IIId. 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.
Angelo Coast Range Reserve

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 dinning 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*.

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**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 dependant 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.
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