcock, have developed a numerical model describing the building and consumption of stratigraphy in a gravel-bed river. The model will be made available online as part of the SR toolbox.
- Parker, Viparelli, and Wilcock are also finalizing the results of a numerical model of gravel augmentation, which will result in another new tool for the SR toolbox.

Lectures and presentations
NCED PIs will continue their extensive lecture and presentation activities as an effective method of disseminating SR IP knowledge to the wider community.

 KT07: Promotion and development of education and training programs in stream restoration

NCED Certificate in Stream Restoration Science and Engineering
NCED continues to lead one of the few stream restoration certificate programs in the country. This program provides graduate students and working professionals the opportunity to study stream restoration in a science-based, multi-disciplinary context. Part of the program is based on existing courses at UMN, while two additional courses have been developed specifically for the program. Voller and Paola have taken leading roles in teaching these courses. The OSL is now used as the field site for the program. Fourteen students have graduated from the program thus far.

Upper Midwest Stream Restoration Symposium (UMSRS)
NCED sponsored and co-developed the second Upper Midwest Stream Restoration Symposium (UMSRS). With 85 participants, eight presentation sessions, six invited speakers, and a full poster session, the Symposium delivered extensive networking opportunities and topical coverage that included sediment management, large river restoration, stream and river structures, organism-focused restoration, restoration monitoring, and channel-floodplain connection. The symposium offered
stream restoration practitioners in the Upper Midwest the opportunity to gather as a community and integrate basic research discoveries with applied knowledge, techniques, and case histories. NCED-affiliated participants included staff scientist Sara Johnson; NCED graduate students; and SAFL OSL Manager Jessica Kozarek; and Wilcock.

Short courses

- Geomorphic and Ecological Fundamentals for Stream Restoration. One week short course taught by PI Wilcock in Truckee California.
- Channel design for stream restoration. Short course taught by PI Wilcock in Logan, Utah.
- River morphodynamics. Short course taught by NCED PI Parker sponsored by the Water Resources Agency Ministry of Economic Affairs in Taichung Taiwan.
- Introduction to Modeling River Flow, Sediment Transport, Habitat and Morphodynamics within the iRIC Modeling Interface. Short course organized by NCED PI Parker at the University of Illinois at Urbana-Champaign.

Plans

Stream Restoration Training Partners Group
This group will focus their work on planning, organizing, and building the next UMSRS.

Regional stream restoration conferences
Three regional stream restoration meetings are held annually around the country and have become critically important arenas for exchange between practitioners and scientists: RRNW, Southeast Regional Stream Restoration Conference, and Mid-Atlantic Stream Restoration Conference. Through the establishment of a fourth meeting for the upper Midwest region of the country, the UMSRS, NCED will continue further shape training and education in the field of stream restoration.

KT08: Interactions with Subsurface Architecture Science Partner Groups

Delta restoration partners
The CLEAR program is a collaborative effort among state, federal, and LSU scientists and engineers to test how deltaic systems work relative to specific restoration hypotheses. This partnership provides a conduit for NCED research and tools to reach Louisiana’s coastal restoration managers and decision makers. Additionally, the fieldwork and associated scientific findings of NCED’s REU Team Delta (details available in the Education and Diversity sections of this document) were incorporated into the CLEAR modeling framework after the REU LSU visit in the summer of 2010.

Industrial partners
The NCED collaboration with our industrial partners group has been long-lasting and mutually beneficial. This group includes the Industrial Consortium (JOGMEC and Shell Oil) as well as three American petroleum companies involved in training courses offered by NCED researchers – ExxonMobil, CononcoPhillips, and Chevron. Interactions include collaborative research and experiments, data sharing, and training. This partners group, created when the Subsurface Architecture (SA) IP focused on deep-time stratigraphy, continues to play an important role in providing data (seismic reflection data, cores, well logs, and experimental methods) that is vital to predicting the outcome of delta-restoration scenarios. New collaborators in the partnership are researchers at Imperial College in London and at the University of Wyoming.

Plans

Delta restoration partners
Work with this partner group will continue to provide a conduit for NCED research and tools to reach Louisiana’s coastal restoration managers and decision makers. The group will meet regularly, formally and informally, throughout Year 10 to further the integration of NCED knowledge and data into the arenas where it can best inform ecosystem management and resource- and land-use decisions.
Industrial Partners Group

Two short courses are planned for Year 10 at SAFL. ConocoPhilips personnel will attend a course on shallow water and fluvial deltaic environments in May 2011. ExxonMobil is planning a short course on shallow- and deep-water environments in July 2011. Additional meetings will occur as necessary.

► KT09: Collaborative subsurface architecture research with stakeholders and partners

Delta restoration partners

NCED PI Twilley continues to collaborate and coordinate regularly with the CLEAR group in order to effectively link science, monitoring and modeling into an integrated ecosystem forecasting system in support of Louisiana’s coastal restoration and protection endeavors.

Industrial partners

The Saint Anthony Falls Industrial Consortium for Experimental Stratigraphy continues to thrive and produce two-way transfer of ideas and data between NCED researchers and the oil industry. As a result of these relationships, NCED researchers are now able to conduct experimental studies of growing deltas using a new proprietary, weakly cohesive sediment mix developed at ExxonMobil Upstream Research. This sediment mix mimics the delta dynamics and morphology of the Mississippi River Delta and Wax Lake Delta, producing better predictions for restoration planning and numerical model development. Most recently, this sediment mix has been used to perform laboratory experiments on growing deltas under various scenarios of sea-level rise and tidal dynamics. These experiments inform channel-resolving predictive models of delta formation in development by NCED PIs Paola and Voller.

Additionally, Twilley participated in the Shell/LSU Breton Sound Ecosystem Project, which has a goal of developing the backbone of a delta observation system to study two different hydrologic basins including Breton Sound and Barataria Bay. Twilley also participated in a Shell Oil Company stakeholder panel discussion.

Plans

Delta restoration partners

NCED PI Twilley will combine existing CLEAR models with studies of the modern Mississippi River Delta system, laboratory experiments, and theoretical models to make ecogeomorphic predictions for restoration planning. The ultimate goal of this partnership is the development of a set of numerical models designed to accomplish two tasks: 1) evaluate the land-building efficiency of a diversion structure, and its effect on the main river channel, and 2) predict land building, of both a laterally averaged delta surface with hypsometric descriptions of sedimentation processes, ecology, and nutrient cycling, and of deltas with resolved channels. These models will interface with the CLEAR GIS-based model for southern Louisiana that connects science, policy, and resource management.

Industrial partners

Two short courses will be held at SAFL in Year 10. The courses will again study deep-ocean physical processes through the use of flumes and tanks as well as steady-state and changing base-level conditions in fluvial and deltaic environments. The courses will include experimental work on cohesive delta evolution under tidal influence.

► KT10: Dissemination of subsurface architecture knowledge, approaches, and tools outside of NCED

NCED PIs presented and discussed SA IP research through a number of presentations and lectures in Year 9.

Presentations and invited lectures

- Twilley gave invited presentations on “Landscapes on the edge: the mississippi river delta restoration as science and policy issues of earth surface processes” at Boston University, the Governor province of Noord-Holland in Amsterdam, The Netherlands; the Ecological Society of America, SuperComputing (SC) 10 in New Orleans; the Ohio State University; the America Wetland Foundation, Restoring America’s Estuaries Panel; World Delta Dialogue of the America Wetland Foundation; and the National Sea Grant Office. PI Twilley lectured on “Oil,
Hurricanes, Floods and Wetland Loss: Calibrating the Risks of the Mississippi River Delta” at East Carolina University; America Wetland Foundation, National Consortium of State Legislatures; and the Bell Museum of Natural History; Twilley spoke on systems ecology at the University of North Dakota and the Dauphin Island Sea Lab: Restoration Teachers Workshop. Twilley spoke on Mississippi River Delta restoration at the International Long Term Ecological Research program of Mexico and Environmental Defense Fund, Science Day.

- NCED PI Mohrig was an invited speaker at the AAPG/SEPM Annual Meeting.

**Media coverage**

- Please see the media section of this report.

**Plans**

Our interactions with stakeholders will continue into Year 10, as the NCED-LSU CLEAR partnership has significant potential to influence decision-making for Louisiana coastal restoration. Industrial short courses will continue in 2011 as a means of two-way exchange with the US petroleum industry.

**Executive summary – plans**

**Partnerships:** A priority for all research IPs is to continue to develop and deepen partnerships, as they are a key to the legacy of NCED. The RC model will continue to guide our collaborative efforts while we make adjustments to suit unique NCED goals. We will also continue to develop new partnerships as we see opportunities, including those that support the development of CSDMS, and SRDADG; the UMSRS; and the strategic partnerships with IonE and IMA.

**Major initiatives:** The F2F, Visitor, and Working Groups Programs will expand on their very successful track records of bringing NCED researchers together with researchers from outside institutions for collaborative research. The Visitor Program will continue to take advantage of the unique OSL research facility to foster large, multi-investigator projects between NCED researchers and groups from outside institutions. The F2F and Working Groups Programs will continue to foster their current partnerships, as they have resulted in fruitful research collaborations and knowledge transfer in recent years. The CSDMS and the SIESD are new additions to NCED’s Knowledge Transfer activities. Both programs will provide fruitful partnerships in forthcoming year.

**Web and tool development:** Webpages for the three IPs will be updated with ongoing research, model development, and data access. The NCED data repository will continue to be enriched with past NCED research as well as with other legacy datasets. The E-clips program will complete more videos and make these available on the NCED website, on our new Facebook fan page, our Twitter account, and our YouTube Channel, and the National Science Foundation’s Science 360 video news.

**Progress towards milestones/deliverables**

<table>
<thead>
<tr>
<th>ID</th>
<th>Milestones</th>
<th>Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>KT01</td>
<td>Select members for the DW Science Partners Group (Yr 6)</td>
<td>Six partner groups have been established and each is resulting in fruitful communication and information exchange.</td>
</tr>
<tr>
<td>KT01</td>
<td>Hold first formal meeting of DW science partners (Yr 6-7)</td>
<td></td>
</tr>
<tr>
<td>KT01</td>
<td>Hold regular meetings with DW science partners (Yr 8-10)</td>
<td></td>
</tr>
<tr>
<td>KT02</td>
<td>Establish annual working groups on DW fish population model (Yr 5-6)</td>
<td>The DW working group for fish population models has been established and has produced fruitful results – Ripple: A Coho Salmon Population Model was released to the public in July 2008. Efforts are underway to use lessons learned in creating Ripple to build models for other species, most notably Chinook and Steelhead salmon.</td>
</tr>
<tr>
<td>ID</td>
<td>Milestones</td>
<td>Progress</td>
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<td>------</td>
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<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>KT03</td>
<td>Develop webpages for the DW IP, including tool downloads and other data (Yr 5).</td>
<td>New DW tools, the Ripple model and GeoNet, are now available for download from NCED website. NCED PIs have developed educational opportunities for introducing research products to the community, such as the Ripple presentation given at SIESD.</td>
</tr>
<tr>
<td>KT03</td>
<td>Develop short course on Ripple model (Yr 6-7).</td>
<td></td>
</tr>
<tr>
<td>KT03</td>
<td>Develop other educational and training opportunities as DW components are developed.</td>
<td></td>
</tr>
<tr>
<td>KT04</td>
<td>Convene regular meetings with SR Science Partner Groups to advise NCED SR IP.</td>
<td>Each of the SR Science Partner Groups has met regularly throughout Year 9, whether formally or informally via email and telephone conferences. PRRSUM has organized and hosted the second annual Upper Midwest Stream Restoration Symposium.</td>
</tr>
<tr>
<td>KT04</td>
<td>Convene regular technical workshops with SR Science Partner Groups.</td>
<td></td>
</tr>
<tr>
<td>KT05</td>
<td>Define and implement application working groups.</td>
<td>The application working groups have been defined and implemented, with associated outside collaborations. Metrics for evaluating the impacts of research on practice are in development, as are tools for the evaluation of restoration design effectiveness, costs, and benefits.</td>
</tr>
<tr>
<td>KT05</td>
<td>Develop other ongoing collaborations outside of NCED.</td>
<td></td>
</tr>
<tr>
<td>KT05</td>
<td>Establish metrics for evaluating impacts of research on practice.</td>
<td></td>
</tr>
<tr>
<td>KT06</td>
<td>Develop community-wide technical newsletter for SR.</td>
<td>The SRN content has been incorporated into the NCED electronic newsletter. The SR website continues to improve, with tools such as an eBook on sediment transport and a threshold channel calculator in development.</td>
</tr>
<tr>
<td>KT06</td>
<td>Develop SR community website.</td>
<td></td>
</tr>
<tr>
<td>KT06</td>
<td>Develop SR toolbox containing free models and tools that support stream restoration practice.</td>
<td></td>
</tr>
<tr>
<td>KT07</td>
<td>Develop and maintain an expansion of education and training opportunities in stream restoration.</td>
<td>The SR certificate program continues to grow and educate students in science-based, multidisciplinary restoration practice. Through the venue of the SRN, and the Upper Midwest Stream Restoration Symposium, we are fostering a community-wide dialog on stream restoration education and certification.</td>
</tr>
<tr>
<td>KT07</td>
<td>Expand impact of SR certificate program at UMN.</td>
<td></td>
</tr>
<tr>
<td>KT07</td>
<td>Explore the need for establishing a formal standard of proficiency for stream restoration practice.</td>
<td></td>
</tr>
<tr>
<td>KT08</td>
<td>Establish members of SA Science Partner Groups.</td>
<td>SA Science Partner Group membership has been established and the group is holding regular meetings and workshops to advise SA research. Technical workshops and the annual oil consortium meeting were held in May, and July of Year 9 at SAFL.</td>
</tr>
<tr>
<td>KT08</td>
<td>Convene regular meetings with SA Science Partner Groups to advise NCED SA IP.</td>
<td></td>
</tr>
<tr>
<td>KT08</td>
<td>Convene regular technical workshops with SA Science Partner Groups.</td>
<td></td>
</tr>
<tr>
<td>KT09</td>
<td>Define and implement Application Working Groups.</td>
<td>Delta restoration and industrial working groups have been created and are engaging in on-going collaborative work. Metrics for evaluating the impacts of research on practice are in development, including work on developing a method for understanding and documenting the societal implications and benefits of delta restoration.</td>
</tr>
<tr>
<td>KT09</td>
<td>Develop other ongoing collaborations outside of NCED.</td>
<td></td>
</tr>
<tr>
<td>KT09</td>
<td>Establish metrics for evaluating impacts of research on practice.</td>
<td></td>
</tr>
<tr>
<td>KT10</td>
<td>Develop webpages for SA research, tools, and training opportunities.</td>
<td>SA research, tools, and training opportunities are available online. Education and training opportunities have been developed through the REU program and through the prolific speaking and outreach activities conducted by SA researchers.</td>
</tr>
</tbody>
</table>
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V. External Partnerships

External Partnerships are listed in this section. Goals, activities, and plans are described in the Knowledge Transfer, Education, and Diversity sections of the report.

Knowledge Transfer Partners

Stream Restoration Partners

Governmental and corporate organizations involved with stream restoration activities

<table>
<thead>
<tr>
<th>Organization Name</th>
<th>Organization Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allred Restoration, Inc.</td>
<td>Environmental Consulting Firm</td>
</tr>
<tr>
<td>Barr Engineering Company</td>
<td>Environmental Consulting Firm</td>
</tr>
<tr>
<td>Blue Earth County Planning</td>
<td>Local Government</td>
</tr>
<tr>
<td>Bureau of Land Management, National Science and Technology Center</td>
<td>Government Agency</td>
</tr>
<tr>
<td>Canaan Valley Institute</td>
<td>Non-profit organization</td>
</tr>
<tr>
<td>City of Baltimore</td>
<td>Local Government</td>
</tr>
<tr>
<td>Federal Interagency Sedimentation Project</td>
<td>Federal Interagency</td>
</tr>
<tr>
<td>Graham Mathews and Associates</td>
<td>Industry</td>
</tr>
<tr>
<td>Inter-Fluve, Inc.</td>
<td>Environmental Consulting Firm</td>
</tr>
<tr>
<td>Intermountain Center for River Rehabilitation and Restoration</td>
<td>Research Institution</td>
</tr>
<tr>
<td>Minnesota Department of Agriculture</td>
<td>State Government</td>
</tr>
<tr>
<td>Minnesota Department of Natural Resources</td>
<td>State Government</td>
</tr>
<tr>
<td>Minnesota Department of Transportation</td>
<td>State Government</td>
</tr>
<tr>
<td>Minnesota Geological Survey</td>
<td>State Government</td>
</tr>
<tr>
<td>Minnesota Pollution Control Agency</td>
<td>Government Agency</td>
</tr>
<tr>
<td>NASA, Goddard Space Flight Center, Hydrological Sciences</td>
<td>Government Agency</td>
</tr>
<tr>
<td>National Cooperative Highway Research Program</td>
<td>Government Agency</td>
</tr>
<tr>
<td>National Parks Service, Geologic Resources Division</td>
<td>Government Agency</td>
</tr>
<tr>
<td>National Parks Service, Water Resources Division</td>
<td>Government Agency</td>
</tr>
<tr>
<td>NOAA Fisheries</td>
<td>Government Agency</td>
</tr>
<tr>
<td>Otis Bay Consulting</td>
<td>Environmental consulting firm</td>
</tr>
<tr>
<td>Provo River Restoration Program</td>
<td>State Government</td>
</tr>
<tr>
<td>R2 Resource Consultants</td>
<td>Environmental consulting firm</td>
</tr>
<tr>
<td>Sandy River Basin Watershed Council</td>
<td>Local Government</td>
</tr>
<tr>
<td>St. Croix Watershed Research Station</td>
<td>Research Institution</td>
</tr>
<tr>
<td>Stillwater Science</td>
<td>Environmental consulting firm</td>
</tr>
<tr>
<td>Swanson Hydrology, Inc.</td>
<td>Environmental consulting firm</td>
</tr>
<tr>
<td>US Army Corps of Engineers</td>
<td>Government Agency</td>
</tr>
<tr>
<td>US Bureau of Reclamation, River Sedimentation and Hydraulics Group</td>
<td>Government Agency</td>
</tr>
<tr>
<td>US Bureau of Reclamation, Trinity River Restoration Program</td>
<td>Government Agency</td>
</tr>
<tr>
<td>US Fish and Wildlife Service</td>
<td>Government Agency</td>
</tr>
<tr>
<td>USACE, Research and Development Center, Coastal &amp; Hydraulics Laboratory</td>
<td>Government Agency</td>
</tr>
<tr>
<td>USACE, Research and Development Center, Environmental Laboratory</td>
<td>Government Agency</td>
</tr>
<tr>
<td>USACE, St. Paul District</td>
<td>Government Agency</td>
</tr>
</tbody>
</table>
### External Partnerships

**Partnership for River Restoration and Science in the Upper Midwest (PRRSUM)**

Partners interested in river research and restoration in the upper Midwest region of the country

<table>
<thead>
<tr>
<th>Organization Name</th>
<th>Organization Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barr Engineering Company</td>
<td>Environmental Consulting Firm</td>
</tr>
<tr>
<td>Inter-Fluve Inc.</td>
<td>Environmental Consulting Firm</td>
</tr>
<tr>
<td>Metropolitan Council</td>
<td>Governmental Unit - Local</td>
</tr>
<tr>
<td>Saint Anthony Falls Laboratory</td>
<td>Research</td>
</tr>
<tr>
<td>United States Forest Service</td>
<td>Governmental Unit - Federal</td>
</tr>
<tr>
<td>United States Geological Survey</td>
<td>Governmental Unit - Federal</td>
</tr>
<tr>
<td>United States Geological Survey/ Minnesota Water Science Center</td>
<td>Governmental Unit - Federal</td>
</tr>
<tr>
<td>University of Minnesota St. Anthony Falls Laboratory</td>
<td>University</td>
</tr>
<tr>
<td>University of Minnesota Stream Restoration Certificate Program</td>
<td>University</td>
</tr>
<tr>
<td>University of Minnesota Water Resources Center</td>
<td>University</td>
</tr>
<tr>
<td>University of Wisconsin, La Crosse</td>
<td>University</td>
</tr>
</tbody>
</table>

**Delta Restoration Partners**

Partners interested in the long-term dynamics of delta systems

<table>
<thead>
<tr>
<th>Organization Name</th>
<th>Organization Type</th>
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</thead>
<tbody>
<tr>
<td>Louisiana Department of Natural Resources</td>
<td>Government Agency</td>
</tr>
<tr>
<td>US Army Corps of Engineers</td>
<td>Government Agency</td>
</tr>
<tr>
<td>WesternGeco</td>
<td>Geophysical Services Company</td>
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</tbody>
</table>

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Stratigraphic Partners

Oil companies interested in the long-term dynamics of channel systems

<table>
<thead>
<tr>
<th>Organization Name</th>
<th>Organization Type</th>
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</thead>
<tbody>
<tr>
<td>ConocoPhillips</td>
<td>Oil exploration company</td>
</tr>
<tr>
<td>ExxonMobil</td>
<td>Oil exploration company</td>
</tr>
<tr>
<td>Japan Oil, Gas and Metals Corporation</td>
<td>Oil exploration company</td>
</tr>
<tr>
<td>Shell Oil Company</td>
<td>Oil exploration company</td>
</tr>
</tbody>
</table>

Research Partners

Our research relationships to other institutions are most often based on interpersonal collaboration and are described in the three Integrated Project reports. A tabular summary of these institutions with which research partnerships are active or in development follows:

Research Partners

Non-NCED institutions that partner with NCED to perform join research

<table>
<thead>
<tr>
<th>#</th>
<th>Organization Name</th>
<th>Description of Partnership</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Allred Restoration, Inc</td>
<td>Environmental consulting firm</td>
</tr>
<tr>
<td></td>
<td>Joint research on dam removal</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Arizona State University</td>
<td>University</td>
</tr>
<tr>
<td></td>
<td>Joint research on stream ecosystems</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Barr Engineering</td>
<td>Environmental consulting firm</td>
</tr>
<tr>
<td></td>
<td>Research on bedload transport</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Bunda College, Malawi</td>
<td>University</td>
</tr>
<tr>
<td></td>
<td>Joint stream restoration and watershed research</td>
<td></td>
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<tr>
<td>5</td>
<td>Boston College</td>
<td>University</td>
</tr>
<tr>
<td></td>
<td>Collaboration on SA research</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Bowling Green University</td>
<td>University</td>
</tr>
<tr>
<td></td>
<td>Joint research in lake biogeochemistry</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>California Institute of Technology</td>
<td>University</td>
</tr>
<tr>
<td></td>
<td>Joint SA research</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Center of Freshwater Ecology Institute of Hydrobiology, Chinese Academy of Sciences</td>
<td>University center</td>
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<td></td>
<td>Collaboration on DW research</td>
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<td>9</td>
<td>Carl-von-Ossietzky University Oldenburg, Germany</td>
<td>University</td>
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<td></td>
<td>Joint stream ecosystem research</td>
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<td>10</td>
<td>Case Western Reserve University</td>
<td>University</td>
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<td></td>
<td>Joint research on decision analysis</td>
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<td>11</td>
<td>Cache River Wetlands Joint Venture Partnership</td>
<td>Non-profit organization</td>
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<td></td>
<td>Joint SR research</td>
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<tr>
<td>12</td>
<td>Center of Freshwater Ecology, Institute of Hydrobiology, Chinese Academy of Sciences</td>
<td>Governmental research organization</td>
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**External Partnerships** 121
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<td>St. Croix Watershed Research Station</td>
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<td>Trinity River Consortium</td>
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<td>Joint studies of large river systems and river engineering</td>
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<td>Joint stream restoration research through the 2008 Visitor Program; Joint SA research</td>
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### External Partnerships

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<td>Joint research on stream restoration and watersheds</td>
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### Education and Diversity Partners

Partners involved in our Education and Diversity initiatives

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<td>AISES: American Indian Science and Engineering Society</td>
<td>Minority Professional Organization</td>
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<td></td>
<td>NCED sends Native American students in our programs to</td>
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<td>AISES science fair. Fond du Lac’s Ojibwe School has also</td>
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<tr>
<td></td>
<td>joined AISES with sponsorship from NCED. NCED exhibits</td>
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<td>at annual meeting for recruiting purposes.</td>
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<td>AlBrook School</td>
<td>MN School</td>
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<td>Collaborates on programs for teachers and students.</td>
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<td>American Museum of Natural History</td>
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<td>Collaborates with NCED/SMM on exhibit development.</td>
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<td>Association for Women Geoscientists, Minnesota chapter</td>
<td>Professional Association</td>
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<td>Purpose: Connections to local professionals, career</td>
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<td>development for students, networking events, K-12</td>
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<td></td>
<td>activities for children, events at regional</td>
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<td>conferences; Karen Campbell, past president.</td>
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<td>NSF Center</td>
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<td>Collaborates on K-12 and undergraduate programs for</td>
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<tr>
<td></td>
<td>Native youths.</td>
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<td>Center for Embedded Network Sensing</td>
<td>NSF Center</td>
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<td>participant.</td>
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<td></td>
<td>Minnesota</td>
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<td>Collaborates with NCED on <em>gidakiimanaaniwigamig</em> camps.</td>
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<td>10</td>
<td>City Technology of New York</td>
<td>Non-Profit</td>
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<td>Collaborates on developing culturally-appropriate</td>
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<td>science and math curricula.</td>
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<td>Organization Type</td>
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<td>Cloquet Forestry Center, University of Minnesota</td>
<td>University Center</td>
<td>Partners with <em>gidakiimanaaniwigamig</em> Native American youth science immersion program.</td>
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<td>Cloquet School District</td>
<td>MN School</td>
<td>Collaborates on programs for teachers and students.</td>
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<tr>
<td>13</td>
<td>Fond du Lac Ojibwe School</td>
<td>Public School</td>
<td>Partners with NCED on <em>gidakiimanaaniwigamig</em> Native American youth science immersion program.</td>
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<td>Louis Stokes Mississippi Alliance for Minority Participation (LSMAMP)</td>
<td>NSF LSAMP</td>
<td>Collaborates to find research internships and graduate opportunities for LSMAMP participant students at NCED.</td>
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<td>SAHRA: Sustainability of Semi-Arid Hydrology and Riparian Areas</td>
<td>NSF Science and Technology Center</td>
<td>Collaborates on joint recruiting of underrepresented undergraduate and graduate students, AGU booth, and Future Earth exhibit.</td>
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<td>18</td>
<td>SERC: The Science Education Resource Center@Carleton College</td>
<td>Non-Profit</td>
<td>Collaborates with NCED on designing/sponsoring/conducting workshops for college faculty, distribution of 3D maps.</td>
</tr>
<tr>
<td>19</td>
<td>St. Louis County Schools</td>
<td>MN School District</td>
<td>Collaborates on programs for teachers and students.</td>
</tr>
<tr>
<td>20</td>
<td>NAGT: National Association for Geoscience Teachers</td>
<td>Non-Profit</td>
<td>Collaborates with NCED on designing/sponsoring/conducting workshops for college faculty and middle-to-high-school teachers.</td>
</tr>
<tr>
<td>21</td>
<td>NOAA</td>
<td>Federal Agency</td>
<td>Collaborates with NCED/SMM on exhibit development.</td>
</tr>
<tr>
<td>22</td>
<td>St. Louis Riverwatch</td>
<td>State Agency</td>
<td>Collaborates with NCED on <em>gidakiimanaaniwigamig</em> camps.</td>
</tr>
<tr>
<td>23</td>
<td>University of Minnesota, Duluth, Department of Engineering and Robotics</td>
<td>University</td>
<td>Collaborates with NCED on <em>gidakiimanaaniwigamig</em> camps.</td>
</tr>
<tr>
<td>24</td>
<td>University of Minnesota, Duluth E-Portfolio</td>
<td>University</td>
<td>Collaborates on developing technology for education programs.</td>
</tr>
<tr>
<td>25</td>
<td>University of Minnesota, Duluth School of Medicine</td>
<td>University</td>
<td>Collaborates with NCED on <em>gidakiimanaaniwigamig</em> camps.</td>
</tr>
<tr>
<td>26</td>
<td>University of Minnesota Institute of Technology, North Star STEM Alliance (an NSF LSAMP)</td>
<td>University</td>
<td>Collaborates with NCED on the <em>giwed'nanung</em> (North Star) undergraduate AISES Alliance.</td>
</tr>
<tr>
<td>27</td>
<td>Little River Research</td>
<td>Non-Profit</td>
<td>Collaborates with NCED on stream table design.</td>
</tr>
<tr>
<td>#</td>
<td>Organization Name</td>
<td>Organization Type</td>
<td>Description of Partnership</td>
</tr>
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</tr>
<tr>
<td>28</td>
<td>Electronic Visualization Laboratory, University of Illinois at Chicago</td>
<td>University</td>
<td>Collaborates with NCED on scientific visualization for education.</td>
</tr>
<tr>
<td>29</td>
<td>Center for Coastal Margin Observation and Prediction</td>
<td>NSF STC</td>
<td>Collaborates with NCED on NSF Future Earth Initiative.</td>
</tr>
<tr>
<td>30</td>
<td>Center for Microbial Oceanography: Research and Education</td>
<td>NSF STC</td>
<td>Collaborates with NCED on NSF Future Earth Initiative.</td>
</tr>
<tr>
<td>31</td>
<td>Center for Multiscale Modeling of Atmospheric Processes</td>
<td>NSF STC</td>
<td>Collaborates with NCED on NSF Future Earth Initiative.</td>
</tr>
<tr>
<td>32</td>
<td>Center for Remote Sensing of Ice Sheets</td>
<td>NSF STC</td>
<td>Collaborates with NCED on NSF Future Earth Initiative.</td>
</tr>
<tr>
<td>33</td>
<td>Institute on the Environment, University of Minnesota</td>
<td>University</td>
<td>Collaborates with NCED on NSF Future Earth Initiative.</td>
</tr>
<tr>
<td>34</td>
<td>St. Catherine University (formerly College of St. Catherine)</td>
<td>Women’s University</td>
<td>Collaborates with NCED on the design and teaching of STEM programs for undergraduates and teachers.</td>
</tr>
<tr>
<td>35</td>
<td>Center for Global Environmental Education</td>
<td>Educational provider for teachers</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>ANDRILL Antarctic drilling program</td>
<td>Research facility</td>
<td>Collaborate on outreach activities.</td>
</tr>
<tr>
<td>37</td>
<td>Will Steger Foundation</td>
<td>Non-profit</td>
<td>Collaborate on outreach activities.</td>
</tr>
<tr>
<td>38</td>
<td>Institute on the Environment</td>
<td>University of Minnesota unit</td>
<td>Collaborate on outreach activities.</td>
</tr>
</tbody>
</table>
VI. Diversity Initiative

Project team

Diversity Director: Diana Dalbotten

Faculty and Staff: Andrew Wold, Holly Pellerin, Lowana Greensky, Robby Schreiber, Antony Berthelote, Gillian Roehrig

Contributing Principal Investigators: All

Executive summary

Goal: The overall goal of NCED’s Diversity Initiative is to increase participation by underrepresented groups in NCED scientific disciplines until minority representation is reflective of the U.S. national population. The specific goals of our initiative include: 1) an immediate improvement in participation by members of all underrepresented groups in NCED itself and 2) an improvement in representation of Native Americans in NCED-related disciplines.

Approach: NCED uses the intrinsic appeal of landscapes and surface dynamics to engage diverse communities in the study of Earth-surface science at all levels and to attract diverse participants into its research programs. The following key elements are included in our approach:

1. Use a vigorous Undergraduate Summer Internship Program (USIP) to bring upper-level students from underrepresented groups to NCED facilities for a summer to do research on NCED topics. We specifically structure these programs to include interesting field trips, hands-on laboratory experimentation, and theoretical modeling studies.

2. Build research ties with faculty members from schools with large minority enrollments, particularly minority-serving institutions (MSI’s), through the Faculty-To-Faculty (F2F) Program. Identify faculty members who work in NCED research areas and bring them with their students to NCED as visiting researchers, seminar speakers, and participants in NCED workshops.

3. Work with, and support efforts by, NCED participating institutions, science and technology center (STC) partners, and other broader, national efforts, such as the Louis Stokes Alliance for Minority Participation (LSAMP), to recruit and fund students from underrepresented groups in NCED-related graduate research.

4. Increase the number of potential future recruits by collaborating with local communities, including the Fond du Lac (FDL) Reservation, to provide Native American youth science enrichment and immersion programs, including seasonal camps and after-school activities.

5. Use the Youth Science Center (YSC) at the Science Museum of Minnesota (SMM), and especially the Big Back Yard (BBY) Park Crew, to team underrepresented youths with faculty and graduate student mentors from NCED and create NCED-based hands-on activities.

Highlights: Over the past nine years, NCED has worked with our diversity partners to develop and perfect programs that provide new pathways for young people into geosciences careers. We have developed a full suite of collaborations, networks, and alliances that in the past year has had a ripple effect that has leveraged new funds and partnerships to multiply the impact of our investments in diversity. This year saw many examples of how laying the groundwork for these alliances is paying off in the form of new opportunities for students and new educational infrastructure to meet the needs of our institutional partners.

We began with a locally focused K-12 program, gidakiimanaaniwigamig (‘Our Earth Lodge’ in Ojibwe--GIDA) which introduced native students in grades 8-12 to the Earth sciences, and built on the ‘Circle of Learning’ concept, which uses traditional Native teaching and learning practices, as the foundation of our program. With the introduction by NCED and its collaborators of an undergraduate program in 2006, the giwwed’anang (North Star) American Indian Science and Engineering Society (AISES) Alliance, we built a support network that provides advice and opportunities for Native American undergraduates across the state of Minnesota. Realizing the importance of mentors and professional internship opportunities for these students, NCED helped to launch the North Star AISES Professional Alliance (MN AISES), which applied for official status as a professional
AISES chapter in 2010. These dedicated Native American science and engineering professionals are committed to working with giiew’ anang to mentor students during and beyond their undergraduate degrees. The Geoscience Alliance (GA) is an NCED-led national alliance to promote broadened participation of Native Americans in the geosciences. In October 2010 we had our first GA National Conference, with support from an NSF Opportunities for Enhancing Diversity in the Geosciences (OEDG) grant. The conference, held on the FDL Reservation, brought together a group of 150 students and faculty from tribal colleges and universities, other universities, K-12 students and teachers, and representatives from government and other institutions to talk about Broading Participation of Native Americans in the Geosciences. The outcome from the conference was a determination to maintain a permanent GA that will foster collaborations, student opportunities and future research.

NCED’s Faculty-to-Faculty (F2F) and Undergraduate Summer Internship (USIP) Programs have increasingly taken a Native American focus as a dividend of these alliance structures. The formation of the GA led almost immediately to a new F2F partnership with Antony Berthelote of Salish Kootenai College (SKC), who became acquainted with NCED at an NCED-sponsored GA workshop before the AISES National Conference in Portland, Oregon in September 2009. Berthelote learned of NCED’s F2F program at the workshop and proposed a collaboration between NCED and SKC focused on establishing the first four-year hydrology/water resources degree offered at a tribal college. This degree was accredited in 2010 and the first class of students began taking classes in fall of 2010. NCED is continuing the collaboration by working in partnership with SKC to develop new courses for the degree, working together to recruit students, and putting in place essential research opportunities for students in the program. When the Research Experience for Undergraduates (REU) Site on River and Coastal Restoration (REU-RCR) completed our 3-year award cycle, our renewal proposal was oriented towards supporting these new initiatives. This summer we will launch the new REU Site on Sustainable Land and Water Resources (REU-SLAWR), which will be a partnership between NCED, SKC, and Fond du Lac Tribal and Community College (FDLTCC). We believe this partnership will lead to a new alliance of tribal colleges, reservation resource managers, and university researchers, aimed at developing the next generation of land and water resource scientists.

NCED has demonstrated the success of the “Circle of Learning” concept for attracting and retaining Native American youth into Earth sciences. Since NCED’s establishment in 2002, the partnership between FDLTCC and other NCED partners has grown and made an impact within and outside of NCED. Originally focused locally in the northern Minnesota community of the Fond du Lac Band of Lake Superior Chippewa (FDL) and nearby cities, the GIDA program, focused on native youths, now reaches across the state and nationally. The legacy of the NCED collaboration with Fond du Lac Tribal and Community College (FDLTCC) will be partnerships that not only extend well beyond the NCED funding cycle but will reach well beyond the original NCED partners. The manoomin (Wild Rice) Project, funded by a $1.5M award from the NSF Opportunities for Enhancing Diversity in the Geosciences (OEDG) program is a collaboration between NCED, the LacCore Lacustrine Core Repository (UMN), and FDL Reservation natural resources scientists, and is building a community-wide effort to better understand wild rice production on the FDL Reservation. As we approach the second summer of this 5-year project, we are co-managing the undergraduate research of the manoomin Project with that of the REU-SLAWR so that the two programs can be interwoven and students can become a single community with shared goals and events. The two programs will culminate in a joint workshop at the end of the summer (funded by both programs) that will bring all of the teams to SAFL for sessions on research ethics (including responsible research on Native American reservations), hands-on experimental research, and a summer research symposium highlighting the summer research projects. With the addition of a new award from NASA, NCED is launching a new initiative that brings together teachers from all the tribal regions across northern Minnesota. The program is called CYCLES: Teachers Discovering Global Climate Change from a Native Perspective, and is in partnership with the UMN STEM Center and the TRIBES (Teaching Relevant Inquiry-Based Environmental Science) Program.

We noted last year that, as a result of the GA conference and its potential to build our alliances, we expected to feel the impact on our diversity programs grow exponentially as NCED sunsets. The excitement and synergy that have resulted, not just from the GA, but from the growth and maturity of NCED’s network of alliances, has led to a focus and excitement that has moved beyond this expectation.
Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Project Name</th>
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<tbody>
<tr>
<td>DV01</td>
<td>Faculty-to-Faculty (F2F) Program</td>
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<tr>
<td>DV02</td>
<td>Direct recruitment of underrepresented students to NCED graduate and postdoctoral programs</td>
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<tr>
<td>DV03</td>
<td>Undergraduate Summer Internship Program (USIP)</td>
</tr>
<tr>
<td>DV04</td>
<td>gidakiimanaaniwigamig (Our Earth Lodge) Native American Youth Science Immersion Program—GIDA</td>
</tr>
<tr>
<td>DV05</td>
<td>EarthScapes in the Science Museum of Minnesota’s Youth Science Center</td>
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</table>

► DV01: Faculty-to-Faculty (F2F) Program

Building durable connections to minority-serving institutions and universities with high minority enrollments

By involving faculty from MSIs in NCED research projects, we are fostering long-term relationships that will lead to a natural increase in the flow of underrepresented individuals into graduate and postgraduate positions at NCED and other national research centers. Through the F2F program:

- Faculty will gain a new level of excitement and interest in NCED research,
- Faculty will also be able to inject some of this excitement into their courses, potentially recruiting an untapped source of future research scientists,
- Faculty will provide a link to students at MSIs, increasing the natural flow of students into NCED research groups and the geoscience community at large,
- Research partnerships will help to build the research infrastructure of the faculty members’ home institutions, and Junior faculty will be greatly assisted in their professional development.

In Year 9, we began an exciting new F2F partnership with Salish Kootenai College (SKC), a tribal college in Montana. Antony Berthelote, an instructor at SKC, worked with NCED as a partner to initiate a four-year degree in Hydrology at SKC, the first at a tribal college in the nation. Berthelote summarized what he felt would have been different if he had not become an NCED PI in January 2010:

*I would have not been able to complete the degree accreditation in the short time we did it in or possibly at all or ever. I may not have been still working at SKC because the program and initial funds would have not been in place. I would not have been able to learn what I did about how to operate within the constraints of a Tribal College administration (grant writing, budget items, administrative duties, mentoring student interns, working with the business office on purchase orders, equipment, supplies, travel and such things). This may seem trivial but it has put me on good terms with the college administrators on many levels that I would not have been able to achieve without the initial support of NCED. My relationship with my department head became much stronger and less precarious after NCED offered to have him visit, which has undoubtedly allowed many doors and opportunities to open up with less scrutiny and mistrust from the Tribal College towards NCED and my other partners.*

*Without NCED I would not be on the CUAHSI Education and Outreach committee or an integral part of the GA (which I love). I have had collaborations with the Geocognition Laboratory (Michigan State Univ.), Haskel Indian Nations University, Stone Child Community College, and the GLOBE Program all because of NCED. The collaborations with gidaa and manoomin have been a few highlights in what is possible through NCED. The cross-cultural STEM educational exchange between our tribal peoples has been seen in two news releases and has highlighted the hydrology program and my efforts/collaboration with NCED in a way not otherwise possible.*
It should also be noted that the first undergraduate research projects directly under the hydrology program were started in direct response to NCED collaborations (Ashley Mark’s Artificial Neural Network Research into Groundwater Responses to Dam Removals). I also helped host the 5th Annual Tribal Water Rights Conference at SKC due in part from the exposure that NCED provided for the program. Above and beyond all this, I have been successful in obtaining a NASA Space Grant and have been highly competitive in the ITEST and other NSF grant proposals due directly to NCED’s assistance. These collaborations will continue for many years and in the near future will include collaborations on NSF-ATE, NSF-TUES, AIANCCWG, NASA, and NOAA proposals which are all at various stages of completion.

The extent to which our NCED partnership has benefited my career, the new Hydrology program, Salish Kootenai College, and Native American participation in the geosciences is incalculable and not all readily apparent. In short NCED has taken good ideas for Tribal peoples and turned them into realities which will benefit Natives for generations.

**Progress towards milestones/deliverables**

<table>
<thead>
<tr>
<th>Milestone/Deliverable</th>
<th>Progress</th>
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</thead>
<tbody>
<tr>
<td>Five new faculty introduced to NCED in Years 6-10. Faculty will conduct major research projects or collaborate closely with NCED on diversity recruiting.</td>
<td>Florida International University F2F participant Assefa Melesse finishes a two-year collaboration and as an NCED affiliated PI. William Velez continues summer internship-recruiting partnership with NCED to place minority students from Arizona State University’s Mathematics Department in NCED summer research positions. SKC F2F participant Antony Berthelote begins collaboration with NCED and becomes affiliate PI.</td>
</tr>
<tr>
<td>New collaborations and recruiting visits by NCED faculty.</td>
<td>NCED Diversity Director Dalbotten co-organized the Geoscience Alliance conference (co-organized by Berthelote) which exposed many other tribal college faculty to the potential benefits of partnerships with STCs. NCED Director Foufoula-Georgiou attended sessions and gave the banquet welcome address, in which she announced that NCED would support five students from the GA to attend the AGU National Meeting in San Francisco, December 2010.</td>
</tr>
</tbody>
</table>

**Plans**

In Year 10, NCED is focusing our F2F efforts on working with SKC to support continued development and strengthening of the four-year hydrology degree at SKC. SKC is a partner in our new REU Site on Sustainable Land and Water Resources. A team of 4-5 students will be housed at SKC and will work on research projects focused on hydrology of the reservation. An ongoing focus of our collaboration will be in the collection of resources for courses in the hydrology degree program, and packaging and disseminating these resources to other tribal colleges. A long-term goal of our partnership is to create an alliance of tribal college programs focused on the geosciences and the environment, and research centers with a similar focus in support of our Geoscience Alliance goal of broadening participation of Native Americans in the geosciences. These efforts will include strengthening the two- to four-year pipeline and the four-year degree to graduate pipeline, as well as focused efforts at interweaving our institutions’ K-12 outreach efforts.

► **DV02: Direct recruitment of underrepresented students to NCED graduate and postdoctoral programs**

Since its inception, NCED has made steady progress in increasing the diversity of our researchers and staff. Participation by members of underrepresented groups in our research program, including graduate students, postdoctoral research associates, affiliated researchers, and faculty has risen from 8% at NCED’s inception to 14% by the end of Year 9.

**Progress towards milestones/deliverables**

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<th>Milestone/Deliverable</th>
<th>Progress</th>
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<tbody>
<tr>
<td>Bring percentage of graduate students from underrepresented groups to parity with overall US national population (~25%) by the end of Year 10.</td>
<td>Percent of NCED graduate students and postdoctoral research associates who are from underrepresented groups has risen from 2% at NCED’s inception to 11% by end of Year 9.</td>
</tr>
</tbody>
</table>
Plans

We will continue our vigorous program of graduate recruiting, including visits to national recruiting venues such as the AISES National Conference, the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS) National Conference, and the state and regional Louis Stokes Alliance for Minority Participation (LSAMP) conferences. We will continue to promote diversity through the new NCED-managed REU-SLAWR. This summer will bring 15 visiting undergraduate students to do research at NCED, FDLTCC, LacCore and SKC, with a focus on recruitment of Native American students. Two former undergraduate summer interns, one from NCED’s Team Marmot (advised by PI Peter Wilcock) and one from NCED affiliated PI Kimberly Hill’s 2007 REU Site (advised by PI Chris Paola), continue as NCED graduate students. A student from NCED’s 2010 REU site, Cailan Halliday, has been accepted into the Department of Civil Engineering and plans to do his research at SAFL (advisor NCED PI Kimberly Hill).

► DV03: Undergraduate Summer Internship Program

Each year, the USIP brings undergraduate students from underrepresented groups to NCED institutions for a 10-week summer program and has played an important part in accomplishing our diversity mission. Year 9 saw the third and final year of our REU on River and Coastal Restoration, which was funded by NSF based on the Marmot Year 6 pilot, and supported ten students on two teams: “Team Marmot” (based near Portland, Oregon) and “Team Delta” (based in coastal Louisiana), Team Marmot participated in an ongoing campaign to document the geomorphic response of the Sandy River to the 2007 removal of the Marmot Dam. NCED research staff, in collaboration with state and federal agencies, used high-resolution measurements to compile a detailed record of how the river redistributed sediment formerly trapped behind the 50-ft. tall Marmot Dam. Sediment redistribution of this magnitude has important implications for ecological habitat, in this case, for salmonid species. This project provides a real-world experiment, critical to the development of more effective river management and restoration practices. Team Delta participated in research related to coastal restoration of the Mississippi River Delta. NCED’s Wax Lake Delta field laboratory (http://www.sce.lsu.edu/wbi) presents an excellent opportunity to examine linkages between geomorphology and ecology in a coastal restoration context. Additional historical field research areas in the deltaic plain provide students the opportunity to integrate short-term projects into a longer-term perspective of geomorphic, biogeochemical, and ecological processes. Just as with the pilot Team Marmot, all the interns began their research experience at NCED and the St. Anthony Falls Laboratory (SAFL): they participated in hands-on modeling at the laboratory in order to prepare for their field work. In summer 2010, with the completion of NCED Marmot research, we had two teams at SAFL working with NCED PI Fotis Sotiropoulos, post-doc Ali Khosronejad and graduate student Stephanie Day.

In summer 2011, we will launch our new REU Site on Sustainable Land and Water Resources. In addition, in collaboration with the Minnesota North Star STEM Alliance, an NSF-funded Louis Stokes Alliance for Minority Participation (LSAMP), we are arranging research experiences for four students from the giwed’anang (North Star) AISES Alliance. Working in collaboration with former Outdoor Stream Lab manager Anne Lightbody, now a faculty member at University of New Hampshire and NCED Affiliate PI, we are collaborating to arrange research experiences in the Outdoor Stream Laboratory for three students supported by her project “Quantifying feedbacks between fluvial morphodynamics and pioneer riparian vegetation in sand-bed rivers.” And we are working with our partners in the manoomin (Wild Rice) Project to coordinate with the undergraduate research projects that are part of that grant and conduct a two-week-long ‘mini-REU’ for students who are

Figure 2. 2010 REU participant Lyman Petersen leads students down to the Le Sueur River research site on an NCED field trip.
interested but not ready to commit to the longer 10-week REU experience. We will work in partnership on all aspects of these research experiences, from recruiting, to arranging events, and culminate in a two-week Ethics Talking Circles--Hand’s-On Experimental Research--Research Symposium at the end of the summer.

NCED’s USIP is now producing graduate students from underrepresented groups. Of the students supported through the USIP, 72% are in or have completed graduate programs, or plan to go to graduate school when they complete their undergraduate programs.

**Progress towards milestones/deliverables**

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<tr>
<td>Ongoing participation of five undergraduate students (from under-represented groups) each summer. Consistent recruitment of USIP students to NCED-related graduate programs with the majority of USIP students going to graduate school.</td>
<td>• 49 students have been supported: 32 women and 17 men&lt;br&gt;• 2 have done graduate work with NCED and graduated with master of science (MS) degrees&lt;br&gt;• 18 are currently in graduate programs, 2 with NCED&lt;br&gt;• 15 more students plan to apply to graduate programs when they finish their undergraduate programs&lt;br&gt;• 7 students have graduated and are currently working in industry,&lt;br&gt;• 7 students are no longer in contact&lt;br&gt;• In addition, 3 students have taken part in the NCED International Research Experience Program, advised by NCED graduate students</td>
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</table>

**Plans**

As we look beyond NCED funding, we intend to continue collaborations between NCED institutions, NCED young researchers, and affiliate PIs and our network of alliances to support ongoing research experiences for students from underrepresented groups. Our model of team research, team mentoring, and multidisciplinary and multi-institutional research experiences in Earth-surface dynamics has become an established model for successful REU’s, which has been shared at national meetings such as the American Geophysical Union National Meeting (December 2010), where we organized poster and oral sessions on exemplary practices for undergraduate research. NCED also supported five undergraduate/graduate students from the GA to attend and sponsored a GA dinner meeting. As part of the alignment of the planets which brings both the American Indian Science and Engineering Society and the Geophysical Society of America’s annual meetings to Minneapolis in Fall 2011, we have planned sessions and other activities that highlight this model and provide opportunities to showcase our undergraduate interns at both meetings.

► **DV04: gidakiimanaaniwigamig (Our Earth Lodge) Native American Youth Science Immersion Program**

The NCED gidakiimanaaniwigamig (Our Earth Lodge) program offers Native American youths a science immersion experience. This program provides ongoing opportunities for K-12 students from the Fond du Lac reservation and other nearby Native American communities to explore and gain knowledge about the Earth sciences. More than 350 students have participated in NCED GIDA camps and related activities, with 65% attending more than one activity.

Year 8 saw the launch, and Year 9 the development of a new five-year collaboration between NCED, FDLTCC, and the LacCore National Lacustrine Core Repository (LacCore) headquartered in the Geology Department, University of Minnesota (UMN). The project, manoomin—Investigation of Past, Present, and Future Conditions of Wild Rice on the Fond du Lac Reservation, brings Figure 3. Students at gida camp are learning about the effects of global warming on local forests with visiting faculty member Sarah Hobbie, who talked about her B4Warmed project.
Together K-12 and undergraduate students, FDL reservation natural resource managers, and UMN and FDLTCC faculty to research wild rice—a cultural and economic treasure for the Ojibwe. We have received a $1.5M NSF OEDG award for this project, which ensures that NCED’s collaboration with the FDL community will live beyond NCED funding with full capacity for our K-12 and undergraduate work. In Year 9, our Lake Teams cored three wild rice lakes in January, February, and March, and brought their cores first to camp and then to the LacCore facilities, where they did extensive analysis on the cores. The Lake Teams will return to LacCore this summer for more in-depth research. Student and teachers in the program have been wildly enthusiastic about their work. Three of our teachers arranged coring expeditions with their classes in addition to our regular GIDA activities. In addition, we are working collaboratively with the FDL reservation to place undergraduate students from the manoomin Project and from the REU SLAWR on teams that will be mentored by FDL reservation natural resources managers. Although a primary focus of this research will be the wild rice cores, supplementary research in all areas of resource management will be considered for additional research projects. manoomin has had the side benefit of creating a highly-effective working relationship between FDL reservation natural resources division managers and UMN researchers, which is serving to enhance the reputation of the University in the community and validate students’ interest in pursuing STEM degrees.
A highlight of our work with *manoomin* and with SKC, sponsored by a supplement to the *manoomin* award, was a workshop on Place-Based Education and the 7 Elements of STEM Learning, which first brought SKC faculty and students, and local Pueblo, Montana teachers and students to Minnesota in March 2010 to learn about our wild rice research, experience a coring at first hand at our March camp, tour the St. Anthony Falls Laboratory, and learn about GIDA’s Circle of Learning and the 7 Elements of STEM Learning developed at NCED. This was followed, in July 2010, by a visit of five *manoomin* teachers and seven students, as well as *manoomin* PI’s Emi Ito and Diana Dalbotten, to SKC in Montana, where we were hosted in teepee’s. We toured SKC, visited Glacier National Park, and with the same group of Montana teachers, students, and tribal college faculty and students had the 2nd part of our workshop on Place-Based STEM Education. In Glacier we visited a lake coring expedition, led by Amy Myrbo, Laboratory Director of LacCore. We also had a mountain-side GLOBE training, conducted by University of Montana faculty member Dr. Georgia Cobbs. The institutional and personal relationships developed as a result of this NSF supplement have the potential to continue impacting our students a decade and more from now by the positive influence these learning experiences have had on the students, teachers, and researchers.

GIDA students’ building enthusiasm for STEM topics can be seen from their enthusiastic participation in the NCED/ FDLTCC-sponsored American Indian Regional Science Fair, which had over 300 middle- and high-school student exhibitors in its first five years. Between 2005-2010, NCED collaborated with FDLTCC and the Ojibwe School to send 82 students from this group to the AISES National American Indian Science and Engineering Fair (NAISEF). The six students who attended this year presented 5 projects (one was a team projects), and brought home 15 awards, including first place awards in 4 of the 5 subject categories, and one 2nd place, and 9 special awards including the American Meteorological Society Outstanding Achievement Award (Courtney Jackson), American Chemical Society Outstanding Chemistry Project Award (Cassandra Roy), Excellence in Materials Engineering Award (Alec and Preston), Corwin Arthur Ost Memorial Award (Courtney Jackson), NOAA Taking the Pulse of the Planet Award (Emily Roy), Tribal Connections Award (Cassandra Roy), Pay Lucero Memorial Award (Courtney Jackson), US Navy Stem Award (Courtney Jackson), and the Office of Naval Research Award (Cassandra Roy). Best of all, four of our high-school students were chosen as Grand Award winners and will be among the eight who will represent AISES at the Intel International Science and Engineering Fair (ISEF). Courtney Jackson, last year’s NCED High-School Student Special Achievement Award winner, became famous this year when the AISES national leadership sponsored her to attend the White House Science Fair and meet President Obama (see her interview in the Media section). She is a graduating senior this year and will attend Peen State University on a full-ride scholarship.

In order to continue support of these students, and other Native American undergraduates in the state, collaborative efforts with the Minnesota Northstar STEM Alliance and the CCEFP have led to the formation of several *giwe’d-an’ang* (North Star) AISES Alliance chapters in Minnesota, including UMN (Twin Cities, Morris, and Duluth), FDLTCC, Bemidji State University, and St. Cloud State University (fledgling chapter). AISES is a national organization whose goal is to increase participation of Native American college students in science, technology, engineering, and math (STEM) fields. Through our partnership...
with the Minnesota Northstar STEM Alliance and CCEFP, NCED is coordinating, sponsoring, and hosting all activities of giiewdanang. Goals of the Alliance include: 1) engaging students in STEM-related activities, 2) interesting students in pursuing their education at two-year and/or four-year schools and universities, 3) developing a Minnesota student cohort network, and 4) increasing the number of AISES chapters.

In order to obtain the above goals, giiewdanang has created a supportive network of AISES chapters in Minnesota, providing tools and resources to assist the students that participate in AISES. Specifically, the Alliance promotes educational opportunities and academic guidance; opens research doors; and bridges the gap between high school, pre- and post-secondary education, and industry employment in STEM fields. By networking with Minnesota corporations and educational institutions, this Alliance fosters fundraising capabilities and professional support, and in doing so will increase the number of AISES chapters in Minnesota for a larger representation of Native Americans in STEM fields and disciplines.

Our collaborative efforts seek to deliver direct support for all Native American students in STEM disciplines in Minnesota. This alliance aims to provide tools and resources to assist the students who participate in the state of Minnesota’s AISES chapters and to encourage their participation in the Northstar Alliance. Through the meetings we organize, we are also developing personal relationships with all of the students in giiewdanang and are encouraging them to participate in NCED research opportunities.

In Year 9, NCED helped to launch the AISES Northstar Professional Alliance, an alliance of professional Native American engineers and scientists. With the formation and sustainability of the AISES Northstar Professional Chapter, and the development of an AISES Alliance with Minnesota undergraduate and K-12 AISES chapters, Minnesota will have a permanent, ongoing AISES Alliance that incorporates K-12, undergraduate, graduate, and professional members who are all pledged to support one another, mentor new chapters, and lend support to a large and strong AISES community within Minnesota. The professional society plans to work directly with our giiewdanang undergraduates to mentor and support their undergraduate AISES chapters.

In Year 10, GIDA begins our new collaboration with the Reach for the Sky Program, the TRIBES program, and the STEM center (new NCED PI Gillian Roehrig is Director of the STEM Center). Along with Roehrig, Diversity Director Dalbotten and Education Director Campbell have successfully jointly proposed the CYCLES: Teaching Global Climate Change from a Native Perspective project to NASA, and received a three-year $680K NASA GCCE award to offer hands-on teacher professional development workshops beginning in summer 2011. NCED PI’s, including NCED’s Director Efi Foufoula-Georgiou, Geology Professor Emi Ito (manoomin PI), and affiliate-PI Anne Lightbody, will be science advisors for the project.

**Progress towards milestones/deliverables**

<table>
<thead>
<tr>
<th>Milestone/Deliverable</th>
<th>Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forty students per year participate in GIDA programs in Years 6-10.</td>
<td>220 students have participated in the GIDA program.</td>
</tr>
<tr>
<td>Majority of participants attend college, with a substantial portion majoring in science, math, engineering, or technology.</td>
<td>There were 2 graduating seniors in Year 9 with one planning on attending FDLTCC and the other attending Penn State. 9 other GIDA students are continuing as college students, two are Master’s candidates and one has just been accepted into a graduate program.</td>
</tr>
</tbody>
</table>

**Plans**

By the end of Year 10, NCED expects to have created a permanent network of support for Minnesota Native American STEM education that spans from K-12 to undergraduate and graduate programs. Our GIDA camps, which we strive to institutionalize through new partnerships within and outside UMN, will recruit new young students each year as other students graduate and attend college. The giiewdanang North Star AISES Alliance is set to provide support to undergraduate students and to encourage them to pursue graduate careers. By forming the GA, a national working group on increasing Native American participation in the geosciences, we have moved these efforts to the national arena, instituting new research on best practices and creating new collaborations. The AISES North Star Professional Alliance furthers this network by providing corporate support, mentoring, and career opportunities for our K-12 and undergraduate participants. The network of tribal college alliances we will develop through our new partnership with SKC will support movement of tribal college students into graduate programs and geoscience careers.
Diversity

National Center for Earth-surface Dynamics
Annual Report 2011

► DV05: EarthScapes in the Science Museum of Minnesota’s Youth Science Center

Information about the Youth Science Center is reported in the Education section.

Progress toward milestones/deliverables

<table>
<thead>
<tr>
<th>Milestone/Deliverable</th>
<th>Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substantial participation by minority students in YSC park crew and other activities</td>
<td>13 students participated: 6 males and 7 females with 10 students from underrepresented groups</td>
</tr>
<tr>
<td>Number of youth from community groups taught and demographics.</td>
<td>~450 youth taught by YSC park crew, ~250 from underrepresented groups</td>
</tr>
<tr>
<td>Number of activities conducted outside SMM by YSC program/hours</td>
<td>5 activities / 46 program hours per Park Crew youth</td>
</tr>
<tr>
<td>Number of educational outreach activities conducted outside SMM by YSC program/hours</td>
<td>28 activities / 52 program hours</td>
</tr>
</tbody>
</table>

Table 1. Evaluation and Performance Indicators

<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NCED Community</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Increasing the number of undergraduates</td>
<td>Number of undergraduate students from underrepresented groups doing research at SAFL in Year 9.</td>
<td>14</td>
</tr>
<tr>
<td>participating in summer research in collaboration with NCED.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Increasing the representation of under-</td>
<td><strong>NCED Researchers</strong></td>
<td></td>
</tr>
<tr>
<td>represented groups within NCED</td>
<td>Percent of underrepresented researchers in current year</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>Percent of underrepresented researchers in previous year</td>
<td>17%</td>
</tr>
<tr>
<td><strong>NCED Participants and Affiliates</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent of underrepresented participants/affiliates in current year</td>
<td>Participant: 27% Affiliate: 10%</td>
<td></td>
</tr>
<tr>
<td>Percent of underrepresented participants/affiliates in previous year</td>
<td>Participant: 26% Affiliate: 9%</td>
<td></td>
</tr>
<tr>
<td>3. Enhancing educational and career outcomes for NCED participants from underrepresented groups</td>
<td>List of outcomes</td>
<td>See Table 2 below</td>
</tr>
</tbody>
</table>

**Native American Students**

<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Number of Native students participating in NCED programs, camps, science fairs, field trips, and other activities</td>
<td>Number of Students</td>
<td>397</td>
</tr>
</tbody>
</table>
### MEASUREMENT

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of repeat contacts</strong></td>
<td></td>
</tr>
<tr>
<td>1 camp</td>
<td>32</td>
</tr>
<tr>
<td>2 camps</td>
<td>45</td>
</tr>
<tr>
<td>3 camps</td>
<td>42</td>
</tr>
<tr>
<td>4 camps</td>
<td>25</td>
</tr>
<tr>
<td>5+ camps</td>
<td>76</td>
</tr>
</tbody>
</table>

### Youth Science Center

1. **Number of kids enrolled/demographics**
   - Number of students | 11 |
   - Female | 5 |
   - Male | 6 |
   - % from underrepresented groups | 72% |

2. **Number of visitor kids/demographics**
   - Number of visitors | 450 |
   - Number from underrepresented groups | 250 |

3. **Number of activities conducted outside SMM by YSC programs/hours**
   - Number of activities | 32 |
   - Number of program hours | 87 |
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VII. Management

Management team

**Director:** Efi Foufoula-Georgiou  
**Administrative Director:** Mary Kosowski  
**Staff:** William Dalbotten (administrative specialist), Sara Johnson (Visitor Program manager), Charles Nguyen (information technology professional), Debra Pierzina (events coordinator), and Andrew Zenk (application programmer)

**Goal:** The overall responsibilities of NCED management are to articulate the Center’s vision, to keep the Center moving towards it, and to maximize the Center’s added value by ensuring that the whole is greater than the sum of its parts. NCED management does this by: working with Center participants to formulate compelling, well-focused initiatives; facilitating communication about the Center’s goals, initiatives, and expectations among Center participants; and promoting synthesis and synergy across Center initiatives. In Year 9, concerted effort has been focused on deliverables, engaging the broader Earth-surface dynamics community, and ensuring sustainability of key NCED activities beyond Year 10.

**Approach:** NCED is neither a “top down” nor a “bottom up” organization but rather one that encourages shared goals and rapid, clear communication throughout its network of participants. NCED seeks an optimal balance between consensus and efficiency as well as between creative adaptation to changing circumstances and organizational stability. NCED’s management is driven by the goals expressed in our statement of purpose and developed in our Strategic and Implementation Plan (SIP). NCED uses an array of metrics to measure progress towards these goals; metrics for management are shown at the end of this section and at the end of the appropriate report section for each of NCED’s initiatives.

**Accomplishments and plans**

**Changes in Principal Investigators and NCED management**

**New personnel**

**Karen Gran (University of Minnesota): PI**
Karen Gran has been collaborating with NCED PIs over the past five years and has expertise on river morphodynamics and sediment transport modeling, and has been instrumental to the success of the Minnesota River Basin research as part of the SR Integrated Project. She was invited to submit a proposal and the Executive Committee invited her to become an NCED PI in 2010. She co-advises several NCED students at the University of Minnesota with other NCED PIs.

**Change of status**

**David Olsen - resigned as Administrative Director**
David Olsen started with NCED in 2004 and was involved in almost every aspect of the Center, including accounting, designing publications, leading the annual report effort and organizing the annual site visits. In 2010 he stepped down as NCED Administrative Director (a position he was promoted to in 2009 following the retirement of Rochelle Storfer). He is currently working at SAFL with a partial appointment with NCED.

**Mary Kosowski - NCED Accountant and Administrative Director**
Following the resignation of David Olsen, an open search for a senior accountant was announced and Mary Kosowski was hired in March 2011 based on her previous experience and accomplishments at the University of Minnesota. Mary has been fulfilling all NCED’s accounting needs since March 2010 and covers also some of the administrative needs for the Center. The annual report completion and site visit preparation has been distributed among other NCED staff.
William Dalbotten - promoted to Administrative Specialist

William Dalbotten has been with NCED since 2009 and was promoted to Administrative Specialist in 2010. In this position he is involved in various aspects of the Center, including designing publications, overseeing the annual reporting effort, helping to maintain the NCED web site, and providing general and technical support for the NCED staff.

NCED Affiliate Scientists

NCED initiated in 2010 the “Affiliate Scientist” program to foster collaboration between NCED and the broader Earth Sciences community, with emphasis on mentoring young researchers. Current affiliate members include: Patrick Belmont (Assistant Professor, Utah State University); Nicole Gasparini (Assistant Professor, Tulane University); Leslie Hopkinson (Assistant Professor, West Virginia University); Doug Jerolmack (Assistant Professor, University of Pennsylvania); Wonsuck Kim (Assistant Professor, University of Texas, Austin); Laurel Larsen (USGS, Menlo Park); Anne Lightbody (Assistant Professor, University of New Hampshire); Paola Passalacqua (Assistant Professor, University of Texas, Austin); Kyle Straub (Assistant Professor, Tulane University); Paul Venturelli (Assistant Professor, University of Minnesota); and Jane Willenbring (Assistant Professor, University of Pennsylvania).

Partner institutions

During 2009-2010 we added two new member institutions to NCED: Salish Kootenai College (SKC), and the Desert Research Institute of the University of Nevada, Reno. The list of participating institutions now stands as follows: University of Minnesota (lead institution), Desert Research Institute (DRI), Fond du Lac Tribal and Community College (FDLTCC), The Johns Hopkins University (JHU), Louisiana State University (LSU), Salish Kootenai College (SKC), Science Museum of Minnesota (SMM), Southern Illinois University Carbondale (SIU), University of California at Berkeley (UCB), University of Illinois- Urbana Champaign (UIUC), and University of Texas at Austin (UTA).

Management and communication systems

A center-mode of research is built upon the interaction among principal investigators, staff, postdoctoral research associates, external stakeholders, and students. To achieve this level of integration, NCED leadership relies heavily on the following administrative bodies and communication methods:

External Advisory Board

The External Advisory Board (EAB) is comprised of a distinguished group of scientists, educational experts, and members of the public and private sectors. The role of the EAB is to offer an independent assessment of the Center’s progress through a thoughtful, but rigorous, annual review of our goals and achievements. In 2010, two new members were added to the EAB: Jacquelyn Bolman, Director, Indian Natural Resources, Sciences and Engineering Program (INRSEP), Humboldt State University, Arcata, CA; and Frank Nutter, President of the Reinsurance Corporation of America. Appendix C: External Advisory Board contains a list of all current members, and the report from the EAB meeting held in Minneapolis, Minnesota, February 17-18, 2011. The Director’s response to the EAB’s comments can also be found in this appendix.

Executive Committee

The EC is charged with ongoing review of Center performance, including progress on research projects and with individual PIs, and also with assisting the Director in formulating policy, allocating funds, selecting Center research personnel, and evaluating NCED management performance. NCED’s EC is comprised of the following members: Efi Foufoula-Georgiou (director), Bill Dietrich (lead PI for Desktop Watersheds), Peter Wilcock (lead PI for Stream Restoration), David Mohrig (lead PI for Subsurface Architecture), Chris Paola (member at large and NCED PI), Mary Power (member at large and NCED PI), Vaughan Voller (member at large and NCED PI), Karen Campbell (education director), Diana Dalbotten (diversity director), and Mary Kosowski (administrative director).
**Partner groups**

Partner groups act not only as a mechanism to encourage two-way collaboration between NCED and the community-at-large, but they also act as a conduit for keeping research informed and societally relevant. The recommendations from NCED partners are critical to our success and strongly influence NCED policy and direction. Each group, along with the KT manager and Integrated Program (IP) leaders, communicate informally throughout the year. Once a critical mass of material is developed, a meeting of all partners within an IP is convened to disseminate research findings and evaluate research direction.

**Graduate Student Council**

The Graduate Student Council (GSC) is a self-organized body of NCED graduate students that fosters unity among graduate students throughout all of NCED’s participating institutions, represents student interests in NCED meetings, and communicates relevant information on NCED issues back to the students. In addition to acting as a liaison to NCED leadership, the GSC also organizes a number of events throughout the year for students and is provided funds in the form of travel/research grants.

**Science Team Meetings**

NCED conducted two Center-wide science team meetings over the reporting period. The first meeting was held in June 2010 and capitalized on the availability of PIs, postdoctoral research associates, and staff who were in Minneapolis for NCED’s Year 8 site visit. NCED graduate students took this opportunity to network, share experiences, and discuss research interests with one another, PIs, and the site visit panel.

The second meeting, held in January 2011, was hosted in Burnet, Texas by PI David Mohrig and included participation by the majority of PIs, staff, and postdoctoral research associates. In addition, numerous members from agencies and industry, as well as students, were invited to participate. Significantly larger in scope than the June retreat, the goal of the NCED PI meeting was not only to facilitate research collaboration among NCED PIs, but also to critically assess how the Center is progressing in packaging and distributing NCED deliverables, as well as planning for sustainability.

**Annual reporting**

NCED views our annual reporting process as an opportunity to take stock of how progress is made in achieving the goals of each IP as articulated in the SIP. In February of each year, PIs are asked to generate 8-10 page progress reports detailing the developments of their research program, their efforts in collaborating with other NCED PIs, as well as how she contributed to NCED’s education, knowledge transfer, and diversity initiatives. In addition, each PI is asked to fill out a metrics questionnaire that details the outputs produced during the current year, which in turn provides the basis for tracking the Center’s progress towards our goals.

**Weekly cyberseminars**

NCED holds weekly cyberseminars throughout the year featuring topics of interest to PIs and students. While the purpose of the cyberseminars is primarily to disseminate results from research (both within and external to the Center), the videoconference also provides an open environment in which to debate and discuss the research in the context of NCED’s IP structure. Invited speakers include researchers from the broader scientific community as well as partners from industry, federal agencies, and other institutions with which NCED seeks to foster a collaboration (e.g., CSDMS).

**Allocation of center resources**

In Year 7, each PI was requested to submit a proposal, in addition to their annual report, on research to be performed through Year 10, including contribution to education, knowledge transfer, and diversity efforts of NCED. The proposals were thoroughly reviewed by the Executive Committee using the following criteria: (1) the extent to which the proposed research serves the goals of one or more IPs; (2) the extent to which the research capitalizes on the center mode, i.e., including collaboration among PIs, across institutions, and across disciplines; and (3) the extent to which the proposed research broadens NCED’s educational, knowledge transfer, and diversity activities.

Based on the above criteria, recommendations were made by Executive Committee members on the individual PI proposals, including possible adjustments to the requested resources and realignment of research to better meet the IP goals. Recommendations were discussed and approved by the Director and final decisions and written comments were provided for each proposal, mainly focusing on: topics to emphasize or de-emphasize to meet the IP goals; synergies that could be further strengthened; and additional activities that the EC thought promising for that PI to undertake over the next three years.
In Years 8 and 9, priority for allocation of resources was given to accelerating progress on deliverables: a new synthesis post-doc was funded for SR towards development of the SR manual; a synthesis post-doc was funded in DW towards accelerating the completion of the light model needed in Ripple, and a synthesis post-doc was funded in SA towards work on the delta and the sediment budget of the MRB. For the next year, a synthesis post-doc has been committed towards accelerating the integration of the numerical modeling work of OSL and the collected measurements that can be used for model verification.

**Strategic and Implementation Plan**

The current version of our SIP is available as Appendix E: Strategic and Implementation Plan. No major revisions to the SIP have occurred over the past year.

**Legacy and sustainability**

As NCED approaches its sunset as a National Science Foundation (NSF) Science and Technology Center (STC), one of our priorities has been to develop a concrete plan for transitioning NCED to a new mode of operation. That mode is envisioned to include the continuation of a substantial part of the cross-disciplinary, collaborative research among PIs, the coadvising of graduate students and postdoctoral research associates, the continuation of some key elements of our education (ED) and diversity (DV) initiatives, and a sustainable knowledge transfer (KT) component related to stream and delta restoration.

**Managing Center legacy and sustainability**

Over the past year, an informal transition team (led by Foufoula-Georgiou and comprising members of the EC) has made significant progress towards framing our legacy both as a whole and within each of NCED’s six primary Integrative Programs (IPs).

**Legacy**

NCED’s major achievements have been grouped into nine categories that define our *legacy products*:

- **Intensive field research sites (from uplands to deltas):** NCED has invested in three major field observatories that span a broad range of natural environments: Angelo Coast Range Reserve (ACRR), Minnesota River Basin (MRB), and Wax Lake Delta (WLD). These environments encompass the natural range of erosional and depositional processes driving source to sink landscape evolution in North America. As investments, these field observatories have produced major new discoveries and have laid the foundation for future work, not only by NCED investigators, but also by the broader Earth Sciences community.

- **Advanced experimental facilities:** NCED has invested in developing unique expertise in designing state-of-the-art experimental facilities for environmental research. Major accomplishments include the EarthScapes facility at SMM, the rotating drum facility at Richmond Field Station (University of California, Berkeley), and the first meso-scale, integrated Earth observatory, the Outdoor StreamLab (OSL), which provides a unique environment for laboratory-quality monitoring in a natural scale and setting.

- **Synthesis and synergies across engineering, ecology, Earth Science, and social science:** NCED has pioneered a unique synergy across disciplines (hydrology, ecology, geomorphology, social sciences, and engineering), a true coming-together of methodologies (mechanistic approaches; advanced mathematical and computational methods; seamless synergy between experiments, theory, and fieldwork). NCED continually strives to transfer these developments into practice.

- **Minimal to full complexity predictive models:** NCED has pioneered modeling concepts that serve as pillars for advancing scientific hypotheses on cause and effect, guiding collection of new observations, and providing a framework for decision making. These models are made available to the community via NCED and via CSDMS.

- **Discoveries about Earth-surface dynamics:** NCED’s integrated approach to Earth-surface dynamics has resulted in a paradigm shift of how problems in Earth-surface sciences are approached. NCED’s approach is based on 1) a predictive understanding of coupled processes operating at multiple scales, 2) prediction of ecosystem functioning.
and other resource attributes using high resolution topography, 3) development of geomorphic transport laws that can incorporate extremes and multi-scale variability, 4) upscaling methodologies, and 5) eco-hydro-geomorphologic theories and models in erosional and depositional environments.

**Predictive landscape restoration practice:** NCED has developed the scientific basis and modeling tools to transform the practice of stream and delta restoration and basin management decisions for ecosystem services.

**The next generation of researchers:** NCED topics, approaches, and spirit of collaborative interdisciplinary research have trained a new generation of young researchers on how to approach problems in Earth-surface dynamics. Some of these researchers are now training their own students following a similar style.

**Broadening participation of underrepresented groups in the Earth sciences:** NCED has demonstrated the success of the “Circle of Learning” concept for attracting and retaining Native American youth into Earth Sciences.

**Academia-museum partnerships for communicating Earth-surface process science:** NCED has pioneered the development of major partnerships between academia and science museums and has demonstrated the success of using this mechanism for educating K-12 students, the general public, school teachers, and policy makers.

**Sustainability**
Over the last two years, NCED has begun to establish partnerships aimed at enhancing the viability of the Center after its NSF-funded life. To establish the contextual framework for this effort, we have structured our sustainability plans around five categories:

**Collaborative research funding:** Concerted efforts have been made in developing and submitting collaborative research proposals for competitive funding of the PIs’ research activities. NCED is also pursuing partnerships with applied research firms and other government institutions and plans to develop formal memorandum of understanding (MOUs). These MOUs will not only continue the goal of transforming practice through research, but they will also create revenue for research, especially in stream and coastal restoration activities.

**Developing infrastructure:** NCED’s investment in research infrastructure has provided our facilities a competitive edge when it comes to seeking future funding. A big legacy of NCED, which will ensure its infrastructure sustainability, is the success of our proposal submitted to NSF, under the ARI-R2 ARRA solicitation for Improving Academic Research Infrastructure. This grant will bring the NCED/SAFL facilities to the next higher level of sophistication and will open them up to the broader community as it will secure a remote-access component of viewing and manipulating experiments off-site. A proposal for a Wax Lake Observatory is currently under review, and if successful, will leverage and increase NCED’s investment in developing the first observatory in a deltaic environment to support basic research, development of models and testing restoration scenarios. A proposal is also under review for the Minnesota River Basin (MRB) field site, which has been experiencing unprecedented hydrologic, ecologic and sediment transport changes over the past decade.

**Creating institutional buy-in:** NCED PIs continue to pursue institutional buy-in and to position themselves individually, and as groups, as key players/contributors in the strategic initiatives of their own universities. The University of Minnesota has embraced the environment as one of their strategic initiatives and has invested in establishing the Institute on the Environment (IonE) to serve as an umbrella organization for coordinating research, education, and outreach across departments and colleges involved in environmental research. NCED PIs are actively participating in IonE’s efforts and some concrete partnerships have already been established through: 1) an IonE Discovery Grant awarded to NCED’s partner institution SMM (led by NCED PI Patrick Hamilton) to develop and distribute Science on a Sphere® content to international audiences and 2) the selection of two NCED PIs, Hamilton and Foufoula-Georgiou, as members of the first cohort of 20 IonE resident fellows. Also the VP for Research at the University of Minnesota has committed bridge funding to NCED ($110K/year for the period of 2012-2015) and efforts are underway to secure more funds from other entities within the U of M and from the other Institutions. The new partnership of NCED with the STEM Center at the University of Minnesota establishes synergies which are expected to flourish over the next few years contributing to the sustainability of our education and diversity efforts.
Institutionalizing education, outreach, and knowledge transfer programs: A major NCED-led graduate education initiative has been the establishment of a stream restoration certification program. It is envisioned that UMN will be able to continue this program beyond 2012 by providing the resources (two teaching assistants and partial support for a faculty coordinator) that NCED is now annually investing in this program.

Under NCED’s leadership, the Partnership for River Restoration and Science in the Upper Midwest (PRRSUM) group has been formed; this group is composed of industry, agency and academic partners. PRRSUM has already demonstrated its region-wide impact on the practice of river restoration and technology exchange. We anticipate that this group will become self-supported through membership fees or industry donations.

The newly-established NCED Summer Institute on Earth-surface Processes (SIESP) was a great success in its first and second offerings in the summers of 2009 and 2010. It is envisioned to become a national and international forum for young researchers to engage in interdisciplinary research, with emphasis on the integration of theory, physical experiments, fieldwork, and numerical modeling. Funding for SIESP will be supported by NCED for the next year, and we anticipate that the program will be self-sustained in subsequent years by funding that will result from submitting proposals to NSF and other agencies.

Fostering diversity: NCED’s diversity program has been a catalyst in uniting other STCs, academic institutions, and NGOs with the underrepresented populations, particularly the Native American community. NCED will continue to explore opportunities for external funding and for marketing our diversity programs to UMN’s central administration by aligning them with the UMN-wide initiatives in broadening participation of minorities in science and engineering.

Deliverables (and Legacy products)

NCED is continuously packaging its research and models into products that can be used by researchers and practitioners in the broader community to further advance the science and practice of restoring the Earth’s surface environment based on integrative predictive modeling. NCED’s deliverables include:

4. GeoNet – feature extraction from high resolution topography -- released in 2010 with updates in 2011. GeoNet is part of the NCED-Google collaboration and it will be implemented in 2011-2012 within Google’s Earth Engine (EE) API (Advanced Programming Interface) environment.
7. Shalstab – this will become part of NCED’s collaboration with Google.org and will be implemented in 2011-2012 within Google’s EE-API environment.
8. 3D model for determination of shallow landslide size – to be released in 2011.
9. Stream morphodynamics and Hydraulic Geometry toolboxes – released and posted on web 2009 and also disseminated via CSDMS.

Priority over the next year will be placed into accelerating the development of these tools and in marketing them to the community by presenting them at meetings, creating training opportunities including the NCED Summer Institute, partnership meetings (PRRSUM), etc. and advertising on the NCED web site.
### Metrics

<table>
<thead>
<tr>
<th>Target</th>
<th>Metric</th>
<th>Done by</th>
<th>Frequency</th>
<th>Current status</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI evaluation</td>
<td>Standard measures (publications etc) + collaboration + contributions to ED, DV, KT</td>
<td>Directors, EC</td>
<td>Annually</td>
<td>Progress reports have been reviewed by IP leaders and feedback is given to PIs.</td>
</tr>
<tr>
<td>Project progress</td>
<td>Progress relative to deliverables; see SIP tables</td>
<td>Directors, EC</td>
<td>Semi-annually or as needed</td>
<td>Reported in individual IP sections.</td>
</tr>
<tr>
<td>Research integration</td>
<td>Collaboration + research synthesis + cross-IP synthesis + coadvised students, postdoctoral research associates</td>
<td>Directors</td>
<td>Semi-annually or as needed</td>
<td>Reported in individual IP sections.</td>
</tr>
<tr>
<td>Research – KT integration</td>
<td>Development of research applications + adoption by partners</td>
<td>Directors, EC, IP managers</td>
<td>Annually or as needed</td>
<td>Reported in KT section.</td>
</tr>
<tr>
<td>Research – ED integration</td>
<td>Use of research results and tools in Education</td>
<td>Directors, EC</td>
<td>Annually or as needed</td>
<td>Reported in ED section.</td>
</tr>
<tr>
<td>Research – DV integration</td>
<td>Diversity of participants in research programs</td>
<td>Directors, EC</td>
<td>Annually or as needed</td>
<td>Reported in DV section.</td>
</tr>
<tr>
<td>ED – DV integration</td>
<td>Diversity of participants in education programs</td>
<td>Directors, EC</td>
<td>Annually or as needed</td>
<td>Reported in DV and ED sections.</td>
</tr>
<tr>
<td>Center-wide communication</td>
<td>Participation in centerwide activities: videoconferences, retreats, field sites, joint experiments</td>
<td>Admin staff, Directors</td>
<td>Weekly or per-event</td>
<td>Retreats, seminars, and cyberseminars well-attended. Graduate student council revitalized.</td>
</tr>
<tr>
<td>Center visibility</td>
<td>Participation in: short courses, working groups, Visitor Program, special sessions. Total number of outside professionals supported by NCED programs</td>
<td>Admin staff, Directors</td>
<td>Ongoing</td>
<td>While the PI’s efforts to increase visibility are excellent, NCED as an organization, will continue focusing efforts on improving our public face and increasing the number of working groups, short courses, and opportunities to interact with the public. Also in 2010, NCED initiated a new series, “Sip of Science,” which brings NCED-relevant science to the public. In 2010, NCED’s presence on facebook and twitter helped to promote NCED research and public events, and became a crucial link to NCED friends and alumni. The production of short movies showcasing NCED’s research on highly pressing problems, such as the Mississippi Delta restoration, is also a priority for the coming year.</td>
</tr>
<tr>
<td>Target</td>
<td>Metric</td>
<td>Done by</td>
<td>Frequency</td>
<td>Current status</td>
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<td>---------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>International presence</td>
<td>Number and intensity of international collaborations</td>
<td>Directors, PIs</td>
<td>Ongoing</td>
<td>NCED PIs have active collaborations with scientists throughout the world, have given lectures in several summer institutes, and have coadvised undergraduate and graduate students. New efforts are under way in 2011 for new formal international collaborations.</td>
</tr>
<tr>
<td>External buy-in to center activities</td>
<td>Leveraged funding by NCED PIs</td>
<td>Directors, PIs</td>
<td>Annually</td>
<td>Total for Year 9: $7,497,847</td>
</tr>
<tr>
<td>Research community building</td>
<td>Community buy-in to transdisciplinary surface process science</td>
<td>Directors, EC, PIs</td>
<td>Ongoing</td>
<td>NCED PIs are leading community-wide efforts in related disciplines (CUAHSI, CSDMS, etc.) and have initiated collaborative efforts with non-NCED researchers.</td>
</tr>
<tr>
<td>Financial management: review of headquarter (HQ) and subaward accounts</td>
<td>Relevant federal audit standards; rapid, effective communication between HQ and other NCED institutions</td>
<td>Administrative Director, staff</td>
<td>Monthly</td>
<td>New subawardee audit completed with cooperation from all sub-awardee institutions and without complications.</td>
</tr>
<tr>
<td>Financial management: review of overall Center spending and allocation</td>
<td>Resources used in a timely and effective manner; deployed appropriately relative to project goals and progress</td>
<td>Directors, staff</td>
<td>Quarterly</td>
<td>Monitoring expenditures for allocability, allowability, accountability, and reasonableness is accomplished within an acceptable timeframe.</td>
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<tr>
<td>Staff evaluation and mentoring</td>
<td>Provide written objectives and performance evaluation for all staff employees</td>
<td>Administrative Director, Directors</td>
<td>Annually</td>
<td>Staff are evaluated annually. Good communication and unofficial mentoring of staff happen via the directors' 'open door' policy and weekly staff meetings.</td>
</tr>
<tr>
<td>EAB communications</td>
<td>Impact of EAB report and comments on NCED activities</td>
<td>Directors, EC, EAB</td>
<td>Annually</td>
<td>The EAB offers advice through our annual EAB meeting and report, and on an informal basis. Their input is an integral part of NCED planning. The EAB sends a representative, generally the chair of the EAB, to NCED PI retreats and site visits.</td>
</tr>
<tr>
<td>Website effectiveness</td>
<td>Content contribution by NCED participants; website use (hits)</td>
<td>Directors, staff</td>
<td>Ongoing</td>
<td>NCED revamped the look of its website and the new version was released in May 2009. We have seen a substantial increase in web site hits over the past year.</td>
</tr>
</tbody>
</table>
VIII. Center-wide Outputs

Center Publications

This list includes all NCED research publications that explicitly acknowledge NCED support either published in the current reporting year or in previous years, are in the various stages of prepublication, or were omitted from previous annual reports. They are divided into: 1) journal articles, 2) books, 3) book sections, 4) textbooks, and 5) proceedings of major conferences.

Journal Articles

In Press:


In Review:


Singh, A., S. Lanzoni, P.R. Wilcock and E. Foufoula-Georgiou (In review), Multi-scale statistical characterization of migrating dunes in sand-bed rivers, *Water Resources Research*.

Smith, S. M. C., P. Belmont, and P.R. Wilcock (In review), Closing the gap between watershed modeling, sediment budgeting, and stream restoration, *Geophysical Monograph, American Geophysical Union*.


Tsui, M.T.K. and J.C. Finlay (In review), Influences of land cover on methylmercury concentrations in water and invertebrates in Minnesota stream ecosystems, *Environmental Science and Technology*.


**2011:**


2010:


doi:10.1029/2008JF001222,


150 Center-wide Outputs


**2009:**


O’Connor, B.L., M. Hondzo and J.W. Harvey (2009), Incorporating both physical and kinetic limitations in quantifying dissolved oxygen flux to aquatic sediments, *Journal of Environmental Engineering*, 12, 1304-1314.


Tsui, M.T.-K., J.C. Finlay and E.A. Nater (2009), Spatial variation of mercury bioavailability in a river network, *Environmental Science & Technology*.


Wilcock, P. (2009), Identifying sediment sources in the Minnesota River Basin, Minnesota Pollution Control Agency.


2008:


O’Connor, B., and M. Hondzo (2008), Dissolved oxygen transfer to sediments by sweep and eject motions in aquatic environments, Limnology and Oceanography, 53, 566-578.


2007:


2006:


**2005:**


**2004:**


**2003:**


**BOOK SECTIONS**

**2011:**


**2009:**


**2008:**


**2007:**


**2005:**


**2004:**


2003:


**TEXTBOOKS**

2007:


**CONFERENCE PROCEEDINGS**

*In Press:*


2010:


2009:


2008:


2006:


## Awards & Honors

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<tr>
<th>Recipient</th>
<th>Award Name and Sponsor</th>
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<tr>
<td>Dietrich, William</td>
<td>Arthur Holmes Medal (2011) European Geophysical Union</td>
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<tr>
<td>Dietrich, William</td>
<td>Advisory Board (ongoing) Biosphere 2</td>
</tr>
<tr>
<td>Dietrich, William</td>
<td>Board of Earth Sciences and Resources (ongoing) NRC</td>
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<tr>
<td>Dietrich, William</td>
<td>Senior Advisory Council (2008-2010 ) CUAHSI</td>
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<tr>
<td>Dietrich, William</td>
<td>Committee on Challenges and Opportunities in the Field of Hydrologic Sciences (2009-2011) NRC</td>
</tr>
<tr>
<td>Fan, Yi</td>
<td>Anderson Award, (2010) SAFL</td>
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<tr>
<td>Finlay, Jacques</td>
<td>McKnight Presidential Fellowship (2010)</td>
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<tr>
<td>Foufoula-Georgiou, Efi</td>
<td>Publications Committee Member, American Geophysical Union</td>
</tr>
<tr>
<td>Foufoula-Georgiou, Efi</td>
<td>Member, Argentinian Advisory Board to the Ministry of Water</td>
</tr>
<tr>
<td>Hood, James</td>
<td>EPA STAR Fellowship</td>
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<tr>
<td>Hobbs, Benjamin</td>
<td>Overseas Fellow, 2009-2010 Academic Year</td>
</tr>
<tr>
<td>Hondzo, Miki</td>
<td>Associate Editor, Limnology and Oceanography: Fluids and Environments American Society of Limnology and Oceanography</td>
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<tr>
<td>Hondzo, Miki</td>
<td>Invited keynote speaker, EUROMECH Colloquium 523 (2011)</td>
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<tr>
<td>Jacobi, Sarah</td>
<td>2009 Smith Conservation Research Fellowships (2010-2012)</td>
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<tr>
<td>Kenney, Melissa</td>
<td>AAAS Science and Technology Fellowship (2010-2011)</td>
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<tr>
<td>Parker, Gary</td>
<td>Lifetime Research Award, Community Surface Dynamics Modeling System CSDMS</td>
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<tr>
<td>Passalacqua, Paola</td>
<td>Associate Editor of HESS</td>
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<tr>
<td>Power, Mary</td>
<td>Ecological Society of America: Past President, (2010-2011)</td>
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<tr>
<td>Singh, Arvind</td>
<td>Doctoral Dissertation Fellowship</td>
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<tr>
<td>Twilley, Robert</td>
<td>Associate Editor of HESS Coastal and Estuarine Research Federation</td>
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<tr>
<td>Twilley, Robert</td>
<td>Board Member, Coalition to Restore Coastal Louisiana</td>
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<tr>
<td>Twilley, Robert</td>
<td>Committee Member – Biennial Review of Everglades Restoration Program, National Academy of Science</td>
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<tr>
<td>Twilley, Robert</td>
<td>Gulf Oil Spill Advisory Group, National Wildlife Federation</td>
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<tr>
<td>Twilley, Robert</td>
<td>Executive Board Member, LUMCON</td>
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<tr>
<td>Twilley, Robert</td>
<td>Chair, Horizon Science and Engineering Review Team, Office of Coastal Protection and Restoration</td>
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<tr>
<td>Yohannes, Bereket</td>
<td>Silberman Fellowship, SAFL</td>
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### Graduated Students

<table>
<thead>
<tr>
<th>Student Name</th>
<th>Degree and Year</th>
<th>Advisor</th>
<th>Placement</th>
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<tbody>
<tr>
<td>Gangodagamage, Chandana</td>
<td>PhD 2010</td>
<td>Foufoula</td>
<td>Researcher, Lawrence Livermore Labs</td>
</tr>
<tr>
<td>He, Laien</td>
<td>MS 2010</td>
<td>Wilkerson</td>
<td></td>
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<tr>
<td>Hood, James</td>
<td>PhD 2010</td>
<td>Finlay</td>
<td>Post-doc U Montana</td>
</tr>
<tr>
<td>Hsu, Leslie</td>
<td>PhD 2010</td>
<td>Dietrich</td>
<td>Post-doc Columbia University</td>
</tr>
<tr>
<td>Jacobi, Sarah</td>
<td>Ph.D. 2010</td>
<td>Finlay</td>
<td>Lincoln Park Zoo (Smith Conservation Fellow)</td>
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<tr>
<td>Kang, Seokoo</td>
<td>PhD 2010</td>
<td>Sotiropoulos</td>
<td>Post-doc, SAFL</td>
</tr>
<tr>
<td>Kenney, Melissa</td>
<td>MS 2010</td>
<td>Hobbs</td>
<td>Assistant Research Scientist, Johns Hopkins University</td>
</tr>
<tr>
<td>Leonardson, Rebecca</td>
<td>PhD 2011</td>
<td>Dietrich</td>
<td>Consultant</td>
</tr>
<tr>
<td>Nelson, Peter</td>
<td>PhD 2011</td>
<td>Dietrich</td>
<td>Post-doc Genoa</td>
</tr>
<tr>
<td>Nittrouer, Jeffrey</td>
<td>PhD 2010</td>
<td>Mohrig</td>
<td>NSF Post-doctoral Fellow, University of Illinois at Urbana-Champaign</td>
</tr>
<tr>
<td>Passalacqua, Paola</td>
<td>PhD</td>
<td>Foufoula</td>
<td>Assistant Professor in Civil Engineering, U of Texas, Austin</td>
</tr>
<tr>
<td>Prava, Venkat</td>
<td>MSE 2010</td>
<td>Hobbs</td>
<td>Ph.D. Student, Johns Hopkins University</td>
</tr>
<tr>
<td>Tsui, Martin</td>
<td>PhD 2010</td>
<td>Finlay</td>
<td>Post-doc U Michigan</td>
</tr>
<tr>
<td>Whittinghill, Kyle</td>
<td>PhD 2010</td>
<td>Finlay</td>
<td>University of Michigan</td>
</tr>
<tr>
<td>Zheng, Pearl</td>
<td>PhD 2010</td>
<td>Hobbs</td>
<td>Abt Associates (Consulting)</td>
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### Summary Listing of NCED Partners

<table>
<thead>
<tr>
<th>Organization Name</th>
<th>Organization Type</th>
<th>Address</th>
<th>Contact Name</th>
<th>Partner Type</th>
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</thead>
<tbody>
<tr>
<td>Advanced Materials for Water Purification</td>
<td>NSF – STC</td>
<td>University of Illionois 3253 Digital Computer Lab 205 N. Mathews Ave. MC-250 Urbana, IL 61801</td>
<td>Susan Herricks</td>
<td>Education &amp; Diversity Knowledge Transfer</td>
<td>N</td>
</tr>
<tr>
<td>Anadarko Petroleum Corporation</td>
<td>Oil Exploration Company</td>
<td>1201 Lake Robbins Drive The Woodlands, TX 77380</td>
<td>Todd Green/ James Parr</td>
<td>Knowledge Transfer</td>
<td>N</td>
</tr>
<tr>
<td>Association for Women in Geoscience, Minnesota Chapter</td>
<td>Professional Organization for Women</td>
<td>NA</td>
<td>Karen Campbell/ Lesley Perg</td>
<td>Knowledge Transfer</td>
<td>N</td>
</tr>
<tr>
<td>Bureau of Land Management</td>
<td>Government Agency</td>
<td>Office of Public Affairs 1849 C Street, Room 406-LS Washington, DC 20240</td>
<td>Jim Fogg</td>
<td>Stream Restoration Partner</td>
<td>N</td>
</tr>
<tr>
<td>CALFED – Bay-Delta Program</td>
<td>State Government</td>
<td>605 Capitol Mall, 5th Floor Sacramento, CA 95814</td>
<td>Bill Dietrich</td>
<td>Knowledge Transfer</td>
<td>N</td>
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<tr>
<td>Canaan Valley Institute</td>
<td>Non-profit Organization</td>
<td>P.O. Box 763 Davis, WV 26260</td>
<td>N/A</td>
<td>Stream Restoration Partner</td>
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<td>Organization Name</td>
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<tr>
<td>Center for Embedded Network Sensing</td>
<td>NSF – STC</td>
<td>UCLA 3731 Hilgard Ave Boelter Hall Los Angeles, CA 90095</td>
<td>Deborah Estrin, Director</td>
<td>Knowledge Transfer</td>
<td>N</td>
</tr>
<tr>
<td>Center of Research Excellence in Science and Technology</td>
<td>NSF Center</td>
<td>Department of Environmental Science Texas A&amp;M University—Kingsville Kingsville, TX 78363</td>
<td>Lee Clapp/ Jianhong Ren</td>
<td>Education &amp; Diversity</td>
<td>N</td>
</tr>
<tr>
<td>ChevronTexaco</td>
<td>Oil Exploration Company</td>
<td>4800 Fourmace Place Bellaire, TX 77401</td>
<td>Martin Perlmutter</td>
<td>Knowledge Transfer</td>
<td>N</td>
</tr>
<tr>
<td>CHRONOS</td>
<td>NSF funded research center</td>
<td>Iowa State University Dept of Geol 275 Science I Ames, Iowa 50011-3212</td>
<td>Cinzia Cerbato</td>
<td>Knowledge Transfer</td>
<td>N</td>
</tr>
<tr>
<td>ConocoPhillips</td>
<td>Oil Exploration Company</td>
<td>P.O. Box 2197 Houston, TX 77252-2197</td>
<td>Al Shultz</td>
<td>Knowledge Transfer</td>
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<tr>
<td>ExxonMobile Upstream Research Co.</td>
<td>Oil Exploration Company</td>
<td>P.O. Box 2189 Houston, TX 77252-2189</td>
<td>Penny Patterson</td>
<td>Knowledge Transfer</td>
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<tr>
<td>Florida A&amp;M University</td>
<td>University</td>
<td>Tallahassee, FL, 32307</td>
<td>NA</td>
<td>Education &amp; Diversity</td>
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<tr>
<td>Geowall Consortium</td>
<td>Consortium</td>
<td><a href="http://www.geowall.org">http://www.geowall.org</a></td>
<td>Paul Morin</td>
<td>Knowledge Transfer</td>
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<tr>
<td>Inter-Fluve, Inc.</td>
<td>Environmental</td>
<td>9594 First Avenue NE St. 615 Seattle, WA 98115</td>
<td>NA</td>
<td>Stream Restoration Partner Group</td>
<td>N</td>
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<tr>
<td>International Center for Geohazards (IGC)</td>
<td>International</td>
<td>P.O. Box 3930 Ullevaal Stadion N-0806 Oslo, Norway</td>
<td>Anders Elverhoi</td>
<td>Partner</td>
<td>N</td>
</tr>
<tr>
<td>Japan Oil, Gas, and Metals Corporation</td>
<td>Oil Exploration Company</td>
<td>Fukoku Seimei Bldg. 2-2-2 Tokyo 100-8511, Japan</td>
<td>Osamu Takano</td>
<td>Knowledge Transfer</td>
<td>N</td>
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<tr>
<td>Minnesota Geological Survey</td>
<td>State Agency</td>
<td>2641 University Ave. W. St. Paul, MN 55114-1057</td>
<td>Harvey Thorleifson</td>
<td>Knowledge Transfer</td>
<td>N</td>
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<tr>
<td>NASA/Goddard Space Flight Center, Hydrologic Sciences</td>
<td>Government Agency</td>
<td>Code 974, Hydrological Sciences NASA/Goddard Space Flight Center Greenbelt, MD 20771</td>
<td>David Toll</td>
<td>Knowledge Transfer</td>
<td>N</td>
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<tr>
<td>National Park Service Water Resources Division</td>
<td>Government Agency</td>
<td>1201 Oakridge Drive St. 250 Fort Collins, CO 80525</td>
<td>Several</td>
<td>Stream Restoration Partners Group</td>
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<td>Organization Name</td>
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<tr>
<td>National River Restoration Science Synthesis (NRRSS)</td>
<td>Project</td>
<td>Plant Sciences, Bldg 4112 University of Maryland College Park, MD 20742</td>
<td>Margaret Palmer</td>
<td>Research</td>
<td>N</td>
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<tr>
<td>NOAA Fisheries Service</td>
<td>Government Agency</td>
<td>1315 East West Highway 9th Floor Silver Spring, MD 20910</td>
<td>Several</td>
<td>Stream Restoration Partners Group</td>
<td>N</td>
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<tr>
<td>Nova/Mentorn TV</td>
<td>Educational Television Producer</td>
<td>43 Whitfield St London, WIT 4HA</td>
<td>Ben Fox</td>
<td>Education &amp; Diversity</td>
<td>N</td>
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<tr>
<td>NSF Center for Airborne Laser Mapping (NCALM)</td>
<td>NSF Center</td>
<td>365 Weil Hall P.O. Box 116580 University of Florida Gainesville, FL</td>
<td>Bill Dietrich</td>
<td>Research</td>
<td>N</td>
</tr>
<tr>
<td>Office of Naval Research, Coastal and Geosciences Program</td>
<td>Government Agency</td>
<td>800 N Quincy Street Arlington, VA 22217</td>
<td>Tom Drake</td>
<td>Knowledge Transfer</td>
<td>N</td>
</tr>
<tr>
<td>R2 Resource Consultants</td>
<td>Corporation</td>
<td>15250 NE 95th Street Redmond, WA 98052</td>
<td>Paul DeVries</td>
<td>Knowledge Transfer</td>
<td>N</td>
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<tr>
<td>SciTech Hands On <a href="http://scitech.mus.il.us/">http://scitech.mus.il.us/</a></td>
<td>Museum</td>
<td>18 W Benton Street Aurora, IL 60506</td>
<td>Ronen Mir, Executive Director</td>
<td>Education &amp; Diversity</td>
<td>N</td>
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<tr>
<td>Shell International Exploration and Production Company</td>
<td>Oil Exploration Company</td>
<td>3737 Belaire Blvd Houston, TX 77025</td>
<td>Carlos Pirmez</td>
<td>Knowledge Transfer</td>
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<tr>
<td>The Science Center at the Maltby Nature Reserve</td>
<td>Non-Profit</td>
<td>Maltby Nature Preserve 789 Sciota Trail East Randolph, MN 55065</td>
<td>Seliesa Pembleton</td>
<td>Education &amp; Diversity</td>
<td>N</td>
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<tr>
<td>Stillwater Sciences</td>
<td>Environmental Consulting Firm</td>
<td>2855 Telegraph Ave., Suite 400 Berkeley, CA 94705</td>
<td>Yantao Cui</td>
<td>Knowledge Transfer</td>
<td>N</td>
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<tr>
<td>US Army Corps of Engineers Rocky Mountain Research Station</td>
<td>Government Agency</td>
<td>Southbend, IN 46628</td>
<td>Meg Jonas</td>
<td>Knowledge Transfer</td>
<td>N</td>
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<tr>
<td>US Department of Agriculture: Forest Service Rocky Mountain Research Station</td>
<td>Government Agency</td>
<td>316 E Myrtle Street Boise, ID 83702</td>
<td>Jim McKeen</td>
<td>Knowledge Transfer</td>
<td>N</td>
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<tr>
<td>US Department of Agriculture: Forest Service Pacific Northwest Station</td>
<td>Government Agency</td>
<td>3200 SW Jefferson Way Corvallis, OR 97331</td>
<td>Gordon Grant</td>
<td>Stream Restoration Partners Group</td>
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<td>US Department of Agriculture: National Sedimentation Laboratory Water Quality and Ecology</td>
<td>Government Agency</td>
<td>Agricultural Research Service National Sedimentation Laboratory PO Box 1157 Oxford, MS 38655</td>
<td>Doug Shields</td>
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<td>US Department of the Interior: Bureau of Reclamation, Sediment and River Hydraulics Group</td>
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<td>Sedimentation and River Hydraulics Group (D-8540) US Bureau of Reclamation Technical Service Center</td>
<td>Tim Randle</td>
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<td>US Environmental Protection Agency</td>
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<td>WW-16J US Environmental Protection Agency 77 West Jackson Boulevard</td>
<td>Tom Davenport</td>
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<td>Universidad Central de Venezuela</td>
<td>University</td>
<td>Instituto de Mecanica de Fluidos Facultad de Ingenieria Universidad Central de Venezuela</td>
<td>Jose L. Lopez</td>
<td>Research</td>
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<tr>
<td>Universidad Nacional del Litoral</td>
<td>University</td>
<td>Department of Eng and Water Universidad Nacional de Litoral Santa Fe, Argentina</td>
<td>Mario Luis Amsler</td>
<td>Research</td>
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<tr>
<td>University of Colorado/ INSTARR</td>
<td>University</td>
<td>Institute of Arctic and Alpine University of Colorado at Boulder 1560 30th Street, Campus Box 450 Boulder, CO 80309-0450</td>
<td>James P. M. Syvitski</td>
<td>Research</td>
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<tr>
<td>Utah Museum of Natural History</td>
<td>Museum</td>
<td>University of Utah 1330 E Presidents Circle Salt Lake City, UT 84112</td>
<td>Rebecca Menlove</td>
<td>Education &amp; Diversity</td>
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**Summary Table**

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<td>Number of participants</td>
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IX. Indirect & Other Impacts

NCED International Activities

Earth science is an inherently international discipline, both in its subject matter and its participants. NCED PIs, individually and collectively, have close collaborators around the world (Fig. 1), many of whom are former graduate advisees. Moreover, NCED’s student body includes many students from countries outside the U.S., and NCED research is informed by experimental, theoretical, and field-based projects throughout the world.

Ongoing Collaborations

Ten NCED PIs report ongoing international collaborations. Dietrich works with two groups in Brazil on landscape evolution. He also has ongoing field monitoring of debris flows with collaborator Brian McArdell in Switzerland. Finlay investigates stable isotope ecology with Japanese colleagues. Foufoula has ongoing collaborations in Italy (University of Padova), Austria (BOKU: Universität für Bodenkultur Wien), Switzerland (EPFL: École Polytechnique Fédérale de Lausanne) and France (University of Grenoble); Hill works with colleagues in France and Canada. Hobbs has been working with colleagues in the United Kingdom since his sabbatical there in 2009, while Hondzo is working on nutrient transport in streams with Korean colleagues. Paola collaborates with colleagues in France (IPGP: Institute Physique du Globe de Paris) and recently in Bangladesh as part of an NSF-funded PIRE project; Parker works with colleagues in the Netherlands, Italy, Canada, New Zealand, France, Germany and Japan. Power has collaborators in China; Sotiropoulos works on modeling related to wind turbine farms with colleagues in France, and Voller is developing a conference on quantitative modeling of Earth surface processes in collaboration with the Oxford Center for Collaborative Applied Mathematics (OCCAM). These are only limited examples of the international exchange of NCED PIs. More details are included in the metrics tables filled annually by NCED PIs.

Presentations given or courses taught outside of the U.S.

Lectures were presented by several NCED PIs in international meetings in Year 9. Dietrich gave several presentations at a Workshop in Taichung, Taiwan, cosponsored by the Bureau of Reclamation. He also presented at Federal University Minas Gerais, Brazil and Federal University Rio de Janeiro, Brazil. Hill presented at the International Union of Theoretical and Applied Mechanics, Reggio Calibria, Italy. Hobbs presented at the Workshop on Implications of Climate Change and Variability on African Water Resources, University of Cambridge, Cambridge, England. Paola presented at the European Geophysical Union Annual Meeting, Vienna, Austria, at Imperial College London, and at IPGP in France. Power gave three lectures, a departmental seminar and led a field trip at the University of Puerto Rico; she also spent a sabbatical semester in Sweden where she collaborated and taught ecology courses. Sotiropoulos presented at the Chilean Congress of Hydraulic Engineering, Vina del Mar, Chile, and at Yonsei University, Seoul, Korea and Wilcock presented an invited paper at the National Telford Institute, Glasgow Scotland. Foufoula presented invited talks in Argentina as part of an advisory board member to the Ministry of the Environment, in Malawi as a member of a collaborative project, and in Vienna at the European Geophysical Union meeting.

![Figure 1: NCED collaborations with international partners.](image-url)
Informal education

The “Water” exhibition, developed jointly by SMM/NCED and the American Museum of Natural History, was replicated to enable concurrent travelling exhibitions: one domestic and one international. The international edition has visited Singapore, Istanbul, São Paolo, Brazil and is currently in Canberra, Australia. The domestic edition has been shown at the American Museum of Natural History, the Science Museum of Minnesota, the San Diego Museum of Natural History, and the Field Museum (Chicago, IL). In Year 9, it visited The Great Lakes Science Center (Cleveland, OH) and in 2010 it visited the Dallas Museum of Nature and Science in Toronto, CA.

International Collaboratory on Earth-surface Dynamics

Deteriorating streams and threatened landscapes, flood and landslide hazard prediction and control, delta ecosystem restoration, and exploration of subsurface resources are all problems of international character. Over the past year we have begun to formalize our international collaborative efforts with the intention of developing the International Collaboratory on Earth-surface Dynamics (ICED), an organization that will be committed to establishing key formal international collaborations in research, data and model exchange, and graduate student education for the advancement of research and practice of Earth-surface dynamics within a broader world view.

NCED researchers already have a strong record of international exchange. Seeking to build on that history, NCED promoted and financially supported several activities of international character. Recent examples include:

- **MYRES:** NCED postdoctoral research associates, alumni, and colleagues collaborated to propose, plan, and bring to fruition the first Meeting of Young Researchers in Earth Sciences (MYRES) focused on Earth-surface processes. The product of this labor: MYRES 2008, a conference on “The Dynamic Interaction of Life and its Landscape,” through which early career researchers from across the globe connected to set a research agenda for future investigation of landscape-ecosystem co-evolution.

- **SIESD:** In August 2009, NCED established the first Summer Institute on Earth-surface Dynamics (SIESD), a training program that offers the next generation of scientists instruction in NCED’s approach of integrating theory, laboratory experiments, numerical modeling, and fieldwork to build an interdisciplinary predictive science of the surface of the Earth. Scientists from twenty-five academic institutions from seven countries participated in the inaugural SIESD, building future collaborative networks for predictive Earth-surface science.

- **RCEM:** In September 2009, NCED co-sponsored the 6th Symposium on River, Coastal and Estuarine Morphodynamics (RCEM 2009) at the Universidad Nacional del Litoral (UNL) in Santa Fe City, Argentina. NCED PI Parker and NCED post-doc Eke; NCED alumni Michal Tal and Doug Jerolmack; and collaborators Y. Shimizu, Y. Watanabe, and T. Masumoto participated in the conference; a key forum for exchange of ideas with our international colleagues.

Next Steps

To further the partnerships that will form the backbone of ICED, NCED is in the process of developing a proposal to be submitted to NSF as part of its Research Coordination Networks (RCN) solicitation. This proposal will center on large rivers around the world and will include several international groups as partners.

NCED is also taking a leadership role in promoting the International Year of the Deltas (IYD). A draft statement which is soon to be published is currently circulating among international organizations for formal support. The purpose of the IYD 2012 is to 1) increase awareness and attract attention to the value and vulnerability of deltas worldwide; 2) promote and enhance successful international and regional cooperation at the scientific, policy, and stakeholder level; and 3) develop a focused, accelerated and comprehensive path forward towards understanding and modeling these complex socioecological systems as the cornerstone of ensuring preparedness in protecting and restoring them in a rapidly changing environment.
X. Budget

The NCED budget has been deleted from the public version of this report due to the confidential nature of the information contained therein. Please contact Mary Kosowski (kosowski@umn.edu) with any questions pertaining to the NCED budget.
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Appendix A: Biographical Information of New PIs

KAREN BOBBITT GRAN

(a) EDUCATION:

<table>
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<th>Institution</th>
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<td>University of Minnesota</td>
<td>Geology</td>
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<tr>
<td>University of Washington</td>
<td>Geology</td>
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(b) APPOINTMENTS:

2007-present: Assistant Professor, Dept. of Geological Sciences, Univ. of Minnesota, Duluth.
2006-07: Research Associate, National Center for Earth-surface Dynamics, Univ. of Minnesota.
2000-05: Graduate fellow/assistant, Dept. of Earth & Space Sciences, Univ. of Washington.
2000: Visiting Instructor, Department of Geology, University of St. Thomas.
1999: Acting Technical Director, Department of Geology, Carleton College.
1997-99: Graduate fellow/assistant, Dept. of Geology & Geophysics, University of Minnesota.

(c.i and ii) PUBLICATIONS:

Day SS, **Gran KB**, Belmont P, Wawrzyniec T, Change detection on bluffs using terrestrial laser mapping technology. Accepted pending revisions at *Earth Surface Processes and Landforms*.

**Gran, KB**, Belmont, P, Day, SS, Finnegan, F, Jennings, C, Lauer, JW, and Wilcock, PR, Landscape evolution in south-central Minnesota and the role of geomorphic history on modern erosional processes. Accepted pending revisions at *GSA Today*.


SYNERGISTIC ACTIVITIES

1) **Peer Review and Panel Member:** Participated on a review panel for NSF’s Geomorphology and Land Use Dynamics Division. Peer reviewer for proposals in GLD and Hydrology Divisions; manuscripts for *Quaternary Research, Earth Surface Processes and Landforms, Environmental Management: Journal of Environmental Quality; JGR Earth Surface; Arctic, Antarctic, and Alpine Research*; and manuscripts for submission by federal employees in the U.S. Geological Survey and U.S. Forest Service.

2) **Geological Society of America, QG&G Panel:** I was elected to a three-year appointment on the panel of the Quaternary Geology and Geomorphology Division of the GSA, starting in Fall 2010.

3) **Stream restoration education:** From 2006-07, I was the program coordinator for a graduate certificate program in stream restoration science and engineering. This program is run through the U. of Minnesota by the National Center for Earth-surface Dynamics, an NSF Science and Technology Center. I was responsible for getting the program up and running including developing curricula for two new courses, organizing and co-teaching the two courses, and administrative and recruiting duties associated with the program.

4) **New experimental techniques:** For my Master’s research, I developed several new techniques for modeling the effects of riparian vegetation on stream channels in an experimental environment and measuring depth and velocity in the system. The technique of using alfalfa sprouts for modeling vegetation has now been used on several new experiments at the St. Anthony Falls Laboratory at the University of Minnesota and in the Richmond Field Station at the University of California Berkeley.

5) **Le Sueur River community outreach:** As part of a research project investigating sediment source in the Le Sueur River in central Minnesota, I have had several opportunities for outreach to the community and periodic meetings with the Minnesota Pollution Control Agency. One example involves a workshop I organized in May 2008 for technical staff working in the area. This was an opportunity for agency staff responsible for implementing plans for basin remediation and best management practices to get together with researchers working in the basin. Over 30 people attended, and many responded with great enthusiasm.

COLLABORATORS AND CO-EDITORS:

Patrick Belmont (Utah State University), Carrie Jennings (U. of Minnesota), J. Wesley Lauer (Seattle University), Elizabeth Minor (U. of Minnesota Duluth), David Montgomery (U. of Washington), Gary Parker (U. of Illinois), Shawn Schottler (St. Croix Watershed Research Center), Dan Engstrom (St. Croix Watershed Research Center), Jane Willenbring (Penn. State University), Michal Tal (Aix en Marseilles), Enrica Viparelli (U. of Illinois), Peter Wilcock (Johns Hopkins), Noah Finnegan (U. California, Santa Cruz), Julia Halbur (University of Minnesota Duluth)

GRADUATE AND POST-DOCTORAL ADVISORS:

David Montgomery, Department of Earth & Space Sciences, University of Washington
Chris Paola, Department of Geology & Geophysics, University of Minnesota
Vaughan Voller, Department of Civil Engineering, University of Minnesota

THESIS ADVISOR:

Andrea Johnson, Emily Dunn, Jenny Magyar, University of Minnesota, Duluth
Stephanie Day, Ted Fuller, University of Minnesota
PREFACE

The NCED External Advisory Board (EAB) met on February 16th to 18th, 2011 at the University of Minnesota and St. Anthony Falls Laboratory, Minneapolis, MN. This report constitutes the recommendations of the Committee to the NCED Director. It is organized around the charge to the board from NSF and NCED and important points identified by the EAB. The findings and recommendations of this report are based on documents provided to the Board and presentations by NCED management, staff, and principal investigators. The meeting agenda is provided in Appendix I.

CHARGE TO THE BOARD

Cooperative Agreement EAR-0120914 indicates that the EAB is “to provide guidance, advice, and oversight for all the Center’s activities, consistent with its vision, goals, and objectives”. In addition, NCED Director Efi Foufoula-Georgiou again asked the External Advisory Board to provide specific advice on two main themes: 1) maximizing the legacy of NCED —from research to implementation to policy and broader impacts; and 2) big ideas for “NCED of the future” —thinking out of the box.

FINDINGS AND RECOMMENDATIONS

Preamble

The External Advisory Board (EAB) congratulates the NCED management, staff, and PIs for the progress made over the last year. It is apparent that NCED’s impact has been truly transformative. You have generated new basic scientific knowledge through discovery research, developed new ways of organizing scientific inquiry in earth surface studies, encouraged a new journal and professional associations, produced a new cadre of researchers and educators different in both outlook and approach from those of traditional graduate programs, and created new courses, new degree programs, and exciting public outreach to under-represented Americans and beyond. Now these transformations must be sustained after the expiration of the NSF grant. The EAB recognizes that there are various kinds of legacy—the NCED brand, the created knowledge, the human resources—but here we focus on possible organizational models that can provide continued organized leadership in earth surface dynamics.

Establishing NCED’s Legacy and Sustainability

The key question facing NCED is what organizational model will provide the continued leadership for the community in integrative research and laboratory/field experiments. The EAB suggest three viable models:

Community Center for Earth Surface Dynamics (CCED)

The EAB thinks there is great value in continuing a funded center in the United States to provide continued organized leadership in earth surface dynamics. A logical outgrowth of the NCED STC would be a community Center, much in the spirit of CSDMS. NCED has a community identity and a momentum, and it would be a great loss to lose a connection to the facilities at SAFL (ie., Outdoor Stream Lab), Angelo (ie., Outdoor Hillslope Lab), and Wax Lake Delta. The EAB recommends that...
NCED PIs consider approaching the NSF Geosciences Directorate with a request for multi-year operational funds to enable a broadened NCED or “CCED” to retain a critical mass of synergistic researchers, maintain this community’s access to experimental infrastructure, provide expertise that would teach others in the community the NCED experimental approach, and continue to bring different disciplinary groups together. Albeit at a reduced level, CCED also could maintain its valuable educational and outreach initiatives. Operational funds might be obtained by support from the Surface Section of EAR (GLD, but also the Hydrology, Biogeosciences, and Education programs) linked to a University of Minnesota endowment for continuation of outreach programs for support of the Geoscience Alliance.

**An International Research Coordination Network on ESD (ICED)**

As envisioned by NCED PIs this would be a organization of institutions committed to international collaboration in research, data exchange, and graduate education in Earth surface dynamics. Some example participates are Deltares, IBGP, the University of Padova, and the University of Natural Resources and Life Sciences, Vienna, Austria. The EAB thinks there is a need for coordination of this sort and recognizes that its nurturing and development is a natural extension of NCED leadership. Funding might be sought from NSF for building this International Research Coordination Network, as for example from the NSF RFP for a Research Coordination Network (due July 5th 2011). The EAB wonders however, whether this approach in and of itself, will maintain the present creative momentum, satisfy the various needs of the US ESP community, and provide a steady funding stream. Coupling with CCED would make sense in this regard.

**The National Community Earth Surface Dynamics Laboratories (CESDL)**

Another post-NCED organizational model could be one that focuses on the instrumentation and facilities that have been created (or at least enhanced) by NCED over the last 10 years. We envision CESDL to be a collection of experimental facilities and outdoor labs (Angelo, Berkeley, SAFL, Wax Lake, and Le Seuer) for linked eco- and earth surface-studies that provide continued training and staff knowledge, all coordinated by a central administration. Multi-year funding from NSF could provide base-level resources, with additional support from NASA and private companies. The field labs might be offered to NASA as excellent sites for ground-truthing space-based observations. Sponsored memberships could be developed in which, for an annual fee, private companies (e.g., those engaged in environmental restoration) would have access to beta versions of CESDL tools, to professional versions of a CESDL tool, or to training programs.

**IP-Specific Comments**

**Subsurface Architecture (Delta Restoration) IP**

We are aware of three products beyond the expected papers in scientific journals—a delta land-building manual, a summary article in Annual Review of Marine Science (“Using Natural Processes to Restore River Deltas”, January 2011), and a numerical models simulating delta growth, habitat, and fish populations. These are all valuable syntheses of NCED research. We are pleased that the manual, “Managed Delta Rehabilitation”, is moving forward with a draft by late summer and a final version released in 2012 and has a publication venue, Journals of Coastal Engineering and Engineering Monographs. For widespread application it is important to secure joint authorship with USACE. We did not hear about the fish model this year but trust that the relationship between this model and the LSU CLEAR model has been clarified. Competing for an NSF FESD award is a wonderful way to sustain the Delta IP beyond the life of the NCED STC.

**Desktop Watersheds**

NCED watershed scientists have contributed significantly to improved understanding of the physical processes that govern landscape evolution, and at modelling these processes, as is demonstrated by an impressive output of publications. Acquisition and use of very high resolution LiDAR datasets for NCED’s watersheds played a key role in this research. The EAB is enthusiastic about the recently completed negotiations with Google.org to offer NCED products such as LiDAR and software models on the Google Earth platform. The EAB sees this as an almost foolproof legacy of the NCED STC and recommends that NCED continue to finalize and further specify the precise nature and functionality (including documentation and “help” functions) of these data and tools. It is our understanding (and hope) that the following predictive and analysis models will acquire a Google Earth home: 1) GEONET, the new tool to extract catchment characteristics from very high resolution LiDAR datasets; 2) RIPPLE 1.3; and 3) SHALSTAB & SHALRUN, the simple landslide and runout models. As you are well aware, preventing misapplication is critical. Guidance is needed on many topics, such as how the accuracy of Shalstab and Shalrun depend upon the resolution of the DEM. Helping the Google.org research team shape how their API works so that it will be...
more useful to other geoscientists is also time well spent. Finally, we suggest that you explore the educational applications that might arise from this new alliance with Google. It seems natural for NCED personnel to create instructional materials that exploit these publically available resources to teach complex thinking through modeling coupled Earth systems. Local communities also could be involved, as for example, Native American tribes in northern California who have numerous tribal archive photos that could test the landslide predictions.

Stream Restoration
The EAB is pleased to learn of NCED communication plans to work via university faculty, workshops, practitioner meetings, and through the U.S. Army Corps of Engineers, to promote the NCED Stream Restoration manual. The EAB thinks this is a very important legacy. The following questions may have already been considered by the IP team, but we think they are important enough to deserve mention: Who publishes the manual? What legal issues are there to get the manual accepted in courts of law? What is the best path to insure that the Corps of Engineers (in its capacity as the regulatory agency for re-engineering streams) will adopt this design guidance? The legacy of the Le Sueur study is a bit cloudy to the EAB. Is the legacy a general best practices manual or is it a final consulting report to its stakeholders? What are the transferable lessons?

Knowledge Transfer and Education
The EAB appreciates NCED’s innovative approach to broader impacts, which have focused primarily on museum-based education and outreach efforts. This approach has made it possible to build on the expertise of museum staff to develop innovative exhibits and supporting resources for informal visitors to the museum, as well as visiting educators and students. Furthermore, partnerships have been developed to broaden access to these exhibits and resources to other museums through traveling exhibits, kiosks, and follow-on collaborative efforts. What is not clear is how the public, students, and educators not local to Minnesota, nor one of the collaborating museums, will have any access to the resources developed through this National Center. It is unfortunate that this program design effectively selects against use of the resources developed by members of the public, students, and educators without access to the museum, due to the requirement to pay fees to enter the museum.

The EAB again encourages the NCED education team to pursue the numerous opportunities that exist to broaden access to these resources. Specific suggestions include publishing one or more articles on classroom activities developed through the project in a publication focused on reaching teachers with exemplary resources such as The Earth Scientist, a publication of the National Earth Science Teachers Association. Indeed, the team could consider sponsoring an entire issue of the journal on NCED topics – an approach which would ensure that the broader educational impacts of NCED are sustained into the future through a dedicated publication. Additionally, the team should make these educational resources available through high-traffic educational websites, to ensure that they have the potential to be accessed and used by educators and their students in coming years, after the NCED effort has been completed. The EAB recommends that the education team work with education teams from other STCs to develop an approach for sustaining the valuable Summer Institutes that have been developed through these programs.

Diversity
NCED has made significant contributions to enhancing diversity in the Earth Sciences through its programs with Native Americans. The EAB is pleased that the University of Minnesota has given a three-year financial commitment to help NCED transition to new opportunities. We support the suggestion that some of this money provide NCED personnel with the opportunity to continue programs among under-represented Native Americans and seek new funding sources.
Appendix I

NCED External Advisory Board Meeting
February 17-18, 2011 • Minneapolis, MN

DAY 0 – Wednesday, February 16, 2010
18:45 – 19:00 Travel from hotel to the meeting
19:00 – 22:00 Dinner with EAB Members (Campus Club)

DAY 1 – Thursday, February 17, 2010 (TCF Bank Stadium)
07:45 – 08:00 Travel from hotel to the TCF Bank Stadium conference room on campus
08:00 – 08:30 Breakfast / Introductions
08:30 – 09:30 Overview of NCED - Efi Foufoula-Georgiou (45 min presentation & 15 min discussion)
09:30 – 10:15 Desktop Watersheds – Bill Dietrich (30 min presentation & 15 min discussion)
10:15 – 10:30 Break
10:30 – 11:15 Stream Restoration – Peter Wilcock (30 min presentation & 15 min discussion)
11:15 – 12:00 Deltas – David Mohrig (30 min presentation & 15 min discussion)
12:00 – 13:00 Lunch
13:00 – 13:30 SAFL Research and ARI - Fotis Sotiropoulos (20 min presentation & 10 min discussion)
13:30 – 14:00 Education - Karen Campbell (20 min presentation & 10 min discussion)
14:00 – 14:30 Diversity - Diana Dalbotten (20 min presentation & 10 min discussion)
14:30 – 15:30 Open Discussion: NCED of the Future, ICED, Strategic partnerships with other initiatives,
Engaging the broader community, Policy and broader impacts
15:30 – 17:30 Open Discussion
19:30 – 21:00 Dinner (Sawatdee Restaurant)
DAY 2 – Friday, February 18, 2010 (St. Anthony Falls Lab)
08:15 – 08:30 Travel from hotel to the SAFL
08:30 – 09:00 Breakfast
09:00 – 09:30 Engaging the international community (ICED): Efi Foufoula-Georgiou
09:30 – 10:00 Reflections from EAB and discussion on ideas for the future
10:00 – 11:00 SAFL Tour
11:00 – 12:00 Committee Report Writing
12:00 – 13:00 Working Lunch
13:00 – 16:00 Committee Report Writing
The NCED team sincerely appreciates the work of the External Advisory Board in evaluating our progress and guiding our growth, year after year, with vision and insight. This year (NCED’s Year 9), your major recommendations focused on operational models for sustaining NCED’s legacy beyond the ten year NSF funding. Specifically, you have proposed three possible post-NCED organizational models that can provide a continued organized leadership in the community of Earth-surface Dynamics:

(1) Community Center for Earth Surface Dynamics (CCED)

Indeed, we agree with your recommendation to approach the NSF Geosciences Directorate with a request for multi-year operational funds to enable a broadened NCED. We plan to do so in the coming year. The scope of this broadened NCED would be to provide a critical mass of synergy across the Earth Surface Dynamics (ESD) community and facilitate access to experimental infrastructure and expertise that embraces an integrated interdisciplinary approach to ESD based on experiments, theory, numerical modeling and field work, a legacy approach of NCED. Some NCED activities that are absolutely critical to continue are: the Summer Institute for Earth-surface Dynamics that has already established itself internationally as the hub of interdisciplinary training of the next generation of Earth surface scientists, the Visitors’ program that opens up experimental facilities to the community, the summer field campaigns at our field sites in Wax Lake Delta and Angelo Coast Range Reserve, the Young Affiliate Scientist program that invites young scientists to visit and collaborate across the NCED sites (http://www.nced.umn.edu/content/affiliate-scientists), community level experimental expertise on ESD, and a few targeted Education and Diversity programs, such as the Geosciences Alliance Conference and teacher training workshops.

(2) International Research Coordination Network on ESD (ICED)

The NCED leadership has talked for more than a year now about the idea of ICED (International Collaboratory on Earth-surface Dynamics) and efforts along this direction have been initiated. We are in the process of preparing a proposal to NSF to be submitted to their RCN-SEES solicitation. The focus of this proposal is to organize a network of researchers and facilities focusing on the sustainability of large rivers around the world. At this time we consider groups that study the Danube river in Europe, the Parana (La Plata) river in South America, and the Mississippi River in the United States.

(3) National Community ESD Laboratories (CESDL)

Following the renovation of the St Anthony Falls Laboratory (SAFL) with NSF ARI-R2 funds and a generous matching contribution by the University of Minnesota, SAFL will become the first state-of-the-art modern laboratory for studying ESD and advancing science at the intersection of energy and the environment. The renovated facility will have enhanced remote access features allowing active participation to experiments from researchers around the world. We are exploring modes of operation that can open up this facility and make it a true community resource.

IP specific comments:

Subsurface Architecture (Deltas) IP:

Thank you for your positive response to our progress on the “Managed Delta Rehabilitation” manual and some targeted synthetic activities on this IP, such as the review article and the integrated numerical models on delta growth. You recommended we work towards securing co-authorship of this manual by USACE. We are exploring another option, preparing our manual in time to be made available to the Science and Engineering Board, Office of Coastal Protection & Restoration, charged with reviewing the 2012 update of Louisiana’s Comprehensive Master Plan for a Sustainable Coast. This board and master plan will lay the framework for preferred land-building strategies within the state of Louisiana and the Mississippi River Delta. As you know, we are eagerly waiting to hear the results of the Frontiers in Earth surface Dynamics (FESD) competition and we hope that our proposal to create a Wax Lake Delta Laboratory will be successful. This effort would bring NCED and non-NCED PIs into a large multi-disciplinary team capable of addressing the scientific challenges of deltas and translating them into plans for sustainable management and restoration.
Desktop Watersheds (Watersheds) IP:

As you immediately recognized, the highlight of this IP for Year 9 has been the completion of the NCED-Google.org contract to lead the way towards developing terrain-based applications within the Google Earth Engine (EE) environment. We see this as the beginning of a long-term relationship by which the whole Earth and water sciences communities will benefit by popularizing its data and methods for prediction of water, landform and ecosystems processes in an easy-to-use Google supported environment (Google EE API). Right now we are working on making available to Google the GeoNet (channel network extraction model) and the Shalstab and Shalrun (landslide hazard and debris runout prediction models). Ripple is not part of the current Google contract but we hope that it will be in the future.

Stream Restoration (Streams) IP:

Thank you for your positive response to our efforts towards the Stream Restoration manual. You ask about publication plans for the manual and its role in design guidance and legal matters. Our strategy is to publish the manual as a USACE document, in order to (i) provide rapid dissemination, (ii) establish ongoing responsibility for updates, especially software, and (iii) promote adoption. We have established an Oversight Board at USACE headquarters, consisting of representatives from the regulatory, planning, engineering, and military functional groups. We anticipate that the Corps will develop design guidance from the manual. Official design guidance identifies recommended (but not required) methods, which has legal relevance.

Our strategy to promulgate a national and international legacy for the Le Sueur study has several parts. Our sediment budget for the watershed is complete and we are pursuing an aggressive publication strategy (11 papers currently published or in review). The Le Sueur will be featured prominently when the Geological Society of America meets in Minneapolis this fall. The broader message focuses on the essential importance of combining multiple lines of evidence (including new technology like isotopic sediment fingerprinting, traditional stream gauging, topographic analysis, and multiple temporal and spatial scales). We have identified a significant shift in sediment source to the Mississippi River that will require a fundamental refocusing of restoration investments. Our broader goal is to demonstrate a tight coupling between decision analysis and watershed modeling in support of environmental management at the watershed scale. This work will continue beyond NCED; we have two active proposals to begin this phase of the work. We note that there is interest in NCED methods in solving similar sedimentation problems in the Chesapeake Bay and New York City watersheds.

Knowledge Transfer and Education:

Thank you for your praise of our KT and Education programs and our prototype Science Museum/Academia partnership. In response to your concerns about our museum collaborations having limited accessibility (due to museum access fees), we wish to make the following points:

1) The Water Exhibition (WE) is, in two copies, traveling North America and the world. It contains many elements, including components on dam removal and the Mississippi Delta, developed in collaboration with NCED. The WE of course, has no control over the fees charged by these museums to visitors, but the exhibition includes a teachers’ guide and many of the museums who rent the exhibition participate in educational programs around exhibits such as those described in points 4 and 5 below.

2) Many of our Earth Buzz kiosks are in fully public locations and all of the Buzz content is available free on the web-based Science Buzz site.

3) We have had booths at two national-scale, free, exhibitions on the National Mall—the 2005 Smithsonian Folklife Festival (over 1 million visitors) and the 2010 USA Science and Engineering Festival (over 500,000 participants), in each case featuring components developed in cooperation with SMM.

4) Locally, the Science Museum of Minnesota participates, as do many museums nationally, in programs to make free museum passes available through public libraries. NCED’s Big Back Yard Crew youth program actually pays the “at risk” teenagers who participate in the program, to learn about the science behind the park and bring activities they devise to community centers in the metropolitan area, free of charge. We have also provided many opportunities for the Fond du Lac youth to visit the museum free of charge.
5) While it is true that school districts pay to join the Science House resource center at SMM, NCED supported free school residency programs around our Elwha dam removal model for many years and there is no cost to individual teachers to use the models and other resources in the resource center. Reduced museum entrance rates are available for school field trips to the museum and the Big Back Yard and none of NCED’s teacher workshops, whether conducted with or without the museum, has ever charged a fee to teachers to participate. We hope this clarifies your concern.

The Summer Institute on Earth surface Dynamics (SIESD) is a thematic-disciplinary institute and thus involving more STCs in this is not possible or advantageous. Regarding publishing our findings, we agree that a special issue on lessons learned will be a legacy of NCED and we still have this in our plans for Year 10.

Diversity:

Thank you for supporting and recognizing the national impact of our Diversity program. The Diversity team has been contacted this year from many teams around the country competing for new centers and we hope that some of them will be successful and we can continue providing leadership in increasing the participation of Native Americans in Science and Engineering. Efforts to secure more “bridge” funding for the salary of ED/Diversity leadership continue as, paradoxically, it is hard to charge salaries for such positions in NSF projects, although without the dedication, knowledge and leadership of these people nothing would be possible.

Again, we sincerely appreciate and greatly value your advice on the progress we have made and the opportunities for NCED leadership that still lie ahead.
Appendix D: Site Visit Report & Director’s Response

8th Annual Site Visit Report
National Center for Earth-surface Dynamics
Minneapolis, MN
June 8-10, 2010

Over the past eight years, NCED has developed an extensive array of research approaches, facilities, cognitive paradigms, training methodologies, and community partnerships. These products of NCED activities have had and will continue to have a significant impact on the Earth-surface dynamics research community and on the application of Earth-surface sciences to practice and training.

This report documents the findings of the 8th NCED annual site visit, with focus on progress of the center during the past eight years. The site visit took place June 8-10, 2010 at SMM and NCED headquarters in Minneapolis, MN. The NSF Site Visit Team (SVT) consisted of four external members: Teresa Jordan (chair; Cornell University), Joanne Bourgeois (University of Washington), Thomas Henyey (University of Southern California, retired), and Julie Libarkin (Michigan State University). The SVT was observed by three NSF Program Officers (Bruce MacFadden, Dragana Brzakovic, Robert Detrick), and via teleconferencing with H. Richard Lane. The SVT was charged with evaluating the Center’s legacy and sustainability as NCED ramps down its NSF STC support over the next two years.

LEGACY

Research Legacy Accomplishments
NCED has been instrumental in developing the new field of ecogeomorphology, examining the complex interactions amongst earth, water and life. NCED researchers have focused on the riverine, watersheds and deltaic Earth systems. They have made important advances in generating tools for predicting the evolution of these systems, and for restoring human-impacted systems. Not only have they transcended disciplinary boundaries, their research is having a significant impact on user communities working in restoration and mitigation.

A hallmark of NCED’s approach is to use high-resolution topographic data, mapped substrate and biota, and transport laws to generate testable hypotheses and predictions about earth-surface processes. In particular, they have generated simple to complex models of coupled processes across multiple scales. NCED has generated and disseminated significant data and models to the broader community. The quantitative and predictive nature of NCED’s approach will serve as a template for future research.

An overriding legacy of NCED is the training of the next generation of interdisciplinary earth-surface scientists. The imprint of NCED is ubiquitous at professional meetings, and many graduates of the program are emerging leaders. These young scientists are imbued with a sense of interdisciplinarity, the value of novel research approaches in solving problems, and the importance of connecting research to broader impacts.

The field and laboratory facilities developed and enhanced by NCED are a major legacy of the program. The NCED group already has been successful at acquiring additional funding beyond the STC grant, for example, to make a major renovation of St. Anthony’s Falls [NSF ARI-R2 matched by the University of Minnesota] and to enhance the Angelo Coast Range Reserve [W.M. Keck Foundation]. Two new field sites have been developed by NCED – the LeSueur River Basin and the Wax Lake Delta. A number of other experimental labs around the U.S. have been developed or augmented by NCED; for example, the Richmond Field Station has been augmented by debris-flow drum experimental facilities.
Research Legacy Opportunities
NCED is poised to make additional, lasting contributions to environmental issues ranging from the recent oil spill in the Gulf of Mexico to the global impact of climate change and sea-level rise on natural and built communities.

We think that NCED has greater opportunities for impact across the geological-biological divide, a divide that is breaking down in the 21st century. We encourage NCED researchers to continue to engage with other communities, such as ecologists, in transformative ways that will maximize the variety of audiences who can embrace the NCED approach.

We also see opportunities for further research impact in social and education sciences.

The ongoing development of international interactions and partnerships will also broaden NCED’s impact and legacy.

Knowledge Transfer
Knowledge Transfer Accomplishments
NCED’s Knowledge Transfer initiative disseminates their science to stakeholders, the interested public, and NCED partners. They accomplish their goals through the development of educational programs, partnerships, working groups, and strategic communications. Products for knowledge transfer are developed throughout the center and coordinated with end users through NCED’s Knowledge Transfer Initiative. Models of Earth-surface dynamics and manuals for decision-makers and practitioners are examples of NCED end-user products.

In year six, the center developed a model focused on the establishment of Research Cooperatives (RC’s) for knowledge transfer with industry and agency partners. They include the following features:

1) small numbers of participants with multidisciplinary expertise;
2) focus on a specific research topic;
3) regular meetings aimed at fulfilling goals;
4) eventual self sustaining capabilities after establishment; and
5) two-way communication.

Thirteen RC’s so far have been established among the three Integrated Programs (IP’s).

Each of the IP’s is active in knowledge transfer. For example, the Desktop Watersheds IP is actively and successfully promoting its Ripple model throughout the western US. The Stream Restoration IP is in the final stages of developing its Stream Restoration Decision Analysis and Design Guide, and the Subsurface Architecture IP has an active ongoing partnership with oil companies in the Mississippi delta. In addition, NCED unveiled its new website in 2009 that features increased accessibility and improved content. The panel was impressed with the extent and breadth of the knowledge transfer program, and noted that there has been steady growth in these activities over the last eight years. Moreover, there is clear evidence of meaningful two-way communication between NCED scientists and others.

Knowledge Transfer Opportunities
NCED articulated the perspective that researchers have become much more aware of issues regarding sovereignty, impacts of research on Native lands, and Native treaty rights. This has aided them in understanding policy issues that would previously have not been clear when dealing with complicated stakeholder negotiations. Utilization of this awareness in recommendations to decision- and policy-makers is untapped, and could have a transformative effect on enhancing diversity in cross-cultural communication and knowledge transfer.
Dissemination of lessons learned from Science Museum of Minnesota (SMM) and Fond du Lac education and diversity efforts should be a priority to allow others to learn from NCED’s rich experience.

Completion of the work begun to bring data sets and models into community archives is important for NCED’s legacy. The SVT recommends that this plan be completed by the next site visit.

**Education & Diversity**

**Education & Diversity Accomplishments**

NCED houses and supports a range of Education and Diversity initiatives that impact learners of all ages. Learning and outreach is occurring with local populations in programs like gidaa, and to state and national populations via SMM exhibits. Targeting of specific learners for future workforce training occurs through programs such as the REU, faculty-to-faculty, and graduate training efforts. Many of these initiatives clearly include a range of NCED personnel, and are likely to have far-reaching impact across diverse learners with respect to age, gender and under-represented minorities.

Collaboration with significant external personnel and resources at SMM and Fond du Lac has produced strong diversity and education efforts targeted towards outreach and materials development. SMM work is well integrated with NCED research, and has high visibility nationally and even internationally. Native American outreach has some national recognition that is expected to increase with recent ramping up of newer efforts (e.g., Geoscience Alliance). The NCED leadership is clearly dedicated to diversity and education efforts. This dedication is exemplified by expenditure of significant funding for diversity and education as well as by collaboration of NCED researchers on proposals and new initiatives spearheaded by the diversity and education directors.

**Education & Diversity Opportunities**

The integration of NCED research into SMM exhibits is well articulated. Similar integration of research into education needs to be mirrored within the diversity initiative, or better articulated if such integration exists. This integration needs to move beyond the discussion of curriculum development and should explain how culture has been considered in translating NCED research into materials and experiences for diverse audiences.

The potential exists for stronger connection with education and diversity researchers, and with literature related to education research on water, environmental, and Earth systems science. The addition of science educator Gillian Roehrig as a PI is an important step in making stronger connections to the research community. The most often articulated goal for this new collaboration is the transformation of NCED products into materials that can be distributed to a broader science education community. The NCED diversity and education directors also recognize the value that education research can provide to learning assessment. Additional incorporation of education research can open NCED to opportunities and grants that are currently inaccessible.

**SUSTAINING THE CORE WORK OF NCED**

**The NCED Vision**

The NCED leadership team has given considerable thought to the question of how their collaborative and interdisciplinary research will continue beyond the end of the NSF STC funding in 2012. Concrete steps have been taken to realize their vision of continuity, and more actions are planned.

It is clear that the NCED leadership has collectively discussed the center’s future, and the articulated vision seems to be consistent among the team members. In their view, the quality of research into Earth-surface dynamics will suffer if they cease to work together as an integrated research network.

The NCED leadership believes that the level of interdisciplinary integration that has been achieved in NCED is a valuable resource to the U.S. research community. They are dedicated to maintaining the momentum that
they have already achieved. This sentiment is inclusive of the education and diversity efforts.

The leadership team does not feel that their message is stale. In the 10 years since they created NCED, themes of considerable societal importance have emerged that directly concern water and landscape. These include climate change, sea level rise, rising stream flows as a part of hydrological change, and land-use for energy production (i.e., wind; biofuels). They see these as core opportunities for devising a new vision for post-NCED collaboration that remains focused on creation of a new predictive Earth-surface science that is based on the integration of the various dynamic systems.

NCED is not ramping down from most ongoing activities, though they are narrowing the focus to completion of the goals set for NCED. Nevertheless, they continue to bring in new graduate students, assuming that they will leverage the NCED initial funds with long-term alternative funds to sustain the student programs. The University of Minnesota has promised bridge funding to NCED for three years past the NCED sunset.

Assessment of the Appropriateness of NCED’s Vision

Overall, the SVT recognizes the NCED leadership’s desire to continue as a unified team. The planning and accomplishment of steps to achieve this end are signs that the NCED investment will pay off into the post-2012 future. The community needs the sort of leadership that NCED has shown.

In order to ensure sustainability of positive NCED outcomes, we recommend that over the next two years:

1. NCED engage the community of researchers in town hall meetings to discuss vital breakthrough research in Earth-surface dynamics, as well as organizational structures required to carry out this research.
2. NCED should continue to implement their plan to ramp down NSF support while simultaneously finding other mechanisms for funding new initiatives.

In summary, after eight years NCED shows the maturity commensurate of an STC that should pay off over the next two years. The SVT is encouraged by NCED’s plan for future sustainability and legacy.
The NCED team greatly appreciates the insightful review by the site visit team (SVT) of our accomplishments and our vision to sustain NCED beyond NSF funding. The report succinctly summarizes the role that NCED has played in the community (in leading the new field of ecogeomorphology for terrain-based predictive modeling), the transfer of science to end-users for restoring human-impacted systems, the training of the next generation of leaders, and the unique and successful education and diversity programs that NCED has established. Below we provide a brief reply to suggestions made in the report.

LEGACY
We are pleased with the SVT comment that “the quantitative and predictive nature of NCED’s approach will serve as a template for future research” and that “NCED’s imprint is ubiquitous at professional meetings and many graduates of our program are emerging leaders”. It takes a sustained center-model of operation to make such an impact.

Regarding Legacy opportunities, we appreciate your forward looking comments. Towards this end: (1) NCED is increasing its visibility and impact in the restoration of coastal environments (sea level rise and human impacts, including the recent oil spill). (2) We feel that our engagement with the ecological community is very strong already but there is always room for more: we will explore in the coming year more visible engagement (possibly via a special volume in an ecological journal, or special sessions in other than AGU meetings). (3) We are pleased that the SVT applauded our recent addition of a new NCED PI in the education sciences (Gill Roehrig). We have already submitted two collaborative proposals with Gill and new ideas are developing for furthering NCED’s research into curricula development; and (4) International presence is important to NCED PIs and accelerated efforts for formal and informal collaborations will take place in the coming year.

KNOWLEDGE TRANSFER
Thank you for recognizing the special effort and strategy of NCED in translating our science into predictive tools that can be used for decision making in restoration practice. We believe our extensive effort in this regard will be well represented by some of our deliverables (Stream Restoration Decision Analysis and Guidance Tool, Delta Building Manual, GeoNet, Ripple, Stream Restoration Toolbox).

The idea to utilize the awareness that NCED has built by working with Native Americans to influence decision and policy making is a great one and one that we will consider seriously over the next year. The addition of a new NCED PI who is a researcher and a Native American teaching in a tribal college will provide an even closer connection between our core science and the diversity initiative. The NCED-led 1st Water Resources Science degree program in a tribal college (to initiate in the Fall of 2010) should provide an important opportunity to influence water resources management and policy on tribal lands.

We appreciate the comment to disseminate more broadly lessons learned from NCED’s successes with the SMM (Science Museum of Minnesota) and the FDTCC (Fond du Lac Tribal and Community College) and we plan to do so. We are especially sensitive to the sustainability of our data and models beyond 2012 and plans to assimilate them within CSDMS (Community Sediment Dynamics Modeling System) are under way. An NCED synthesis post-doc (Enrica Viparelli) has been appointed as the NCED-CSDMS liaison and efforts to transit our data and models to CSDMS will accelerate over the next year.
EDUCATION AND DIVERSITY

The unique education and diversity programs that NCED has developed are reaching not only the nation (via the SMM and the new Geosciences Alliance initiative) but the whole world (via traveling exhibits). Our emphasis this year on new media (short movies, Facebook and Youtube) have increased our web site visibility (close to 90,000 visits during the last year only).

Regarding suggested opportunities, we believe that the integration of NCED research into the diversity initiative is very strong already and parallels that of our education initiative. Addition of a new NCED PI (Antony Berthelote, Hydrology Instructor at Salish Kootenai College) is an innovative and effective way to further accelerate this integration. The same applies for the integration of research and education with the addition of the new NCED PI (Gillian Roehrig). We are happy to see that the SVT appreciated the establishment of these two new collaborations and recognized that they will open opportunities for new grants in education and diversity research in the Geosciences.

SUSTAINING THE CORE WORK OF NCED

We are pleased that the SVT clearly saw that NCED researchers have a strong desire to continue the NCED vision beyond the NSF STC funding period and capitalize on the momentum that has grown into a coherent approach to predictive earth surface dynamics, as well as the development of new experimental and field integrative sites that are an asset to the whole community. We recognize that problems related to “earth's surface environment” (interaction of water, earth, biota) are amplifying in the years to come, rather than diminishing. Finding sustainable solutions to those problems requires sustained, collaborative and interdisciplinary work along the lines that NCED has pioneered.

Over the next two years, NCED will accelerate its efforts to engage the broader community by instigating/organizing forums to identify research opportunities and gaps across disciplines and between science and engineering. At the same time, we are strategically engaging members outside NCED to form teams that can build on NCED's interdisciplinary research and research infrastructure and propose integrative efforts on problems of critical societal importance, as amplified by climate change and anthropogenic influences.
INTRODUCTION

Global Climate Models predict changes in precipitation in a watershed.

*How will this affect key watershed properties like sediment yield and fish populations?*

Millions of dollars are invested annually in efforts to restore engineered streams.

*Will the restorations achieve their goals?*

Land loss in the Mississippi Delta threatens increasing exposure of population centers like New Orleans to hurricanes.

*Can the Delta be rebuilt?*

Addressing these socially relevant questions requires a sophisticated, cross-disciplinary understanding of the dynamics of the Earth’s surface (the “critical zone”).

*The National Center for Earth-surface Dynamics was created to provide this understanding.*
**NCED’s PURPOSE**

NCED’s purpose is to predict the coupled dynamics and evolution of landscapes and their ecosystems, in order to transform management and restoration of the Earth-surface environment.

**NCED’s MISSION**

NCED is a partnership of research and educational institutions, government agencies, and industry that pursues its goal of predictive Earth-surface science by integrating physical, biological, and social sciences. Our research mission is to provide the science needed for landscape prediction and restoration. We achieve research synthesis by focusing on a fundamental component of the Earth-surface system—channel networks and their surroundings—that recurs in varying but fundamentally related forms across a wide range of environments and scales. We collaborate in the application of our research with partners to identify knowledge gaps and develop tools to forecast landscape dynamics, guide landscape management, restore river and deltaic systems, and promote environmental awareness. NCED shares the excitement of landscape science with a diverse community, exchanging perspectives through partnering, nurturing, and interacting in formal and informal education settings.

The overall question driving NCED’s research program is: How will the dynamics of the coupled processes that shape the Earth’s surface—physical, biological, geochemical, and anthropogenic—respond to climate, land use, and management change?

This overall question implies four major tasks:

1) Develop material flow and conservation laws appropriate for Earth-surface prediction on event to centennial time scales and areas comprising single processes to whole channel networks;

2) Quantify, via experimental, theoretical, and field work, key physical-biological-geochemical interactions and their role in shaping Earth’s surface;

3) Understand the origin and structure of channel networks and other forms of landscape self-organization, and develop techniques to use landscape structure to improve prediction; and

4) Link understanding of human preferences and decision-making with Earth-surface modeling to optimize environmental management and restoration outcomes.

To address these overarching tasks, our research is organized into three Integrated Programs (IPs), each focused on a major landscape component: watersheds (“Watersheds,” formerly “Desktop Watersheds,” IP), individual stream reaches (“Streams,” formerly “Stream Restoration,” IP), and depositional systems and associated subsurface records (“Deltas,” formerly “Subsurface Architecture,” IP). All three IPs include important issues of human impact, management, and restoration such that progress requires two-way collaboration between those developing new knowledge and those applying it. Our Knowledge Transfer, Education, and Diversity programs, together with the three research IPs, comprise the six primary initiatives by which all NCED activity is organized.
NCED’S PRIMARY INITIATIVES

1. Desktop Watersheds (Watersheds) (DW) Integrated Program

Motivation: Digital topographic data offer the possibility of building watershed-scale numerical models of real landscapes to explore problems ranging from the long time-scale controls on landscape evolution to short time-scale response of aquatic ecosystems to land-use change. Such modeling efforts are inhibited, however, by a lack of knowledge and quantitative expressions for many of the fundamental geomorphic and biotic processes. Closure of this knowledge gap and introduction of new theories and approaches by NCED and collaborators will lead to discoveries about landscape evolution, and to the construction of practical numerical models that will revolutionize land-use management and environmental forecasting. NCED’s unique breadth of researchers, experimental facilities, and field programs enables it to assume this leadership role.

Goal: To discover and advance the fundamental relations needed to predict landscape evolution and to model the coupling of ecosystem, landscape, and land-use dynamics.

Approach: High-resolution digital topography provides the template for Watersheds modeling. To unlock the potential of digital topography, we introduce new theories, propose new analytical approaches, conduct innovative experimental studies, and perform intensive field studies to discover, parameterize, and evaluate the fundamental driving equations. Our findings are made available to others to improve watershed-scale numerical modeling across the community. We use our current digital-terrain based models (prototype Desktop Watersheds), to guide prioritization of research and maintain a tight coupling between modeling and observation. In their simplest form, in which the topography is used to estimate such features as biological productivity, probable landslide location, channel morphology or bed grain size, Desktop Watersheds models can provide a relatively parameter-free prediction of landscape attributes useful in guiding field work and in applications such as planning timber harvests and stream restoration projects. The advances from the new research will lead to the ability to model cumulative watershed effects, controls on total maximum daily load levels of sediment, and to “game” management scenarios in order to optimize land-use activities for ecosystem protection and restoration.

Science questions: (1) What is the topographic signature of tectonic, climatic, and other external forcings on watersheds? (2) Where in the landscape do ecological regimes change, what factors cause these changes, and how would the locations of these ecological boundaries shift under altered climate, land use, or biological states? (3) How does the physical organization of the landscape provide a template for organization of the ecologic and channel-scale processes in the watershed? (4) Do biotic processes influence large-scale topographic form? (5) How predictable is landscape evolution, what are the principal sources of uncertainty, and how does uncertainty influence decisions about landscape management? (6) What are the driving equations of landscape evolution and how can they be scaled up temporally and spatially? (7) What are the long-term environmental consequences of various approaches to land use, and what public priorities and decision processes control which approaches are used?

2. Stream Restoration (Streams) (SR) Integrated Program

Motivation: The stream restoration program is motivated by the collision of social demand for stream restoration with a limited understanding of stream disturbance and restoration dynamics. The science basis for stream restoration is weak, the success of existing projects is poorly known, and the connection between research and practice is poorly developed. Progress requires a two-way collaboration between those developing new knowledge and those applying it.

Goal: To advance the science and practice of stream restoration by conducting and coordinating research and by working with agency and industry partners to identify information needs, develop improved tools, and transfer this knowledge into practice.

Approach: Together with agency and industry partners, we examine stream restoration practice, its scope, details, and missing links, so that we can define the most pressing research priorities and determine the best ways to get new information to those who use it. By combining expertise in biological, physical and social sciences with a research focus spanning the space and time scales needed to characterize stream disturbance, NCED is well placed to develop the integrated knowledge needed to improve the practice of stream restoration. By its position – affiliated with, but separate from both government and industry – NCED can define problems, propose solutions, and provide continuity and coordination without the constraints that can restrict those advocating, regulating and conducting restoration practice.
Science questions: (1) How can we determine resilient, dynamically stable channel bed, cross section, and planform characteristics in terms of water and sediment supply? (2) How do stream morphology and riparian vegetation influence the structure and function of the fluvial ecosystem and how can these be manipulated for ecological benefit? (3) How can we extend grain-scale understanding to the reach and network scale in order to better predict water and sediment supply and place restoration projects within their watershed context? (4) How can we estimate natural stream variability and incorporate variability and uncertainty in restoration design? (5) How can societal restoration objectives be more effectively identified and combined with physical and biological models in predictive restoration design?

3. Subsurface Architecture (Deltas) (SA) Integrated Program

Motivation: As channels evolve under conditions of net deposition, they leave records of the natural variability of the surface and of its response to imposed changes. These records provide insight on how depositional systems organize and maintain themselves in the absence of human interference. “Reverse engineering” the stratigraphic record to extract this information requires an understanding of the complex, nonlinear processes by which surface dynamics is encoded into 3D stratal geometry. In the course of this, we also provide insight that can improve prediction of variations in the distribution of porosity and permeability that control the flow and accumulation of water, oil, and gas in the subsurface. These variations in porosity and permeability also set the spatial patterns of mechanical compaction that control land subsidence and influence the ecology of lowland settings.

Goal: To use information from modern systems, experiments, and stratigraphic records to develop a predictive understanding of delta evolution, and apply this understanding to delta restoration.

Approach: The theme of the Deltas Integrated Program is “surface to subsurface”. Extracting information from preserved deposits entails understanding how surface channel properties, spatial patterns, ecology, and temporal evolution interact with net deposition to create the architecture of sedimentary deposits. The main field area for the Deltas IP is the Mississippi Delta. Natural channel systems evolve slowly, so the Deltas IP also relies heavily on experimental research that, in effect, speeds up time and complements field and theoretical studies.

Science questions: (1) How can we extract quantitative information on the rates, spatial pattern, and variability of transport and depositional processes from preserved strata? (2) How do low-lying depositional systems respond to external changes such as changes in sediment supply, channelization, differential subsidence, and rising relative sea level? (3) How do depositional channel networks self-organize, and how does spatial organization influence delta evolution? (4) How does biota influence depositional processes and depositional environments? (6) How can stratigraphic information on natural variability and channel-system response to change be used to inform environmental management? (7) How can social and natural science tools be combined to develop a quantitative adaptive analysis approach for planning that projects social response to, and benefits of, coastal restoration, including uncertainty, learning, and social values?

4. Education (ED)

Motivation: The familiarity and natural appeal of landscapes and the methods of NCED’s integrative research approach provide rich opportunities to excite students about science and encourage them to pursue careers in many areas of science and policy.

Goal: To bring Earth-surface dynamics to life for a broad spectrum of learners, in order to educate future leaders in NCED’s key mission areas of land, resource, and ecosystem management.

Approach: NCED uses the familiarity and natural appeal of landscapes to promote active learning about critical concepts: (1) that the Earth’s surface is “the environment” in which human, ecologic and physical dynamics are intimately interwoven; (2) that the Earth’s surface is naturally dynamic; and (3) that the landforms we see around us – whether from the ground, from the air, or via maps and 3D imagery – tell us about what the Earth’s surface is doing and how it has evolved.

At the graduate level, NCED engages students across Center institutions in integrative research and unique center-based activities, such as video-conferenced seminars, joint advising, integrative seminars and short courses, retreats, museum assistantships and internships with Partners. At the undergraduate level, NCED engages students within and outside NCED institutions in research experiences and infuses the methods, perspectives and results of NCED research into undergraduate coursework. At the K-12 level, NCED engages pre- and in-service teachers in research experiences and field-based institutes, develops
teaching materials to supplement K-12 curriculum, brings experimental research to classrooms, and conducts environmental camps at middle- and high-school levels. NCED engages the public in NCED research through innovative museum experiences, such as outdoor parks and traveling exhibits, and media, such as films and television programs.

5. Knowledge Transfer (KT)

**Motivation:** NCED has a strong commitment to creating new insights and tools relevant to Earth-surface science. We have an equal commitment to communicating and disseminating our science, insights and tools to our stakeholders and the public.

**Goal:** Create and maintain collaborations among NCED, our science stakeholders, and the broader community in order to insure that NCED research is informed by the greatest societal needs and the insights and tools that NCED produces are incorporated into practice in a significant way.

**Approach:** NCED’s knowledge transfer activities are integrated into the three research IPs. To inform our research, we establish a Science Partner Group for each IP: appropriately selected practitioners committed to informing research and advancing practice. Through regular interaction with Science Partner Groups each IP establishes avenues for open communication and exchange of research needs and new knowledge. The major export of NCED knowledge and tools is through our Application Working Groups: long-term, collaborative research relationships involving NCED researchers and subsets of our science partners. Application Working Groups are focused, interdisciplinary research efforts that combine NCED expertise with science partners from industry and agencies on important problems involving fundamental science and application. Application Working Groups represent a coupling of NCED science and application through collaboration between researchers and practitioners and provide a highly efficient means for NCED research to be incorporated into practice. Beyond our partner activities, we have established a website that serves as a repository of information, tools, data, images, and a platform for information exchange for the Earth-surface science community. We also impact our community through education and training programs. This includes workshops and short courses.

6. Diversity (DV)

**Motivation:** NCED’s research mission is enriched by the inclusion of diverse voices. The environmental sciences have generally underperformed other areas of science and engineering in minority representation. For long-term success, efforts must be made to interest minority students in the sciences at an early age, and to sustain that interest over the course of their educational careers. To achieve this, NCED must itself be a model of a diverse research and learning community.

**Goal:** Increase participation by underrepresented groups in NCED scientific disciplines until minority representation is continuously reflective of the US national population. This includes an immediate improvement in participation by members of all under-represented groups in NCED itself, and a specific focus on improvement in representation of Native Americans in NCED-related disciplines.

**Approach:** NCED actively pursues research collaborations with faculty from institutions with high minority enrollments, and particularly with Tribal Colleges, to spread the excitement of NCED research beyond the boundaries of our institutions. NCED provides research experiences for underrepresented undergraduate students so that they can engage in field and laboratory experiments and gain the desire to be research scientists. NCED networks with local communities in order to immerse youths in science so that they can discover and gain necessary skills for pursuing careers in science, technology, engineering, and mathematics.

**RESEARCH FOCUS AREAS**

Research Focus Areas group investigators by common interests and skills. They inform each of our Integrated Programs and provide an important vehicle for the cross-disciplinary collaborations necessary for transformative advances:

1. **Channel Network Dynamics and Scaling:** The spatial structure of landscapes provides an organizing template for many of the hydrologic, geomorphic, and ecologic processes that occur on them. This spatial organization, often manifested through self-similarity and scaling, provides one of NCED’s major unifying themes. This Focus Area seeks to understand the space-time organization of channel networks, including morphology, hydrology, and ecology.
2. **Channel and Floodplain Dynamics:** Channel and floodplain dynamics encompasses the local “unit processes” by which channels and their associated floodplains evolve, and as such forms the natural complement to the Channel Network Dynamics and Scaling group’s focus on network-scale behavior and properties. This Focus Area works to understand the flux and morphodynamic laws governing channel and floodplain evolution.

3. **Advanced Mathematical and Observational Methods:** The complexity of the surface environment – space and time scales spanning many orders of magnitude, strong nonlinearity, spontaneous pattern formation, and strong coupling between physical and biological processes – is a major reason why study of it has remained descriptive for so long. Transformation of surface process science requires infusion of advanced techniques in quantitative analysis and observation that can address these complexities. This Focus Area identifies and develops effective mathematical and observational techniques for analysis of channel systems, including localization, scaling, instability, and the coupling of physical and biological dynamics.

4. **Ecogeomorphology:** The physical structure of the landscape provides an organizing template for life, influences habitat quality and diversity, and controls inputs, production, transformations and fluxes of materials, energy, and organisms. In turn, organisms shape the landscape through microbial weathering, mixing, dilation, and diffusion of soil, flow baffling, and the stabilization of bars, banks, and floodplains. This Focus Area investigates interactions of physical, biologic and biogeochemical processes in channels and floodplains.

5. **Long-term Dynamics:** Planetary time and space scales are the arena in which slowly changing variables such as topographic long profile and overall sediment budget are determined; these in turn control channel evolution on shorter time scales. This Focus Area seeks to understand and model the behavior of channels and channel systems on planetary (geologic) time scales.

6. **Human Dynamics:** The “fingerprint” of human influence extends across nearly all aspects of Earth-surface dynamics. Thus it is essential that we understand how humans make decisions that affect landscapes. This Focus Area integrates multicriteria decision analysis methods and economic valuation methods to develop a more comprehensive decision-making framework for landscape management.

**RESEARCH ORGANIZATION AND EVOLUTION**

NCED’s Integrated Programs represent priority applications of our core channel-system research that are: (1) scientifically compelling, (2) broad and cross disciplinary, but also (3) focused enough to allow for measurable progress each year and major progress over several years, (4) societally relevant, and (5) integrative in terms of our core scientific expertise. In particular, all three IPs capitalize on NCED’s strength in combining field, laboratory, and theoretical approaches.

The three Integrated Programs provide a natural means of establishing goal sets and work clusters that are intermediate in scale between broad, long-term goals and day-to-day research tasks. Thus they serve to maintain a clear “line of sight” between individual research activities and the center’s overall mission. They provide natural pathways for synthesis across the six Research Focus Areas. Each Integrated Program is led by a project leader who, together with NCED management, establish priorities and targets for work on the IP.

The Integrated Programs have evolved over time. They have been and will continue to be evaluated in terms of their scientific importance, societal relevance, and appropriateness for NCED. To insure that we remain open to new possibilities for growth, we will also initiate small research programs in areas that are possible targets for future work and/or high-risk but potentially high-return topics consistent with our mission but outside our current IP structure.

**IMPLEMENTATION PLAN**

NCED’s three research Integrated Programs are organized around NCED’s goal of providing tools for landscape restoration and prediction, building on our core science: the dynamics of channels and channel networks. This common goal and scientific core across scales and environments is the primary vehicle for integration and synthesis of NCED research. It provides a network of pathways for cross-fertilization and the application of theoretical ideas, observational techniques, and research findings across apparently disparate fields. Thus the primary way we achieve center-scale research synthesis is by applying common concepts and methods across Integrated Programs. Our second approach to achieve synthesis is to insure that each IP can incorporate and build on results from the other IPs.
Common research concepts and methods that link and energize the IPs include: recurring structures, such as tributary and distributary networks, incisional valleys, cyclic steps, and scour-lobe couplets; common processes such as channel meandering and braiding, bedform dynamics, channel-floodplain interaction, and avulsion; scaling and self-similarity; biological-physical coupling; self-organization and pattern formation; stochastic behavior and uncertainty; mapping for prediction; and humans as geomorphic agents. In many cases, experiments are particularly useful in clarifying the essential dynamics of these common processes. In addition, we seek ways in which IP results build on each other. Examples include: using Watershed models to provide the landscape context for stream restoration; making source-to-sink connections from watersheds and individual stream channels to downstream depositional systems; and using stratigraphic results to understand long-term trends and variability in sediment yield and channel dynamics.

NCED’s center structure adds value by promoting synergy and common themes among its education, knowledge transfer, diversity and research activities. Our strategy for promoting synergy across all Center initiatives is analogous to that for promoting synergy across our research: we seek common themes that cut across multiple initiatives; and we seek ways that results from one initiative can feed and energize other ones.

At the end of Year 10, NCED will have provided a set of scientific tools that can be used to guide land-use decisions, aid in restoration design, and predict landscape response to imminent changes such as rising sea level and changing climate. By demonstrating the predictive power of combining the disciplines that contribute to understanding the Earth’s surface – the “critical zone” – NCED will have transformed both Earth-surface science and environmental management.

1. Watersheds

Implementation Approach: We tackle the essential elements, listed below, needed to build Desktop Watershed models through theory building, modeling, experimentation, and fieldwork. Initial focus is on steep, relatively rapidly eroding landscapes, and fieldwork is concentrated on the Angelo Coast Range Reserve (ACRR), in the Eel River basin, California. We will build from a static form of the Desktop Watersheds model, in which fixed topography and steady state fluxes are used to estimate environmental properties, to a dynamic form in which solutes and sediment are routed from hillslopes through channel networks, and ecosystems respond to changing environmental conditions.

2. Streams

Implementation Approach: NCED research addresses three key areas of stream restoration practice: watershed context for evaluating and locating restoration alternatives, predictive relations for the physical and ecological response of stream channels to project actions, and decision making methods incorporating improved information, predictive methods, and uncertainty. To define watershed context, methods from the Watersheds IP are applied to identify favorable locations for restoration actions and to define effective and sustainable actions at proposed project sites. We focus on mechanisms connecting the project site to its watershed via the supply of water, sediment, and nutrients. Project planning and design requires predictive relations for stream composition and configuration. NCED research focuses on the physical components of streambed and channel geometry and their interaction with the fluvial ecosystem. As the ability to predict landscape and restoration dynamics improves, we must also anticipate the challenges to putting these tools to work. Our goal is a professional practice in which project goals are predictive targets quantitatively linked to public preference, regulatory and policy guidelines, and management actions. Our focus on transforming stream restoration practice also leads to an emphasis on training, which is discussed in the Knowledge Transfer section.

3. Deltas

Implementation Approach: The Deltas program applies NCED’s integrated, predictive approach to understanding controls on the permeability and porosity structure of channel-related sedimentary deposits in lowland settings, taking advantage of current intensive interest in land loss in coastal zones due to subsidence by deposit compaction, as well as interest in locating and developing subsurface fluid resources. The overall approach is to adapt techniques from geomorphology, hydrology, and engineering to quantitative stratigraphic prediction, and in turn feeding back information on long-term trends and variability to environmental management. To provide additional focus and connect the Deltas IP with stream restoration and the Streams IP, we have developed the Wax Lake Delta as our depositional field site in coastal Louisiana.
to floods versus cyclonic storms, and how vegetation moderates these patterns. As well as on the nearby Atchafalaya Delta, are providing constraints on sediment transport processes in distributary networks. Measurements collected at WLD, as most active, and least interfered-with, land-building sites in the Delta. WLD provides an ideal prototype area for studying how natural processes build new wetlands and coastal forest in the Gulf Coast region. Wax Lake Delta (WLD), an area roughly 40 km² that has been building since the 1970s through an accidental river diversion. It is one of the most active, and least interfered-with, land-building sites in the Delta. WLD provides an ideal prototype area for studying how natural processes build new wetlands and coastal forest in the Gulf Coast region. Measurements collected at WLD, as well as on the nearby Atchafalaya Delta, are providing constraints on sediment transport processes in distributary networks. Data collected from WLD is also used to resolve characteristic patterns of sediment deposition and erosion on wetlands due to floods versus cyclonic storms, and how vegetation moderates these patterns.

Angelo Coast Range Reserve: Early in Year 2, we selected Angelo Coast Range Reserve (ACRR) in the rugged, rapidly uplifting Coast Range of northern California as our primary erosional field site. The ACRR is located in the South Fork of the Eel River, about 3.5 hours by car from the UC Berkeley Campus and the San Francisco or Oakland airports. The entire study area is protected from unrestricted public access by a gated road, which provides easy transportation of material and equipment to field sites. Co-PI Mary Power is the Faculty Manager of this University of California Natural Reserve System Preserve. Various buildings and outbuildings on the reserve are available for year-round housing, laboratory use, and equipment storage. A new $1.4M Environment Science Center includes two large laboratories (with ovens, muffle furnace, fume hood, and extensive workspace), a computer lab and DSL connectivity to all rooms where sensors can be calibrated etc., an herbarium, and a facility providing access to the canopy of old growth redwood and Douglas fir trees along a river-to-ridgeline gradient. In collaboration with fellow STC the Center for Embedded Network Sensing (CENS), we have constructed a wireless network at ACRR. The network supports automated environmental light, temperature, tropospheric ozone, and soil moisture sensors, plus imaging for algal blooms and acoustic detection of bats. We currently have 1,238 sensors installed in ACRR, the data from which are collected on wireless networks and stored and distributed through a UC Berkeley campus data repository. Recently acquired LiDAR also supports analysis of relations between network structure and habitat, local channel properties, and vegetation as discussed above under the Watersheds IP.

Le Sueur River Watershed: In 2008 we established the Le Sueur River Watershed (LSRW) field site, located in southern Minnesota, in an effort to study sediment dynamics on a watershed scale with direct implications for sustainable watershed management and policy. The LSRW has been implicated as a primary source of sediment to the Minnesota River and Lake Pepin, a naturally dammed lake on the Mississippi River. The Le Sueur River, Minnesota River, and Lake Pepin are all impaired for turbidity under Environmental Protection Agency standards in the Clean Water Act Section 303d. The Le Sueur watershed represents a rare opportunity to study fundamental processes in landscape evolution as well as the effects of pervasive, mostly human, modifications. Catastrophic drainage of glacial Lake Agassiz through the Minnesota River 11,500 years ago caused a steep gradient, or knickpoint, to develop at the mouth of the Le Sueur. That knickpoint has rapidly propagated 35km upstream in the Le Sueur and its two primary tributaries. In the wake of the knickpoint, steep bluffs and ravines have developed, connecting the flat uplands with the incised river. The record of incision has been preserved in the strath terraces that are ubiquitous within the incised valley. The landscape of the LSRW enables us to study processes of knickpoint propagation, bedrock incision, strath terrace formation, floodplain development and channel morphodynamics in such a way that is typically only possible on a smaller scale in physical experiments in a laboratory. Additionally, sedimentation rates in Lake Pepin have increased approximately ten fold in the past 170 years since the onset of extensive agricultural land use in the area. The recent human modifications to the ecology, geomorphology, and hydrology of the system present new opportunities for studying the effects of anthropogenic landscape modifications.

Wax Lake Delta: NCED’s transdisciplinary approach, emphasis on prediction, and status as an independent national research center make it ideally suited to provide predictive understanding and tools to support restoration of the Mississippi Delta, an issue long recognized as fundamental to protecting New Orleans and the Gulf Coast from hurricanes. From its inception, NCED’s plans have included a center-wide initiative on restoration of the Mississippi Delta. As our research program has evolved, we have continued work on this initiative to develop a second, depositional field site in the Delta region that would be of societal benefit and also link our Streams and Deltas Integrated Programs. The overall goal is to combine studies of the modern delta with quantitative reconstruction of the behavior of the delta in the past to provide predictive tools that can be used to evaluate the complex scenarios involved in large-scale reconstruction of lost delta surface. Because of the large size of the Mississippi Delta, we have chosen a specific field site within the delta system for detailed work: Wax Lake Delta (WLD), an area roughly 40 km² that has been building since the 1970s through an accidental river diversion. It is one of the most active, and least interfered-with, land-building sites in the Delta. WLD provides an ideal prototype area for studying how natural processes build new wetlands and coastal forest in the Gulf Coast region. Measurements collected at WLD, as well as on the nearby Atchafalaya Delta, are providing constraints on sediment transport processes in distributary networks. Data collected from WLD is also used to resolve characteristic patterns of sediment deposition and erosion on wetlands due to floods versus cyclonic storms, and how vegetation moderates these patterns.
4. Education (ED)

Implementation Approach: NCED adopts a broadbrush approach to education, targeting informal as well as formal learners, and emphasizing strong connections between research and education programs. Key elements of our Education Initiative include:

1. Work intensively with the Science Museum of Minnesota (SMM) and other science museums to develop engaging new methods for informal education centered on Earth-surface dynamics and environmental awareness.

   1.1. Work with the SMM to develop engaging new methods and experiences for delivering NCED-related science to the Museum’s annual audience of 800,000 visitors.

   1.2. Work with the SMM and the American Museum of Natural History to incorporate both new and existing NCED-related science exhibit components into a major new national and international traveling exhibition about water.

   1.3. Work with the SMM and five other geoscience-oriented, NSF-supported Science and Technology Centers to develop collaborative means by which the research and science of all six STCs can reach larger informal science education audiences.

   1.4 Work with the SMM and the University of Illinois’ Electronic Visualization Laboratory to advance the use of scientific visualization technologies to communicate NCED-related science to both formal and informal science education audiences.

2. Enhance the education of NCED student participants by providing unique opportunities and an extended, cross-disciplinary peer and mentor network.

3. Develop a new, practice-oriented program in Stream Restoration that will help advance training in restoration as well as attract a broader student population into NCED areas, including students who are not intent on research careers.

4. Adapt research tools such as 3D visualization, wireless sensors, and laboratory experiments to provide novel K-16 educational tools.

5. Design programs to engage science teachers in NCED research in ways that allow them to bring this knowledge to their students in practical ways, and share the products of this work via the NCED website.

5. Knowledge Transfer

Implementation Approach: Knowledge transfer programs are incorporated into NCED’s research Integrated Programs. Each research IP has specific KT activities designed to support the goal of establishing two-way exchange between research and practice. The following elements are common to our approach to knowledge transfer across the IPs:

1. Establish regular communication between NCED and Science Partner Groups for each IP area.

2. Provide opportunity for collaborative research between NCED and non-NCED researchers within each IP through joint research, the Application Working Groups (AWG) program, the Faculty to Faculty program, and the Visitor Program.

3. Develop website and electronic newsletter content for each IP including recent research products (articles, data, technologies, software), links, and future directions.

4. Conduct application-oriented certificate programs, short courses and workshops at NCED facilities and other locations.
As part of NCED legacy planning, metrics are established to track impacts of NCED Research on stakeholder practice. This evaluation focuses on tracking process and impacts of established Application Working Groups (AWG). AWGs are working groups of NCED and non-NCED researchers focused solving critical projects within the IPs. AWGs have the following elements in common: 1) they require multidisciplinary, fundamental science, 2) They address important applied needs, 3) They involve close collaboration and joint research with NCED researchers and federal, state and industrial partners. Application Working Groups represent a coupling of NCED science and application through collaboration between researchers and practitioners and provide a highly efficient means for NCED research to be incorporated into practice.

6. Diversity

Implementation Approach: NCED uses the intrinsic appeal of landscapes and surface dynamics to engage diverse communities in the study of Earth-surface science at all levels, and to attract diverse participants into its research programs. Key elements in our approach are:

1. Use a vigorous Undergraduate Summer Internship Program to bring upper-level students from underrepresented groups to NCED facilities to participate in research on NCED topics.

2. Develop a Faculty-to-Faculty program to build research ties to faculty from schools with large minority enrollments, particularly Minority Serving Institutions (MSIs). Identify faculty at MSIs who work in NCED research areas and bring faculty with their students to NCED as visiting researchers, to participate in conferences and workshops, and to speak at seminar series.

3. Work with and support efforts by NCED participating institutions, STC partners, and other broader efforts to recruit and fund students from underrepresented groups into NCED-related graduate research.

4. Use the NCED certificate program in Stream Restoration Science and Engineering to provide an additional gateway to NCED graduate programs.

5. Increase the number of potential future recruits by collaborating with local communities, including the Fond du Lac Reservation, to provide Native American youth science enrichment and immersion programs, including seasonal camps and after-school activities.

6. Use the Youth Science Center at the Science Museum of Minnesota, especially the Big Back Yard Park Crew, to team underrepresented youths with faculty and graduate student mentors from NCED and to create NCED-based hands-on activities.

Legacy

NCED is now working to establish a substantial and long-lasting legacy. Here we lay out strategic legacy goals for the center as a whole and for our six primary initiatives.

Scientific transformation

NCED’s purpose is to catalyze the development of an integrated, predictive science of the processes shaping the surface of the Earth. Attaining this goal implies a permanent transformation in Earth-surface science toward a more integrated, predictive approach. Thus the fundamental center-wide component of NCED’s legacy is tangible, community-wide changes in the nature of research in Earth-surface dynamics. The metrics for this most important aspect of our legacy are: (1) changes in existing national research programs in the direction of our goal of integrative, predictive surface science, (2) development of new national research programs reflecting our goal of integrative, predictive surface science, (3) development of new infrastructure dedicated to NCED-style integrated Earth-surface research.
Research legacy: Integrated Projects

NCED’s research is organized around three interlocking Integrated Programs (IPs), described in detail throughout this document. There are thus legacy components associated with each IP:

Watersheds: The legacy of Watersheds will be a quantum step in the scientific basis for analyzing and predicting the fate of watersheds in an integrative manner, especially coupling ecology, landscape dynamics, and human effects. The tangible face of this is the Desktop Watersheds application program, which embodies, in a continuously updated and adaptive manner, our evolving predictive understanding of how landscape systems work. The Watersheds program forms the centerpiece of an ongoing dialog among planners, decision-makers and researchers that we are confident will continue after NCED’s sunset. Ripple, a digital terrain based model for limiting factors analysis of Coho salmon populations, is already being applied to watersheds over much of California as well as in Alaska. We believe Ripple and its descendents will become one of the standard tools nationally for watershed prediction and management.

Streams: The legacy goal of the Streams program is to transform stream restoration from a template-based practice to a professional practice in which objectives and predictive methods are quantitatively linked in a rational design framework. The Streams program focuses its research in areas in which improved knowledge will most immediately improve practice: watershed context, predictive relations for channel design, and incorporating improved knowledge in the decision-making process. A primary legacy of this research will be methods and tools for evaluating and designing stream restoration projects, as outlined in a Stream Restoration Decision Analysis and Design Guidance document and accompanying software that will define and implement a rational, objectives-driven approach to evaluating and designing stream restoration projects. Close collaboration with research and training partners in universities and government agencies broadens our reach and helps to shift the culture of stream restoration to one in which research, training, and practice are closely linked in an active, professional network. A transformed stream restoration practice will be supported by research leading to improved understanding and development of practical tools, but will also require a change in culture and expectations of those in practice. The NCED role in implementing this transformation takes a variety of forms, from tool development and dissemination through short courses, degree programs and the NCED web site; collaboration on improved methods and design guidelines with research and training partners; and the establishment of a regional stream restoration conference in the Midwest. A major implementation focus is the newly funded demonstration project in the Minnesota River Basin.

Deltas: In its original configuration, the Deltas IP was focused on improving prediction in the subsurface. Its primary application area was the oil industry, and we have evidence ranging from colleague testimonials to million-dollar-scale investments that our work has transformed research activities (e.g. with ExxonMobil and Shell). As currently configured, Delta’s legacy will be a major advance in the scientific basis for delta restoration. NCED’s signature contributions here include integration of physical and ecological dynamics, and development of methods to use stratigraphic records of past delta dynamics as a guide to restoration. The tangible face of this will be a delta land-building manual and models with capabilities for delta growth, habitat, and fish prediction. Another legacy component is a suite of externally funded programs in delta prediction that are expected to outlive NCED. But our most important legacy will be, if we are successful, new wetlands in the Mississippi Delta, including a thriving and productive ecosystem and may help protect New Orleans.

Education

A key element of NCED’s education legacy is development of a partnership between a major science museum (Science Museum of Minnesota, SMM) and a network of research universities that is perhaps the strongest ever created. The specific legacy of our partnership with SMM is creation of permanent exhibits and other informal education components that have national and international impact. Through its own extensive network and new initiatives such as Water: $H_2O=Life$ and the Future Earth Initiative, SMM will expand the university-museum network that NCED has nucleated.

The most important NCED educational legacy, however, is the cadre of uniquely trained students and postdocs who have participated in NCED and been steeped in our integrated, predictive approach to Earth surface science and our transdisciplinary culture. New degree programs represent permanent enhancements to NCED educational institutions. The most prominent of these is the first post-baccalaureate Certificate Program in Stream Restoration Science and Engineering at the University of Minnesota.
Diversity

Our diversity legacy will be (1) training of a cadre of minority researchers and teachers who, in addition to their own research, can serve as mentors and spread the word about the opportunities for exciting, societally relevant research in quantitative environmental sciences; (2) creation of a network of Minority Serving Institutions and other schools with significant minority populations where key faculty are aware of these research opportunities; and (3) creation of a long-lived pipeline in which the science of the Earth’s surface provides a gateway for Native American students to get involved in science and engineering at the undergraduate level and beyond. Our minority-intern and other research-level training programs are ongoing, so the main implementation effort is ensuring that they continue to thrive. The same is true for our Native American science camps; we are currently working to find ways to fund them after NCED’s sunset. We have also taken a major step towards institutionalizing some of our minority work at the University of Minnesota through our participation in the Louis Stokes Alliance for Minority Participation (LSAMP)

Organizational

Strategic and implementation planning for NCED’s legacy is carried out by the NCED Executive Committee. Our primary goal is framed in terms of scientific transformation toward an integrative, predictive science of the Earth’s surface. The principal metric of this is the development of long-lived initiatives and structures at the national and international level that reflect NCED’s transdisciplinary, predictive approach to surface dynamics. NCED leadership has been closely involved with NSF and other agencies to bring this about. Specific examples of scientific transformation with which we have been involved include: the Community Surface Dynamics Modeling System (CSDMS); the Critical Zone Observatory (CZO) initiative; the creation of the new JGR - Earth Surface journal at AGU; the creation of new, focused NSF programs in Geomorphology and Land-use Dynamics and Stratigraphy and Paleontology; a new emphasis on prediction across the Earth sciences in the 2009 NSF Geovision document; the creation of a new AGU Focus Group on the Earth’s surface; and the 2010 NRC report “Landslides on the Edge” which presents a community research agenda in Earth-surface dynamics.

Institutional

The investments NCED is making now in facilities will form the basis for a part of our permanent legacy. At St. Anthony Falls Laboratory (SAFL), we have built the world’s first Outdoor Stream Lab (OSL), a facility that combines many of the advantages of a field site and an experimental basin. OSL builds on our successful StreamLab06 and StreamLab08 experimental programs. SAFL has also recently been awarded $7.1 million for laboratory repair and renovation via the Academic Research Infrastructure Program of the American Recovery and Reinvestment Act of 2009, an award which NCED’s research, activities, and personnel were instrumental in procuring. Together with an $8.7 million match from the University of Minnesota, the new grant will provide for the construction and renovation of facilities that will enable critical new research on Earth-surface science, energy, and environmental sustainability. NCED investments at Angelo Coast Range Reserve (ACRR), supplemented by a major grant from the Keck Foundation, enabled the development of a new wireless network backbone, the most sophisticated such installation of its kind anywhere. This facility will also serve as a prototype and test bed for the large-scale observational facilities being developed through the NSF CZO program. NCED development of the Wax Lake Delta field site is focused on establishing a site for long-term monitoring.
### Appendix: Project Plans

#### 1. Watersheds

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<tr>
<th>Project name</th>
<th>Explanation</th>
<th>Milestones</th>
<th>Links</th>
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<tbody>
<tr>
<td>DW1</td>
<td>Numerical techniques for feature extraction</td>
<td>Develop methods to identify and quantify important features in high resolution lidar data, i.e. channel dimensions, landslides location, channel slope, fan detection, floodplain detection, terrace detection, etc. from.</td>
<td>1) Channel bank identification and automated channel dimension mapping (Yr 6-7)</td>
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<td>2) Channel head location detection (Yr 6)</td>
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<td>3) Automated mapping of deep-seated landslide features (Yr 8)</td>
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<td>4) Automated road mapping (location, slope, width, channel crossings) (Yr 9)</td>
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<tr>
<td>DW2</td>
<td>Topographic signatures of properties and processes</td>
<td>Use static topographic features and steady state assumptions to estimate location and size or morphology of features such as river bed gravel size, potential landslide location, and potential high sediment load from roads.</td>
<td>1) Improved model for grain size prediction (Yr 7)</td>
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<td>2) Shallow landslide size and location model (Yr 7)</td>
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<td>3) Empirical use of mapped roads to estimate average fines yield to channels (Yr 9)</td>
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<td>DW3</td>
<td>Predictive mapping of key biotic populations: relationships to habitats</td>
<td>Link distribution and abundance of organisms to habitat state and availability in a spatially explicit channel network framework.</td>
<td>1) Spatially explicit coho salmon model for rivers (Yr 6)</td>
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<td>2) Model for frog reproductive patterns (Yr 7)</td>
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<td>3) Model for seasonal peak algae distribution (Yr 8-9)</td>
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<tr>
<td>DW4</td>
<td>Understand linkages among solutes, soil production and biota</td>
<td>Use experimental plots modeling effects of climate change to document responses in the microbial community.</td>
<td>1) Document how microbial community in soil responds to changes in seasonal water loading (Yr 6 to 9)</td>
</tr>
<tr>
<td>DW5</td>
<td>Controls on rate of landslide transport to channels</td>
<td>Document rates and develop theory for landslide contribution to channels</td>
<td>1) Document rates of erosion associated with deep-seated landsliding (Yr 6), 2) Develop a deep seated landslide flux “law” (Yr 9)</td>
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<td>3) Develop a shallow landslide flux “law” (Yr 8)</td>
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<tr>
<td>DW6</td>
<td>Sediment routing; coarse sediment transport in shallow flow; fine sediment interaction with coarse bed</td>
<td>Document and explain: 1) how gravel moves over boulders, and under what conditions boulders move, and 2) how fine sediment (sand and smaller) dynamically is deposited and eroded from the bed. Do this through a river network</td>
<td>1) Theory for gravel over boulder transport (Yr 5-7)</td>
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<td>2) Theory for boulder transport (Yr 6-7)</td>
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<td>3) Theory for fines interaction with the bed (Yr 8-9)</td>
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<tr>
<td>DW7</td>
<td>Predictive models for channel incision</td>
<td>Quantify and model processes causing valley incision into bedrock</td>
<td>1) Observation and theory for river incision by fluvial sediment wear (Yr 6-7)</td>
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<td>2) Observation and theory for debris flow incision (Yr 6-8)</td>
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## NCED Strategic and Implementation Plan

**National Center for Earth-surface Dynamics**

### Strategic and Implementation Plan, 2011

<table>
<thead>
<tr>
<th>Project name</th>
<th>Explanation</th>
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</table>
| DW8 | Upscaling transport laws and biotic processes | Develop mathematical procedures for upscaling local surface processes and ecologic interactions to entire watersheds | 1) Upscale local algae production rates (Yr 6-8)  
2) Upscale local hillslope flux processes to entire landscape (Yr 7-9) |
| DW9 | Link food webs and channel networks, including dynamic response | Develop models for seasonal and interannual dynamics in physical and biotic processes | 1) Model for stream temperature throughout the year using lidar data (Yr 7-8)  
2) Model for fish populations dynamics (Yr 8-9) |
| DW10 | Desktop watersheds model code development | Base code development for static and dynamic watershed models | 1) User friendly model for coho salmon population released to public (Yr 6)  
2) User friendly model for frogs (Yr 8)  
3) User friendly model for algae (Yr 9) |
| DW11 | Use of Desktop watershed models in landuse management decisions | Make Watersheds tools and models available to agencies and private industry for practical uses | 1) Development and release of topographic analysis tools for lidar (Yr 8)  
2) Release of Ripple and demonstrated use by agencies (Yr 8) |

In the above table, the two solid lines represent major breaks. The first is between the static and dynamic model. The second is between the dynamic model and the problem of implementation (model development and model use). The project identifier is shown in the first column (e.g., W1) and the last column shows projects to which there are strong links.

### 2. Deltas

<table>
<thead>
<tr>
<th>Project name</th>
<th>Explanation</th>
<th>Milestones</th>
<th>Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA1</td>
<td>Current sediment budget and subsidence distribution in Mississippi Delta</td>
<td>(1) Develop quantitative measures of bedload, suspended, and wash load supply near Baton Rouge; (2) Determine net loss to in-channel deposition d/s of Baton Rouge; (3) Determine regional spatial distribution of subsidence from seismic records.</td>
<td>(1) Sediment delivery rates (sand &amp; mud) for the Mississippi &amp; Atchafalaya rivers (Yr 7); (2) Estimate conveyance losses over delta (Yr 8-9); (3) Regional maps of Delta subsidence in the critical coastal zone (Yr 8-9).</td>
</tr>
</tbody>
</table>

W3, S2 |
| SA2 | Behavior and deposition of cohesive sediment | (1) Determine role of flocs (biotic vs abiotic) in transport and deposition of silt and clay; (2) Determine the right flux law to use in modeling deposition of clay with silt and sand | (1) Preliminary numerical model based on existing understanding (Yr 7); (2) Refined numerical model with experimental and field data (Yr 9). |

W2, W6, S1 |
| SA3 | Vegetation-sedimentation interaction in island & marsh development & maintenance | (1) Determine role of growing plants in inducing and stabilizing sedimentation; (2) Determine correlation between bed elevation and plant community and physical plant properties | (1) Synthesize existing field data from Wax Lake Delta (Yr 6); (2) Carry out targeted set of field measurements on WLD with experiments on island levee and marsh growth and in-channel sedimentation (Yr 8). |

W3, S2 |
<table>
<thead>
<tr>
<th>Project name</th>
<th>Explanation</th>
<th>Milestones</th>
<th>Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA4 Reconstructing delta dynamics from seismic records</td>
<td>(1) Map fault location and offset (2) Map interaction of active faults and channels (3) Measurement of geometry, spatial arrangement, and variability of deltaic depositional units as a function of relative sea level rise and fall</td>
<td>(1) Produce statistics of subsidence &amp; sedimentation patterns associated with growth faulting in Breton Sound Yr 6-7. Additional milestones are functions of procuring external funding and industrial data.</td>
<td></td>
</tr>
<tr>
<td>SA5 Reconstructing delta dynamics from cores and other records</td>
<td>(1) core collection and basic data analysis (grain size, C14), initial focus on Barataria Bay &amp; WLD; (2) Use core data to constrain bulk spatial distribution of grain size and sedimentation rate for La Fourche lobe (40-8ka); (3) for WLD, use sedimentary structure and textures to constrain depositional conditions from D6 numerical model</td>
<td>(1) Use existing core set from WLD to put quantitative constraints on levee &amp; marsh building events during last 35 yrs (Yr 6-7). Additional milestones depend on procuring external funds.</td>
<td></td>
</tr>
<tr>
<td>SA6 Modeling land building; integration with LSU CLEAR</td>
<td>(1) Development of laterally averaged lobe-construction model; (2) use results of network analysis, field data, and experiments to estimate fine-scale properties and variability of evolving delta lobes</td>
<td>(1) Tested laterally and time-integrated land building model (Yr 6); (2) Channel resolving model tested against experimental and WLD data (Yr 7-8); (3) Land-building model in use for restoration planning (Yr 9)</td>
<td>W6</td>
</tr>
<tr>
<td>SA7 Self-organization of distributary systems including elevation statistics</td>
<td>(1)Adapt existing network analysis tools to (static) distributary networks (2) Develop methods for quantifying space-time statistics of active, evolving distributary systems to forecast distribution of elevation, grain size, and rate of deposition.</td>
<td>(1) PDFs of elevation, channel size and distance from channels for one experimental and WLD (Yr 6-7); (2) Physically based theory for self-organization dynamics &amp; controls fully incorporated into land building model (Yr 9).</td>
<td>W1, W2</td>
</tr>
<tr>
<td>SA8 Upscaling short-term rates and small-scale geometries</td>
<td>(1) Develop methodology for upscaling laboratory delta data to natural scales for use in numerical models; (2) Develop physical theory to explain spatial distribution of deposition rate as function of time scale.</td>
<td>(1) Relation of rates and geometries between experimental deltas and Wax Lake (Yr 8); (2) Integration and upscaling of data from lab &amp; modern systems to Quaternary stratigraphic records (Yr 9-10).</td>
<td>W8</td>
</tr>
<tr>
<td>SA9 Coastal system response to rising relative sea level</td>
<td>(1) Develop and calibrate suite of numerical models for rivers that forecast lowland sediment accumulation and shoreline advance/retreat under conditions of relative sea-level rise.</td>
<td>(1) Use existing channel-based NCED models to explore behaviors of select GOM rivers (Yr 7); (2) Add realistic floodplain deposition component (Yr 9).</td>
<td></td>
</tr>
<tr>
<td>SA10 Social tradeoffs in Delta restoration</td>
<td>(1) Conflicts between marsh restoration, business and society; (2) Risk and uncertainty analyses.</td>
<td>(1) Initial exploration of potential of social tradeoff analysis in delta restoration (Yr 6). Additional milestones depend on procuring external funds.</td>
<td></td>
</tr>
</tbody>
</table>
### 3. Streams (SR)

<table>
<thead>
<tr>
<th>Project name</th>
<th>Explanation</th>
<th>Milestones</th>
<th>Links</th>
</tr>
</thead>
</table>
| **SR1**      | Watershed context for stream restoration. | (1) specify location and type of restoration action for reduced sediment loading in large (3,000 km²) watershed (Yr 9)  
(2) Demonstrate application of LiDAR topographic analysis tools for evaluating restoration options in different landscapes (Yr 10) | W2, W3 |
| **SR2**      | Improved models for sediment source, routing, storage and yield | (1) Tested, improved reach-averaged sediment routing models with explicit sediment storage functions for both sand and gravel rivers (Year 7)  
(2) Establish sediment fingerprinting methods for sediment source and history. (Year 8)  
(3) Complete sediment budget for 2800 km² watershed combining geochemical fingerprinting and flux/storage estimates with valley bottom sediment storage and streambank erosion in a network routing model (Yr 9) | W5, W6, D1, D2 |
| **SR3**      | Dynamics of mixed-size sediment | (1) Complete initial model for vertical sorting and morphodynamics in spatially homogeneous beds (Yr 7).  
(2) Management guidelines for gravel augmentation and sand infiltration (Yr 7)  
(3) Strategy for scaling up lateral variability in reach to network modeling (Yr 7)  
(4) Tested model of sorting and morphodynamics for field data sets (S7) (Yr 8) | W8, D8 |
| **SR4**      | Predictive relations for channel and floodplain geometry. | (1) develop sand-bed and universal hydraulic geometry relations and design guidelines incorporating variability (Yr 7)  
(2) Integrate hydraulic geometry and dimensional analysis to upscale nutrient concentrations in terms of stream reach length and drainage area (Yr 8)  
(3) Basis for scaling laboratory bank strength and vegetation effects to the field (Yr 7)  
(4) Numerical StreamLab for testing effect of channel geometry and in-stream structures on channel stability and habitat (Yr 7) | D2, D3 |
### SR5 Predictive relations for the effect of physical channel structure and disturbance regime on primary productivity, nutrient transport, and species recovery.

For the numerous restoration projects that have ecological and/or water quality objectives, develop relations to guide planning and design of stream projects for ecological purposes of water quality and habitat improvement, and species recovery.

(1) Initiate Outdoor StreamLab, bringing experimental control and high resolution measurement to field-scale ecogeomorphology studies. (Yr 7)
(2) Quantify relations among channel attributes, fluid mechanics, nutrient transport/transformation, ecosystem metabolism, and species habitat (Yr 7)
(3) Use hydraulic geometry to establish framework for upscaling local biotic and metabolic processes in terms of stream reach length (Yr 8).
(4) Dimensionless groups of biotic and abiotic variables to describe functional relations (Yr 10)
(5) Model impact of fine sediments on carrying capacity and productivity of fish habitat (Yr 7).

### SR6 Linking public preference, objectives, and stream restoration alternatives

Improve the link between restoration objectives and actions, currently often ill-defined; restoration goals should be predictive targets quantitatively linked to public preference, regulatory & policy guidelines, and management actions. Develop techniques for identification of public preferences and evaluation of tradeoffs among restoration alternatives, accounting for uncertainty and the impact of improved information.

(1) Demonstrate survey method for measuring public preference, considering uncertainty. (Yr 7)
(2) Demonstrate watershed framework for optimizing water quality improvement under risk. (Yr 7)
(3) Implement Bayesian methods for estimating the value of reduced uncertainty (Yr 8)
(4) Assess value of improved models vs improved data in stream restoration decision making (Yr 10)

### SR7 Dam reoperation and removal for ecosystem restoration

Use gravel augmentation and dam removal as field experiments to develop and test models of reservoir erosion and downstream impacts.

(1) Develop field data sets on the effects of injected and dam-released sediments on downstream channel geometry and habitat (Yr 8)
(2) Predictive relations for the control and management of reservoir erosion. (Yr 8)
(3) Tested application of reach-scale models for sediment routing and channel change (Yr 8)

### 4. Education (ED)

<table>
<thead>
<tr>
<th>Project name</th>
<th>Milestones</th>
<th>Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>ED1</td>
<td>Bring surface dynamics to informal education with the Science Museum of Minnesota</td>
<td>Big Back Yard (BBY) exhibits fully functioning, at least one new component added, and functioning Youth Science Center –NCED docent program for Big Back Yard; BBY visitor target of 150,000 reached or surpassed; initial NCED components of Water Planet and Science on a Sphere developed; 3D film outline developed with SMM</td>
</tr>
<tr>
<td>ED1.1</td>
<td>Deliver NCED-related science to the Museum’s annual audience of 800,000 visitors.</td>
<td>Big Back Yard (BBY) and associated Youth Science Center NCED docent up and running since June 2004. At least one new component added each season. BBY visitor target of 150,000 reached or surpassed.</td>
</tr>
</tbody>
</table>
### ED1.2 Incorporate both new and existing NCED-related science exhibit components into a national and international traveling exhibition about water.

**Milestones**: Open exhibition at the American Museum of Natural History in November 2007 then replicate the exhibition so that two copies are available for the national and international tours beginning in May 2008.

**Links**: all

### ED1.3 Develop collaborative means by which the research and sciences all six STCs can reach larger informal science education audiences.

**Milestones**: Through SMM’s pending Future Earth Initiative, fabricate and distribute SMM’s Science Buzz kiosks to all STCs in 2008. SMM and all six STCs collaborate on creating on-line science content.

**Links**: all

### ED1.4 Advance the use of scientific visualization technologies to communicate NCED-related science to both formal and informal science education audiences.

**Milestones**: Develop new scientific visualization programs, especially for GeoWall and Science on a Sphere, and distribute them to educational institutions throughout the U.S. that utilize these visualization systems.

**Links**: all

### ED2 Enhance the education of NCED student participants by providing unique opportunities and an extended, cross-disciplinary peer and mentor network.

**Milestones**: Strong graduate student participation in cross-disciplinary research & seminars, Grad Student Council, videoconferences, NCED retreats, site visits, partner research, internships; thriving Grad Museum Assistantship program.

**Links**: all

### ED3 Stream Restoration Science and Engineering certificate program

**Milestones**: Functioning certificate program in stream restoration science and engineering.

**Links**: S, DV, KT

### ED4 NCED enhancements to K-16

**Milestones**: Students supported, continued use of 3D maps and physical models around the country.

**Links**: all

### ED5 K-12 teacher development

**Milestones**: Materials developed and made available for broad use over the web, through the Teacher Resource Center at the Science Museum of Minnesota, through the Science Educator Resource Center (www.serc.carleton.edu) and promoted at local and national conferences.

**Links**: all

### 5. Knowledge Transfer

#### Watersheds

<table>
<thead>
<tr>
<th>KT1</th>
<th>Interactions with Watersheds Science Partner Group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Explanation</strong></td>
<td>(1) Establish members of Science partners Group; (2) Convene regular meeting with Science partners to advise NCED Watersheds IP; (3) Convene regular technical workshops with Science partners</td>
</tr>
<tr>
<td><strong>Milestones</strong></td>
<td>(1) Select member for the Watersheds science partners group (Yr 6); (2) Hold first formal meeting of W science partners (Yr 6-7); (3) Hold regular meetings with W science partners (Yr 8-10)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KT2</th>
<th>Collaborative Watersheds research with stakeholders and partners</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Explanation</strong></td>
<td>(1) Define and implement Application Working Groups; (2) Develop other ongoing collaborations outside of NCED; (3) Establish metrics for evaluating impacts of research on practice</td>
</tr>
<tr>
<td><strong>Milestones</strong></td>
<td>(1) Establish AWG on Watersheds Fish Population model (Yr 5-6).</td>
</tr>
<tr>
<td><strong>Links</strong></td>
<td>(2)</td>
</tr>
<tr>
<td>Project name</td>
<td>Explanation</td>
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<tr>
<td>--------------</td>
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</tr>
<tr>
<td>KT3</td>
<td>Disseminate <em>Watersheds</em> knowledge, approaches, and tools outside of NCED</td>
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</tbody>
</table>

**Streams**

<table>
<thead>
<tr>
<th>KT4</th>
<th>Interactions with <em>Streams</em> Science Partners Group</th>
<th>(1) Convene regular meeting with Science partners to advise NCED <em>Streams</em> IP; (2) Convene regular technical workshops with Science partners</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(1) Continue Training Partners meeting II (Yr 6-10); (2) Dam Removal and Augmentation partners meeting (Yr 6-8); (3) Convene ecohydrodraulics partners meetings (Yr 7-10)</td>
</tr>
<tr>
<td>KT5</td>
<td>Collaborative <em>Streams</em> research with stakeholders and partners</td>
<td>(1) Define and implement Application Working Groups; (2) Develop other ongoing collaborations outside of NCED; (3) Establish metrics for evaluating impacts of research on practice</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) Define AWG for Training, Gravel Augmentation, and Ecosresponse to structures. (Yr 6); (2) Plans for StreamLab08 (Yr 6); (3) Long term plans for StreamLab (Yr 7-10); (4) Establish metrics for evaluating AWGs</td>
</tr>
<tr>
<td>KT6</td>
<td>Disseminate <em>Streams</em> knowledge, approaches, and tools outside of NCED</td>
<td>(1) Develop <em>Streams</em> community website; (3) Develop <em>Streams</em> toolbox containing free models and tools that support stream restoration practice</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) Continue to add content to <em>Streams</em> Website (Yr 6-10); (3) Continue to expand <em>Streams</em> Toolbox including non-NCED contributions (Yr 6-10)</td>
</tr>
<tr>
<td>KT7</td>
<td>Promote and develop education and training programs in stream restoration</td>
<td>(1) Develop and maintain an expansion of education and training opportunities in stream restoration (SR); (2) Expand impact of SRSE Certificate Program at UMN; (3) Explore the need for establishing formal standard of proficiency for stream restoration Practice</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) Increase PI participation in teaching SR Shortcourses (Yr 6-10); (2) Expand SRSE Certificate Program to reach professionals in practice (Yr 7-8); (3) Work with Training Partners AWG to explore certification in SR (Yr 6-8)</td>
</tr>
</tbody>
</table>

**Deltas**

<table>
<thead>
<tr>
<th>KT8</th>
<th>Interactions with <em>Deltas</em> Science Partner Group</th>
<th>(1) Establish members of Science partners Group; (2) Convene regular meeting with Science partners to advise NCED <em>Deltas</em> IP; (3) Convene regular technical workshops with Science partners</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(1) Select member for the <em>Deltas</em> science partners group (Yr 6); (2) Hold first formal meeting of <em>Deltas</em> science partners (Yr 6-7); (3) Hold regular meetings with <em>Deltas</em> science partners (Yr 8-10)</td>
</tr>
<tr>
<td>KT9</td>
<td>Collaborative <em>Deltas</em> research with stakeholders and partners</td>
<td>(1) Define and implement Application Working Groups; (2) Develop other ongoing collaborations outside of NCED; (3) Establish metrics for evaluating impacts of research on practice</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) Establish Application Working Groups for <em>Deltas</em> for social tradeoff in delta restoration and other topic TBD (Yr 6-7); (2) Establish metrics for evaluating AWGs</td>
</tr>
<tr>
<td>KT9</td>
<td>Disseminate <em>Deltas</em> knowledge, approaches, and tools outside of NCED</td>
<td>(1) Develop web pages for <em>Deltas</em> research, tools, and training opportunities; (2) Develop education and training opportunities for <em>Deltas</em> research products</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) Develop web pages for <em>Deltas</em> IP including posting of data sets(Yr 6); (2) Conduct shortcourses and workshops on delta dynamics and stratigraphy (Yr 6-10); (3)</td>
</tr>
</tbody>
</table>
### 6. Diversity

<table>
<thead>
<tr>
<th>Project name</th>
<th>Explanation</th>
<th>Milestones</th>
<th>Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>DV1</td>
<td>Faculty-to-Faculty</td>
<td>Building durable connections to Minority-Serving Institutions and faculty who advise students from underrepresented groups</td>
<td>5 new faculty introduced to NCED research through visits or participation in conference or workshop, including multiple visits to NCED facilities; new collaborations, and recruiting visits by NCED faculty (Yr 10)</td>
</tr>
<tr>
<td>DV2</td>
<td>Diversity Recruiting</td>
<td>Direct recruiting of under-represented students to NCED graduate and postdoc program</td>
<td>Bring up percentage of graduate students from underrepresented groups as % of total graduate students and postdocs including participation in the SR certificate program: Yr 8: 12%; Year 10: 18%</td>
</tr>
<tr>
<td>DV3</td>
<td>Undergraduate Summer Internship Program</td>
<td>Bring undergraduate students from underrepresented groups to NCED to do research with NCED PIs and graduate students. Encourage students to attend graduate school. Recruit students when appropriate as NCED graduate students.</td>
<td>Ongoing participation of 5 undergraduate students each summer, with consistent recruitment of USIP students to NCED graduate program and the majority of USIP students going to graduate school: (5 each in Yrs 6-10)</td>
</tr>
<tr>
<td>DV4</td>
<td>gidakiimanaaniwigamig (Our Earth Lodge) Native American youth science immersion program</td>
<td>Students from the Fond du Lac Band of the Ojibwe are recruited to participate in a science immersion program that encourages students to do well academically and develop an interest in science careers.</td>
<td>40 students per year participate in the camps and programs; documented improvement in grades and test scores for students in both programs; majority of participants attend college, with substantial fraction majoring in science, math, engineering or technology (90 students per year, Yrs 6-10)</td>
</tr>
<tr>
<td>DV5</td>
<td>Earthscapes in the SMM Youth Science Center (YSS)</td>
<td>High school students from underrepresented groups are recruited to be docents in the Big Back Yard, the NCED developed exhibit at the SMM</td>
<td>Substantial participation by minority students in YSC park crew and other activities; (60% underrepresented groups Yrs 6-10)</td>
</tr>
</tbody>
</table>

### Legacy

<table>
<thead>
<tr>
<th>Program</th>
<th>Legacy goal</th>
<th>Legacy metric</th>
<th>Current status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformation of field</td>
<td>Creation of new long-lived programs and organizations</td>
<td>Number and national visibility of programs and organizations</td>
<td>Implemented: NSF GLD and SGD programs; JGR-ES journal Funded; CSDMS, CZO; WATERS network; AGU ES focus group</td>
</tr>
<tr>
<td>Scientific impact</td>
<td>Create a long-lived scientific impact via center-style publications</td>
<td>Research publications: number; citation statistics, multi-PI/multi-institution</td>
<td>Numbers updated yearly; NCED special journal volume in JGR-ES</td>
</tr>
<tr>
<td>Institutional impact</td>
<td>Facilities investment for continuation of NCED research</td>
<td>Scale of investment; ability of facilities to attract additional investment</td>
<td>SAFL OSL under construction opened spring 2008; ACRR wireless network functional; SAFL received major renovation grant.</td>
</tr>
<tr>
<td>Watersheds</td>
<td>Long-lived impact on watershed prediction and management</td>
<td>Development status of Ripple implementation model; adaptation by agencies nationwide</td>
<td>Ripple now in use across California and in Alaska; initial effort to generalize to agricultural/Midwestern conditions beginning in concert with Streams IP</td>
</tr>
<tr>
<td>Program</td>
<td>Legacy goal</td>
<td>Legacy metric</td>
<td>Current status</td>
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<tr>
<td><strong>Deltas</strong></td>
<td>Creation of long-term program for restoration of Mississippi Delta via river diversions and related activities</td>
<td>Development status of land-building and social-science components of Desktop Delta model; status of restoration effort in Mississippi Delta</td>
<td>Initial land-building model complete; efforts ongoing to link to other components of CLEAR; development of social science components beginning; Delta restoration based on river diversion under active consideration by state of LA and US ACE</td>
</tr>
<tr>
<td><strong>Streams</strong></td>
<td>Transformation of stream restoration to a professional practice in which objectives and predictive methods are quantitatively linked in a rational design framework</td>
<td>Development status of NCED restoration application tools; adoption by restoration practitioners of tools and methods for evaluation and design; development of network of regional centers promoting standards and linking research, monitoring, and practice.</td>
<td>NCED developed methods incorporated in US ACE HEC river modeling tools; NCED methods in use in nationally visible restoration programs (e.g. Trinity River, CA); large annual participation in NCED short courses and workshops; NCED-founded regional stream restoration partnership network established among NCED and university and agency collaborators.</td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td>(1) Unique, successful NCED graduate and postdoc programs; (2) success of SMM Earthscapes; (3) new programs with SMM; (4) new long-lived educational programs</td>
<td>(1) Total number of students/postdocs; student/postdoc publications; job placement; time to finish degrees (2) number of Earthscapes visitors; visitor polls (3) scale and success level of new SMM/NCED programs (4) student interest; job placement</td>
<td>Graduate and postdoc metrics strong across the board (documented in annual reports and site visits); Earthscapes visitor numbers/experience remain strong; new Water: H₂O=Life exhibition open at AMNH New York October 2008; Future Earth Initiative project established through SMM; U Minn Stream Restoration Certificate program successful.</td>
</tr>
<tr>
<td><strong>Diversity</strong></td>
<td>(1) Creation of a cadre of minority students trained in NCED style env science (2) creation of long-lived pipeline for Native American pre-college students into science via environmental science camps (3) institutionalization of diversity programs</td>
<td>(1) total minority participation in NCED; Standard measures of success (discussed elsewhere) (2) number of students participating and continuing to college; standard measures of success (discussed elsewhere)</td>
<td>(1) Overall minority participation improving and strong (documented in annual reports and site visits) (2) Native American camps have documented success; room for improvement but functioning well (3) Recent UM success with LSAMP minority-program proposal; developing Native American national geoscience network (4) Successful development of multi-institutional, multi-centered manoomin program</td>
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Appendix F: Data Repository

Introduction

In early 2007, NCED unveiled its Data Repository where all NCED-funded research data can be cataloged and made available for download by the public (http://www.repository.nced.umn.edu). The site allows users to view existing archived data and, as of fall 2007, allows users to select and download data. The hardware running the Repository is a dual CPU 2.2ghz Opteron with 3GB of RAM run on a NCED server housed at the Minnesota Supercomputer Institute (MSI). It is connected to the MSI’s Storage Area Network (SAN) and we have 4TB of space allocated on their server. In addition to NCED data, we also make accessible to the community important legacy datasets outside of NCED but of interest to researchers in surface process science, e.g., SRTM elevation data, the “Church and Rood” data set, and Brownlie alluvial channel data. The repository is publicly visible and searchable, and as of April 2011, over 529 individuals downloaded data 777 times for a total of approximately 920GB served.

Data Repository: Process and Plans

A collaboration has been formed with the NSF-funded Community Surface Dynamics Modeling System (CSDMS; http://csdms.colorado.edu/) which has a need for spatially and temporally rich data from different locations and at various scales to validate their collection of Earth surface dynamics models. This relationship has given us insight and direction into data accessibility. With CSDMS guidance, we are working toward a better system for acquiring data from NCED researchers that will result in a smooth submission process and, in turn, more effective use of the datasets by a wide range of researchers, including CSDMS modelers.

As a result, we are updating the collection method for NCED-generated data that comprise the repository. A more structured on-line metadata questionnaire has been developed that will help to categorize the submitted data. To maximize utility, this same information also serves as the search terms for end users. Metadata categories will include common keywords, types of data, variables (flow rate, sediment size, sediment transport rate, etc.), file types, geographic location or laboratory facility, temporal frequency, spatial resolution, stage of research (planned, ongoing, complete), etc. Additional information collected includes author(s), contact information, publications associated with the research, and thumbnail pictures that show a visual example of the type of data one can find in a given set.

Year 9 Progress

The data repository is continuing to provide a rich archive of NCED’s data as well as an active and navigable collection available to colleagues and the public to access and download to further new research endeavors. The current collection includes approximately 862,000 files in 9,300 folders comprising 31 datasets and occupying 3TB of storage.

Over the past year, a new online metadata survey was created to document data being submitted to the repository. This survey expanded on the 2008 version by increasing the number and function of fields used to describe both the projects and the data sets within each project. We also optimized the data collection and input process to process data more efficiently.

After a comprehensive list is developed, we will be distributing data requests that reference the project name and instructions for data submission among past and current NCED researchers. Participants will be able to go online and fill out the metadata questionnaire describing the data, and then upload the datasets themselves. A reporting system will be put in place so that repository administrators can monitor the completeness of the data submissions and more efficiently curate the collection.
Current Contents

► 3D Maps (7.32 GB; Campbell, Morin)

This collection has various 3-D maps and supporting materials that are available for download. Maps can be printed, viewed on computer monitors, or projected on to screens for larger audiences.

Data subsets

World Map: 3-D map that highlights oceanic bathymetry and plate boundaries.
Continental United States: 3-D grayscale map of the Lower 48.
Western United States: 3-D grayscale map of the Western United States with state boundaries.
Regional Map: 3-D greyscale map stretching from Hudson Bay to the Central Great Plains. This map includes the Western Great Lakes and the Canadian Shield.

Minnesota Map: 3-D greyscale map of Minnesota with county and state boundaries.
Twin Cities: 3-D map extending beyond Minneapolis and St. Paul.
Twin Cities Confluence Map: 3-D map highlighting the confluence of the Mississippi and Minnesota Rivers. This map includes most of Minneapolis and St. Paul.

Minneapolis, MN: 3-D topographical map of Minneapolis.
Bassets Creek, Minneapolis: 3-D topographical map of the Bassets Creek watershed.
North Minneapolis: 3-D topographical map highlighting North Minneapolis and the Mississippi River.


Western Suburbs, Twin Cities: 3-D topographical map of St. Louis Park, Hopkins and Minnetonka area.
Minnesota River Valley Suburbs, Twin Cities: 3-D topographical map of Bloomington, Eden Prairie and Edina area.
Southern Suburbs, Twin Cities: 3-D topographical map of Burnsville, Lakeville and Prior Lake area.
Southeast Suburbs, Twin Cities: 3-D topographical map of South St. Paul, Mendota Heights, Apple Valley and Eagan area.
Northeast Suburbs, Twin Cities: 3-D topographical map of White Bear Lake, Maplewood and Roseville area.
Northwest Suburbs, Twin Cities: 3-D topographical map of North Minneapolis, Brooklyn Center and Maple Grove area.

Blaine, MN: 3-D map of Blaine and the Mississippi River.
White Bear Lake, MN: 3-D topographical map of White Bear Lake and the surrounding area.
Maple Grove, MN: 3-D topographical map of the NW suburbs of the Twin Cities.

Minnesota River: 3-D topographical map of the Minnesota River Valley highlighting the river bend in Mankato.
St. Croix River: 3-D topographical map of the St. Croix extending from Taylors Falls to the Mississippi confluence.
Mississippi River, Lake Pepin: 3-D topographical map of the confluence of Chippewa Creek and the Mississippi River.
Red Wing, MN: 3-D topographical map of Redwing, MN on the Mississippi River.

Winona, Minnesota: 3-D topographical map of Winona, MN highlighting the Mississippi River.
Cannon Falls, MN: 3-D topographical map of Cannon Falls area.
Rochester, MN: 3-D topographical map of Rochester and the surrounding area.
Northfield, MN: 3-D topographical map of Northfield and the surrounding area.
St. Louis River, MN: 3-D map of the St. Louis River and Duluth, Minnesota.
Lake Itasca, MN: 3-D map of the source of the Mississippi River.
Elmore, MN: 3-D topographical map of Elmore, MN in south-central Minnesota.
Glencoe, MN: 3-D topographical map of Glencoe, MN.
New Prague, MN: 3-D topographical map of the New Prague in south-central Minnesota.
Plainview, MN: 3-D topographical map of Plainview, MN.
Waterville-Morristown: 3-D map of the Waterville-Morris area in south-central Minnesota.
Eau Claire, WI: 3-D map of Eau Claire highlighting abandon river channels.
Dubuque, IA: 3-D topographical map of Dubuque and the Mississippi River.
Londonderry, NH: 3-D topographical map of Londonderry, NH.
Santa Cruz, CA: 3-D topographical map of Santa Cruz, California.
Crater Lake, OR: 3-D topographical map of Crater Lake, Oregon.
Mt. Rainier, WA: 3-D topographical map of Mt. Rainier in Washington.
Grand Canyon, AZ: 3-D topographical map of the Grand Canyon.
District of Columbia: 3-D map highlighting the confluence of the rivers and the Mall.
Ireland: 3-D grayscale map of Ireland.
New Jersey: 3-D grayscale map of New Jersey.
SP Crater, AZ: 3-D map of random craters in the San Francisco Mountains.

► Mars Water Features: 3-D grayscale map showing surface water features from Mars. (8.46 GB; Belugi, Bode)

► Digital Elevation Models (DEM) of Angelo Coast Range Reserve and South Fork Eel Watershed in Mendocino County, CA.

They all are 1x1 meter grid resolution, using UTM, zone 10, NAD83 projection. These are ESRI grids.
1. Bare-earth DEM: eel1mdem
2. Canopy DEM: eel1mcanopy
3. Vegetation Heights, i.e. the difference between the bare earth and canopy: eel1mdiff

Data was flown for the purposes of improving algorithms for LIDAR bare-earth processing and to be the basis of interdisciplinary geology, ecology, hydrology modelling as performed by the National Center for Earth-surface Dynamics. NCALM, University of Florida flew the LIDAR and processed it to 9 column ascii files. They also created the bare-earth DEM. NCALM, UC Berkeley processed the canopy and veg heights DEMs and is responsible for distribution.

► Angelo 1m DEMs - Derived Data Sets (8.18 GB; Belugi, Bode)

Digital Elevation Models (DEM) of Angelo Coast Range Reserve and South Fork Eel Watershed in Mendocino County, CA.

This set contains a zip file with derived DEMs and coverages. They were processed from the original Angelo 1 meter DEM. They all are 1x1 meter grid resolution, using UTM, zone 10, NAD83 projection. NCALM, University of Florida flew the LIDAR and processed it to 9 column ascii files. They also created the bare-earth DEM. NCALM, UC Berkeley processed the DEMs and is responsible for distribution.

The National Center for Airborne Laser Mapping (NCALM) processed the source DEM as follows:

1. merged the tiles into one grid.
2. reprojected from geographic to UTM, zone 10, nad83 projection using bilinear interpolation.
3. Ran a series of analyses on the dataset to produce the following DEMS GRIDS:
   - eel1mdemab: A over B: Area over gridcell size.
   - eel1mdemacc: Flow accumulation. Grid shows how many other grids flow into each square. Used for watershed delineation and for channel creation.
   - eel1mdemd: Azimuth. Shows direction from north a grid cell is facing. Only 8 directions used, moving clockwise.
- eelmdemfil: Sinkfill. To get the flow accumulation, you must fill holes and pockets in the elevation model. This grid is essential a step in the processing.
- eelmdemrad: Slope of the gridcell. Coverages:
- eelchannel: Result of Bill Dietrich's & Dino Belugi's work on channel formation. This is derived from the grids listed above.
- eelcontour05: 5 meter topographic contours of the bare-earth DEM.
- eelcontour10: 10 meter topographic contours of the bare-earth DEM.

► Angelo Basic GIS Coverages (36.87 MB; Bode, Dietrich, Power)

Projection: UTM, zone 10, datum NAD83.

GIS file format: ESRI Shapefile for vector, ESRI arcinfo binary GRID format for raster.

Data Sources: National Center for Airborne Laser Mapping (NCALM, http://ncalm.berkeley.edu): Lidar DEM of the South Fork Eel watershed at Angelo reserve was created by NCALM.

This data is new and still is being post processed. The dem is extremely high quality (1m resolution). California Spatial Information Library (CASIL, http://gis.ca.gov): public and federal datasets, including USGS drg, doqq, and blue-line datasets.

Naming Conventions: This is not strictly followed. Files start with their spatial scale and end with their projection. Maps will often end with their DPI resolution. Eel: entire eel watershed Sfk: South Fork Eel Nfk: North Fork Eel Angelo: Angelo Reserve

► Blue Earth County LIDAR (419.23 GB)

► Church and Rood Alluvial River Channel Regime Data (8.8 MB)

Data compiled from various sources on 284 streams and rivers: river morphology, river process, discharge, hydraulic geometry and grain size.

► Colorado River Sediment Storage (28.15 GB; Grams)

► Cosmogenic Isotope (906.05 KB)

► Delta Basin (565.18 GB; Martin, Paola)

The Delta Basin is a square flume measuring approximately 5 meters by 5 meters, and is 0.61 meters deep. The exact experimental configuration may vary depending on the scientific objectives - the specific scheme at right represents that for the DB03-1 and DB03-2 experiments.

A mix of sediment and water are introduced at a single infeed point in one corner of the basin. This produces a radially symetrical delta-like deposit. A syphon-based ocean controller at the opposite corner allows for precise base-level manipulation, and specifically for the creation of accomodation space via a slow base-level rise.

**Data Subsets**

Topography on the fluvial surface is measured using a laser-line system: laser lines (three are shown in the schematic) are projected onto the fluvial surface, and photographs taken at regular intervals by a camera on a fixed mount.

Surface processes are recording using the same camera in time-lapse mode.

Stratigraphy is recorded by slicing the resulting deposit and photographing the faces (with the same camera). “Peels” are also taken of the faces.

By using the same camera in the same position, image data from all three data sets may be directly compared.
DB03-1 Corrected surface images: Images of the fluvial surface taken during the DB03-1 High Frequency Topography. See project description for details. The original images were taken every 15 seconds of run time and stored in Nikon’s NEF format. These images have been corrected (for lens distortion and perspective) using Andromeda Software’s Lendsoc Photoshop filter, and saved in JPG format. Images are stored in folders by calendar date. The file names are of the format “Ryyyy-mm-dd-hhmss.jpg” where “R” stands for “run” (vs “T” in other experiment images for “topography”) - note that the date/time is calendar not runtime - images with the runtime in the file name are elsewhere in the archive.

DB03-1 Deposit Face Images: Images of the DB03-1 Deposit stratigraphy. The deposit was sliced at the 1.5, 1.75, and 2.0 meter downstream transects, corresponding to the locations where surface topography measurements were taken. Another set of images is of a stream-wise face approximately at the center of the delta. Images are in Nikon’s proprietary NEF format, and are uncorrected.

DB03-1 Elevation Data: These Excel workbooks contain fluvial surface elevation data from the DB03-1 experiment. See the readme. In the “cleaned_and_renamed” folder, the data have been cleaned up (redundant data removed, out-of-range data removed, worksheet names corrected, etc) but otherwise are unaltered. The “runtimetablefinal.xls” workbook has a table for converting the topo image file names (built from calendar time) into experiment run time. Data records pixels-above-bottom-of-image. Bottom-of-image is common to the topo images, surface images and deposit face images for correlation purposed. The data was created by analyzing the topo images (see project description) and establishing a weighted average elevation of the topo line at each point. Read the readme document for more information.

DB03-1 Topography Data with event data: This folder contains cleaned up elevation data from the DB03-1 experiment, plus aggradation and erosion event data. The main folder contains the elevation and event data workbooks: one Excel workbook per run day, and three sheets per workbook corresponding to the three topo lines, plus worksheets of event counts and durations. All elevation data is in pixels-above-bottom-of-image. The data was collected by analyzing images of laser lines (see project description) - note that the laser-line images were all corrected based on the calibration grid for the middle (x=1.75 meters) line, which may introduce minor errors in the data for the other two lines. In addition to the basic elevation data, the workbooks contain Event data (Aggradation and Erosion) for each day, plus the Excel macros that created the event data There are two workbooks with combined results - see the readme file.

DB03-2 Final Deposit Images: These images are cocomposite images of the deposit. For each cross-stream transect, a series of overlapping images were taken, and these were stitched together to create these composites. The original images are elsewhere in this archive.

► Eel River 10m DEM (1021.37 MB; Bode)
Eel Watershed digital elevation models (DEM). This DVD contains DEMs of the entire Eel River watershed. The Eel River is located mostly in Mendocino County on the coast of California. The source data for these DEMs comes from NED, USGS. Source data was 10x10 meter resolution in ESRI ArcInfo grid format and in geographic (lat/long) projection with NAD83 datum.

► Eel River Flipchart (32.64 MB; Bode, Power)
This is a 34 page flipchart of the Angelo Reserve. Each page is an 8.5x11 map of a river segment. The maps show the location of the highest accumulated streamflow (using DEM) as the river, even though the channel is wider, and use the vegetative canopy DEM colored by vegetation height. Note the decision to use canopy instead of the traditional bare-earth is to provide visual references while out in the field. Bare-earth provides little help when maps are zoomed in this close. Laminated versions will be available at the ACCR Science Center to be used during field sampling. Sampling sites can be drawn directly on the maps with a sharpie then removed later using alcohol. Marked up maps are to be either copied using the xerox machine, or scanned. Scanned versions can be sent to Collin Bode to convert the points into a GIS coverage.

► Eel River Quads (1.36 MB)
A listing of Quads available from the USGS covering some or all of the Eel River basin, and location maps in jpg and pdf formats.
Throughout the world, historically large populations of native anadromous salmonids are in severe decline or extinct. In the United States alone, twenty-six Evolutionarily Significant Units of Pacific salmonid are currently threatened or endangered. These declines are most commonly attributed to degradation of spawning and rearing habitat resulting from increased loading of fine sediments. Although excessive loading of fine sediments into rivers is well known to degrade salmonid spawning habitat, its effects on the demographically critical rearing juveniles have been unclear. We experimentally manipulated fine bed sediment in a northern California river and examined responses of a juvenile salmonid. Increasing concentrations of deposited fine sediment decreased growth and survival of juvenile steelhead trout. These declines resulted from a shift in invertebrates toward burrowing taxa unavailable as prey and from increased steelhead activity and injury at higher levels of fine sediment. The relationship between deposited fine sediment and juvenile steelhead growth is linear. This suggests that there is no threshold below which exacerbation of fine sediment delivery and storage in gravel bedded rivers will be harmless, but also that any reduction will produce immediate benefits for salmonid restoration.

Removal of the Glines Canyon and Elwha Dams on Washington’s Elwha River will allow anadromous fish species to once again access the full length of this river, which is contained almost entirely within the Olympic National Park. NCED Visitor Chris Bromley, advised by Colin Thorne, University of Nottingham, UK, and Gordon Grant, US Forest Service and Oregon State University, working with NCED staff, designed and built a 30 feet model of the Glines Canyon (upstream) dam and Lake Mills reservoir in which he conducted repeated delta-builds and dam removals. The removals represented different possible scenarios, from a slow deconstruction of the dam to a fast one.

Cantelli, A., Paola, C. and Parker, G., 2004, Experiments on upstream-migrating erosional narrowing and widening of an incisional channel caused by dam removal, Water Resources Research, 40, W03304, doi:10.1029/2003/WR002940 The present paper reports on a laboratory investigation of the erosion of a deltaic front induced by the removal of a dam. We built a laboratory model of a dam, and observed both the sedimentation in the reservoir due to the downstream propagation of a delta front and the erosion of the delta front during dam removal, including measurement of channel morphology and flow field. Based on an analysis of bank erosion two principal erosive trends were detected: during the initial stage of erosion the width of each section quickly decreased to a minimum value, after which the section widened. Undistorted Froude similitude is used to scale the results up to field dimensions.

This is a series of maps produced by the California Division of Mines and Geology (now known as the California Geological Survey). This contains most of the 7.5’ USGS Quads in and around Angelo.

These are .wmv files of field and laboratory granular flows and debris flows. The purpose of these videos is to show the great range in behavior of granular and debris flow. Videos numbered 0-3 were taken at the Illgraben Torrent, a debris flow channel in Switzerland. Videos numbered 5-8 were taken in the large rotating debris flow flume (Big Wheel) at the Richmond Field Station, University of California, Berkeley. Videos numbered 9-12 were taken in the small rotating debris flow flume (Maytag) at the Richmond Field Station.
Marmot (123.26 GB; Campbell, Grant, Marr, Podolak, Wilcock)

The Marmot Dam, on Oregon’s Sandy River, a tributary to the Columbia, was removed in summer 2007. An earthen cofferdam redirected river flow through a diversion channel, while the dam was removed. Then, fall rains and high flow, will caused failure of the cofferdam, allowing the river to begin moving the reservoir materials downstream. NCED, in consultation with SAFL, US Forest Service and University of Oregon partner Gordon Grant and dam owners Portland General Electric, collaborated to design and build a 25 foot model of the river reach above and below the dam. The model was used for research and for filming purposes; a documentary film will cover the actual and modeled dam removals. In addition, NCED conducted a pre and post removal field monitoring campaign, supervised by NCED PI Peter Wilcock and JHU graduate student Charles Podolak.

Rice Pile (150.16 MB)

Riparian Vegetation and Braided Stream Dynamics (143.17 GB; Foufoula-Georgiou, Paola, Tal, Tilman)

Ongoing experiments at the St. Anthony Falls Laboratory are designed to isolate the effects of vegetation on braided stream dynamics. These experiments show how a fully braided stream with a noncohesive bed transitions to a single-thread (meandering) system when continuously forced with vegetation. Time-lapse photography and measurements of bed topography, flow depth, sediment output, and flow velocities enable us to study and quantify the morphodynamics of the system associated with this change.

Shuttle Radar Topography Mission (SRTM) (29.05 GB)

This is the SRTM dataset. The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000.

Streamlab 2006 (67.84 GB; Marr, Wilcock)

StreamLab06 was a multiphase research endeavor involving academic researchers, federal agencies and stream restoration practitioners. This ongoing project is being conducted in the Main Channel at the St. Anthony Falls Laboratory in Minneapolis, MN. The StreamLab program brings together a spectrum of research expertise (stream ecology and biology, engineering, hydrology, hydraulics and geomorphology) to conduct focused studies on a laboratory controlled, field scale, indoor stream environment.

The first phase of the StreamLab06 project was completed in late March, 2006, and was focused on testing several existing and one new technology for sampling bedload transport. Technologies were tested in separate sets of sand and gravel trials.

For the former, the channel was pre-loaded with sediment consisting of nearly uniformly sized (approximately 0.8mm) sand. Transported sand was captured in the channel’s weigh pans, weighed, and recirculated. The water discharge varied (from trial to trial) between 2.0 and 3.6 cubic feet per second.

Three standard “manual” samplers were tested: a 3” Helley-Smith, a 3” BL84 and an Elwha Sampler. For each, samples were taken at a fixed lateral position in the flow, just upstream from the weigh pans. Samples were taken over times varying from 15 seconds to one minute to see what sample-time would be necessary to capture natural variability in the sediment transport.

In addition to these samplers, two (1200 and 600 kHz) Acoustic Doppler Current Profilers (ADCP) were installed and tested. These units just touch the water surface, and have the potential to deliver non-destructive information on sediment transport. For this experiment, researchers concentrated on the zones just upstream and downstream of the unit. In the downstream zone, which was just upstream of the weigh pans, a velocimeter (16mHz Micro ADV) provided a velocity profile of the flow, which will be used to calculate bed stresses. Finally, a 100 frame-per-second digital video camera capable of resolving individual grains captured the flow as it passed through the downstream zone.
For the second set of trials, the sand was cleared from the channel, replaced with gravel, and several runs with varying discharges (up to a maximum of 5.5 cubic meters per second) were conducted. The same bedload sampling technologies were in place for the gravel runs, and a Toutle River 2 sampler was added to the mix.

▶ Stream Restoration Toolbox (62.14 MB; Cantelli, Lauer, Marr, McElroy, Parker)

The Stream Restoration Toolbox consists of current basic research cast into the form of tools that can be used by practitioners. The toolbox contains models, code, websites, and small applications that are useful for applied stream restoration. Tools are free to download and use. The Toolbox is not limited to NCED but is open to all contributors. Tools are listed in alphabetical order.

**Data Subsets**

**Bank Stabilization Diagnosis:** Determination as to whether or not bank stabilization should be a part of a river restoration scheme [Lauer]

**The Dam Remover:** Mark I: Models the morphodynamics of the channel that incises reservoir sediments following dam removal. [Cantelli]

**The Gravel River Bankfull Channel Estimator:** This tool consists of a set of regression relations for predicting bankfull geometry of mobile-bed single-thread gravel bed streams in terms of bankfull discharge and bed surface median grain size. [Parker]

**The Gravel River Bankfull Discharge Estimator:** This tool consists of an equation to estimate bankfull discharge in an undisturbed (reference) reach of a single-thread, mobile-bed gravel-bed stream from measured channel characteristics. [Parker]

**Planform Statistics:** Tools to assist in calculating planform statistics (width, curvature, channel migration rate). [Lauer]

**Sand Bed Calculator:** Calculator to estimate bed geometry and bedload transport from sand bed surveys. [McElroy]

**Sediment Transport Morphodynamics with applications to: Rivers and Turbidity Currents:** This ebook is an amazing resource containing fundamental and applied lectures on rivers and turbidity currents as well as many other geomorphic processes. The main lectures are in PowerPoint. These lectures are linked to Excel files, most of which serve as graphical user interfaces for code in Visual Basic for Applications. Extended explanation is given in Word. Phenomena are illustrated with mpeg video clips. [Parker]

**Spawning Habitat Integrated Rehabilitation Approach (SHIRA):** This website provides a comprehensive introduction to the issues and concepts surrounding spawning habitat rehabilitation on regulated rivers. The website includes description of the SHIRA framework, case studies, and reference list. [Pastermack]

**The Spawning Gravel Refresher:** Allows design of controlled flood releases from dams combined with gravel feeding to restore over-coarsened and immobile former gravel spawning grounds. [Parker]

**The Threshold Channel Calculator:** Design of a threshold channel in an e.g., urban setting, for which the sediment supply has been cut off. [Wilcock]

▶ Turbulence Generated from multilevel Vegetation (1.22 GB)

▶ Wax Lake LIDAR (9.21 GB)

▶ William Brownlie Alluvial Channel Data (1.69 MB)

In recent years, attempts have been made to develop numerical models for unsteady flows in channels with sediment transport. This work was conducted to analyze two essential ingredients of any numerical model: the relationship between the hydraulic variables (slope, depth, and velocity), and the predictor of sediment concentration. Report KH-R-43A (not in this archive) presents a detailed analysis of the two components and examines their role in numerical modeling. Six hydraulic relationships
and 13 sediment concentration predictors are examined and compared. New relationships are then developed which appear to be more accurate than the existing techniques. Finally, the new relationships are utilized in a numerical unsteady flow, moveable bed model which uses a four-point implicit finite difference solution scheme.

The data base associated with this report (presented originally as Report KH-R-43B) contains 7,027 records (5,263 laboratory records and 1,764 field records), in 77 data files. The data are provided here as two spreadsheets – field data and laboratory data.

Not all records were used in the final analyses, but they have been included in an attempt to provide a historically complete set of alluvial channel observations. The material presented in these reports is essentially the same as the thesis submitted by the author in partial fulfillment of the requirements for the degree of Doctor of Philosophy. A common list of references, with data sources separated from other references, has been included in both reports.

A compilation of twentieth century observations of alluvial channels, both field and lab, in a standard format, from a wide variety of sources. Source: Compilation of Alluvial Channel Data: Laboratory and Field, by William R. Brownlie, California Institute of Technology, Pasadena, CA, November 1981 Data are arranged by stream, and include measurements of discharge, width, length, depth, slope, temperature, and bedload measures including D50 grain size, gradation, specific gravity, and concentration.

► XES Basin (617.95 GB; Cantelli, Kim, Martin, Mullin, Paola, Strong)

The XES facility is a large experimental basin (13 m x 6.5 m), developed and built with funds from NSF and the University of Minnesota, that permits the formation of stratigraphy through the use of a flexible subsiding floor. The goal is to reproduce the real-world (i.e. spatially variable) kinematics of subsidence, as determined by geophysical modeling and backstripping of real basins.

The floor is a honeycomb of 432 independent subsidence cells through which a gravel “basement” is slowly removed to provide accommodation space for deposition. At the beginning of an experiment, the basin is filled with dry, well sorted commercial gravel. The top of the gravel is covered with a thin rubber membrane. The experimental deposit is formed on top of this membrane. Subsidence is induced by withdrawing gravel from the bottoms of the hexagonal cells. Each hexagon forms the top of a cone that tapers into a standard elbow pipe. The gravel in the cone rests at the angle of repose in this elbow. Subsidence is induced by firing a pulse of high-pressure water into the gravel in the elbow. A small volume of gravel is knocked out of the elbow and falls into an exhaust line, where it is transported out of the system and stored for later reuse. Each subsidence cell has its own sealed pressure tube that drives the pulses via a computer-controlled solenoid valve. We have refined and calibrated the pulsing so that each pulse produces about 0.12 mm of subsidence: the “earthquake slip” in the experiments. This is about equal to the resolution with which the basement elevation can be read (described below), and also to the typical grain size of sediment in the experiments. Hence the subsidence is effectively smooth and continuous in time. The subsidence is also spatially continuous. The cells are separated only at floor level, so the gravel can flow laterally to accommodate differential subsidence with no breaks at the cell boundaries. Firing a single cell, for instance, produces a smooth bowl-shaped subsidence pattern that extends over the six adjoining cells. Extensive testing has shown that the underlying honeycomb structure is not imprinted on the subsidence at the surface until the rubber membrane (the top of the basement) has been lowered to within about 0.2 m of the honeycomb. This leaves about 1.3 m of usable accommodation space in the basin. As long as the gravel basement is loaded, lateral slopes of up to 60 can be produced between adjoining cells.

Premixed sediment and water can be fed from anywhere along the perimeter of the basin, and the level of standing water is independently set by a computer-controlled head tank mounted outside of the basin. Thus, base level (in effect, eustatic sea level) can be raised or lowered independent of events within the basin.

During an experiment, the surface flow pattern is recorded using video and still cameras. In addition a topographic scanning system, based on the design of Rice and Wilson (1988) and Wilson (1990), allows us to document separately the 3-D evolution of the surface topography during the run for later comparison with the surface-flow images, the preserved deposits, and theoretical predictions.

Once the experiment is complete, the tank is pumped dry and the resultant deposits are cut in a series of precise parallel faces, beginning near one edge. Each face is then photographed. At greater intervals, a peel is taken of the cut face. This serial microtome process allows us to build a 3-D image of the deposits by stacking the sequence of photographed slices.
This collection contains several folders of corrected time-lapse images from the XES02-1 experiment. Corrected photos read me

Data Subsets

**XES02-1 Final Topography Data:** This data collection contains the XES02-1 topographic scans, with subaerial (laser) and submarine (sonar) data integrated into a whole. In addition to the topography, the collection contains a “subsided topography” folder, with topo data corrected for subsidence and erosion, and “basement_topography” folder. See the readme file for more details.

**XES02-1 High Resolution Overhead Photos:** These images of the XES02-1 fluvial surface were taken with a high-resolution film camera mounted overhead. The film was professionally scanned to PCD format. See the ‘hires_photo_index.xls’ file for more info.

**XES02-1 Movies - General:** This is a collection of movies of the XES02-1 Experiment - see the readme for a current listing. Note that some specialized movies are stored elsewhere in this archive.

**XES02-1 Sample Overhead Images - Rapid Cycle:** A selection of photos from the Rapid Base Level cycle of the XES02-1 experiment.

**XES02-1 Synthetic Strat Movies:** This folder has movies of the synthetic stratigraphy (both strike and dip) generated from the XES02-1 topography data.

**XES02-1 Topography and Re-constructed Stratigraphy:** Elevation data from the XES02-1 experiment corrected for basement elevation, and various reconstructed stratigraphy data sets. See the readme for a complete description of the files.

**XES96-1 Photomosaics of deposit:** The date set contains a complete set of photomosaic cross sections of the deposit from the variable base-level experiment (see project description).

**XES99-1 Deposit Face Images:** These are several folders of images taken of the deposit faces - see project description for details on how the deposit was sliced to create these faces. There are the official photos (camera in fixed position), and two sets taken with a handheld camera.

**XES99-1 Elevation and Isopach data:** These spreadsheets contain the elevation (topography) data from the XES99-1 experiment. Data was taken at intervals between four and eight hours - each worksheet corresponds to one topography scan. Basin coordinate system: X - downstream Y - crosstram and Z - depth below the rim of the tank.

**XES99-1 Overhead Photos (jpg):** These are photos taken of the fluvial surface during the four states of the XES99-1 experiment, in JPG format.

**XES99-1 The Effects of Variable Subsidence Rate and Geometry on Avulsion: Some Experimental Results:** Surface images from the 2002 Run of Jurassic Tank were used to count, locate and categorize channel avulsions. Powerpoint presentation (GSA Regional Meeting) of the results.
Appendix G: Visitor Program

Year 9 Program Summary

Stream restoration topics dominated the focus of the Visitor Program in Year 9. The program hosted three researchers; two at St. Anthony Falls Laboratory and one at Richmond Field Station.

Vivian Leung from the University of Washington concluded her experiments at St. Anthony Falls Laboratory on sediment transport in the vicinity of large woody debris, and then took her research to the field to attempt to generalize the relationship between natural and experimental systems. She collaborated with NCED graduate student Sara Dayley to collect field data in the Hoh river in Washington. Her expanded 2009 project, Interactions between “Woody Debris, Fluid Flow, Sediment Transport, Channel Morphology and Wood Movement in Rivers,” is now complete and the final reporting is included here.

Lindsey Albertson from the University of California – Santa Barbara worked with NCED Collaborative Investigator Leonard Sklar and others at the Richmond Field Station on her project “Impacts Of Biological Diversity On Sediment Transport Condition In Streams”. She explored the interactions between coexisting caddisfly larvae and how the presence of their silken catchnets physically affects sediment transport over a range of sizes. Results show that the critical shear stress was 50% higher when multiple species were present as compared to the result with no caddisflies, significantly higher than the presence of a monoculture which increases shear stress by only 30%.

The final project completed to date was the research of Leslie Hopkinson of West Virginia University. Leslie ran experiments at the St. Anthony Falls Laboratory looking at the effect of multiple types of riparian vegetation on the near bank velocity distributions and turbulence characteristics and the resultant effect on fluvial erosion of the streambank. She found that 100% flexible vegetation cover will support erosion control and patches of vegetation may promote erosion in locations between areas of vegetation.

2010 Program Abstracts

Vivian Leung The role of woody debris has been recognized to have a fundamental role in river dynamics, comparable to the role of water discharge and sediment transport (Montgomery et al., 2003). Historically, large woody debris was routinely removed from rivers to improve navigation, facilitate fish passage and prevent the destructive impacts of mobile wood during flooding (Collins et al., 2003). At this point very little is understood of the mechanics of how woody debris transport and flooding interactions impact river morphology and floodplain infrastructure.

In recent years there has been a significant body of research showing the habitat forming value of large woody debris in rivers (Gregory et al., 2003), such as increases in hydraulic and topographic complexity that lead to a greater diversity of aquatic habitats and more hiding places for young fish. Large woody debris helps to retain the sediment sizes that are used by spawning salmon. The majority of large pools in forest rivers are found in conjunction with large woody debris (Abbe and Montgomery, 1996) and pools are essential feeding and spawning habitat for fish due to the lower water velocities and lower water temperatures in the summer.

In the past decade engineered logjams have become a widely accepted tool in river management for the purpose of decreasing the rate of riverbank migration and for improving aquatic habitat (Abbe et al, 2003). Sediment deposits around woody debris build up riverbanks and counteract bank migration caused by erosion. Logjams are also used to create the large pools and complex streambed morphology that are important fish habitat and breeding grounds. A better understanding of the underlying sediment physics and hydraulics around naturally occurring woody debris in rivers can lead to improved design criteria for engineered logjams.

Research Objectives and Potential Scientific Impact:

I propose to study how the interaction of sediment transport and woody debris in rivers are a first-order control on wood movement and channel-width scale river morphology. I will focus on positive and negative feedbacks between woody debris, fluid-flow and the spatial patterns of local scour and sediment deposition that initiate wood movement or bury and stabilize...
wood. I will conduct a series of flume experiments to test the effects of root presence, root geometry and log orientation of individual stationary trees on wood movement and streambed morphology in a flume with a deformable sediment bed. I propose to test the following 3 hypotheses for how wood-altered flow patterns interact with sediment transport:

- Spatial patterns of sediment deposition around woody debris will affect the threshold of wood movement.
- Root density (i.e. degree of flow blockage) is a primary control on size and location of sediment deposition as well as scour mechanisms for pool excavation.
- Pool volume and sediment deposition are related to the root cross-sectional area oriented orthogonal to flow.

The interactions between woody debris, fluid flow and sediment transport play a fundamental role in ecogeomorphology, affecting channel roughness, streambed morphology, sediment transport and sediment storage in rivers. The proposed flume experiments will provide scientific insights into a complex interdisciplinary problem as well as guidance and design criteria for use in river restoration and river engineering.

The relationship between physical variation in the environment and the distribution and diversity of biological organisms is one of the most important and well-studied topics in many fields of natural science. Over the past two decades, a growing interest in how species not only respond to but also directly control variation in physical processes has led to the emerging research topic ecogeomorphology, which investigates interactions between organisms and geomorphic processes. However, our understanding of how biology affects physical processes remains limited, in part because we often treat ‘biology’ as a single species and ignore interactions between multiple, coexisting taxa that typically characterize a natural ecosystem. Here I propose a laboratory study that will test whether different species of animals have linear or non-linear, synergistic impacts on the physical process of sediment transport due to species interactions.

I will use a model system in streams to experimentally determine how multi-species assemblages of caddisfly larvae (Trichoptera: Hydropsychidae) impact substrate mobility. Caddisflies are insects that spend the larval portion of their life-cycle in the benthic habitat of streams where they construct silken catchnets across pore spaces between rocks to filter food particles out of the water. Though small, they can reach densities of over 10,000 per square meters, and previous studies have shown that their silk nets reduce the probability of sediment movement during floods. I recently conducted a small-scale pilot experiment to determine whether different species of caddisfly have linear or non-linear impacts on sediment mobility due to spatial niche partitioning that limits where different species construct nets. In laboratory flumes (1.2 m long x 0.15 m wide), I found that critical shear stress in a 2-species polyculture was, on average, 20% higher than the average of the two species in monoculture (Fig. 1a). In addition, critical shear stress was greater than that obtained for Arctopsyche, which had the largest single-species impact on critical shear stress. These results appeared to result from competitive interactions among the species, which led to differential use of pore spaces in the benthic habitat. I documented where individuals of each species constructed nets in

![Fig1](a) Compared to a control with no caddisflies, critical shear stress was, on average, 30% higher in treatments that contained monocultures of Ceratopsyche or Arctopsyche. Because animal density was held constant, the null expectation was that the critical shear stress (black point) for the mixed polyculture would be the average of the two monocultures. However, the observed value was actually 20% higher than the average of the monocultures. (b) Frequency of nets at a given depth for each species in monoculture. (c) Frequency of nets for each species in polyculture. Average net depth is indicated by dotted lines.
mono- vs. polyculture and found that the two species built nets at relatively similar depths in monoculture (Fig. 1b), but when they were allowed to compete in the polyculture, Arctopsyche shifted its distribution to build nets significantly closer to the bed surface ($p = 0.02$, Fig. 1c) whereas Ceratopsyche shifted its distribution to build nets at significantly deeper depths ($p = 0.03$, Fig. 1c).

Results of my pilot study suggest that different caddisfly species may have non-linear effects on sediment transport in streams as a result of competitive interactions that lead to niche differences. However, this potentially important conclusion admittedly stems from experiments that have been performed in relatively contrived, small-scale laboratory flumes that are narrow and have an unrealistic arrangement of substrate sizes, which makes it difficult to scale these patterns to natural systems. Therefore, below I describe a large-scale flume experiment at the Richmond Field Station at UC-Berkeley that will provide a unique opportunity to directly test the hypothesis of non-linear effects of caddisflies on sediment movement through an interdisciplinary collaboration in which my experiments are controlled and scaled appropriately. In combination with other planned behavioral observations that will be conducted in natural streams at the Sierra Nevada Aquatic Research Laboratory (SNARL), I will be able to mechanistically link any non-linear impacts of these organisms on sediment mobility to competition and spatial niche partitioning among species.

Leslie Hopkinson In response to the habitat and water quality impacts of channel instability, approximately $1$ billion/year was spent during 1990-2003 to restore degraded streams. The most common technique used to control streambank retreat involves reshaping streambanks to a stable angle and then establishing riparian vegetation on the streambank face and floodplain (Bernhardt et al., 2005; Bernhardt and Palmer, 2007). Typically lower streambanks are seeded with a wetland seed mixture and herbaceous tubules are planted in an offset pattern. The upper streambanks and riparian zone are also seeded with grass, and a mixture of herbaceous vegetation, shrubs, and woody vegetation are planted. This planting scheme results in multiple levels of vegetation with varying densities, time of establishment, height, and flexibility.

Flow through vegetation has been studied extensively for idealized vegetation of a single vegetation type for both rigid and flexible vegetation under submerged and emergent flow conditions. Flow through multiple layers has recently been addressed for rigid vegetation (Liu et al., 2010), but the vegetation was not scaled to actual vegetation. Vegetation with frontal densities varying with depth has been considered (Lightbody and Nepf, 2006), but flow through a combination of vegetation types typical of stream restoration designs has yet to be addressed. Therefore, there is a critical need to identify the complex vegetation-fluid interactions in a controlled setting. In the absence of such knowledge, the impact that vegetation has on mitigation strategies involving natural vegetation for sediment control will not be understood. This research will provide the basis for further study of sedimentation promotion and erosion control provided by stream restoration designs as vegetation establishes on the bankface and riparian zone.

Project Reports

► Interactions Between Woody Debris, Fluid Flow, Sediment Transport, Channel Morphology And Wood Movement In Rivers.

Vivian Leung, PhD candidate, University of Washington

Research Objectives

The role of woody debris has been recognized to have a fundamental role in river dynamics, comparable to the role of water discharge and sediment transport. My research during the 2009-2010 NCED Visitor’s Program investigates how the interaction of sediment transport and woody debris in rivers are a first-order control on wood movement and fine-scale river morphology. I focus on positive and negative feedbacks between woody debris, local scour and sediment deposition that initiate wood movement or bury and stabilize wood. My previous fluid dynamics experiments using flow visualization around model woody debris on a fixed bed suggest the amount of scour and sediment deposition are primarily related to the presence of roots, root density and the root cross-sectional area relative to flow.

My experiments and fieldwork during the NCED Visitor’s Program investigate how: (1) local sediment scour and deposition will depend on the obstructional area of the wood, and the relationship will be generalizable between natural and experimental systems; and (2) stability for woody debris will depend on spatial patterns of fluid dynamics and sediment transport.
Research Background & Implications

Historically, large woody debris was routinely removed from rivers to improve navigation, facilitate fish passage and prevent the destructive impacts of mobile wood during flooding. At this point very little is understood of the mechanics of how woody debris transport and flooding interactions impact river morphology and floodplain infrastructure.

During periods of high flow, the increase in fluvial transport of woody debris can amplify the destructive impacts of flooding. The resulting “floating log disasters” are a hazard to floodplain communities and infrastructure. Often logs will accumulate around bridges and other infrastructure, creating temporary dams and increasing the hydrostatic forces on the structures. Such high magnitude transport events occur during extreme flooding and stormy conditions when it is impossible to take active measurements. At this point very little is understood of the mechanics of how this style of woody debris transport and flooding interact with river morphology and floodplain infrastructure.

In recent years there has been a significant body of research showing the habitat forming value of large woody debris in rivers, such as increases in hydraulic and topographic complexity that lead to a greater diversity of aquatic habitats and more hiding places for young fish. Large woody debris helps to retain the sediment sizes that are used by spawning salmon. The majority of large pools in forest rivers are found in conjunction with large woody debris and pools are essential feeding and spawning habitat for fish due to the lower water velocities and lower water temperatures in the summer.

In the past decade engineered logjams have become a widely accepted tool in river management for the purpose of decreasing the rate of riverbank migration and for improving aquatic habitat. Sediment deposits around woody debris build up riverbanks and counteract bank migration caused by erosion. Logjams are also used to create the large pools and complex streambed morphology that are important fish habitat and breeding grounds. A better understanding of the underlying sediment physics and hydraulics around naturally occuring woody debris in rivers can lead to improved design criteria for engineered logjams.

Experimental Research

Laboratory experiments at St. Anthony Falls Laboratory follow on my proof-of-concept flume experiments investigating spatial patterns of fluid flow around individual model woody debris. Results from my preliminary experiments suggest that:

- The presence of root structures on woody debris leads to significantly greater areas of sediment scour and deposition.
- As root density increases the amount of sediment scour and deposition increase, and the sediment deposition moves closer to the roots.
- The amount of sediment scour and deposition are related exponentially to the root cross-sectional area, oriented orthogonal to flow.

The experiments will confirm the sediment transport mechanisms that cause pool excavation and the feedbacks that lead to local sediment deposition and wood burial.

The specific hypotheses I propose to test are:

(1) Root density is a primary control on size and location of sediment deposition and on the scour mechanism for pool excavation leading to the formation of the deepest pools.

These experiments use model trees with no roots and model trees with roots in a range of densities. The experiments measure the volume and position of sediment deposition compared to the root density. The experiments also measure the depths and volumes of pools formed, and assess the effects on pool dimensions of specific scour mechanisms, such as horseshoe vortices. Flow depth and flow velocity are kept constant.

(2) Pool volume and sediment deposition are related to the root cross-sectional area oriented orthogonal to flow.

These experiments use model trees with no roots and model trees with a range of root sizes and shapes, oriented at different angles, creating a range of root cross-sectional areas relative to the flow. The experiments measure the size, depth and volume of pools formed around the woody debris compared to the root cross-sectional area. Flow depth and flow velocity are kept constant.
Experiments

Experiments are conducted in an 8 m long, 1.2 m wide and 0.46 m deep flume at St. Anthony Falls Laboratory at the University of Minnesota. Flow discharge ranges up to 0.11 m$^3$/sec and water level is controlled by a downstream weir. These experiments investigate sediment transport and scour around model woody debris. The flume contains a 15 cm deep sediment bed composed of well-sorted coarse sand. Model trees used for the experiments are made of wood and plastic with trunk lengths of 20 cm and 30 cm and trunk diameters ranging from 1.27 and 2.54 cm. Model trees have no roots or roots with root diameters ranging from 3-7 cm, root depths ranging from 1-4 cm. The roots are solid, star-shaped or made of wire mesh.

For these experiments, model trees are placed in the flow until the sediment bed equilibrates. For each model tree, the experiment is repeated with the tree oriented at 0°, 45°, 90°, 135° and 180° relative to flow direction. Bed elevation is measured before and after the experimental run. Water surface elevation, flow velocity and discharge are measured during the run. Sediment bed morphology is measured after the experimental run using vertical laser sheets and a camera mounted to an instrumentation cart. Sediment samples were collected for select experiments for a spatial analysis of grain size variation around woody debris.

Fieldwork

I am using field surveys of woody debris in gravel and cobble rivers to test the hypothesis that local scour and sediment deposition around individual trees is proportional to the degree of flow obstruction by wood, and consistent with patterns of shear stress and pool geometry observed in my experiments.

Field measurement protocol was developed in the Cedar River in Washington and the Devil’s Track River in Minnesota during the 2009 field season. Sediment scour and deposition are measured on gravel and cobble bars under low flow conditions when access is possible. The bulk of field data collection was conducted on the Hoh river in Washington during the 2010 field season. The field area encompasses 12 miles of the Hoh river near the boundary of Olympic National Park. Pebble counts and water surface slope measurements were taken at 3 locations. Streambed morphology around woody debris was measured using a total station and engineer’s level.

Research implications

Although the role of woody debris has been recognized to have a fundamental role in river dynamics, comparable to the role of flow and sediment transport, the mechanisms of the resulting sediment scour and deposition affecting wood movement and changes in local bed topography in forest rivers remains a fundamental hydrophysics problem that has important implications for stream ecology and river engineering. A limitation of my previous experiments, and those of others, is that they employed a fixed bed. My experiments seek to overcome this fundamental limitation by using a mobile bed and investigating the relationship between flow blockage, local bed morphology, sediment deposition and thresholds for wood movement.
There are limitations to both field and experimental approaches to this research problem. My experimental system is a simplified and idealized version of natural rivers, where individual trees are not interacting with other trees or with banks. There may be difficulties scaling experimental results to natural systems. Woody debris transport is episodic and occurs during flood events, so it is difficult to take active measurements. I anticipate that combining flume experiments and fieldwork will allow for a general understanding of wood movement and sediment transport that includes both the episodic nature of wood movement and the complexities of natural systems. Consequently the results of this research will provide guidance and criteria for use in river restoration and engineering as well as scientific insights into a complex interdisciplinary problem.

Conference Abstracts


Workshops and Outreach
2009 NCED Summer Institute for Earth-surface Dynamics
Collaborative Research: Track 2: Manoomin, investigating the past, present, and future conditions of wild rice lakes on the Fond du Lac Band of Lake Superior Chippewa Reservation
SAFL lab tours, MN state fair and UMN Math & Science Fun Fair
Impacts Of Biological Diversity On Sediment Transport Conditions In Streams

Lindsey Albertson, PhD Candidate, University of California-Santa Barbara

1. Background

Variation in the abundance and diversity of organisms has long been recognized as a consequence of physical variation in the environment. Recently, many fields of natural science have suggested that organisms not only respond to, but also directly regulate, the physical processes that structure ecosystems in ways that have major implications for how the current loss of Earth’s biodiversity will affect our planet. An explosion of studies has tried to incorporate the influence of organisms into our understanding of biogeochemical cycles, functioning of ecosystems, and formation of habitats. Despite the growth in this topic, however, most studies still consider the influence of only one species at a time, ignoring the diverse array of species that might have unique impacts when allowed to coexist.

In my research, I explicitly ask how species interactions between coexisting organisms affect the physical process of sediment transport. Using caddisfly larvae (Trichoptera:Hydropsychidae), I study how multispecies assemblages of these animals affect sediment movement in streams. Caddisfly larvae are insects that live in the benthic substrate of streams (Fig. 1), where they construct silken catchnets across pore spaces between rocks to filter food particles from the water. Caddisflies can become incredibly dense in nature (2,000-10,000 m-2), and previous studies have shown that nets from a single species reduce sediment motion during floods. I am investigating how more than one species that coexist in the same stream influence sediment transport conditions. I received funding from NCED in 2010 to run a study in the flume facility at UC-Berkeley that tested whether critical shear stress was higher in sediment patches that contained 2 vs. 1 species of caddisfly. This project is now finished and the results are currently being analyzed.

Prior Results

In a first attempt to assess how 2 caddisfly species (Arctopsyche californica and Ceratopsyche oslari) that are widely distributed throughout the western U.S. impact sediment mobility, I conducted a pilot study in small flumes at my home institution. Using 32 re-circulating laboratory flumes (1.2-m long) in which velocity profiles were used to calibrate near-bed shear stress to discharge, I seeded 10-cm x 12-cm patches containing a heterogeneous substrate mixture and coarse surface layer with 0, 1, or 2 species of caddisfly. Over a 4-day period, the density of caddisflies settling in the patch approached 2000 individuals m-2, which is at the lower end of realistic densities for natural streams that are dominated by caddisflies. After allowing caddisflies to build nets for 4 days, near bed shear stress was gradually increased until at least one rock moved completely out of and downstream of the working patches (movement was documented visually).

As has been demonstrated before, the presence of caddisflies significantly increased the critical shear stress needed to initiate incipient grain motion relative to control patches that had no caddisflies (Fig. 2A, p < 0.01). But more importantly, critical shear stress was 20% higher than the average of the monocultures (i.e., the additive expectation given that total caddisfly density was held constant, Fig. 2A). Critical shear stress was also significantly greater than that achieved by Arctopsyche, which had the largest single-species impact on critical shear stress. These results clearly indicate a non-additive, synergistic effect of the two species on incipient grain motion. The non-additive impact appeared to result from differential use of pore spaces in the benthic habitat. Using glass plated viewing boxes placed in each mesocosm, I was able to document the location of each individual net for species in monoculture patches. When species were in monoculture, each built nets at comparable depths of ~20-mm in the benthic habitat (Fig 2B). However, when the two species were placed together and allowed to interact in polyculture, the larger-bodied Arctopsyche shifted its distribution of nets significantly closer to the bed surface (p = 0.02). In contrast, the much smaller Ceratopsyche shifted its distribution of nets to significantly deeper depths (p = 0.03, Fig 2C).
These results were exciting, but the conclusions that I was able to
draw were limited because this experiment was conducted in
tiny flumes in which the hydrodynamics and sediment sizes
were not scaled appropriately to real streams conditions. Thus,
I conducted a large-scale experiment at RFS to more rigor-
ously quantify sediment transport conditions and scale up to
larger sediment sizes.

NCED Research Activities

Large-scale flume experiment: To overcome the limitations
of my first experiment, I conducted an experiment in the large
flume at RFS to assess whether interacting species of caddis-
fly can impact sediment motion across a range of rock sizes.
This experiment was run as a fully factorial, random block
design in which both sediment size and caddisfly diversity
were manipulated. To establish the rock size manipulation
treatment, the entire flume was first filled with subsurface sedi-
ments with D50 = 8 mm. On top of the subsurface, zones of
surface material were created that ranged from a rock mixture
with D50 of 13, 19, 26, 37, to 45 mm. These rock sizes were
chosen to test similar sizes to what has already been done but
also increase the size to the maximum that the flume is able to
move. Each zone was 3 m long and delineated by paint color.
The zones were arranged in the flume so that the smallest
rock mixture was most downstream and the largest mixture
was most upstream (Fig. 3A). This allowed us to colonize
all zones with caddisflies at the same time but to focus our
monitoring attention on movement in each consecutively
increasing sediment size as shear stress was increased during
a simulated flood. Within each 3 m zone, the first 2 m simply
allowed flow to equilibriate with the rock size as water moved
from large rocks upstream to small rocks downstream. The
experimental patches were located in the bottom 1 m of each
zone. The patches (15 cm L x 20 cm W) were designated
using ½ “Vexar mesh that enclosed only the subsurface
material (i.e. the mesh did not extend into the surface layer).
Vexar mesh was used for two primary reasons: (1) it allowed
a place for attaching netting that could confine the caddisflies
to the specific patch (as described below) and (2) it provided
structure that allowed us to freeze and pull out the patches
from the flume when the experiment was finished to analyze the caddisfly net distribution. After the sediment patches were
created and mobilized to allow for natural sorting, each patch was designated a control with no caddisflies, Ceratopsyche alone,
Arctopsyche alone, or a mixture of the two species together. The patches were seeded with 60 individuals in monoculture or
30:30 mixture of each species for the polyculture. Caddisflies were confined to the sediment patch using 1 mm netting that
prevented migration between patches and were allowed to colonize and construct nets for 4 days. After colonization, shear
stress over the patches was gradually increased until partial mobility was established. As mentioned previously, rock sizes
in the flume were arranged with the smallest most downstream and largest most upstream so that as discharge was gradually
increased, the smaller rocks were monitored for incipient motion first, followed by larger rocks. Movement was recorded using
high definition video cameras looking into the flume from the side (Fig. 3B). A mobile instrument cart was moved directly over
each patch at various discharges so that water surface slope and near bed velocity profiles could be measured to provide an
estimate of near bed shear stress during the flood. After the flood, we froze the patches (Fig 3C) to directly measure the density and location of caddisfly nets in the different treatments. This procedure was repeated 2 times, for a total of 2 blocks, which equaled 4 replicates per caddisfly treatment per sediment size. The experiment has been completed and I am now processing video files to record grain motion and summarize the data. Preliminary results are explained below.

**Mechanism tests:** To further investigate whether species interactions could lead to synergistic impacts on critical shear stress, I asked two additional questions during this study. First, I froze the sediment patches using liquid nitrogen to ask: Do different species build their nets at different depths in the benthic substrate? Because the response variable in the experiment was critical shear stress, we reduced discharge in the flume to almost zero after first motion was detected and then froze each patch with liquid nitrogen, a technique that allowed us to remove the patches with the rocks and caddisfly nets intact. We then stored the patches in a -20 °C freezer until sample processing, at which time we measured how many nets were in each patch and the depth at which each net was built. Second, I collected caddisfly nets and used an automated nanomechanical test system capable of normal and lateral loading (TriboIndenter, Hysitron, Minneapolis, MN) that is part of Dr. Herbert Waite’s laboratory at UC-Santa Barbara to ask: Are there differences in net area, number of threads per net, thread diameter, and net strength across different caddisfly species? By attaching both ends of a caddisfly nets to secure clamps on the nanomechanical test system, I could pull on a net until it broke and then record the strength of the silk material. This allows me to determine if there are differences in the mechanical properties of the nets from different species that could influence the strength with which nets can tie down sediment. Data from these mechanism tests are currently being analyzed, but preliminary results are shown in Fig 4.

**Findings of Major Significance**

**Species diversity increases the critical shear stress required to initiate sediment motion.** My mesocosm experiment showed that compared to a control with no caddisflies, substrate patches (D50 = 22 mm) that contain monocultures of caddisflies increase the critical shear stress required to initiate substrate motion by 30% (Fig 2A). But perhaps most exciting is the finding that a 2-species polyculture increases the critical shear stress by another 20% (50% from the control). Data for the scaled up experiment at RFS are still being processed, but should provide additional insight into these findings for a variety of grain sizes.

**Different species of caddisfly partition benthic pore space.** After the experiment, we froze the patches that had been colonized by caddisflies to see at what depth individuals from the two species were building nets when alone in monoculture or together in a polyculture. These results are still being analyzed, but preliminary analysis suggests that when Ceratopsyche is present in a patch, 2x as many nets contact the subsurface rocks. In both the Ceratopsyche monoculture and the mixture of the two species, we found an average of 7 nets in a patch. In comparison, the Arctopsyche monoculture had only 3 nets on average contacting the subsurface grains in a patch.

![Fig 3. The set-up of the flume experiment. (a) The flume (28-m long x 1-m wide) at the Richmond Field Station was filled with 5 different surface rock mixtures ranging from a D50 of 13 mm (green, most downstream) to 45 mm (yellow, most upstream). Within each rock size zone, sediment patches (15 cm x 20cm) were colonized by monocultures of either Ceratopsyche or Arctopsyche or a polyculture of both species. (b) Patches were then subjected to a flood in which video cameras recorded movement of the surface layer through the side of the flume. (c) After shear stress was increased until at least ~5% of the rocks in each patch had moved, liquid nitrogen was poured on the patches to freeze the caddisflies and their nets in place. These data are still being analyzed but will give an estimate of the net density and location for each species in mono- vs. polyculture.](image-url)
Catch nets used for filter feeding by different caddis-fly species have significant differences in pore space, thread count, and strength. I found that the nets of the larger species, Arctopsyche, used in my experiments have fewer threads per net, larger thread diameters, and stronger silk than the smaller species, Ceratopsyche (Fig. 4). Taken collectively, these findings and the results from section 4.2 suggest that in a 2-species polyculture, the combination of the presence of Ceratopsyche nets at deeper depths and the strength provided by nets of Arctopsyche at the surface synergistically ‘tie’ rocks down and increase the critical shear stress required to initiate sediment motion.

Broader Impacts

During this experiment, I mentored 3 undergraduate students (2 Aquatic Ecology majors and 1 Geology major) from UC-Santa Barbara. All three of these students lived with me at the Sierra Nevada Research Laboratory collecting the study animals and completed independent projects during the summer. One student, Patricia Pontau, worked with me extensively at RFS and was actively involved in setting up the experiment and collecting data. An additional 2 students from San Francisco State University volunteered during the floods and helped document rock movement in the flume.

Multiple Layers Of Riparian Vegetation In Stream Restoration Designs

Leslie Hopkinson Civil and Environmental Engineering, West Virginia University, Morgantown, WV 26506

Introduction

In response to the habitat and water quality impacts of channel instability, approximately $1 billion/year was spent during 1990-2003 to restore degraded streams. The most common technique used to control streambank retreat involves reshaping streambanks to a stable angle and then establishing riparian vegetation on the streambank face and floodplain (Bernhardt et al., 2005; Bernhardt and Palmer, 2007). Often, lower streambanks are seeded with a wetland seed mixture and herbaceous tubules are planted in an offset pattern. The upper streambanks and riparian zone are also seeded with grass, and a mixture of herbaceous vegetation, shrubs, and woody vegetation are planted. This planting scheme results in multiple levels of vegetation with varying densities, time of establishment, height, and flexibility.

Flow through vegetation has been studied extensively for idealized vegetation of a single vegetation type for both rigid and flexible vegetation under submerged and emergent flow conditions. Flow through multiple layers has recently been addressed for rigid vegetation (Liu et al., 2010), but the vegetation was not scaled to actual vegetation. Vegetation with frontal densities varying with depth has been considered (Lightbody and Nepf, 2006), but flow through a combination of vegetation types typical of stream restoration designs has yet to be addressed. This research examined the effectiveness of a stream restoration planting scheme (combination of grasses and herbaceous plantings) as riparian vegetation establishes on the bank face and floodplain by meeting the following objectives:

1. How does the addition of multiple vegetation types to the riparian zone impact three-dimensional velocity distributions and turbulence characteristics?
2. How does the addition of a combination of stiff vegetation and flexible vegetation impact shear stress near the boundary?
3. How can the establishment of a combination of vegetation types potentially influence fluvial erosion of the streambank?
Methods

Flume set-up and vegetation treatments: A flume experiment was conducted in a 1.21 m wide and 6 m long flume at the St. Anthony Falls Laboratory (Minneapolis, MN). Flume vegetation models were created based on a planting scheme followed by an actual stream restoration site (Stroubles Creek, Blacksburg VA) that involved reshaping the banks and establishing bank and riparian vegetation. The lower bank of the restoration site was seeded with a wetland grass mixture and herbaceous tubules were planted in rows with a 0.15 m spacing and 0.76 m offset. The upper section was also seeded with a grass mixture with shrubs planted at a 0.15 m spacing and 1.52 m offset. From these characteristics, eight vegetation treatments were constructed involving various flexible grass lengths (0.7 cm and 3.9 cm), percent coverage (100% and 50%), and herbaceous plantings (with and without): 1) 100% cover of short grass; 2) 50% cover of short grass; 3) 100% cover of short grass with plantings; 4) 50% cover of short grass with plantings; 5) 100% cover of long grass; 6) 50% cover of long grass; 7) 100% coverage of long grass with plantings; and, 8) 50% coverage of long grass with plantings (Figure 1). The grass was simulated using synthetic grass mats of blade lengths 0.7 cm (127 stems/cm²) and 3.9 cm (22 stems/cm²). The flexible vegetation density was reduced by 50% by randomly removing square sections (30.5 cm by 30.5 cm) of the grass. This decreased area with vegetation was used to mimic establishing vegetation (Figure 1c, d). Herbaceous plantings were simulated using wooden dowels (diameter= 0.6 cm; length=15.24 cm) and were planted in rows with a 0.15 m spacing and a 0.76 m offset (Figure 1b, d).

MicroADV velocity measurements

The eight treatments were examined under two discharges (0.02 m³/s and 0.03 m³/s; tailgate height=13.27 cm). Discharge was measured with a sharp-crest weir located at the end of the open channel and was verified with MicroADV velocity measurements. Three-dimensional velocity was measured with a Sontek 16 MHz MicroADV (San Diego, CA; 25 Hz; 2 min sample time). Measurements were made as close to the boundary as allowed without significant interference for the instrument (4 cm). Measurements were taken in a grid pattern in the 30.5 cm by 38.1 cm measurement region (3.8 cm spacing; 9 rows in the lateral direction; 11 rows in the longitudinal direction; n=98 for treatments with dowels; n=99 for treatments without dowels; Figure 1). MicroADV data were filtered as explained by Hopkinson and Wynn (2009).

Data Analysis
The turbulence characteristics, turbulent kinetic energy (TKE; Equation 1) and a Reynolds stress tensor (τ_{xz}; Equation 2), were analyzed for each velocity time series:

\[
TKE = 0.5 \rho (u'^2 + v'^2 + w'^3)
\]

\[
\tau_{xz} = - \rho u' w'
\]

where \( \tau \) is the fluid density, \((u, v, w)\) are the three dimensional velocity components, the apostrophes indicate the instantaneous velocity fluctuations from the mean, and the overbar represents a time average. Because the data did not follow a Gaussian distribution, a Mann-Whitney U test was used to evaluate differences in TKE and Reynolds stresses among vegetation treatments. A significance level of \( \alpha = 0.05 \) was assumed (Daniel, 1990).

**Preliminary Results**

**Reynolds Stresses:** The treatments with 50% grass cover (both lengths) resulted in the highest Reynolds stresses at both discharges, suggesting that establishing dense flexible vegetation along the entire bank face will be beneficial for erosion prevention. However, \( \tau_{xz} \) values were of relatively low magnitude ranging from -0.03 Pa to 0.26 Pa and from -0.02 Pa to 0.45 Pa for the low and high discharges, respectively. Figure 2 shows the distribution of Reynolds stresses in the measurement region (as indicated on Figure 1). Especially apparent for the long grass, treatments with 50% flexible vegetation coverage (with and without dowels) resulted in an area of low Reynolds stresses where the vegetation was omitted for the full longitudinal length of the measurement region. Alternatively, there was an area of high Reynolds stresses in the measurement region between vegetation patches (Figure 2g, o, h, and p). This result indicates that areas between nonvegetated and vegetated portions of the riparian area will be locations susceptible to higher Reynolds stresses, leading to higher local erosion rates.

**Turbulent kinetic energy:** For the short grass, turbulent kinetic energy (TKE) calculated for treatments with herbaceous plantings (dowels) were significantly different than the treatments without the plantings (\( \tau = 0.05 \)). This result is supported by the contour plots showing the distribution of TKE in the measurement region (Figure 3). For the plots including dowels (Figure 3b, d, f, h, j, l, n, and p), a distinct increase in TKE is observed at the dowel location. This increase is evident for the TKE values because the TKE calculation incorporates all velocity components (Equation 1). The vortex shedding occurred in the lateral direction, making the velocity component, \( v \), an important component to define turbulence. Because the Reynolds stress, \( \tau_{xz} \), defined vertical momentum exchange, this increase in turbulence was not observed in Figure 2.

**Conclusions and Future Analysis:** Results indicated that a 100% flexible vegetation cover will support erosion control, and patches of vegetation may promote erosion in locations between areas of vegetation. The impact of the sparsely spaced dowels was only apparent in the TKE results. This influence of the dowels will be further studied by examining the two additional Reynolds stress tensors (\( \tau_{xy} \) and \( \tau_{yz} \)) that include the lateral velocity component. Additionally, turbulence intensities for all velocity components will be examined to better understand the vegetation’s influence on erosion potential. Boundary shear stress as defined by the Reynolds stresses will be used to determine the range of particle sizes expected to dislodge for each vegetation treatment. This work will lead to understanding how establishing riparian vegetation impacts turbulent production and boundary shear stress, ultimately resulting in information about erosion control of stream restoration designs.
Figure 2. Distribution of Reynolds stresses (Pa) in the measurement region of each treatment for both discharges (S is short grass, L is long grass, and d is dowel).

Figure 3. Distribution of turbulent kinetic energy (N/m²) in the measurement region of each treatment for both discharges (S is short grass, L is long grass, and d is dowel).
References


*This work was supported by the STC program of the National Science Foundation via the National Center for Earth-surface Dynamics under the agreement Number EAR- 0120914.*
Appendix H: Partner Meetings, Short Courses, & Working Groups

Summer Institute for Earth-surface Dynamics (SIESD)
University of Minnesota, Minneapolis, MN
August 18-27, 2010

Institute Objective

The Summer Institute focused on the science of rivers and vegetation. Participants gained experience in: the basic physics of water-sediment-vegetation interaction; modeling the co-evolution of landscapes and their ecosystems; quantitative analysis of complex landscapes; LiDAR analysis of river topography and vegetation; and specifics of braided, meandering, and deltaic systems interacting with vegetation. In addition, students gained hands-on experience with a suite of analytical tools including GeoNet (an automatic feature extraction tool for high resolution topography) and InVEST (a modeling environment to support environmental decision-making).

<table>
<thead>
<tr>
<th>Agenda- National Center for Earth-surface Dynamics 2010 Summer Institute: “Rivers and Vegetation”</th>
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</thead>
<tbody>
<tr>
<td><strong>Wednesday, August 18, 2010</strong></td>
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<tr>
<td>Time</td>
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<td><strong>Friday, August 20, 2010</strong></td>
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<td><strong>Saturday, August 21, 2010</strong></td>
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**Sunday, August 22, 2010**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Speaker</th>
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<tbody>
<tr>
<td>08:30 am</td>
<td>AM session 1: Flow through vegetation I: Effects of biomechanical properties and density</td>
<td>Luca van Duren</td>
</tr>
<tr>
<td>10:45 am</td>
<td>AM session 2: Flow through vegetation II: Effects of patchiness</td>
<td>Luca van Duren</td>
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<tr>
<td>12:30 pm</td>
<td>Lunch</td>
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<td></td>
<td>PM session 1: Free</td>
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<td>PM session 2: Free</td>
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<td></td>
<td>Dinner- on your own</td>
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**Monday, August 23, 2010**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Speaker</th>
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<tbody>
<tr>
<td>08:30 am</td>
<td>AM session 1: Outdoor StreamLab (OSL): opportunities for research on ecohydrology and nutrient cycling</td>
<td>Jessica Kozarek</td>
</tr>
<tr>
<td>10:45 am</td>
<td>AM session 2: Outdoor StreamLab (OSL): tour</td>
<td>Jessica Kozarek</td>
</tr>
<tr>
<td>12:30 pm</td>
<td>Lunch</td>
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<td></td>
<td>PM session 1: Working Group</td>
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<td>PM session 2: Working Group</td>
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<td></td>
<td>Dinner on your own</td>
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**Tuesday, August 24, 2010**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30 am</td>
<td>AM session 1: Flow through vegetation III: Practical application of vegetation in flood defenses and ecosystem management</td>
<td>Luca van Duren</td>
</tr>
<tr>
<td>10:45 am</td>
<td>AM session 2: Q&amp;A panel session</td>
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<tr>
<td>12:30 pm</td>
<td>Lunch</td>
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<tr>
<td>02:00 pm</td>
<td>PM session 1: InVEST (Integrated Valuation of Ecosystem Services and Trade-offs): theory</td>
<td>Bonnie Keeler, Peter Hawthorne</td>
</tr>
<tr>
<td>04:15 pm</td>
<td>PM session 2: InVEST (Integrated Valuation of Ecosystem Services and Trade-offs): hands-on experience via examples</td>
<td>Bonnie Keeler, Peter Hawthorne</td>
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<tr>
<td></td>
<td>Dinner on your own</td>
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**Wednesday, August 25, 2010**

<table>
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<tr>
<th>Time</th>
<th>Session</th>
<th>Speaker</th>
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</thead>
<tbody>
<tr>
<td>08:30 am</td>
<td>AM session 1: The role of vegetation in maintaining the hydraulic geometry of single-thread, meandering rivers</td>
<td>Gary Parker</td>
</tr>
<tr>
<td>10:45 am</td>
<td>AM session 2: Vegetation and the process of meander migration</td>
<td>Gary Parker</td>
</tr>
<tr>
<td>12:30 pm</td>
<td>Lunch</td>
<td></td>
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<tr>
<td>02:00 pm</td>
<td>PM session 1: Self-recording river systems: insight from the stratigraphic record; Part I</td>
<td>Chris Paola</td>
</tr>
<tr>
<td>04:15 pm</td>
<td>PM session 2: Self-recording river systems: insight from the stratigraphic record; Part II</td>
<td>Chris Paola</td>
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<td>Dinner on your own</td>
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<tr>
<td>Time</td>
<td>Session</td>
<td>Speaker</td>
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<tr>
<td>Thursday August 26, 2010</td>
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<tr>
<td>08:30 am</td>
<td>AM session 1: Ecohydrologic modeling: Concepts and processes</td>
<td>Erkan Istanbulluoglu</td>
</tr>
<tr>
<td>10:45 am</td>
<td>AM session 2: Ecohydrologic modeling: Spatial organization and topographic controls</td>
<td>Erkan Istanbulluoglu</td>
</tr>
<tr>
<td>12:30 pm</td>
<td>Lunch</td>
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<tr>
<td>02:00 pm</td>
<td>PM session 1: Hands-on experience with numerical modeling of coupled water-vegetation systems at a point and watershed scale</td>
<td>Erkan Istanbulluoglu</td>
</tr>
<tr>
<td>04:15 pm</td>
<td>PM session 2: Working Group</td>
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<tr>
<td>Friday, August 27, 2010</td>
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<tr>
<td>08:00 am</td>
<td>AM session 1: Working Group</td>
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<td>AM session 2: Working Group</td>
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<td>12:00 pm</td>
<td>Lunch</td>
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<tr>
<td>02:00 pm</td>
<td>PM session 1: WG Presentations</td>
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<td></td>
<td>PM session 2: WG Presentations</td>
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<tr>
<td>06:00 pm</td>
<td>Farewell Dinner</td>
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</tbody>
</table>
**Conference Objective**

The second annual Upper Midwest Stream Restoration Symposium brought together leading national and regional stream restoration practitioners for presentations and discussions on important stream and river restoration issues. Symposium topics included restoration design, ecology, monitoring, dam removal, numerical modeling, new research, and related topics of interest. The symposium was designed to foster exchange, conversation, and new collaborations amongst restoration practitioners in the Upper Midwest.

**Symposium Topics**

- Restoration in the Built Environment: Urban Stream Restoration
- Dam Removal in the Midwest: The Past and the Future
- Longitudinal Stream Connectivity
- Floodplain Processes
- Design

Special Wednesday Forum: Impact of Climate Change on Midwest Streams and Rivers: Surviving Extreme Events

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**Agenda- Upper Midwest Stream Restoration Symposium (UMSRS) (PRRSUM)**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Presenter</th>
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<tbody>
<tr>
<td>06:00 pm</td>
<td>Dinner</td>
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<tr>
<td>07:30 pm</td>
<td>Thinking Outside the Box Culvert, New Approaches for Flood management</td>
<td>Dave Fowler</td>
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<tr>
<td><strong>Sunday, February 27, 2011</strong></td>
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<tr>
<td>07:30 am</td>
<td>Breakfast</td>
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<tr>
<td>08:15 am</td>
<td>Submersed macrophytes as an indicator of ecosystem condition for the Upper Mississippi River</td>
<td>Megan Moore</td>
</tr>
<tr>
<td>09:30 am</td>
<td>Longitudinal discontinuity, our ally in Asian carp prevention</td>
<td>Phil Moy</td>
</tr>
<tr>
<td>10:30 am</td>
<td>Controlling the Movement of Invasive Fish Species</td>
<td>Dan Zielinski</td>
</tr>
<tr>
<td>11:00 am</td>
<td>A new landscape ecology based stream restoration prioritization framework</td>
<td>Katie Costigan</td>
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<tr>
<td>11:30 am</td>
<td>Restoring Minnesota’s Impaired Waters: Implications for Stream Restoration</td>
<td>Joe Magner</td>
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<tr>
<td>01:00 pm</td>
<td>Poster Session</td>
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<tr>
<td>02:00 pm</td>
<td>Geomorphic Disturbance, Mining Contamination, and Restoration of the Big River, eastern Missouri</td>
<td>Robert Pavlowsky</td>
</tr>
<tr>
<td>02:30 pm</td>
<td>Development of a model to predict plant composition based on soil moisture regime in a restored floodplain wetland in southwestern Wisconsin</td>
<td>Eric Booth</td>
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<tr>
<td>03:00 pm</td>
<td>Use of Enhanced Stream Floodplains to Reduce Nonpoint Source Loadings</td>
<td>Dr. Neil O’Reilly</td>
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<tr>
<td>03:45 pm</td>
<td>The Dam Removal Permitting Black Hole</td>
<td>Marty Melchior</td>
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<tr>
<td><strong>Monday, February 28, 2011</strong></td>
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<tr>
<td>Time</td>
<td>Session Title</td>
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<tr>
<td>04:15 pm</td>
<td>Thoughts on Applying the World Commission on Dams Life Cycle Process in Southeastern Wisconsin</td>
<td>Jeff Thornton</td>
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<tr>
<td>04:45 pm</td>
<td>Biological and habitat development of a restored stream channel in northeast Indiana</td>
<td>Mark Prankus</td>
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<tr>
<td>05:15 pm</td>
<td>Barr Engineering Happy Hour, followed by cash bar</td>
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<tr>
<td>06:00 pm</td>
<td>Dinner</td>
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<tr>
<td>09:00 pm</td>
<td>Full Swing indoor golf</td>
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**Tuesday, March 1, 2011**

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<thead>
<tr>
<th>Time</th>
<th>Session Title</th>
<th>Speaker</th>
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<tbody>
<tr>
<td>07:30 am</td>
<td>Breakfast</td>
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<tr>
<td>08:15 am</td>
<td>Embracing Uncertainty, Judgments in Riverine Management, Restoration, and Marketing</td>
<td>Marty Rye</td>
</tr>
<tr>
<td>09:30 am</td>
<td>Instream structures in the Outdoor StreamLab (OSL): Implications</td>
<td>Jess Kozarek</td>
</tr>
<tr>
<td>10:30 am</td>
<td>Stream assessment and restoration design within the confines of roadway reconstruction within Southeastern Wisconsin</td>
<td>Tom Slawski</td>
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<tr>
<td>11:00 am</td>
<td>Designing stream crossings for aquatic and benthic organism passage</td>
<td>Michael Trumbauer</td>
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<tr>
<td>11:30 am</td>
<td>River restoration - experiences on integrated approaches from small to large gravel bed rivers</td>
<td>Helmut Habersack</td>
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<td>01:00 pm</td>
<td>Poster Session</td>
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<td>02:00 pm</td>
<td>Quarry Hill Park - Delivering more than just a stream</td>
<td>Drew McGovern</td>
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<td>02:30 pm</td>
<td>Regenerative Stream Conveyance: Stream Restoration Using Principles of Ecological Engineering</td>
<td>Joe Berg</td>
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<tr>
<td>03:00 pm</td>
<td>Creating strong citizen advocates for urban river restoration</td>
<td>Helen Sarakinos</td>
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<tr>
<td>03:45 pm</td>
<td>Stream Relocation Design and Monitoring in a Rapidly Urbanizing Watershed: East Fork White Lick Creek, Indianapolis, Indiana</td>
<td>Charles Hegberg</td>
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<td>04:15 pm</td>
<td>Underwood Creek Rehabilitation - Phase 1 Design and Construction</td>
<td>Thomas Sear</td>
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<td>04:45 pm</td>
<td>Millers Creek Urban Stream Restoration</td>
<td>Martin Boote</td>
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<td>05:15 pm</td>
<td>Interfluve/HR Green Happy Hour, followed by cash bar</td>
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<tr>
<td>06:00 pm</td>
<td>Dinner</td>
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</table>
Appendix I: Media & Publicity Materials

1. npr.org: To Fix Damage From Old Canals, Corps Plans New One (April 2011)
2. Momentum Magazine: Going with the Flow (Fall 2010)
3. The Minnesota Daily: University hosts forum on effects of dams on rivers (November 2010)
5. USGS press release: Climate change and human water use alter rivers, eliminate top predators (October 2010)
7. 2theadvocate.com: Meeting pushes wetland issues (October 2010)
8. WWLTV.com: ‘Delta Dialogues’ Conference brings renewed focus to Louisiana’s wetlands (October 2010)
9. NorthlandNewsCenter.com: Cloquet high schooler set to meet president (October 2010)
10. Coyote Gulch: Climate change and human water use alter rivers, eliminate top predators (October 2010)
12. Arizona State University News: Researchers look at impact left on rivers, streams (October 2010)
13. Science Codex: Dams, rivers and the future of ecosystem management (October 2010)
14. NSF.gov: A River Ran Through It (October 2010)
15. The Minnesota Daily: U talent represented at science expo (October 2010)
16. The Utah Statesman: River research attempts to increase safety (October 2010)
17. tmc.net Asterisk: U of MN Physics of Superheroes Professor to Participate in National Nifty Fifty Program (October 2010)
18. GrandForksHerald.com: Louisiana State professor: Wetlands management is key to flood control (September 2010)
21. e! Science News online: Scientists find the first evidence of genetically modified plants in the wild (August 2010)
22. Char-Koosta News: Lake coring gets to the base of cooperation (July 2010)
23. Our Amazing Planet.com website: Open the Floodgates: Mighty Mississippi Could Fight Oil Slick (June 2010)
24. Softpedia website: Mississippi Delta May Slow Down Oil Contamination (June 2010)
25. sify news website: Mississippi river could fight Gulf oil spill (June 2010)
26. KOLD News 13 website: Flooding from Mississippi River could protect coastline from oil (June 2010)
27. NSF press release: Gulf Oil Spill: Mississippi River Hydrology May Help Reduce Oil Onshore (June 2010)
28. The New York Times: Researchers Ponder a Hurricane Hitting the Oil-Slicked Gulf of Mexico - Featuring commentary by NCED PI Robert Twilley
29. The Daily News, Galveston County: Oil spill spurs debate (May, 2010)
31. 39online.com: Will it Work? Experts Discuss Effort to Cap the Oil (May, 2010)
32. houmatoday.com: Preparedness more important than ever (May, 2010)
33. The INDsider.com: Tar balls hit Key West, hurricane season approaching (May, 2010)
34. University of Minnesota News: Going with the flow (May 2010)
NPR.ORG, To Fix Damage From Old Canals, Corps Plans New One – Featuring NCED PI Robert Twilley

Momentum Magazine: Going with the Flow – Featuring a profile of NCED PI Fotis Sotiropoulos;
The Minnesota Daily: University hosts forum on effects of dams on rivers – Featuring USGS researcher Gordon Grant

NetWorldDirectory.com: A River Ran Through It – Featuring NCED PI Jacques Finlay
USGS press release: Climate change and human water use alter rivers, eliminate top predators
Featuring NCED PI Jacques Finlay

ScienceDaily.com: Nature and humans leaving indelible mark on rivers, harming the intricate food webs they support – Featuring NCED PI Jacques Finlay
2theadvocate.com: Meeting pushes wetland issues – Featuring NCED PI Robert Twilley

WWLTV.com: ‘Delta Dialogues’ Conference brings renewed focus to Louisiana’s wetlands – Featuring NCED PIs Robert Twilley and Chris Paola
NorthlandNewsCenter.com: Cloquet high schooler set to meet president– Featuring NCED Diversity Director Diana Dalbotten and gidaakiimanaaniwigamig student Courtney Jackson

Coyote Gulch: Climate change and human water use alter rivers, eliminate top predators – Featuring NCED PI Jacques Finlay
Conservation Magazine: Breaking The Chain – Featuring NCED PI Jacques Finlay

Arizona State University News: Researchers look at impact left on rivers, streams – Featuring NCED PI Jacques Finlay
Science Codex: Dams, rivers and the future of ecosystem management – Featuring NCED PI Jacques Finlay

NSF.gov: A River Ran Through It – Featuring NCED PI Jacques Finlay
The Minnesota Daily: U talent represented at science expo – Featuring NCED Education Director Karen Campbell and the NCED ‘Rain-Table’ Exhibit

The Utah Statesman: River research attempts to increase safety – Featuring NCED research led by Patrick Belmont and Barbara Utley
tmc.net Asterisk: U of MN Physics of Superheroes Professor to Participate in National Nifty Fifty Program – Featuring NCED’s ‘Earth Sculpting’ exhibit

GrandForksHerald.com: Louisiana State professor: Wetlands management is key to flood control – Featuring NCED PI Robert Twilley
Chemical & Engineering News: Fishing for Methylmercury in Streams – Featuring NCED PI Jacques Finlay

e! Science News online: Scientists find the first evidence of genetically modified plants in the wild - Featuring NCED PI Robert Twilley

Char-Koosta News: Lake coring gets to the base of cooperation – Featuring NCED diversity programs manoomin and gidakiimanaanwiwagim.
Our Amazing Planet.com website: Open the Floodgates: Mighty Mississippi Could Fight Oil Slick – Featuring work by NCED researchers’ use of long-term field plots in Louisiana’s Wax Lake Delta to measure the baseline conditions of, and track the effects of the oil spill on, coastal Louisiana wetlands.

Softpedia website: Mississippi Delta May Slow Down Oil Contamination – Featuring work by NCED researchers to measure and track the effects of the oil spill on coastal Louisiana wetlands.
sify news website: Mississippi river could fight Gulf oil spill – Featuring work by NCED researchers to measure and track the effects of the oil spill on coastal Louisiana wetlands.

KOLD News 13 website: Flooding from Mississippi River could protect coastline from oil – Featuring work by NCED researchers to measure and track the effects of the oil spill on coastal Louisiana wetlands.
NSF press release: Gulf Oil Spill: Mississippi River Hydrology May Help Reduce Oil Onshore - Featuring work by NCED researchers to measure and track the effects of the oil spill on coastal Louisiana wetlands.

The Daily News, Galveston County: Oil spill spurs debate – Featuring commentary by NCED PI Robert Twilley.

39online.com: Will it Work? Experts Discuss Effort to Cap the Oil - Featuring commentary by NCED PI Robert Twilley

houmatoday.com: Preparedness more important than ever – Featuring commentary by NCED PI Robert Twilley.
The INDsider.com: Tar balls hit Key West, hurricane season approaching – Featuring commentary by NCED PI Robert Twilley.

University of Minnesota News: Going with the flow – Featuring research by NCED PI Fotis Sotiropoulos and Postdoctoral Research Associate Iman Borazjani
Appendix J: Nonreferenced Publications

Publications that are related to center activities but do not acknowledge STC award:

In Press:


Eke, E., E. Viparelli and G. Parker (in press), Field-scale numerical modeling of breaching as a mechanism for generating continuous turbidity currents, *Geosphere*.


Kumar, S., J.C. Finlay, and R.S. Sterner (in press), Stable isotope composition of suspended particulate organic matter in Lake Superior and draining rivers, *Biogeochemistry*.


In Review:


Hill, K.M. and J. Zhang (in review), Segregation flux and segregation patterns in a rotating drum: particle size and density.


Kostic, S.a.P., G (in review), Reconstruction of the flow conditions that sculpt the largest sedimentary bedforms on earth: submarine mudwaves, *Nature Geoscience*.
Nonreferenced Publications

National Center for Earth-surface Dynamics
Annual Report 2011


2011:

2010:


**2009:**


2008:


2007:


2006:


2005:

Aalto, R. and W.E. Dietrich (2005), Sediment accumulation determined with 210Pb geochronology for Strickland River flood plains, Papua New Guinea, paper presented at Sediment Budgets I (Proceedings of symposium S1 held during the Seventh IAHS Scientific Assembly), Foz do Iguaçu, Brazil, April.


2004:


**2003:**


**2002:**


Appendix K: Graduate Student Theses

2011:


2010:

Cambell-Craven, A., S.J. Kupferberg and M.E. Power (2010), Impacts of Bullfrog (Rana catesbeiana) larval grazing in a California River: temperature dependence of ingestion rates and diet overlap with native tadpole species, BS Thesis, Department of Integrative Biology, advisor M.E. Power, University of California, Berkeley.


He, L. (2010), Improved Bankfull Hydraulic Geometry Prediction Using 2-year Recurrence Interval Discharge, MS Thesis, Department of Civil Engineering, advisor G. Wilkerson, University of Illinois Urbana-Champaign.


Kang, S. (2010), Numerical simulation of turbulence in streams with complex hydraulic structures, Department of Civil Engineering, advisor F. Sotiropoulos, University of Minnesota, Minneapolis.


Whitman, S. (2010), Partitioning sand transport between channels of a deep river channel bifurcation: Implications for river diversion structures and land building in southern Louisiana, BS Thesis, Department of Geosciences, advisor D. Mohrig, University of Texas, Austin.


2009:


Gaffney, J. (2009), Gravel bed slope response to additional sediments of a smaller size, MS Thesis, Department of Civil Engineering, advisor K. Hill, University of Minnesota, Minneapolis.
Gangodagamage, C. (2009), Scale invariance and scaling breaks: New metrics for inferring process signature from high resolution LiDAR topography, Department of Civil Engineering, advisor E. Foufoula-Georgiou, University of Minnesota, Minneapolis.


Lenaker, P. (2009), Applying the Isotope Pairing Technique to Evaluate How Water Temperature and Habitat Type Influence Denitrification Estimates in Breton Sound, LA, MS Thesis, Department of Oceanography and Coastal Sciences, advisor R. Twilley, Louisiana State University, Baton Rouge.


2008:


Eke, E. (2008), Breaching as a mechanism for generating sustained turbidity currents, MS thesis, Dept. of Civil Engineering, advisor G. Parker, University of Illinois, Urbana-Champaign.


Qian, Q. (2008), Solute exchange with sub-aqueous sediments: hydrodynamic interactions with advection flows induced by surface waves or bedforms, PhD thesis, Dept. of Civil Engineering, advisors V. Voller and H. Stefan, University of Minnesota, Minneapolis.
Sequeiros, O. (2008), Bedload transport, self acceleration, downstream sorting, and flow dynamics of turbidity currents, PhD thesis, Dept. of Civil Engineering, advisor G. Parker, University of Illinois, Urbana-Champaign.


Tsai, C. (2008), Application of the HYMAN Model to evaluate the water and salt budgets in three mangrove sites along Shark River, Everglades, MS thesis, Dept. of Civil and Environmental Engineering, advisors C. Willson and R. Twilley, Louisiana State University, Baton Rouge.

2007:

Ancalle, J. (2007), Experimental study on the hydraulics of high-amplitude kinoshita-generated meandering channels, MS thesis, Dept. of Civil Engineering, advisor G. Parker, University of Illinois, Urbana-Champaign.


2006:

Blumentritt, D. J. (2006), Constraining slip rates using cosmogenic isotopes (10Be and 3He) and ASLM data: Calico fault, Mojave desert, California, MS thesis, Dept. of Geology, advisor L. Perg, University of Minnesota, Minneapolis.


Sittoni, L. (2006), The development and application of a shallow water model for flow over sediment fans, MS thesis, Dept. of Civil Engineering, advisors V. Voller and C. Paola, University of Minnesota, Minneapolis.


Wong, M. (2006), Model for erosion, transport and deposition of tracer stones in gravel-bed streams, PhD thesis, Dept. of Civil Engineering, advisor G. Parker, University of Minnesota, Minneapolis.


2005:


Passalacqua, P. (2005), Scale dependence and subgrid-scale closure in numerical simulations of landscape evolution, MS thesis, Dept. of Civil Engineering, advisor F. Porté-Agel and E. Foufoula-Georgiou, University of Minnesota, Minneapolis.

Suttle, K. B. (2005), Spider interactions with arthropod prey and their consequences in temperate and tropical communities, PhD thesis, Dept. of Department of Integrative Biology, advisor M. E. Power, University of California, Berkeley.

Tilman, E. (2005), Scaling relationships for the depth and width of channels in an experimental braided river, MS thesis, Dept. of Civil Engineering, advisor E. Foufoula-Georgiou, University of Minnesota, Minneapolis.


2004:


Weiss, J. D. (2004), Laboratory measurements of stormwater quality improvement in detention ponds, MS thesis, Dept. of Civil Engineering, advisor M. Hondzo, University of Minnesota, Minneapolis.

2003:


Lima Vivancos, V. (2003), Unsaturated flow in layered media, MS thesis, Dept. of Civil Engineering, advisor V. R. Voller, University of Minnesota, Minneapolis.


Violet, J. A. (2003), Experiment on turbidity currents and their deposits in a model 3D subsiding minibasin, MS thesis, Dept. of Civil Engineering, advisor G. Parker, University of Minnesota, Minneapolis.


2002:


Appendix L: Acronyms

Key to acronyms and abbreviations used in this report:

1D  one dimensional
2D  two dimensional
3D  three dimensional
4D  four dimensional
AA  Associate in Arts
AAAS American Association for the Advancement of Science
AAPG American Association of Petroleum Geologists
ACRR Angelo Coast Range Reserve (NCED field site)
ACWI Advisory Committee for Water Information
ADV Acoustic Doppler Velocimeter
AEM adaptive environmental management
AGEP Alliances for Graduate Education and the Professoriate
AGIC Antarctic Geospatial Information Center
AGU American Geophysical Union
AIHEC American Indian Higher Education Consortium
AISES American Indian Science and Engineering Society
ALSM Airborne Laser Swath Mapping
AMNH American Museum of Natural History (New York)
ANWI Angelo Wireless Network Infrastructure
APEXES Academic Programs for Excellence in Engineering and Science
ArcGIS an integrated collection of GIS software products
ArcIMS Internet map server (ESRI software)
ASCE American Society of Civil Engineers
ASTC Association of Science and Technology Centers
ASU Arizona State University
AWG Association for Women Geoscientists
BACI before, after, control, impact
BBY Big Back Yard (Science Museum of Minnesota)
BMP best management practices
BNHM Berkeley Natural History Museum
BRIC Bedload Research International Cooperative
BS Bachelor of Science
CALFED 25 state and federal agencies working cooperatively to improve the quality and reliability of California’s water supplies while restoring the Bay-Delta ecosystem
CAP LTER Central Arizona-Phoenix Long-Term Ecological Research
CBC California Biodiversity Center
CCEFP Center for Compact and Efficient Fluid Power
CCLI Course, Curriculum, and Laboratory Improvement
CEM Conceptual Ecological Modeling
CENS Center for Embedded Networked Sensing (NSF STC)
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CERC</td>
<td>Columbia Environmental Research Center (USGS research facility located in Columbia, MO)</td>
</tr>
<tr>
<td>CERP</td>
<td>Comprehensive Everglades Adaptive Management Program</td>
</tr>
<tr>
<td>CERP</td>
<td>Comprehensive Ecosystem Restoration Plan (SAIP section)</td>
</tr>
<tr>
<td>CFD</td>
<td>computational fluid dynamics</td>
</tr>
<tr>
<td>CFE</td>
<td>Center for Future Earth (Science Museum of Minnesota)</td>
</tr>
<tr>
<td>CFS</td>
<td>cubic feet per second</td>
</tr>
<tr>
<td>CGEE</td>
<td>Center for Global Environmental Education</td>
</tr>
<tr>
<td>CLEANER</td>
<td>Collaborative Large-scale Engineering Analysis Network for Environmental Research (NSF)</td>
</tr>
<tr>
<td>CLEAR</td>
<td>Coastal Louisiana Ecosystem Assessment and Restoration</td>
</tr>
<tr>
<td>CME</td>
<td>Coastal &amp; Marine Environments</td>
</tr>
<tr>
<td>CNH</td>
<td>Dynamics of Coupled Natural and Human Systems</td>
</tr>
<tr>
<td>CNSF</td>
<td>Coalition for National Science Funding</td>
</tr>
<tr>
<td>CPOM</td>
<td>Coarse Particulate Organic Matter</td>
</tr>
<tr>
<td>CREST</td>
<td>Centers of Research Excellence in Science and Technology</td>
</tr>
<tr>
<td>CRA</td>
<td>Critical Research Area</td>
</tr>
<tr>
<td>CRN</td>
<td>Cosmogenic Radionuclide</td>
</tr>
<tr>
<td>CSC</td>
<td>College of St. Catherine</td>
</tr>
<tr>
<td>CSDMS</td>
<td>Community Surface Dynamics Modeling System</td>
</tr>
<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation (in Australia)</td>
</tr>
<tr>
<td>CUAHSI</td>
<td>Consortium of Universities for Advancement of Hydrologic Science Inc.</td>
</tr>
<tr>
<td>CUAHSI-HIS</td>
<td>Consortium of Universities for Advancement of Hydrologic Science Inc.-Hydrologic Information System</td>
</tr>
<tr>
<td>CU-Boulder</td>
<td>University of Colorado, Boulder</td>
</tr>
<tr>
<td>CUNY</td>
<td>City University New York</td>
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<tr>
<td>CURVIB</td>
<td>Curvilinear Immersed Boundary</td>
</tr>
<tr>
<td>CV</td>
<td>coefficient of variation</td>
</tr>
<tr>
<td>CZEN</td>
<td>Critical Zone Exploration Network</td>
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<tr>
<td>CZO</td>
<td>Critical Zone Observatories</td>
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<tr>
<td>DA</td>
<td>Decision Analysis</td>
</tr>
<tr>
<td>DAQ</td>
<td>data acquisition</td>
</tr>
<tr>
<td>DEM</td>
<td>Digital Elevation Model</td>
</tr>
<tr>
<td>DEM</td>
<td>distinct element model (included in DWIP and Management sections)</td>
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<tr>
<td>DGS</td>
<td>Director of Graduate Studies</td>
</tr>
<tr>
<td>DHVSM</td>
<td>Distributed Hydrology Soil Vegetation Model</td>
</tr>
<tr>
<td>DLESE</td>
<td>Digital Library for Earth System Education</td>
</tr>
<tr>
<td>DNR</td>
<td>Department of Natural Resources</td>
</tr>
<tr>
<td>DO</td>
<td>dissolved oxygen</td>
</tr>
<tr>
<td>DOC</td>
<td>Dissolved Organic Carbon</td>
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<tr>
<td>DRB</td>
<td>Director’s Review Board</td>
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<tr>
<td>DRK12</td>
<td>Discovery Research K-12</td>
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<tr>
<td>DSL</td>
<td>Digital Subscriber Line (Internet access method)</td>
</tr>
<tr>
<td>DV</td>
<td>Diversity</td>
</tr>
<tr>
<td>DW</td>
<td>Desktop Watersheds</td>
</tr>
<tr>
<td>DWIP</td>
<td>Desktop Watersheds Integrated Program</td>
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<tr>
<td>DWPG</td>
<td>Desktop Watersheds Partners Group</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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</tr>
<tr>
<td>E4</td>
<td>energy, environment, economics, and education</td>
</tr>
<tr>
<td>EAB</td>
<td>External Advisory Board (NCED)</td>
</tr>
<tr>
<td>EBD</td>
<td>Emotionally and Behaviorally Disturbed</td>
</tr>
<tr>
<td>EC</td>
<td>Executive Committee</td>
</tr>
<tr>
<td>ECCOMAS</td>
<td>European Community on Computational Methods in Applied Science</td>
</tr>
<tr>
<td>ED</td>
<td>Education</td>
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<tr>
<td>EGS</td>
<td>European Geological Society</td>
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<td>ENSO</td>
<td>El Niño/Southern Oscillation</td>
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<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
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<tr>
<td>ERDC</td>
<td>Engineer Research and Development Center (US Army Corps of Engineers)</td>
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<tr>
<td>ESA</td>
<td>Ecological Society of America</td>
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<tr>
<td>ESLI</td>
<td>Earth Science Literacy Initiative</td>
</tr>
<tr>
<td>ESR</td>
<td>EarthScapes School Residency (SMM): previously referred to as School Contact Program</td>
</tr>
<tr>
<td>ESRI</td>
<td>GIS and Mapping Software (company)</td>
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<tr>
<td>ESTREAM</td>
<td>Earth Science Teacher Researchers Exploring Active Modeling</td>
</tr>
<tr>
<td>ETI</td>
<td>EarthScapes Teacher Institute (SMM)</td>
</tr>
<tr>
<td>EUG</td>
<td>European Union of Geosciences</td>
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<tr>
<td>EVL</td>
<td>Electronic Visualization Laboratory (University of Illinois, Chicago)</td>
</tr>
<tr>
<td>EWRI</td>
<td>Environmental &amp; Water Resources Institute (ASCE)</td>
</tr>
<tr>
<td>F2F</td>
<td>Faculty to Faculty Program</td>
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<tr>
<td>FDLTCC</td>
<td>Fond du Lac Tribal and Community College</td>
</tr>
<tr>
<td>FEI</td>
<td>Future Earth Initiative</td>
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<tr>
<td>FIRST</td>
<td>For Inspiration and Recognition of Science and Technology</td>
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<td>FIU</td>
<td>Florida International University</td>
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<tr>
<td>FPOM</td>
<td>Fine Particulate Organic Matter</td>
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<td>GA</td>
<td>Geoscience Alliance</td>
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<td>GB</td>
<td>Gigabyte</td>
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<tr>
<td>GCMRC</td>
<td>Grand Canyon Monitoring and Research Center</td>
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<td>GEM</td>
<td>National Consortium for Graduate Degrees for Minorities in Engineering and Science</td>
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<tr>
<td>GEO</td>
<td>Geosciences (NSF)</td>
</tr>
<tr>
<td>GG</td>
<td>Generalized Gaussian</td>
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<td>GGRP</td>
<td>Global Great Rivers Partnership</td>
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<td>GIS</td>
<td>Geographic Information Systems</td>
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<td>GLD</td>
<td>Geomorphology and Landuse Dynamics</td>
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<td>GLOBE</td>
<td>Global Learning and Observations to Benefit the Environment</td>
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<td>GMA</td>
<td>Graduate Museum Assistant (NCED)</td>
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<td>GMA</td>
<td>Graham Mathews and Associates (SRIP and KT sections)</td>
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<tr>
<td>GPM</td>
<td>Global Precipitation (satellite) Mission (a new NASA mission)</td>
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<tr>
<td>GPP</td>
<td>gross primary production</td>
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<td>GRA</td>
<td>General Research Area</td>
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<td>GSA</td>
<td>Geological Society of America</td>
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<td>GSC</td>
<td>Graduate Student Council (NCED)</td>
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<td>GSM</td>
<td>Gaussian Scale Distribution</td>
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<tr>
<td>HACU</td>
<td>Hispanic Association of Colleges and Universities</td>
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<tr>
<td>Acronym</td>
<td>Definition</td>
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<tr>
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</tr>
<tr>
<td>HD</td>
<td>high definition (in video)</td>
</tr>
<tr>
<td>HEC-RAS</td>
<td>Hydrologic Engineering Centers River Analysis System (see also USACE)</td>
</tr>
<tr>
<td>HG</td>
<td>Hydraulic Geometry</td>
</tr>
<tr>
<td>H/L</td>
<td>Hispanic/Latino</td>
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<tr>
<td>HPWREN</td>
<td>High Performance Wireless Research and Education Network</td>
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<td>HSC</td>
<td>Headwaters Science Center</td>
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<tr>
<td>IAF</td>
<td>Incremental Area Function</td>
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<td>IAHS</td>
<td>International Association of Hydrological Sciences</td>
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<tr>
<td>IAS</td>
<td>International Association of Sedimentologists</td>
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<tr>
<td>IBSMW</td>
<td>International Bedload Surrogates Monitoring Workshop</td>
</tr>
<tr>
<td>ICG</td>
<td>International Center for Geohazards</td>
</tr>
<tr>
<td>IGERT</td>
<td>Integrative Graduate Education and Research Traineeship</td>
</tr>
<tr>
<td>INSE</td>
<td>Institute of Arctic and Alpine Research</td>
</tr>
<tr>
<td>IonE</td>
<td>Institute on the Environment</td>
</tr>
<tr>
<td>IP</td>
<td>Integrated Program (within NCED) and formerly referred to as Integrated Project</td>
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<tr>
<td>IREP</td>
<td>International Research Experience Program</td>
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<tr>
<td>IRES</td>
<td>International Research Experiences for Students</td>
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<tr>
<td>ISE</td>
<td>Informal Science Education (NSF)</td>
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<tr>
<td>ISEF</td>
<td>Intel International Science and Engineering Fair</td>
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<tr>
<td>ISL</td>
<td>Indoor StreamLab</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>iSURF</td>
<td>inverse surface-based transport calculations (an NCED SR Toolbox tool)</td>
</tr>
<tr>
<td>IT</td>
<td>Information Technology</td>
</tr>
<tr>
<td>IUH</td>
<td>instantaneous unit hydrograph</td>
</tr>
<tr>
<td>JGR-ES</td>
<td>Journal of Geophysical Research-Earth Surface</td>
</tr>
<tr>
<td>JHU</td>
<td>The Johns Hopkins University</td>
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<tr>
<td>KAYSC</td>
<td>Kitty Andersen Youth Science Center</td>
</tr>
<tr>
<td>KT</td>
<td>Knowledge Transfer</td>
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<tr>
<td>LACPR</td>
<td>Louisiana Coastal Protection and Restoration</td>
</tr>
<tr>
<td>LBNL</td>
<td>Lawrence Berkeley National Laboratory</td>
</tr>
<tr>
<td>LCA</td>
<td>Louisiana Coastal Authority</td>
</tr>
<tr>
<td>LES</td>
<td>Large Eddy Simulation</td>
</tr>
<tr>
<td>LIDAR</td>
<td>light detection and ranging (an optical remote sensing technology)</td>
</tr>
<tr>
<td>LPM</td>
<td>long-profile model</td>
</tr>
<tr>
<td>LSAMP</td>
<td>Louis Stokes Alliances for Minority Participation (NSF HRD)</td>
</tr>
<tr>
<td>LSU</td>
<td>Louisiana State University</td>
</tr>
<tr>
<td>LTER</td>
<td>Long Term Ecological Research</td>
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<td>MAST</td>
<td>Multi-Axial Subassemblage Testing</td>
</tr>
<tr>
<td>MCC</td>
<td>Minnesota Conservation Corps</td>
</tr>
<tr>
<td>MCDA</td>
<td>multicriteria decision analysis</td>
</tr>
<tr>
<td>MD-SWMS</td>
<td>USGS’s Multidimensional Surface-Water Modeling System</td>
</tr>
<tr>
<td>MESTA</td>
<td>Michigan Earth Science Teachers Association</td>
</tr>
<tr>
<td>MF</td>
<td>Multifractal</td>
</tr>
<tr>
<td>MIT</td>
<td>Massachusetts Institute of Technology</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>MNLSAMP</td>
<td>Minnesota Northstar Louis Stokes Alliance for Minority Participation</td>
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<td>MNP</td>
<td>Maltby Nature Preserve (now “Science Center at the Maltby Nature reserve”)</td>
</tr>
<tr>
<td>MNRRA</td>
<td>Mississippi National River and Recreation Area</td>
</tr>
<tr>
<td>MOU</td>
<td>Memorandum of Understanding</td>
</tr>
<tr>
<td>MRB</td>
<td>Minnesota River Basin</td>
</tr>
<tr>
<td>MRD</td>
<td>Mississippi River Delta</td>
</tr>
<tr>
<td>MRDDM</td>
<td>Mississippi River Delta Desktop Model</td>
</tr>
<tr>
<td>MRSEC</td>
<td>The University of Minnesota Materials Research Science and Engineering Center</td>
</tr>
<tr>
<td>MS</td>
<td>Master of Science</td>
</tr>
<tr>
<td>MS</td>
<td>From SRIP USGS model</td>
</tr>
<tr>
<td>MSI</td>
<td>minority-serving institution</td>
</tr>
<tr>
<td>MSI</td>
<td>Minnesota Supercomputer Institute (KT section)</td>
</tr>
<tr>
<td>MST</td>
<td>Minimal Spanning Tree</td>
</tr>
<tr>
<td>MYRES</td>
<td>Meeting of Young Researchers in Earth Science</td>
</tr>
<tr>
<td>NABS</td>
<td>North American Benthological Society</td>
</tr>
<tr>
<td>NAGT</td>
<td>National Association of Geoscience Teachers</td>
</tr>
<tr>
<td>NAISEF</td>
<td>National American Indian Science and Engineering Fair</td>
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<tr>
<td>NAS</td>
<td>National Academy of Sciences</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NBTC</td>
<td>Nanobiotechnology Center</td>
</tr>
<tr>
<td>NCALM</td>
<td>National Center for Airborne Laser Mapping (NSF-supported)</td>
</tr>
<tr>
<td>NCAR</td>
<td>National Center for Atmospheric Research</td>
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<tr>
<td>NCEAS</td>
<td>National Center for Ecological Analysis and Synthesis</td>
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<tr>
<td>NCED</td>
<td>National Center for Earth-surface Dynamics</td>
</tr>
<tr>
<td>NCHRP</td>
<td>National Cooperative Highway Research Program</td>
</tr>
<tr>
<td>NDSCMC</td>
<td>National Design, Construction, and Soil Mechanics Center</td>
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<tr>
<td>NDS</td>
<td>Nutrient Diffusing Substrate</td>
</tr>
<tr>
<td>NEES</td>
<td>Network for Earthquake Engineering Simulation</td>
</tr>
<tr>
<td>NEMO</td>
<td>Nonpoint Education for Municipal Officials</td>
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<tr>
<td>NESTA</td>
<td>National Earth Science Teachers Association</td>
</tr>
<tr>
<td>NIWA</td>
<td>National Institute of Water and Atmospheric Research, New Zealand</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
</tr>
<tr>
<td>NPR</td>
<td>National Public Radio</td>
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<tr>
<td>NRC</td>
<td>National Research Council</td>
</tr>
<tr>
<td>NRCEN</td>
<td>National Science Foundation Research Center Educators Network</td>
</tr>
<tr>
<td>NRCS</td>
<td>Natural Resources Conservation Service</td>
</tr>
<tr>
<td>NRRSS</td>
<td>National River Restoration Science Synthesis</td>
</tr>
<tr>
<td>NSBE</td>
<td>National Society of Black Engineers</td>
</tr>
<tr>
<td>NSF</td>
<td>National Science Foundation</td>
</tr>
<tr>
<td>NSTA</td>
<td>National Science Teachers Association</td>
</tr>
<tr>
<td>NWIS</td>
<td>National Water Information System</td>
</tr>
<tr>
<td>OCN</td>
<td>Optimal Channel Networks</td>
</tr>
<tr>
<td>ODM</td>
<td>Observations Data Model</td>
</tr>
<tr>
<td>OLERR</td>
<td>Outdoor Laboratory for Ecogeomorphology and River Restoration</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>ONR</td>
<td>Office of Naval Research</td>
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<tr>
<td>OSL</td>
<td>Outdoor StreamLab</td>
</tr>
<tr>
<td>OSL</td>
<td>Optically Stimulated Luminescence (included in DWIP section)</td>
</tr>
<tr>
<td>OWEB</td>
<td>Oregon Watershed Enhancement Board</td>
</tr>
<tr>
<td>PAR</td>
<td>photosynthetically active (solar) radiation</td>
</tr>
<tr>
<td>PDE</td>
<td>partial differential equation</td>
</tr>
<tr>
<td>PDE</td>
<td>probability density equation</td>
</tr>
<tr>
<td>PDF</td>
<td>Probability Density Function</td>
</tr>
<tr>
<td>PGE</td>
<td>Portland General Electric</td>
</tr>
<tr>
<td>PI</td>
<td>Principal Investigator</td>
</tr>
<tr>
<td>PIV</td>
<td>particle image velocimetry</td>
</tr>
<tr>
<td>PLIF</td>
<td>planar laser induced fluorescence</td>
</tr>
<tr>
<td>PR</td>
<td>Puerto Rico or Puerto Rican</td>
</tr>
<tr>
<td>PRRSUM</td>
<td>Partnership for River Restoration and Science in the Upper Midwest</td>
</tr>
<tr>
<td>PSEO</td>
<td>Post-secondary Education Option</td>
</tr>
<tr>
<td>PUB</td>
<td>Singapore’s national water agency</td>
</tr>
<tr>
<td>QBRB</td>
<td>Quad Beam River Bandit</td>
</tr>
<tr>
<td>QEM</td>
<td>Quality Education for Minorities</td>
</tr>
<tr>
<td>R2</td>
<td>R2 Resource Consultants</td>
</tr>
<tr>
<td>RAM</td>
<td>read access memory</td>
</tr>
<tr>
<td>RANS</td>
<td>Reynolds Averaged Numerical Simulations</td>
</tr>
<tr>
<td>RC</td>
<td>Research Cooperatives</td>
</tr>
<tr>
<td>RCW</td>
<td>River Corridor Width</td>
</tr>
<tr>
<td>REU</td>
<td>Research Experience for Undergraduates (NSF-funded)</td>
</tr>
<tr>
<td>RFID</td>
<td>Radio Frequency Identification</td>
</tr>
<tr>
<td>RFS</td>
<td>Richmond Field Station (University of California, Berkeley)</td>
</tr>
<tr>
<td>ROADnet</td>
<td>Real-time Observatories, Applications, and Data management Network</td>
</tr>
<tr>
<td>RRMNW</td>
<td>River Restoration Northwest</td>
</tr>
<tr>
<td>RWMWD</td>
<td>Ramsey Washington Metro Watershed District</td>
</tr>
<tr>
<td>SA</td>
<td>Subsurface Architecture</td>
</tr>
<tr>
<td>SACNAS</td>
<td>Society for the Advancement of Chicanos and Native Americans in Science</td>
</tr>
<tr>
<td>SAFL</td>
<td>St. Anthony Falls Laboratory</td>
</tr>
<tr>
<td>SAHRA</td>
<td>Sustainability of semi-Arid Hydrology and Riparian Areas (NSF STC)</td>
</tr>
<tr>
<td>SAIP</td>
<td>Subsurface Architecture Integrated Program</td>
</tr>
<tr>
<td>SAN</td>
<td>Storage Area Network</td>
</tr>
<tr>
<td>SAPG</td>
<td>Subsurface Architecture Partners Group</td>
</tr>
<tr>
<td>SCP</td>
<td>School Contact Program (SMM): now referred to as ESR</td>
</tr>
<tr>
<td>SCWRS</td>
<td>St. Croix Watershed Research Station</td>
</tr>
<tr>
<td>SEEDS</td>
<td>Strategies for Ecology Education, Diversity and Sustainability: Diverse People for a Diverse Science</td>
</tr>
<tr>
<td>SEG</td>
<td>Society of Exploration Geophysicists</td>
</tr>
<tr>
<td>SEPM</td>
<td>Society for Sedimentary Geology</td>
</tr>
<tr>
<td>SERC</td>
<td>Science Education Resource Center</td>
</tr>
<tr>
<td>SERC</td>
<td>Smithsonian Environmental Research Center (included in Education section)</td>
</tr>
</tbody>
</table>
SHIRAZ  A computer model developed at the University of Washington to incorporate fish habitat relationships into conservation planning. Part of the Puget Sound Regional Synthesis Model.

SHPE  Society of Hispanic Professional Engineers

SIDS  Sudden Ionospheric Disturbance

SIESD  Summer Institute on Earth-surface Dynamics

SIP  Strategic and Implementation Plan

SKC  Salish Kootenai College

SMC  Seven Mile Creek

SMM  Science Museum of Minnesota

SMRS  Sediment Monitoring and Recirculation System

SNR  signal-to-noise ratios

SOS  Subcommittee on Sedimentation (applies to SRIP section)

SOS  Science on a Sphere®

SPARC  Space Physics & Aeronomy Research Collaboratory

SPD/AAS  Solar Physics Division - American Astronomical Society

SPM  Salmon Population Model

SR  Stream Restoration

SRES  Stream Restoration Certificate Program

SRIP  Stream Restoration Integrated Program

SRN  Stream Restoration Networker

SRPG  Stream Restoration Partners Group (NCED Partners)

SRSE  Stream Restoration Science and Engineering

SRTT  Stream Restoration Training Team

SRTWG  Stream Restoration Training Working Group

STC  Science and Technology Center

STEM  Science, technology, engineering, and mathematics

STEPS  Science, Technology, Engineering, Policy, and Society

STRESS  Stochastic Transport and Emergent Scaling on Earth’s Surface

SURGE  Support for Under-Represented Groups in Engineering Fellowship Program at UIUC

TB  Terrabyte

TMDL  total maximum daily load

TNC  The Nature Conservancy

TOC  top-of-casing

TOS  top-of-screen

TR2  Toutle River II

TRC  Teacher Resource Center (Science Museum of Minnesota)

TRRP  Trinity River Restoration Program

TSS  Total Suspended Solids

UC  University of California

UCAR  University Corporation for Atmospheric Research

UCB  University of California, Berkeley

UCNRS  University of California Natural Reserve System

UF  University of Florida

UIUC  University of Illinois at Urbana-Champaign
Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UMN</td>
<td>University of Minnesota</td>
</tr>
<tr>
<td>UMNTC</td>
<td>University of Minnesota Twin Cities</td>
</tr>
<tr>
<td>UMN WRS</td>
<td>University of Minnesota Water Resources Science</td>
</tr>
<tr>
<td>UROP</td>
<td>Undergraduate Research Opportunities Program</td>
</tr>
<tr>
<td>USACE</td>
<td>US Army Corps of Engineers (see also HEC-RAS)</td>
</tr>
<tr>
<td>USARS</td>
<td>United States Agricultural Research Service</td>
</tr>
<tr>
<td>USBR</td>
<td>US Department of the Interior, Bureau of Reclamation</td>
</tr>
<tr>
<td>USDA</td>
<td>US Department of Agriculture</td>
</tr>
<tr>
<td>USFS</td>
<td>US Forest Service</td>
</tr>
<tr>
<td>USFWS</td>
<td>US Fish and Wildlife Service</td>
</tr>
<tr>
<td>USGS</td>
<td>US Geological Survey</td>
</tr>
<tr>
<td>USIP</td>
<td>Undergraduate Summer Internship Program (NCED)</td>
</tr>
<tr>
<td>UT-Austin</td>
<td>University of Texas at Austin</td>
</tr>
<tr>
<td>VINES</td>
<td>Virtual Network System</td>
</tr>
<tr>
<td>VIP</td>
<td>Virtual Internet Protocol</td>
</tr>
<tr>
<td>VOIP</td>
<td>Voice Over Internet Protocol (internet access method)</td>
</tr>
<tr>
<td>VP</td>
<td>Visitor Program (NCED)</td>
</tr>
<tr>
<td>VSL</td>
<td>Virtual StreamLab</td>
</tr>
<tr>
<td>WaterCAMPWS</td>
<td>The Center of Advanced Materials for the Purification of Water with Systems</td>
</tr>
<tr>
<td>WATERS</td>
<td>Water and Environmental Research Systems</td>
</tr>
<tr>
<td>WLD</td>
<td>Wax Lake Delta</td>
</tr>
<tr>
<td>WSL</td>
<td>Swiss Federal Institute for Forest, Snow and Landscape Research (&quot;Wald, Schnee, und Landschaft&quot;)</td>
</tr>
<tr>
<td>WTMM</td>
<td>Modulus Maxima</td>
</tr>
<tr>
<td>XES</td>
<td>eXperimental EarthScapes facility (&quot;Jurassic Tank&quot;)</td>
</tr>
<tr>
<td>YSC</td>
<td>Youth Science Center (Science Museum of Minnesota)</td>
</tr>
</tbody>
</table>

**Key to Sub-Projects:**

### Diversity (DV)

<table>
<thead>
<tr>
<th>Project</th>
<th>Project Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>DV01</td>
<td>Faculty-to-Faculty: building durable connections to Minority-Serving Institutions</td>
</tr>
<tr>
<td>DV02</td>
<td>Direct recruiting of under-represented students to NCED graduate and postdoc program</td>
</tr>
<tr>
<td>DV03</td>
<td>Undergraduate Summer Internship Program</td>
</tr>
<tr>
<td>DV04</td>
<td>gidakimanaaniwigamig (Our Earth Lodge) Native American Youth Science Immersion Program</td>
</tr>
<tr>
<td>DV05</td>
<td>Earthscapes in the SMM Youth Science Center (YSS)</td>
</tr>
</tbody>
</table>

### Desktop Watersheds Integrated Project (DW)

<table>
<thead>
<tr>
<th>Project</th>
<th>Project Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>DW01</td>
<td>Numerical techniques for feature extraction</td>
</tr>
<tr>
<td>DW02</td>
<td>Topographic signatures of properties and processes</td>
</tr>
<tr>
<td>DW03</td>
<td>Predictive mapping of key biotic populations: relationships to habitats</td>
</tr>
<tr>
<td>DW04</td>
<td>Understand linkages among solutes, soil production, and biota</td>
</tr>
<tr>
<td>DW05</td>
<td>Controls on rate of landslide transport to channels</td>
</tr>
<tr>
<td>DW06</td>
<td>Sediment routing; coarse sediment transport in shallow flow; fine sediment interaction with coarse bed</td>
</tr>
</tbody>
</table>

296 Acronyms
### Acronyms

<table>
<thead>
<tr>
<th>DW07</th>
<th>Predictive models for channel incision</th>
</tr>
</thead>
<tbody>
<tr>
<td>DW08</td>
<td>Upscaling transport laws and biotic processes</td>
</tr>
<tr>
<td>DW09</td>
<td>Link food webs and channel networks, including dynamic response</td>
</tr>
<tr>
<td>DW10</td>
<td>DW model code development</td>
</tr>
<tr>
<td>DW11</td>
<td>Use the Desktop Watershed models in landuse management decisions</td>
</tr>
</tbody>
</table>

### Education (ED)

<table>
<thead>
<tr>
<th>Project</th>
<th>Project Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ED01</td>
<td>Bring surface dynamics to informal education with the Science Museum of Minnesota</td>
</tr>
<tr>
<td>ED02</td>
<td>Enhance the education of NCED student participants by providing unique opportunities and an extended, cross-disciplinary peer and mentor network.</td>
</tr>
<tr>
<td>ED03</td>
<td>Stream Restoration certificate program</td>
</tr>
<tr>
<td>ED04</td>
<td>NCED enhancements to undergraduate education</td>
</tr>
<tr>
<td>ED05</td>
<td>K-12 teacher development</td>
</tr>
</tbody>
</table>

### Knowledge Transfer (KT)

<table>
<thead>
<tr>
<th>Project</th>
<th>Project Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>KT01</td>
<td>Interactions with DW Science Partner Group</td>
</tr>
<tr>
<td>KT02</td>
<td>Collaborative DW research with stakeholders and partners</td>
</tr>
<tr>
<td>KT03</td>
<td>Disseminate DW knowledge, approaches, and tools outside of NCED</td>
</tr>
<tr>
<td>KT04</td>
<td>Interactions with SR Science Partners Group</td>
</tr>
<tr>
<td>KT05</td>
<td>Collaborative SR research with stakeholders and partners</td>
</tr>
<tr>
<td>KT06</td>
<td>Disseminate SR knowledge, approaches, and tools outside of NCED</td>
</tr>
<tr>
<td>KT07</td>
<td>Promote and develop education and training programs in SR</td>
</tr>
<tr>
<td>KT08</td>
<td>Interactions with SA Science Partner Group</td>
</tr>
<tr>
<td>KT09</td>
<td>Collaborative SA research with stakeholders and partners</td>
</tr>
<tr>
<td>KT10</td>
<td>Disseminate SA knowledge, approaches, and tools outside of NCED</td>
</tr>
</tbody>
</table>

### Subsurface Architecture Integrated Project (SA)

<table>
<thead>
<tr>
<th>Project</th>
<th>Project Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA01</td>
<td>Current sediment budget and subsidence distribution in Mississippi Delta</td>
</tr>
<tr>
<td>SA02</td>
<td>Behavior and deposition of cohesive sediment</td>
</tr>
<tr>
<td>SA03</td>
<td>Vegetation-sedimentation interaction in island &amp; marsh development &amp; maintenance</td>
</tr>
<tr>
<td>SA04</td>
<td>Reconstructing delta dynamics from seismic records</td>
</tr>
<tr>
<td>SA05</td>
<td>Reconstructing delta dynamics from cores and other records</td>
</tr>
<tr>
<td>SA06</td>
<td>Modeling land building; integration with LSU CLEAR</td>
</tr>
<tr>
<td>SA07</td>
<td>Self-organization of distributary systems including elevation statistics</td>
</tr>
<tr>
<td>SA08</td>
<td>Upscaling short-term rates and small-scale geometries</td>
</tr>
<tr>
<td>SA09</td>
<td>Coastal system response to rising relative sea level</td>
</tr>
<tr>
<td>SA10</td>
<td>Social tradeoffs in Delta restoration</td>
</tr>
</tbody>
</table>
### Stream Restoration Integrated Project (SR)

<table>
<thead>
<tr>
<th>Project</th>
<th>Project Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR01</td>
<td>Watershed context for stream restoration</td>
</tr>
<tr>
<td>SR02</td>
<td>Improved models for sediment source, routing, storage and yield</td>
</tr>
<tr>
<td>SR03</td>
<td>Dynamics of mixed-size sediment</td>
</tr>
<tr>
<td>SR04</td>
<td>Predictive relations for channel and floodplain geometry.</td>
</tr>
<tr>
<td>SR05</td>
<td>Predictive relations for the effect of physical channel structure and disturbance regime on primary productivity, nutrient transport, and species recovery.</td>
</tr>
<tr>
<td>SR06</td>
<td>Linking public preference, objectives, and stream restoration alternatives</td>
</tr>
<tr>
<td>SR07</td>
<td>Dam reoperation and removal for ecosystem restoration</td>
</tr>
</tbody>
</table>