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REACH (REsilience under Accelerated CHange)

Year 2 Progress Report for 2013–2014

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University of Minnesota Research Summary

This document contains the research summaries for the NSF WSC REACH project for year 2 (2013-2014) for the PI/Co-PIs at the University of Minnesota (UofM):

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Research Themes and Accomplishments during 2013-2014

Our research efforts over the past year have concentrated on five main areas: (1) network approach to river basin vulnerability assessment, (2) effect of agricultural drainage on hydrologic response, (3) expression of geologic controls on multi-scale river network structure, (4) meandering river dynamics, and (5) integrative predictive modeling of river hydro-geo-biological processes with emphasis on the effects of sediment change to riverine health. Application of the developed frameworks is performed in the Minnesota River Basin (MRB), which is the focus of the REsilience under Accelerated CHange (REACH) project funded under NSF's WSC program. However, the developed frameworks are general and transferable to other sites.

1. Network Approach to River Basin Vulnerability Assessment

Rivers form a network of hierarchically connected channels serving as the primary pathways for transport of environmental fluxes toward the outlet of a basin. The branching network structure (defined here as network topology and associated geometry) serves as a template upon which environmental fluxes of water, sediment, nutrients, etc. are conveyed and organized both spatially and temporally within the network. At the outlet of a basin, long-term prediction of environmental response to natural and anthropogenic disturbances becomes highly uncertain using physically-based distributed models, particularly when transport time scales range from tens to thousands of years, such as for sediment. Yet, such predictions are needed as changes in one part of a basin now might adversely affect other parts of the basin in years to come.

We have proposed a simplified network-based predictive framework of sedimentological response in a basin, which incorporates network topology, channel characteristics, and transport-process dynamics to perform a non-linear process-based scaling of the river-network width function to a time-response function [*Czuba and Foufoula-Georgiou*, 2014]. We developed a process-scaling formulation for transport of mud, sand, and gravel using simplifying assumptions (including neglecting long-term storage) and applied the methodology to the Minnesota River Basin. A robust bimodal distribution of the sedimentological response for sand of the basin was identified which we attributed to specific source areas. Also, a resonant frequency of sediment supply was identified where the disturbance of one area followed by the disturbance of another area after a certain period of time, may result in amplification of the effects of sediment inputs which would be otherwise difficult to predict (Fig. 1). The amplification of the sedimentological response may result in greater than expected aggradation of the bed of the river leading to disruption in ecosystem function, increased flood risk, and increased cost associated with remediation. Thus, the proposed framework has identified an important vulnerability of the Minnesota River Basin to spatial and temporal structuring of sediment delivery.

We have extended the network-based framework described by *Czuba and Foufoula-Georgiou* [2014] to a dynamic connectivity framework capable of investigating the internal dynamics of fluxes toward identifying places and times where fluxes concentrate (called hotspots) thus increasing the potential for geomorphic change [*Czuba and Foufoula-Georgiou*, *in preparation*]. The idea is that a persistent connectivity cluster (over space and time) that carries significant flux has the potential to do geomorphic work in the system and thus acts as a predictor of places in the basin where potential change can occur. Identifying where adaptation measures in the basin can reduce these hotspots before they occur provides important management strategies for sustainability.

Beginning with a static river network, the framework tracks the evolution of flux on the network and quantifies the space-time evolving connectivity clusters in terms of their position, size, and magnitude of flux they carry. The developed framework was applied to sand transport on the Greater Blue Earth River Network, a subnetwork of the Minnesota River Network (red subnetwork identified as C in Fig. 1e), where the hypothesis was tested that dynamic connectivity of sediment fluxes would act as a predictor of channel migration rate and specifically that the dominant cluster would coincide with a sub-region of the basin in which very high channel migration rates have been measured (Fig. 2a). By defining an index describing the persistence of mass in clusters on the network, this framework was capable of identifying hotspots of channel migration in low-slope reaches of the network (h1 and h2, Fig. 2b). However, this index was not capable of identifying the hotspot of channel migration in a downstream steep-slope reach of the network, but instead this hotspot was identified as a reach with high bed shear stress (h3, Fig. 2c). This may suggest the presence of two different mechanisms for channel migration at work, one sediment-driven and another streamflow-driven. Furthermore, the source contributions that synchronize on the network to form clusters corresponding to hotspots h1 and h2 were unraveled (Fig. 3). Depending on network structure, process dynamics, and timing of arrival, the potential management options available may differ for reducing sediment generation of these specific source areas or breaking the synchronization of these contributions before they coalesce into an aggregated mass. *By placing dynamical processes occurring at small scales into a network context using the dynamic connectivity framework, it is possible to better understand how reach-scale changes cascade into network-scale effects, useful for informing the large-scale consequences of local management actions.*

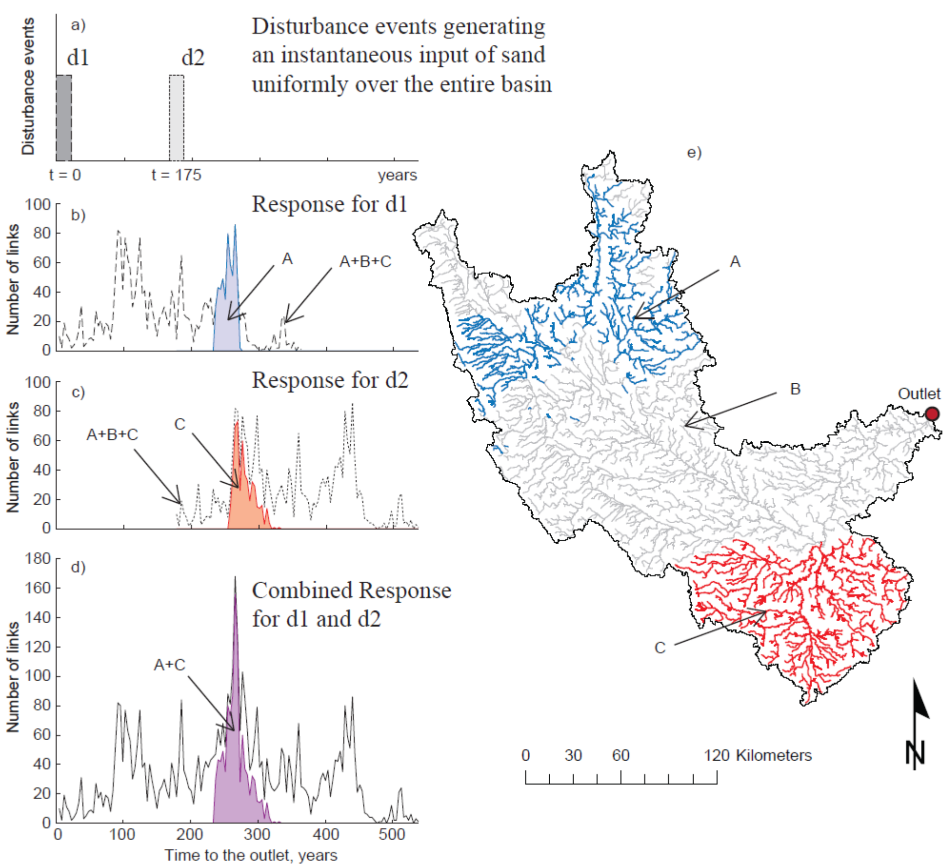

Figure 1. Synchronization of sediment fluxes can lead to amplification of the response for the Minnesota River Basin. (a) Disturbance of the landscape leading to two instantaneous inputs of sand (0.4 mm; uniformly over the basin) at 0 years (disturbance 1 or d1) and 175 years (disturbance 2 or d2). (b) Sedimentological response corresponding to d1; entire basin response [dashed line; basins A+B+C in (e)] and region corresponding to the second peak of the sand response [blue shaded area; basin A in (e)]. (c) Sedimentological response corresponding to d2; entire basin response [dotted line; basins A+B+C in (e)] and Blue Earth River Basin [red shaded area; basin C in (e)]. (d) Superimposed response for sand [sum of (b) and (c)] into an observed response (black line) resulting in amplification of the effects of the sediment inputs. Amplification can also occur if only the regions contributing to the peaks of the response [basin A in (b) and basin C in (c)] are disturbed and responses superimposed [purple shaded area; A+C]. (e) Partition of the basin into 3 regions: the region corresponding to the first peak of the sand response (red; C, Blue Earth River Basin), second peak of the sand response (blue; A), and the rest of the basin (gray; B).

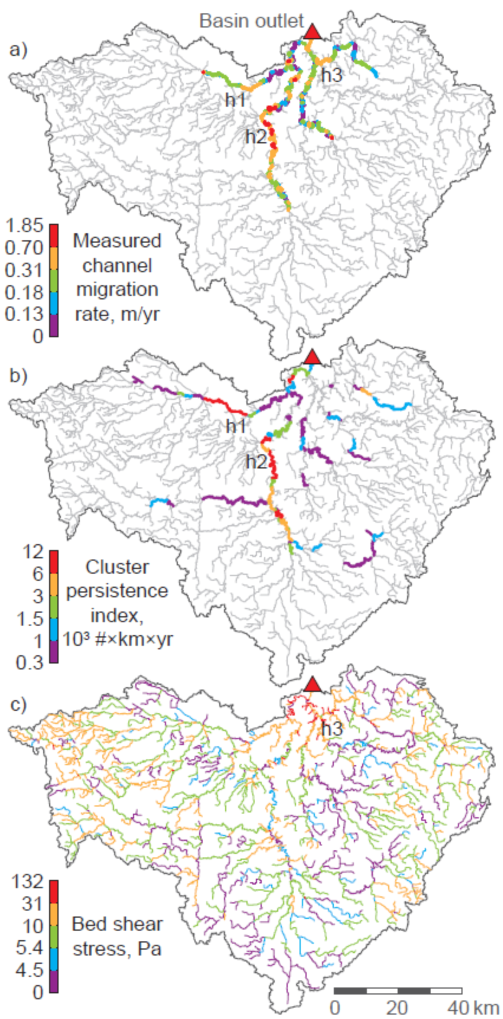

Figure 2. Identification of hotspots of geomorphic change in the Greater Blue Earth River Network. (a) Measured channel migration data. (b) Sediment cluster persistence index (defined as mass in units of hillslope equivalent sand transport multiplied by channel length multiplied by the number of years of cluster persistence). (c) Bed shear stress at the two-year recurrence interval flow. Hotspots are identified as h1-3; hotspots h1-2 were identified by the cluster persistence index and hotspot h3 was identified by the bed shear stress.

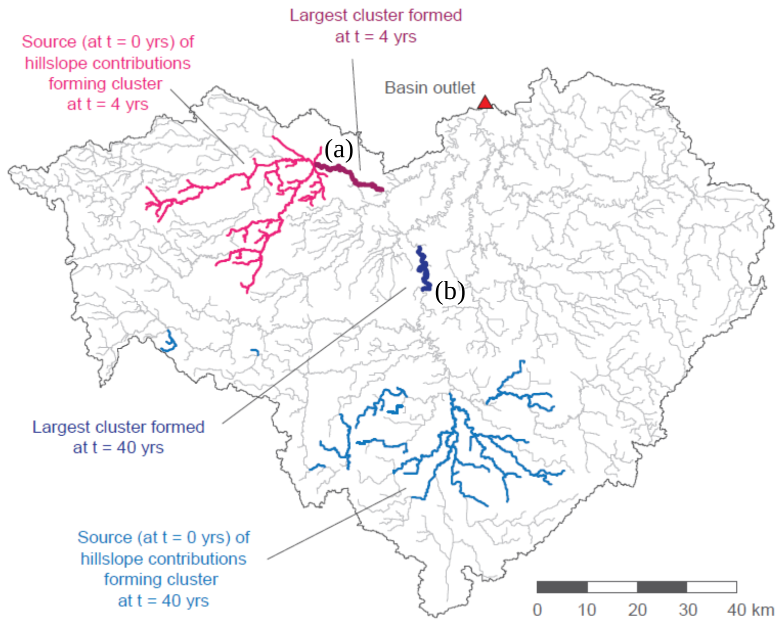

Figure 3. Unraveling the source contributions of two large clusters. (a) The largest cluster formed at time 4 years (dark purple) and the source (at time 0 years; light purple) of the hillslope contributions that formed this cluster, and (b) The largest cluster formed at time 40 years (dark blue) and the source (at time 0 years; light blue) of the hillslope contributions that formed this cluster.

2. Effect of Agricultural Drainage on Hydrologic Response

It has been amply documented that streamflows in the MRB have increased considerably over the past several years, in fact, after about 1970's [*Novotny and Stefan*, 2007]. This change has been observed in the whole frequency distribution of daily streamflows with much more spatially variable change in the low quantiles (low flows) and of the order of a factor of 0 to 5 and more spatially consistent in the high quantiles (high flows) and of the order of a factor of 1.6 to 2 [*Dadaser-Celik and Stefan*, 2009]. At the same time, some changes in precipitation extremes have also been observed with a general tendency for more intense shorter duration storms during the spring and summer. Disentangling human-climatic factors of streamflow change is an issue of significance [*Schottler et al.*, 2014] when considering the future of the MRB agricultural development and practices.

In this study we have addressed the question of whether and how human-induced changes on an agricultural landscape (specifically tile drainage) have affected the hydrologic response, i.e., the multi-scale nature of the hydrograph fluctuations in terms of their magnitude and frequency of occurrence. Although it is visible even by eye that the hydrologic response has changed significantly post-1975 (the year in which agriculture in most of the MRB sub-basins had a drastic shift from small grains to corn and soybeans) – see Fig. 4 – quantification of this change has not been attempted before. Here we have pursued two main analyses to quantify this change. First, was have concentrated on the marginal probability distribution functions (PDFs) of the daily rainfall increments (Q(t)-Q(t-1)) for the months of May and June most affected by tile drainage. These increments measure the relative change in hydrologic response both in terms of increase and decrease of daily streamflow in response to a pulse, or lack of, rainfall. Fig. 5 shows a significant increase in positive daily streamflow increments (faster rising limbs of storm-scale hydrologic response) and also a significant decrease in negative daily streamflow increments (faster falling limbs of storm-scale hydrologic response; notice that the absolute values of the streamflow increments are plotted in Fig 5 b). We note that precipitation is not the reason for this significant change as evidenced from Fig. 6. Second, we concentrate on the joint PDF of daily precipitation and corresponding daily streamflow increments and specifically study their dependence via a non-parametric Copula analysis. Fig. 7 shows that in quantiles of approximately 0.5 (close to the median) a significantly higher dependence between daily precipitation and daily streamflow increments exists in post-1975 period compared to the pre-1975 period. That is, daily rainfall is much more directly manifesting itself into streamflow increase (via artificial drainage to the stream rather than infiltration and subsurface runoff to the stream) in these quantiles. However, for extreme storm events (high quantiles) no significant change in the dependence between precipitation-streamflow increments was observed because for such extreme storms the artificially fast drainage to the streams does not differ much hydrologically from the naturally fast overland flow for those extreme events.

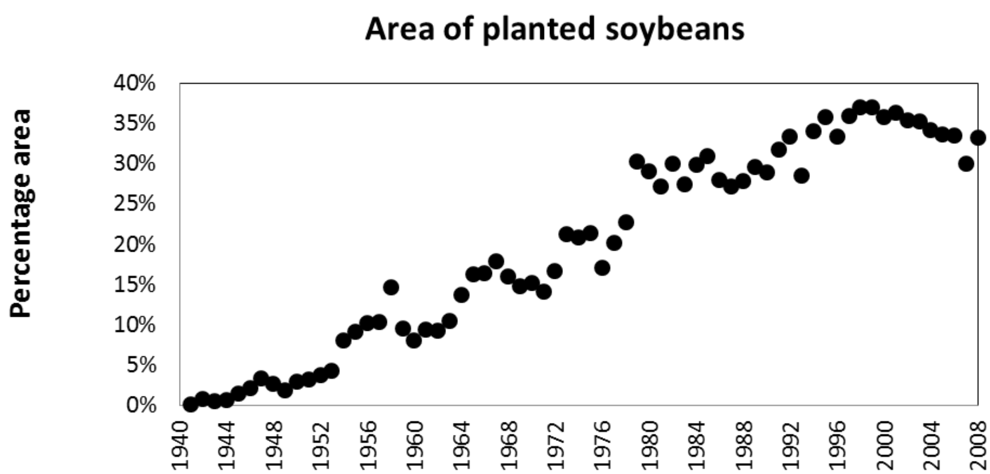

Figure 4. Percentage of planted land as soybeans for the Redwood River Basin (a south-central sub-basin of the Minnesota River Basin).

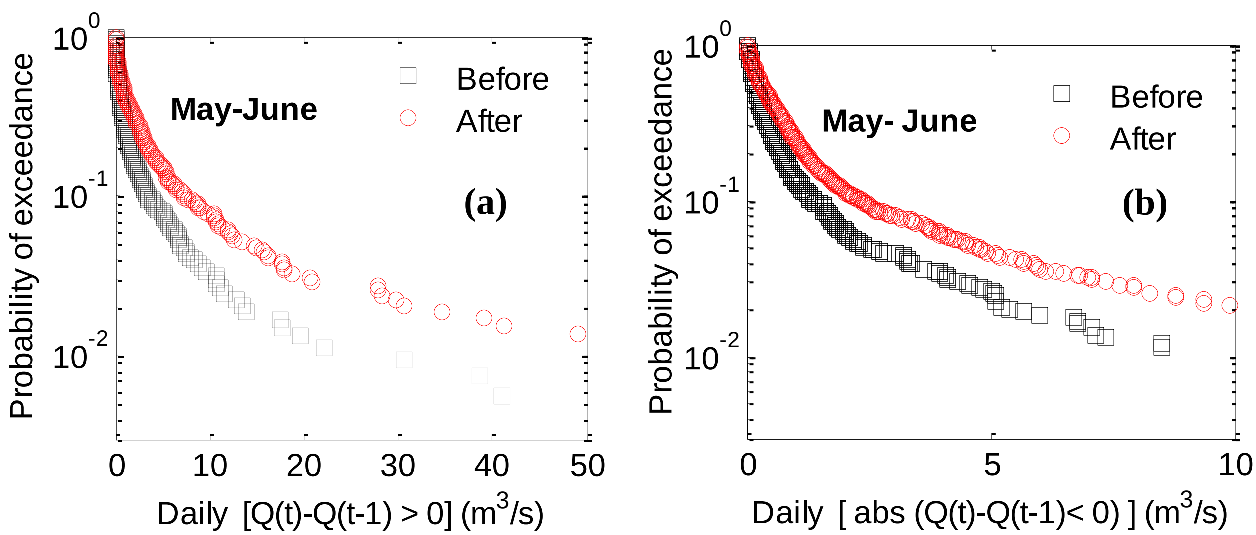

Figure 5. Probability of exceedance of daily streamflow increments; $\Delta Q = Q(t) - Q(t-1)$ in (m^3/s) for May- June of the "Before" (1943-1975 black squares) and "After" (1976-2008 red circles) periods for the Redwood River Basin. (a) Positive increments ($\Delta Q > 0$) and (b) negative increments ($\Delta Q < 0$) have been analyzed separately to capture the increasing and decreasing nature of hydrologic response.

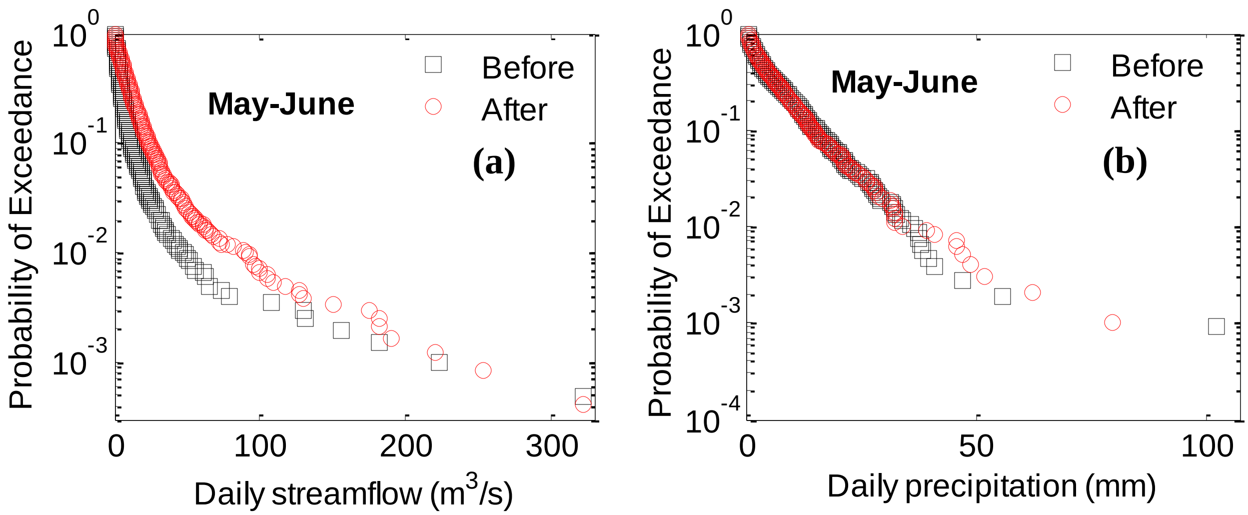

Figure 6. Probability of exceedance of (a) daily streamflow (m^3/s) and (b) daily precipitation (mm) for May-June of 1943-1975 (Before; black squares) and 1976-2008 (After; red circles), for the Redwood River Basin.

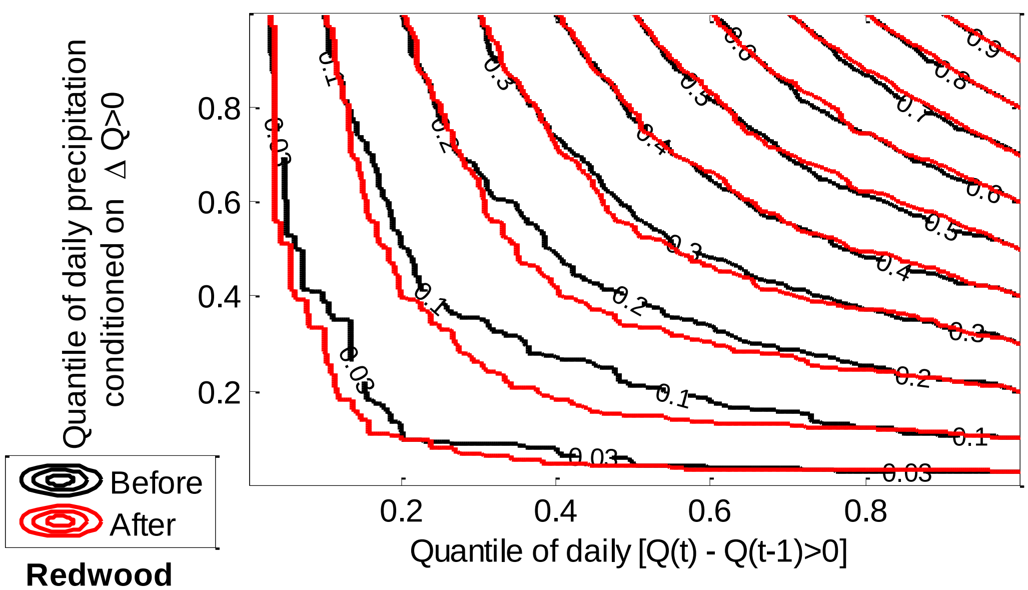

Figure 7. Empirical Copula of positive daily streamflow increments ($\Delta Q = Q(t) - Q(t-1) > 0$) in ($m^3/s$) and the corresponding daily precipitation (mm) for the Redwood River Basin for the May-June periods of 'Before" (1943-1975, black line) and "After" (1976-2008, red line).

3. Expression of Geologic Controls on Multi-Scale River Network Structure

The branching structure of river networks has attracted the attention of many researchers in past decades with application to a variety of hydrological and geomorphological problems. Specifically, self-similarity has been studied extensively as a fundamental property of river networks, which provides a basis to develop scaling relationships for hydrologic fluxes. However, self-similarity does not hold in some river networks begging the question as to what characteristic scales such landscapes possess and how these have propagated to other scales to break the self-similarity [*Danesh-Yazdi et al., in preparation*]. Fig. 8 shows an example of such a drainage network which corresponds to the Headwaters sub-basin of the Minnesota River Basin (one of the twelve major sub-basins of the Minnesota River Basin located in the south-western corner of the basin). It is visually apparent that the western part of this river network has different topological characteristics from the rest of the river network (i.e. larger number of streams, parallel channels, etc.) where (Tokunaga) self-similarity does not hold. As suggested by recent studies, the topology of a river network might have the signature of the underlying geologic controls of the landscape. Thus our goal was to investigate quantitatively how large scale features appear in the smaller scale organization of the landscape, and therefore dictate the organization of the river network topology.

We approached this problem by utilizing the two-dimensional discrete wavelet transformation (DWT) as it is capable of localizing landscape features and identifying details at different scales and locations. In this regard, the effect of large scale features was examined through two consecutive procedures known as decomposition and reconstruction. First, a landscape image was decomposed down to a desired level of interest via DWT which results in sets of approximation and detail coefficients in three directions: horizontal, vertical, and diagonal. Then starting from the last level of decomposition, the detail coefficients including the low frequency components were set to zero and a new image was reconstructed by using the remaining detail coefficients at smaller scales. This procedure was repeated up to the smallest possible level until all the frequencies from low to high were progressively removed (essentially removing features from the landscape beginning from large scale features and progressively removing more and more of the next smaller scale features). Panel (a) in Fig. 9 illustrates the outcome of this procedure for a patch within the Headwaters River Basin (MN) where self-similarity did not hold, and panel (b) shows the results for a patch in the Methow River Basins (WA) where self-similarity held. The major topographical difference between these two patches was the existence of the quasi-periodic ridge-valley structures in the former landscape. In this figure, each panel includes the elevation map of the reconstructed landscapes along with their corresponding probability distribution functions (PDF) at different scales obtained by decomposing both landscapes down to scale level 8 (scale of 7.68 km).

In order to quantify the landscape organization at different scales, we computed the entropy as a measure of the distribution of energy in the landscape system according to

$$S = -\sum_i p_i \ln p_i$$

where p_i corresponds to the PDF of the elevations of the reconstructed landscapes. The computed entropies S from the p_i of the earlier PDFs were plotted versus scale in Fig. 10. We observed that the landscape which contained relatively uniformly spaced features was characterized by the existence of some intermediate scales where entropy did not change. It also showed clearly how the corresponding PDFs of the constant entropy region kept the same shape, i.e. they are identical apart from a small change in the standard deviation. In addition, the wavelet energy spectrum discriminated between the landscape patches in terms of the change in spectral slope in the log-log domain too. It can be seen from Fig. 11 that energy (variance) was propagated slower through the range of scales over which the entropy was constant. *The ultimate scope of our study is to investigate how the total multi-scale variability in landscapes depicts pronounced regularities (probably the result of an externally imposed control such as geology) that "break" away from the typical "cascade of energy" so familiar for landscapes that have evolved in the absence of external controls. The range of scales of this externally imposed "regularity" is then quantified and descriptions of the self-dissimilar network structures investigated to aid in the quantitative analysis of how fluxes in the basin depend on scale.*

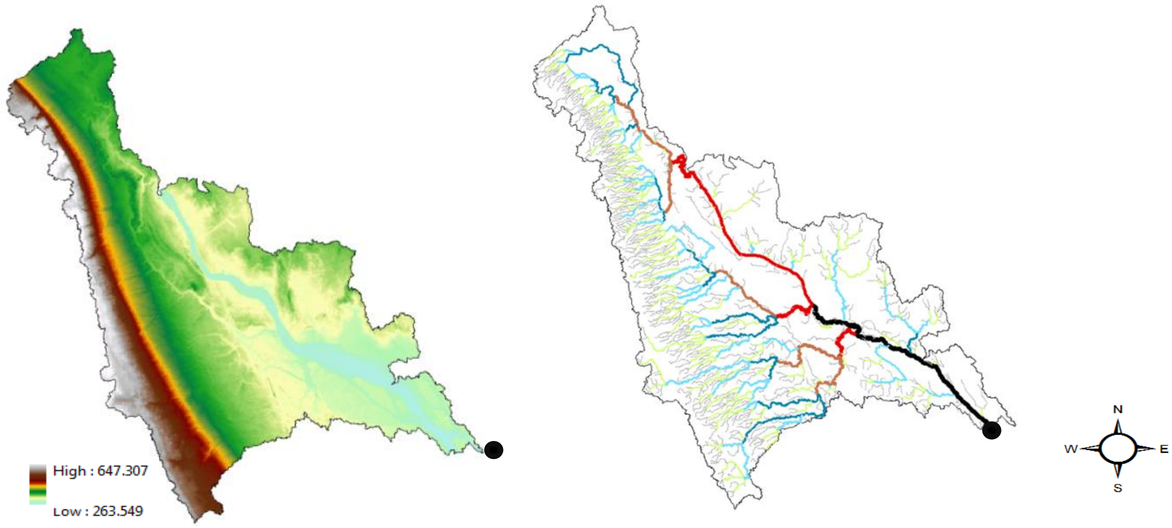

Figure 8. Digital Elevation Model and the river network topology of the Headwaters River Basin, MN. The western region of the landscape consists of quasi-periodic ridge-valley features that are almost evenly spaced.

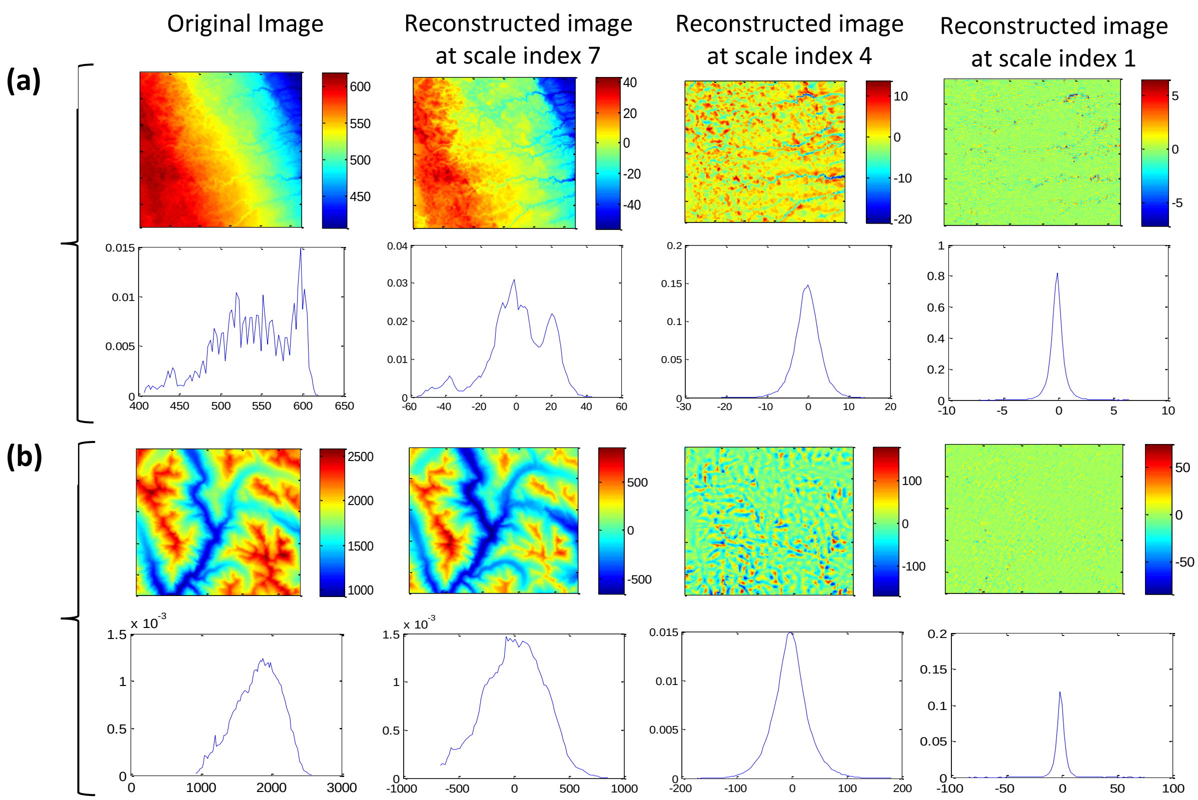

Figure 9. Panels (a) and (b) illustrate the reconstructed landscapes at different scales for two patches within the Headwaters and Methow River Basins (WA). Each panel includes the elevation map of the landscapes and the probability distribution function of elevation. For both patches, the original landscapes were decomposed down to scale level 8 (scale of 7.68 km).

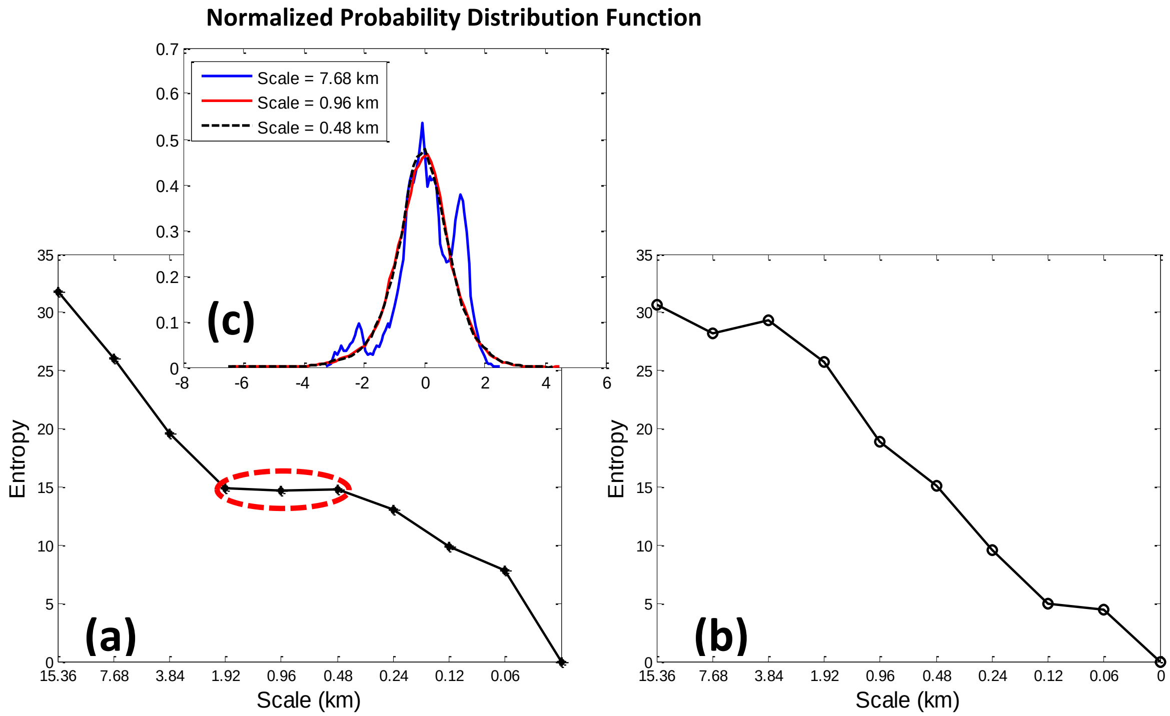

Figure 10. Entropy against scale for a coherent patch (a) in the Headwaters and a non-coherent patch (b) in the Methow River Basin. Both landscapes were decomposed down to level 8 and the horizontal axis shows the scale in km. The first point at the largest scale shows the entropy of the original DEM followed by the entropies derived from the reconstructed landscapes at levels 7, 4, and 1, respectively. The last point pertains to the case at which all the wavelet coefficient were set to zero which trivially lead to zero entropy. The coherent landscape shows itself up as almost constant entropy, while the entropy fluctuated with the overall decreasing trend for a non-coherent landscape. For the coherent landscape, the normalized probability distribution function of the reconstructed images at selective scales was shown in panel (c), which clarifies that the PDFs at constant entropy scales were statistically the same, i.e. they had the same shape or were rescalable. Moreover, the characteristic dissection scales of a coherent landscape (depicted by the red dashed circle in the plot) can be identified by extracting those scales with constant entropy.

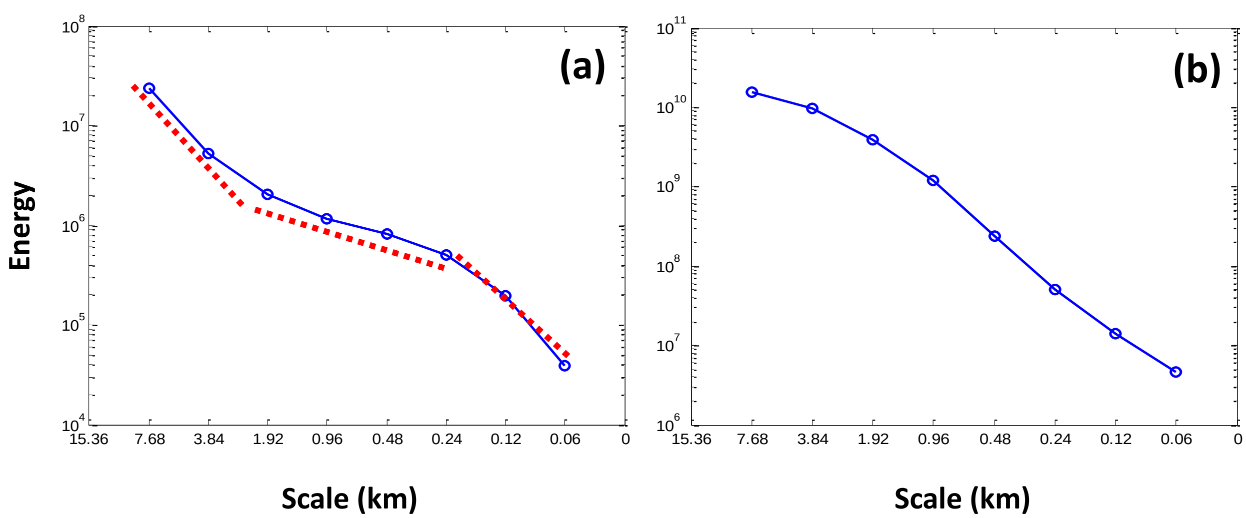

Figure 11. Wavelet energy spectrum. Panel (a) represents the coherent patch in the Headwaters and panel (b) corresponds to the non-coherent patch in the Methow River Basin. The monotonic propagation of energy through smaller scales behaves differently for the coherent landscape, i.e. the slope of wavelet energy spectrum changes when reaching and passing the scales over which the entropy was constant (depicted by the dashed red lines), whereas such a varying slope was not observed in the non-coherent landscape.

4. Meandering River Dynamics

Meandering rivers with high rates of channel migration can deliver large quantities of sediment to rivers, indirectly affect water quality and biotic functioning, and increase the risk to public and private property. In order to understand how and ultimately predict where a river channel will migrate, the challenge lies in linking the meander process to the sinuous river channel planform pattern. To this end we are using numerical modeling to gain insight on the interplay between a meandering river's form (i.e. shape) and its migration dynamics [*Schwenk et al.*, *in preparation*]. Our model follows the classic work of *Ikeda et al.* [1981] and accounts for how variations in channel curvature affect the flow field and migration. Although sediment dynamics are simplified and decoupled from hydrodynamics, the model has been shown to simulate planform patterns that are statistically similar to real rivers [*Stolum*, 1998]. We introduce a new space-time scale referring to the life and dynamics of individual meanders (called "atoms") from inception to cutoff (Fig. 12). An atom tracking algorithm was developed that may be applied to any numerical simulation of long-term meander migration. Atoms provide a bend-scale measure that bridges the gap between reach-wide (e.g. sinuosity) and local (e.g. migration rate at-a-point) measures of river migration. The model dynamics produce a variety of emergent cutoff planform shapes, but three prototypical shape groups were identified. Geometric relationships were established within each group providing insight unavailable via analysis of model equations. Further, an analysis of migration rates and growth rates provided an understanding of atoms' dynamic histories. Relationships between cutoff shape and historical dynamics show that meander loop shapes contain information about their formative dynamics. Results suggest that, for example, oxbow lake shapes may be useful for reconstructing historic migration signals.

The atom perspective also allows investigation of the effect of perturbations on long-term meander migration. Preliminary analyses indicate a vulnerable period early in a meander bend's life when perturbations may greatly influence its dynamic trajectory. Perturbations in the model were due to cutoff, but the results may be extended to anthropogenic perturbations such as dam construction, channelization, and bank armoring, for example. Further analyses and results may inform decision making in the Minnesota River Basin, where actively migrating rivers flow through an agricultural landscape and dissect cities (Fig. 13), as well as provide insight toward understanding the geomorphic history of the region.

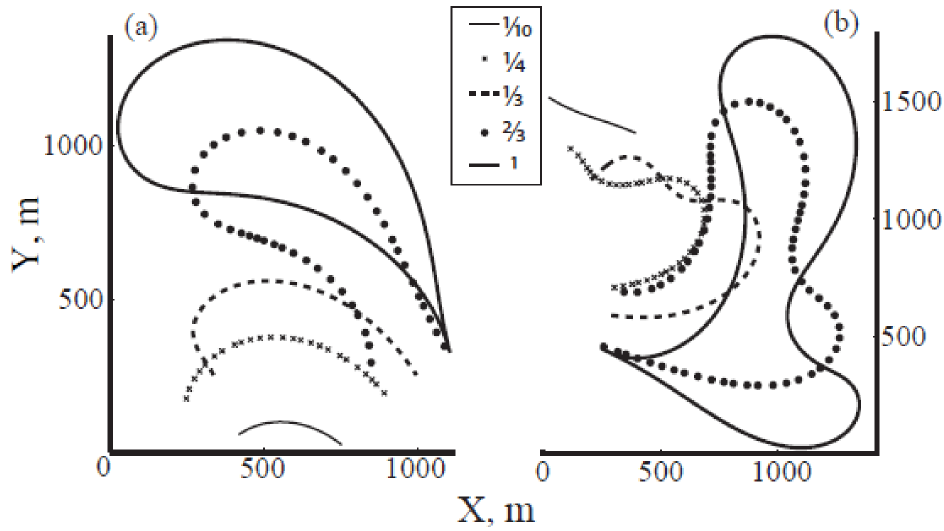

Figure 12. Examples of the atom tracking algorithm. Centerlines of two atoms of different complexity tracked from cutoff backwards to their inception. Legend values represent the fraction of atom length to its length at cutoff, i.e. 1/10 shows the atom near inception and 1 shows the atom at cutoff. (a) shows the growth of an unperturbed single-loop atom, while (b) shows the growth of atoms that develop a second loop due to a cutoff immediately upstream that occurs after 1/4 and before 1/3 of the total length.

Figure 13. An oxbow lake on the Minnesota River, upstream of Jordan, MN. The Minnesota River features many single-looped oxbows of various shapes and sizes.

5. Integrative Hydro-Geo-Biological Predictive Modeling

Freshwater fauna have dramatically declined in both diversity and abundance worldwide concurrent with changes in streamflow and sediment loads in rivers, begging for quantitative understanding of how environmental stressors may adversely affect the integrity of river biotic life. Cumulative effects and interdependency of chronic environmental stressors, e.g. high suspended sediment concentrations and phytoplankton (food) limitations, may obscure a causal linkage but may also be most critical for understanding the population dynamics of longer lived organisms such as freshwater mussels.

To better understand long-term mussel population dynamics in the Minnesota River Basin, we first developed a process-based interaction framework describing the interdependent set of dynamic environmental variables affecting mussels (all variables in Fig. 14). A dynamic, process-based interaction model was then developed under the premise that chronic exposure to increased suspended sediment and food limitation are the primary factors limiting native mussel population growth [*Hansen et al*., *in preparation*]. The model incorporates empirical and theoretical functional relationships to define interactions between mussel population density, streamflow, suspended sediment concentration, and phytoplankton population density (dark shaded variables in Fig. 14) and simulates these interactions at a daily timescale over several decades (Fig. 15).

Using daily streamflow data, locally fitted sediment-streamflow relationships, and some carefully chosen parameterizations from the literature, we run the model and predicted mussel population in 11 sites for which independent observations were available. A period of the available data was used for model calibration and another period for prediction. It was shown that the model can accurately predict the non-linear interactions between streamflow, suspended sediment, phytoplankton, and mussel populations and supported the hypothesis that chronic exposures to suspended sediment and food limitation have recently limited native mussel population growth throughout the Minnesota River Basin. Analyses of the model dynamics show its viability as a tool for identifying locations where management efforts will have the highest likelihood of improving mussel population recovery. Specifically, we simulated changes in average suspended sediment generation due to land use and climate changes and identified a site-specific range where the mussel population was most responsive to changes in average suspended sediment concentration (2 – 20 mg/L; Fig. 16). This range had 2 thresholds; first, the threshold where a stable mussel population was no longer resilient to suspended sediment fluctuations (~2 mg/L) and second, the threshold where mussel populations were extirpated (~20 mg/L). Mussel populations within the transitional region were most sensitive to changing environmental stressors, and small changes in reducing environmental stressors here are likely to have the biggest impact on rehabilitating mussel populations. Accounting for the effects of long-term, dynamic, environmental degradation on freshwater biota, as outlined in the framework, is critical in order to develop strategies for protection or recovery of at-risk populations struggling against the multifaceted aspects of chronically poor ecological conditions.

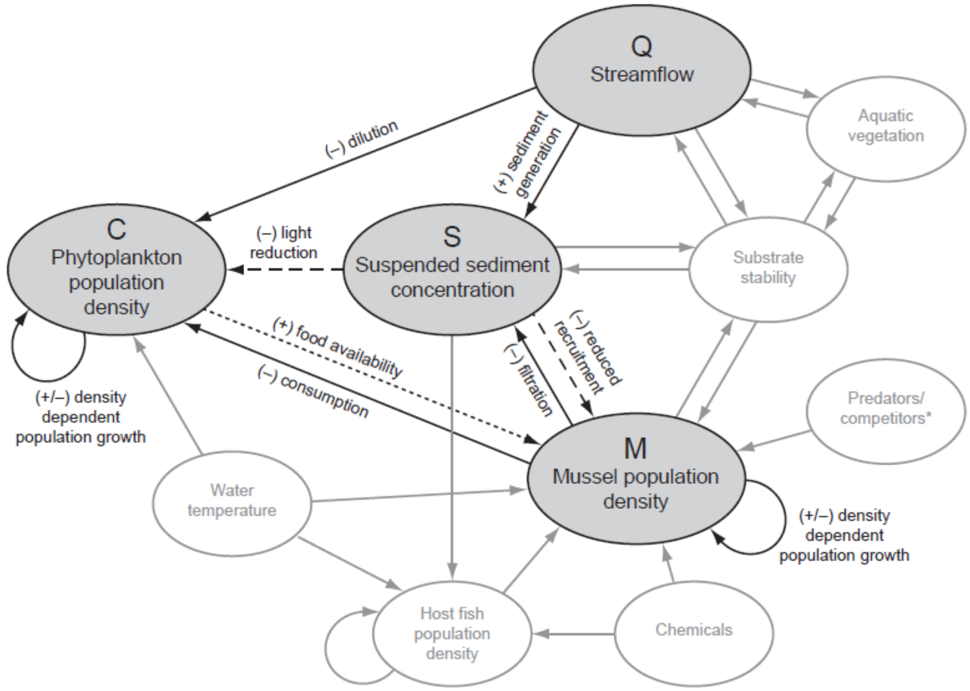

Figure 14. Network of process interactions between the major variables driving the dynamics of the coupled hydro-geo-biological system. Only the dark shaded variables and interactions were incorporated into the developed model. Streamflow (Q) is the main driver of the system, generating suspended sediment and diluting phytoplankton. Suspended sediment concentration (S) reduces the growth rate of phytoplankton and the juvenile recruitment rate of mussels; phytoplankton population density (C) can be low enough to reduce the carrying capacity of the mussel population and can self-limit; mussels (M) filter suspended sediment, consume phytoplankton, and self-limit. The "*" on predators/competitors denotes that only the direct interaction with mussels is shown for this variable.

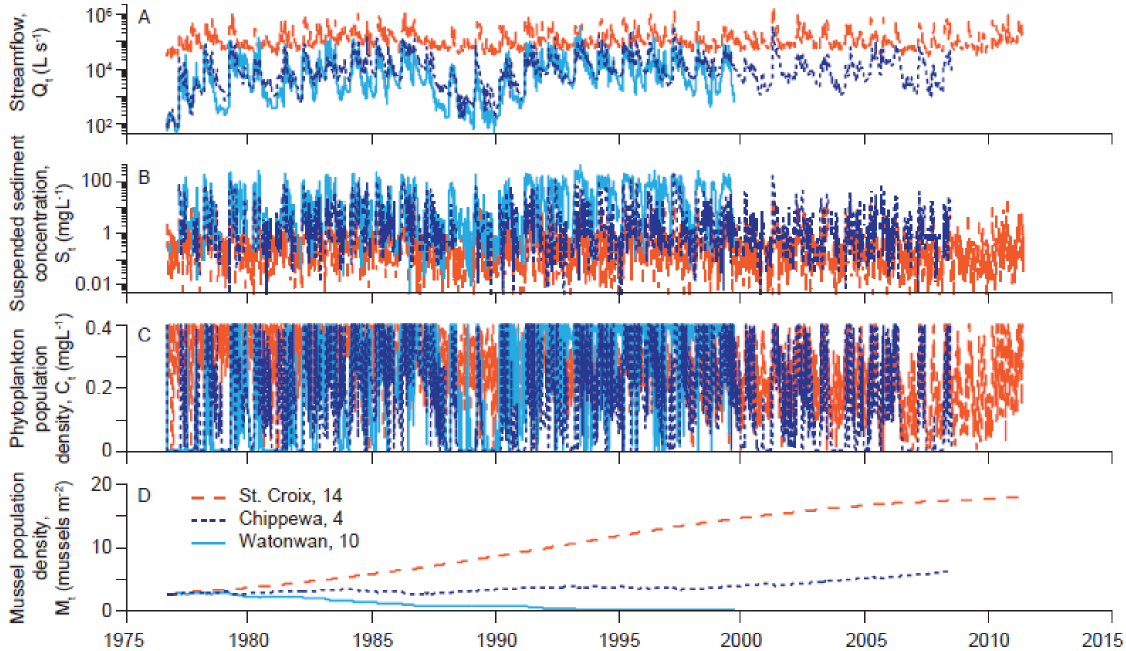

Figure 15. Temporal variability in model variables for St. Croix (long dashed red line), Chippewa (short dashed dark blue line), and Watonwan (continuous light blue line) sites. Model variables included (A) the input streamflow data and the interdependent interacting simulated variables of (B) suspended sediment concentration, (C) phytoplankton population density, and (D) mussel population density.

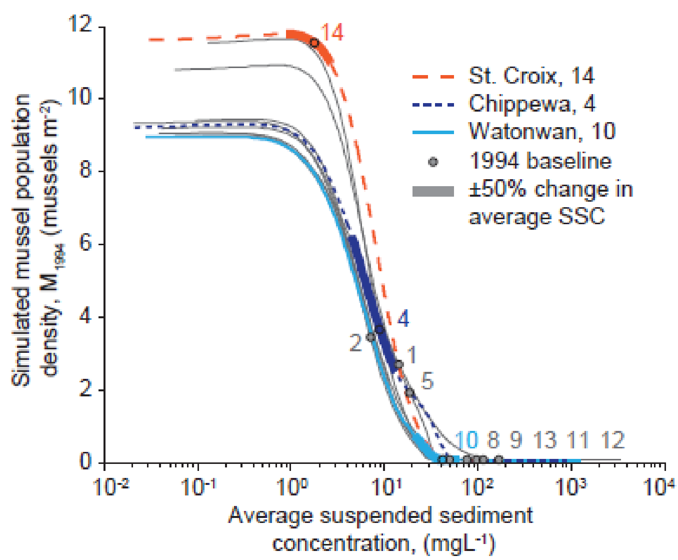

Figure 16. Simulated mussel population response to changing average suspended sediment concentration due to land use and climate changes. Each dot and number represents the baseline conditions for a site in the Minnesota or St. Croix River Basins. For the highlighted sites of the St. Croix (long dashed red line), Chippewa (short dashed dark blue line), and Watonwan (continuous light blue line), the thick colored line segments correspond to a ±50% change in the coefficient of the relation for generating suspended sediment.

Future Research (2014–2015)

In the next year our focus will be along the following lines:

1. Network Approach to River Basin Vulnerability Assessment

- Investigate the transport of sediment (and other material) along the river network using a minimal complexity, simple predictive framework and test this against available data.
- Relax some of the assumptions of the framework related to storage and release of sediment in the system.
- Use this approach to investigate management actions and vulnerability/resilience questions to future changes in the basin.

2. Effect of Agricultural Drainage on Hydrologic Response

- Further quantify the effect of tile drainage on the basin hydrologic response at multiple scales (daily up to weekly) by performing analysis of several sub-basins within the MRB and relating the results to land use change.
- Apply local multi-scale analysis (wavelets), mutual-information metrics of probabilistic dependence, and parameterized Copulas to more precisely quantify how changes in precipitation and land use manifest themselves in changes in streamflow, over the whole spectrum of frequencies and magnitudes.

3. Expression of Geologic Controls on Multi-Scale River Network Structure

- Understand how river networks not obeying the typical self-similar structure can be modeled via extended forms of higher-order branching structure topologies.
- Investigate more closely the break of self-similarity and its physical causes in other sub-basins within the MRB.
- Explore how self-dissimilarity (s-d) in river network topology projects itself into a break in scaling of mean annual and maximum annual peak streamflows and weather/how re-scaling of fluxes can be achieved by appropriate selection of scale parameters besides the upstream contributing area.

4. Meandering River Dynamics

- Use the meandering atom framework to further link reach-wide and local physical processes and test whether the static form of oxbow lakes can be used to back-predict the dynamics of the corresponding meander (inferring process from form).
- Perform localized analysis of curvature dynamics and parameterize the energy as a function of all scales present in an evolving meandering river, as well as understand how local perturbations change the energy-scale relationship at the local and global scales.
- Understand how the natural meandering of rivers in the basin is affected by constraints imposed by human factors and how these external perturbations propagate throughout the system to change the dynamics of meander growth and cut-offs.

5. Integrative Hydro-Geo-Biological Predictive Modeling

- Theoretically study the non-linear dynamics and threshold behavior (two states of attraction) of the developed model and understand what parameters or model component parameterizations mostly control the long-term behavior.

- Perform a more extensive sensitivity analysis to unknown or poorly estimated parameters to pinpoint what quantities need to be known in a basin to be able to accurately predict the water-sediment-mussel population density continuum.
- Use the model as a tool to suggest management scenarios in a basin that might allow declining mussel populations to rebound and avoid further decline toward an extinction threshold.

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With Evelyn Boardman (PhD student) and Brent Dalzell (Research associate)

Research update

Our research assesses landscape and climate change drivers of stream structure and processes in agriculturally dominated watersheds. We are using data synthesis, modeling, and GIS to identify controls of watershed nutrient export through leveraging analyses of existing databases. With new data collection efforts, we are examining relationships between river network physical structure and biological processes to inform predictive modeling of nutrient transport and cycling, and food web structure in highly dynamic landscapes. We focus intensively on understanding the influence of wetlands, lakes, and riparian zones on local and downstream structure and processes in stream networks, and legacy nutrients. All research described below is in early to mid stages of implementation, and results described below should be considered preliminary.

1. Climate and land use effects on watershed nutrient transport

Water quality impairment in the Minnesota River Basin (MRB) basin has been recognized as a major regional issue for decades, leading to the implementation of intensive monitoring programs by USGS and state agencies (Minnesota Pollution Control, Department of Natural Resources, and Department of Agriculture; respectively, MPCA, MDNR and MDA). Changes in precipitation, temperature, drainage, and crop cover (described elsewhere in this report) all influence watershed nutrient export [*Dubrovsky et al*., 2010]. We are working to synthesize available data towards understanding the relative influence and potential interaction of these factors in the MRB, and generating hypotheses for field work in subsequent years. We are using the relatively rich monitoring databases for large scale nutrient monitoring to address the following questions:

1. What is the relative importance of climate and land-use change on observed interannual trends in nutrient transport through channel networks?
2. Is there hysteresis in nutrient losses in response to climate variability?
3. What is the impact of agricultural landscape structure on element cycles and downstream ecological processes, and how can placement of BMP features be optimized for multiple ecological functions?

Springtime nitrate loads in the MRB have increased dramatically since the early 20th century (Fig. 1). Spring nitrate loading to the MRB, a tributary to the Mississippi River, is especially critical as it influences the extent of the annual hypoxic zone in the Northern Gulf of Mexico [*USEPA*, 2007; *Turner et al*., 2012]. High nitrate loads are due to both increases in nitrate concentration, which peaks in June, and increases in water discharge, which typically is highest in April. Each point on the graph represents the decadal daily average nitrate load vs. month. Nitrate loads were calculated by multiplying nitrate concentrations from MPCA monitoring data (taken on average every 2 weeks) by daily average discharge for the same day as the water chemistry data (USGS gage ID 5330000). 1906-07 nitrate concentrations were measured every 2 weeks [*Clarke*, 1927]. Discharge data was not available for this time period so average discharge from 1934-1944 were used (USGS gage ID 5330000).

The form of phosphorus (P) is an important indicator of its transport mechanisms, its bioavailability and its short term vs. long term water quality implications. But P form is dynamic and exchange between dissolved and particulate forms occurs as P travels through the landscape and the riverine network. Minnesota Pollution Control

Agency (MPCA) monitoring data from samples near the Le Sueur River outlet (Rapidan) illustrates that both forms of P are important and variable throughout the year (Fig. 2). Future work will address the interaction of dissolved and particulate P pools spatially, throughout the river network, and temporally, to help understand the process that store, transform and release P in the watershed.

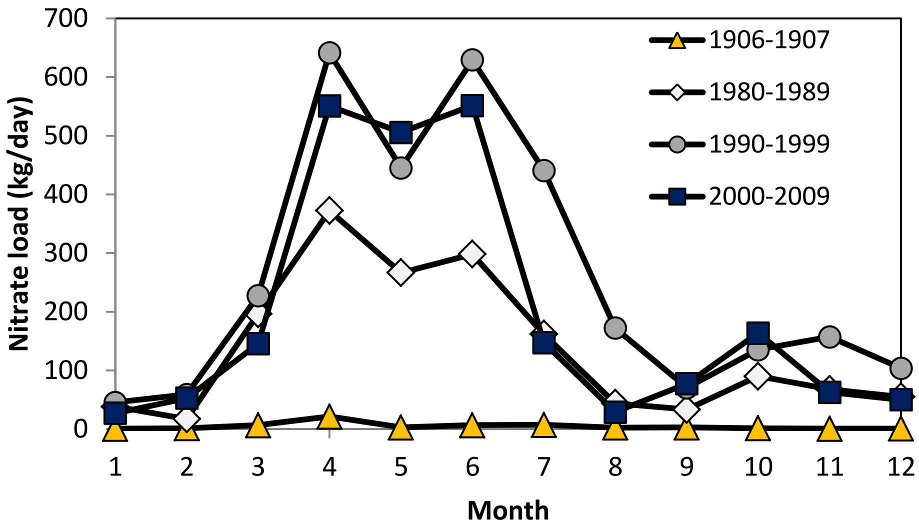

Figure 1. Historical nitrate loads from the Minnesota River at Jordan, MN.

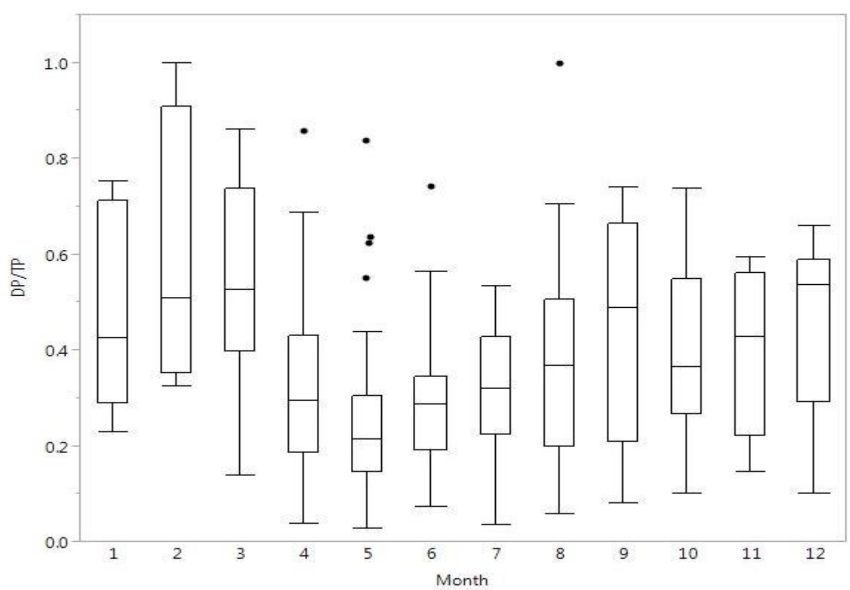

Figure 2. Seasonal variation in dissolved fraction (DP) of total phosphorus (TP) from MPCA monitoring data for the Le Sueur River near Rapidan (1999-2011).

2. River Network Structure and Processes

Climate change and widespread changes in land use over the past century have altered stream hydrology, nutrient loading and in-stream sediment dynamics, often to the detriment of stream ecosystems [*Allan,* 2004]. In agricultural systems, these three impairments are tightly coupled. There is limited current understanding of the relative contribution of each to overall ecosystem functional degradation. Excessive sediment loading may alter stream metabolism and ecosystem functioning by decreasing light availability and decreasing habitat stability [*Sheldon et al*., 2012; *Burdon et al*., 2013]. Excessive nutrient loading may stimulate planktonic production, further decreasing light availability at the benthos. Insufficient supplies of carbon, due to farmed riparian zones and dredged ditches, can limit primary productivity in ditches. Recent research shows that river ecosystems in agricultural watersheds exhibit a wide range of biotic responses to human activities both within a site through time, and across sites. Although understanding of dynamics in human dominated catchment is increasing, we still lack information to predict how specific changes in land cover and climate will affect biological processes. Through field measurements and analysis of the long-term data set we are exploring the interactions of discharge, suspended sediment, organic material availability, light attenuation, and nutrient availability on ecological function and processes. Field measurements focus on the Le Sueur River network (Fig. 3), where sediment sources have been carefully delineated [*Belmont et al.*, 2011; *Maalim et al*., 2013] but are expanding to other watersheds with contrasting climate and lake density features in 2014.

Ongoing work seeks to identify relationships between physical features (such as flow, slope, suspended sediment, and light) on biological processes in agricultural drainage networks. A substantial long-term monitoring record provides much insight into physical variable behavior in larger rivers but little data is available detailing physical relationships within tiles, ditches, and small streams in an agricultural system. Our intent this summer is to quantify the contributions of these smaller components of the network in order to inform our understanding of current system ecological functioning, potential sources of resilience (such as wetlands) and aid our colleagues' modeling efforts.

Initial field measurements of physical variables are largely exploratory in nature and aim to answer the following questions:

1. What contribution does in-channel nutrient cycling make to basin nutrient export at critical seasons or locations within the basin?
2. Is there a scale invariant relationship between discharge and suspended sediment concentration, discharge and nutrient concentration or suspended sediment concentration and light decay?
3. Is the response of benthic biological processes to light, nutrient, and carbon limitation a threshold response or continuous response? Can we describe this response as a variable dependent on discharge or watershed area?

We are using carbon stable isotopes to characterize food webs across a gradient of suspended sediment concentrations and stream size. Carbon stable isotope ratios ($\delta^{13}C$) can be used to determine original sources of dietary carbon for consumers, because values often vary among different types of primary producers, but are relatively unaltered by trophic transfers. For example, greater variability in $\delta^{13}C$ values among primary aquatic consumers (e.g., macroinvertebrates that feed by collecting and gathering or by grazing) may potentially indicate a greater diversity of carbon sources available to these feeding groups. Our preliminary data suggests that the range of macroinvertebrate $\delta^{13}C$ may decrease with watershed area (Fig. 4), suggesting that higher total suspended solids (TSS) at these sites may limit the diversity of food resources available to macroinvertebrates in downstream relative to upstream reaches (Fig. 4). Resource diversity is a primary driver of species diversity for stream macroinvertebrates. Field research efforts in 2014 will follow up on this preliminary finding by identifying potential changes in food resource use among macroinvertebrates as a function of TSS, land cover, and allochthonous vs. autochthonous inputs, while controlling for other possible sources of variability/uncertainty in $\delta^{13}C$ tracers.

Nitrogen stable isotope ratios ($^{15}N/^{14}N$, expressed as $\delta^{15}N$) of organic materials can reflect local sources and transformations of N, and thus potentially serve as an indicator of local rates in denitrification or nutrient sources [*Vander Zanden et al*., 2005; *Diebel and Vander Zanden*, 2009]. However, many assumptions in these methods have not been examined, particularly the spatial and temporal scales that these indicators respond to. Preliminary data from 2013 suggests that benthic denitrification rates measured in streams of the Le Sueur River basin are positively related to dissolved organic carbon (DOC) and $\delta^{15}N$ of macroinvertebrate tissue (Fig. 5). Our research efforts in 2014 seek to better understand and refine indicators of watershed scale denitrification, including macroinvertebrate stable isotope ratios as indicators of biogeochemical transformations in streams.

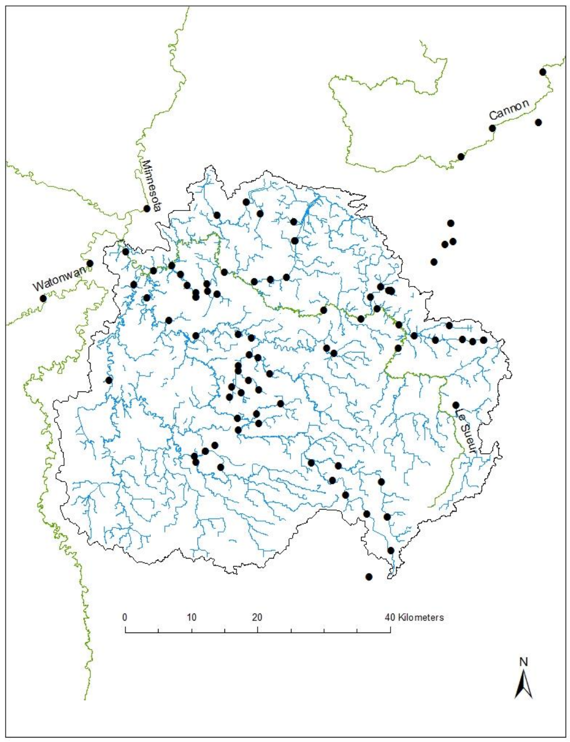

Figure 3. Study sites in the Le Sueur River basin (black dots). Green lines are major river traces; blue lines are 1:24,000 scale streams captured from USGS seven and one-half minute quadrangle maps.

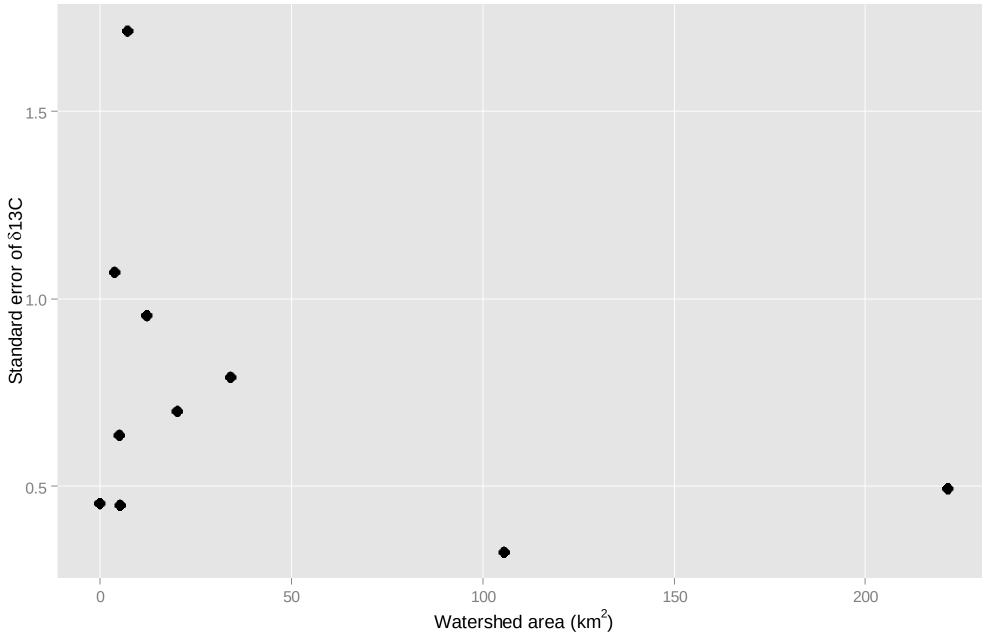

Figure 3. Variation in $\delta^{13}C$ values among macroinvertebrate taxa in relation to watershed area at 10 ditch and stream sites in the Le Sueur River basin. All sites were sampled in 2013. Variation in $\delta^{13}C$ values at each site was quantified using standard error of the mean.

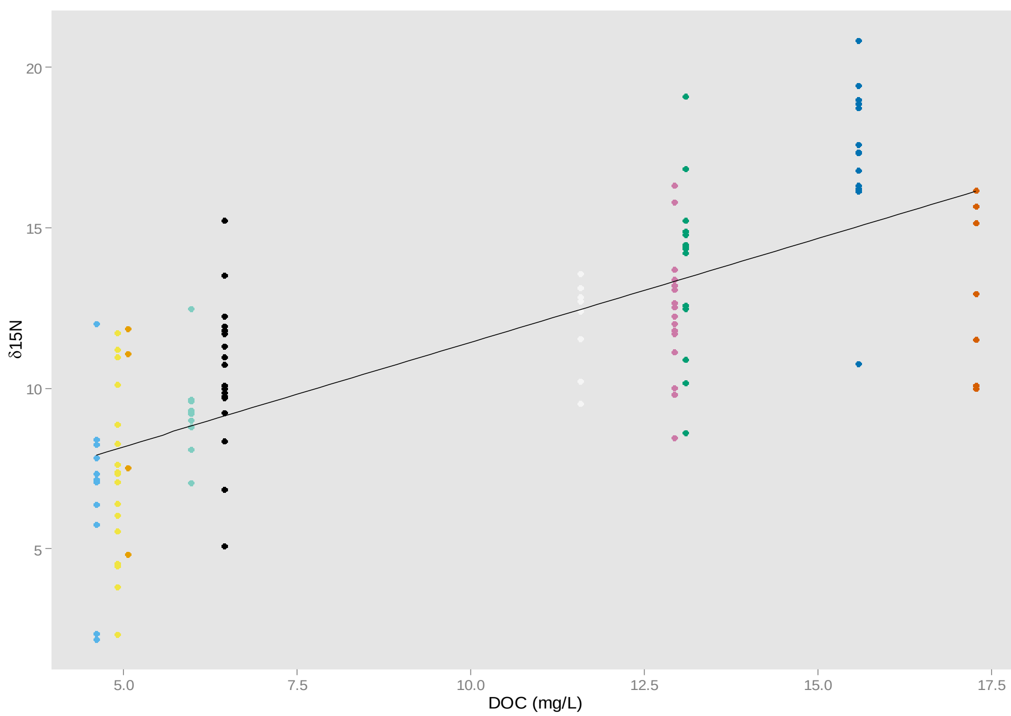

Figure 5. $\delta^{15}N$ values of macroinvertebrate tissue in relation to in-stream DOC at 10 ditch and stream sites in the Le Sueur River basin. All samples were collected in 2013. Different colors represent macroinvertebrate taxa collected at different sites. Black line represents a statistically significant linear regression model ($p<0.5$).

3. Seasonal changes in influences of wetlands and lakes

Wetlands and lakes may add system resilience to an agricultural watershed by dampening storm streamflow response, enhancing denitrification, and trapping sediments. Conversely, they may also function as legacy sources of phosphorus, leading to long time lags in water quality improvement in response to landscape management changes. Seasonally, water sources shift from snowmelt to groundwater in the spring, followed by surface water sources in summer and fall (Fig. 6 and 7). Our work seeks to better understand the function of lakes and wetlands in agricultural watersheds. Preliminary analyses show that lake-rich locations in the MRB, such as the Chippewa and Pomme de Terre Rivers, show evidence of enhanced rates of ecological functioning. In contrast, streams below isolated lakes and wetlands in the LeSueur basin were often enriched in sediment and P in 2013 compared to nearby stream reaches. These observations suggest that lakes and wetlands have positive effects on N removal but may increase P concentration, particularly where sediment loading has occurred at high rates historically. Sampling to explore these observations is ongoing in 2014.

The restoration (or creation) of wetlands and ponds in heavily-drained agricultural landscapes has been shown to yield beneficial ecological effects, including N removal and biodiversity enhancement [*Hefting et al*., 2013]. Increased wetland cover in such landscapes would add additional habitat and water storage capacity, leading to a range of potential benefits [*Strand and Weisner*, 2013; *Tomer et al*., 2013]. However, little is known about how the location of wetlands (i.e., longitudinal position in the stream network, density of wetlands per stream mile) or their various characteristics (i.e., soil type, storage capacity, plant community type, etc.) influence biodiversity and functioning of aquatic stream communities.

We are evaluating the local and longitudinal effects of wetlands on stream biodiversity and trophic structure, with consideration to the placement and characteristics of restored wetlands. Preliminary data collection in summer 2013 included collection of macroinvertebrate samples from stream sites located up- and downstream from both individual wetlands and wetland complexes (i.e., multiple wetlands located in series). This work will be expanded in 2014. In addition, we are working with data from MPCA's biological monitoring program -- including macroinvertebrate, fish and habitat data for sites throughout the Le Sueur basin – to help identify relationships between land use, characteristics of stream networks, and biodiversity.

Complementary to efforts to understand effects of wetlands on stream-ecosystem structure, we are examining the role of wetlands in local and downstream water quality. Data collected across a gradient of wetland cover and basin size during periods of maximum nitrate flux show that relatively small areas of riparian wetlands can substantially reduce N loads, and increase organic carbon availability to stream ecosystems (Fig. 8). Analyses of seasonal changes in relationships between land cover and water quality will be used to interpret water quality patterns in the MRB (see section 1) as well as develop tools to assess the potential for wetland creation to improve water quality in the basin [*Passy et al*., 2012].

During 2014, the field sampling effort has been directed at identifying critical patterns in denitrification rates in ditches. Because spring nitrate loads are so high and critical to downstream ecosystems, we are especially interested in determining what factors limit denitrification rates in ditches in the spring, when temperatures are low but carbon sources are potentially more abundant. Preliminary data indicates that spring denitrification occurs at non-negligible rates and is likely controlled by both carbon supply and temperature. Denitrification rates appear to be enhanced by DOC from wetlands, so wetland functioning due to changes in DOC sources changes seasonally. The role of wetlands as a source of carbon for denitrification is seasonally variable, and more research will focus on this, as well as the role of wetlands as soluble P sources, over the next year.

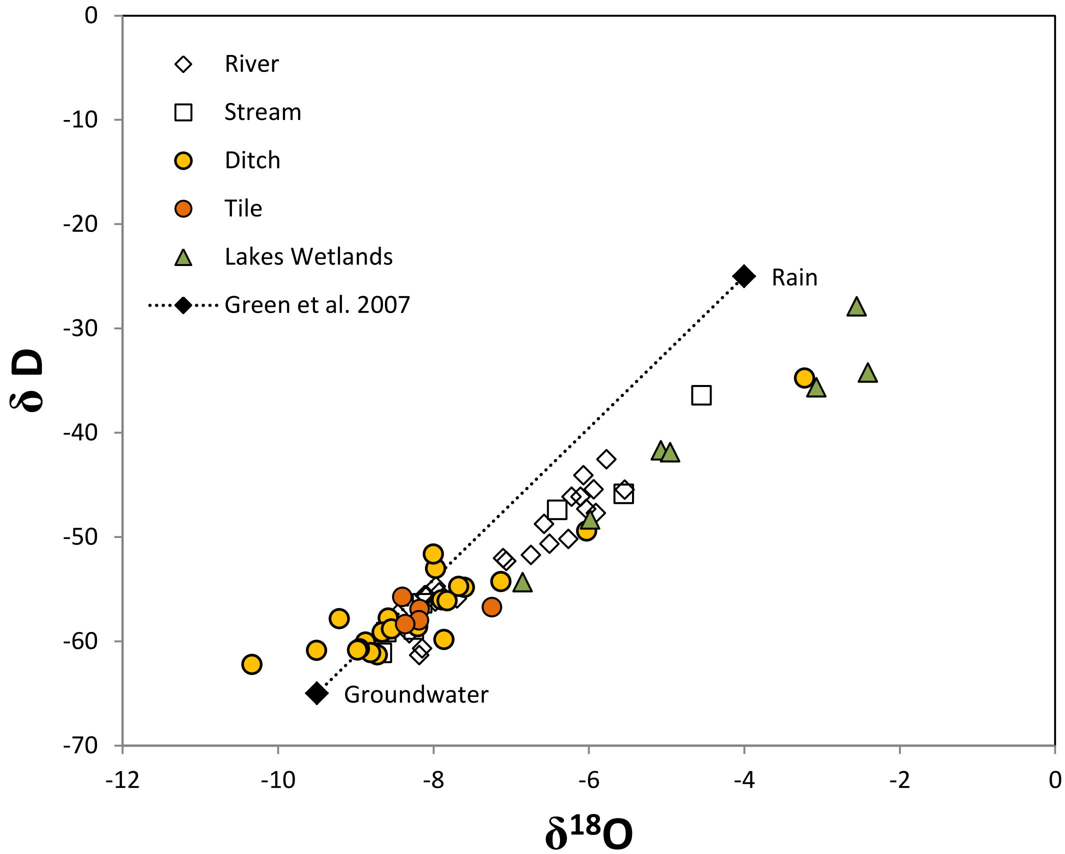

Figure 6. Water stable isotope data from 2013. Groundwater contributions to stream flow decrease during summer and fall as indicated by isotopic enrichment of water as temperatures increase, and ditches dry out. Water isotope data will be used to help constrain the water balance of subwatersheds, and help interpret sources and sinks of nutrients at the watershed scale.

Figure 7. Seasonally changing hydrological conditions in agricultural ditches in the MRB.

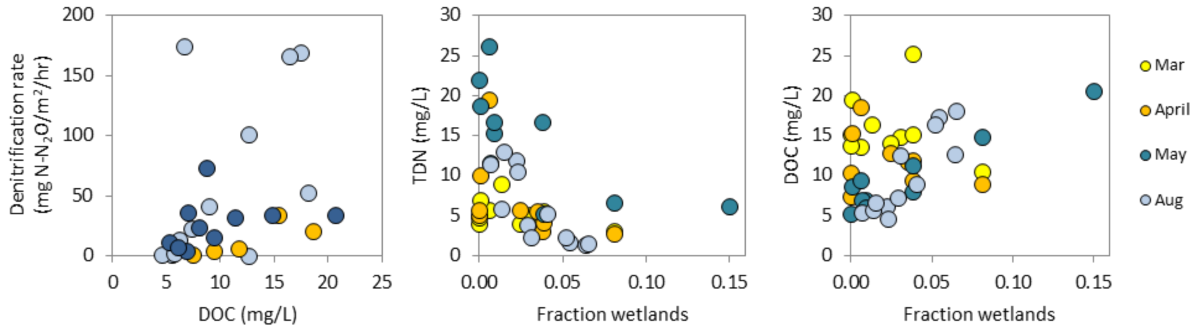

Figure 8. Denitrification rates in ditches are correlated with DOC at many sites, but relationships change seasonally. Upstream wetlands can act as important sources for DOC however, this coupling is not apparent in early spring.

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Overview

Our research group is focusing on how landscape evolution affects modern sediment loading in recently deglaciated basins. Understanding the role of geomorphic history on modern "hot spots" of erosion allows for prediction of hot spot locations and how they may be exacerbated by changing climate or land use. While most of our research has been carried out in the Minnesota River basin, we are also working in incised rivers along the North Shore of Lake Superior, close to the Duluth campus of the University of Minnesota, to allow for more detailed monitoring of erosion and channel change at the event scale. Many of the findings there are relevant to the Minnesota River project.

1. Sediment budgeting and scaling of modern erosion rates across watersheds (Bevis, M.S.)

Understanding how climate change affects erosional hotspots and drives ecological response requires knowledge of modern erosional hot spot locations and rates of change. Previous research in the Le Sueur watershed [*Belmont et al.*, 2011; *Gran et al.*, 2011], found four dominant sediment sources: bluffs, ravines, streambanks, and upland fields (primarily low-gradient to flat agricultural fields). Rates of erosion were determined over annual to decadal timescales for each source using multiple overlapping approaches including historic aerial photo analyses, geochemical fingerprinting, terrestrial laser scanning, and analyses of aerial lidar topographic data. This work not only pinpointed source type and rates of erosion, but also showed that most fine sediment in the Le Sueur watershed was sourced from near-channel sediment sources (bluffs, streambanks, and ravines) in the deeply-incised knick zones in the lowermost valleys. These areas represent the natural erosional hot spots that we hypothesize experience the greatest rates of change under conditions of changing climate and land use. *Belmont et al.* [2011] found a shift in source dominance from near-channel sources to upland sources as land was cleared in the late 1800s and back again to near-channel sources in the mid-late 1900s, driven by large land-use changes in the watershed (i.e. tile installation) and climate change [*Schottler et al.*, 2014]. We are expanding our work into other tributary watersheds with similar geomorphic histories and seek to determine methods for interpolating and extrapolating rates of erosion for different erosional processes.

This past year, we mostly completed the sediment budget on two adjacent channels with similar geomorphic histories, the Blue Earth and Watonwan Rivers (Fig. 1), with significant effort spent on understanding relationships between driving variables and erosion rates in order to best extrapolate erosion rates across the landscape. Because the majority of sediment comes from bluffs, we have spent significant effort on bluff erosion rates and patterns of erosion. Bluff erosion is episodic in both time and space, with periods and locations of erosion and stasis, in part due to meander migration into and away from bluffs. Figure 2 shows meander migration rates on the Blue Earth River, which are both highly variable and higher than on the Le Sueur River. Statistical relationships between long-term (70-year) bluff erosion rates and modern bluff characteristics (vegetation state, relief, aspect, etc.) are poor [*Day et al.*, 2013] in part because of the great variability in conditions over decadal time scales. Instead of running statistical models on individual bluffs, we have adopted a spatially-integrated approach to defining bluff characteristics (Fig. 3). Patterns related to geomorphic structure of the basin are preserved, but the variability on a bluff-to-bluff scale is smoothed.

Most of this project will be completed during summer 2014, as Martin Bevis will be defending his M.S. thesis. Additional work will be done by colleagues at Johns Hopkins to take the results and integrate them into a sediment routing model for use by stakeholders. Results are being integrated into other NCED-REACH research projects as well as shared with stakeholders in the Greater Blue Earth River basin.

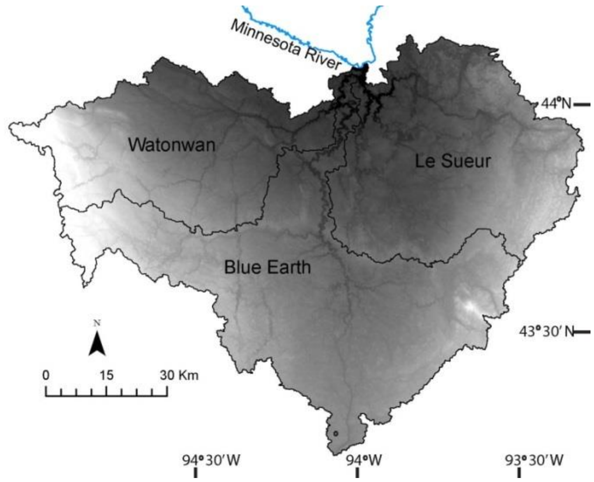

Figure 1. Location of the Blue Earth and Watonwan watersheds, with respect to the Le Sueur watershed and the Minnesota River.

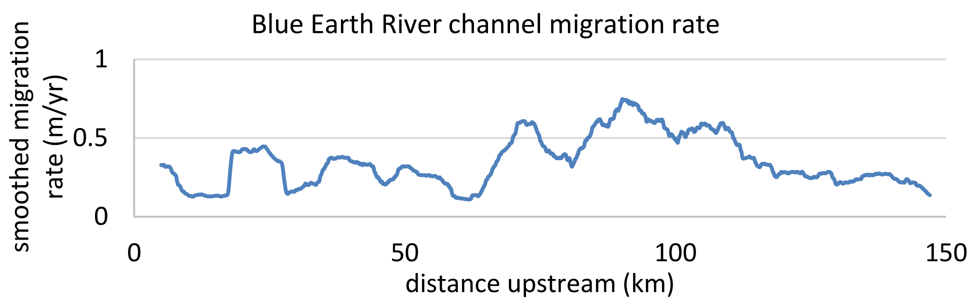

Figure 2. Decadal-scale (70-year) channel migration rates on the mainstem Blue Earth River.

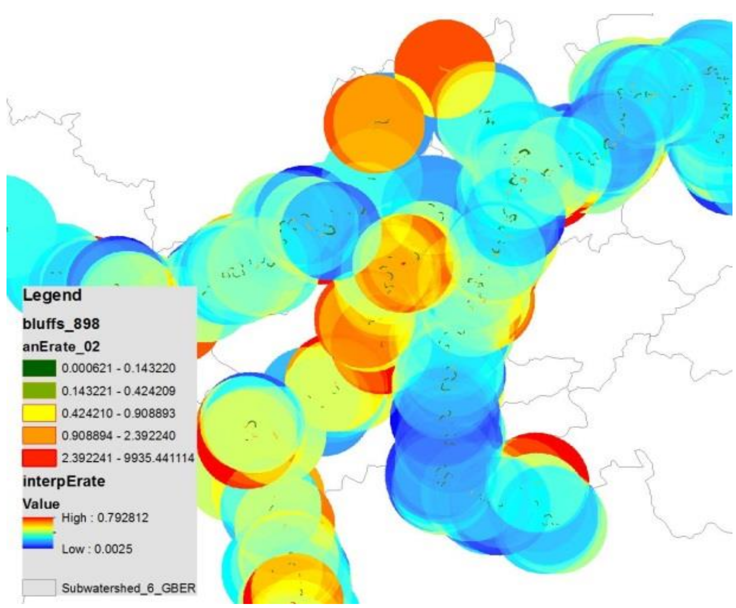

Figure 3. Bluff erosion rates in the GBERB calculated as $\dot{\mathbf{E}} = \Sigma V_E/\Sigma SA$ of bluffs within a 3000m radius: warm colors represent a high rate and cool colors are low rates. Bluffs with measured erosion rates are also shown (green to red scale).

2. High-resolution bluff erosion monitoring (Neitzel, M.S.; Johnson, B.S.)

Bluff erosion contributes over half of the fine sediment load to the Le Sueur River, increasing turbidity and affecting the aquatic ecosystem [*Belmont et al.*, 2011; *Gran et al.*, 2011]. Research into valley evolution on the Le Sueur indicates that bluff erosion rates in the modern system are approximately 3 times higher than bluff erosion rates in the late Holocene, before agriculture dominated the landscape [*Gran et al.*, 2013]. Our hypothesis is that increased flows (as documented by *Schottler et al.* [2014] and *Novotny and Stefan* [2007]) are driving increased bluff erosion rates through additional shear on the toe of bluffs. However, it is unclear what aspect of increased flows is driving increased bluff erosion: increased peaks, increased volume, or increased time spent above a threshold discharge.

Previous research in the Le Sueur watershed utilized terrestrial laser scanning (TLS) to conduct annual to semi-annual scans of individual bluff surfaces. Geomorphic change detection techniques were developed to measure both when, where, and how much erosion was occurring on individual bluff surfaces [*Day et al.*, 2012]. Our TLS study found a positive relationship between volume of sediment eroded and peak flow encountered between scans. This makes sense physically if shear stress on the bluff toe is a primary driver of bluff erosion. However, the time between scans was 6 months to 1 year, making direct analyses challenging, so this project sought to reduce the time between scans to see if we could measure event-scale erosion. Rather than work in the Minnesota River basin, we have been working in a basin closer to the Duluth campus to facilitate ease of access before and after individual storms. Twelve bluffs were monitored, with data collected before and after major storm events. While this work started before the REACH project began, the results are intended to be applicable to stream bluff erosion in general, with an emphasis on building a stronger understanding of the interplay between increasing flows and increasing rates of bluff erosion seen in the Minnesota River watershed [*Gran et al.*, 2013; *Schottler et al.*, 2014].

Monitoring work in Amity Creek and Lester River near Duluth, MN, shows a positive relationship between peak flow and bluff retreat rates in individual storms and over snowmelt (Fig. 4) and between flow volume and bluff erosion rates [*Neitzel*, 2014]. Relationships were complicated by a 500-year event in June 2012. We collected an additional year of data in 2013, analyzed by an undergraduate research student (K. Johnson). Her preliminary results show sediment eroded from bluffs in Amity Creek compose the majority of the fine sediment load even in a normal water year.

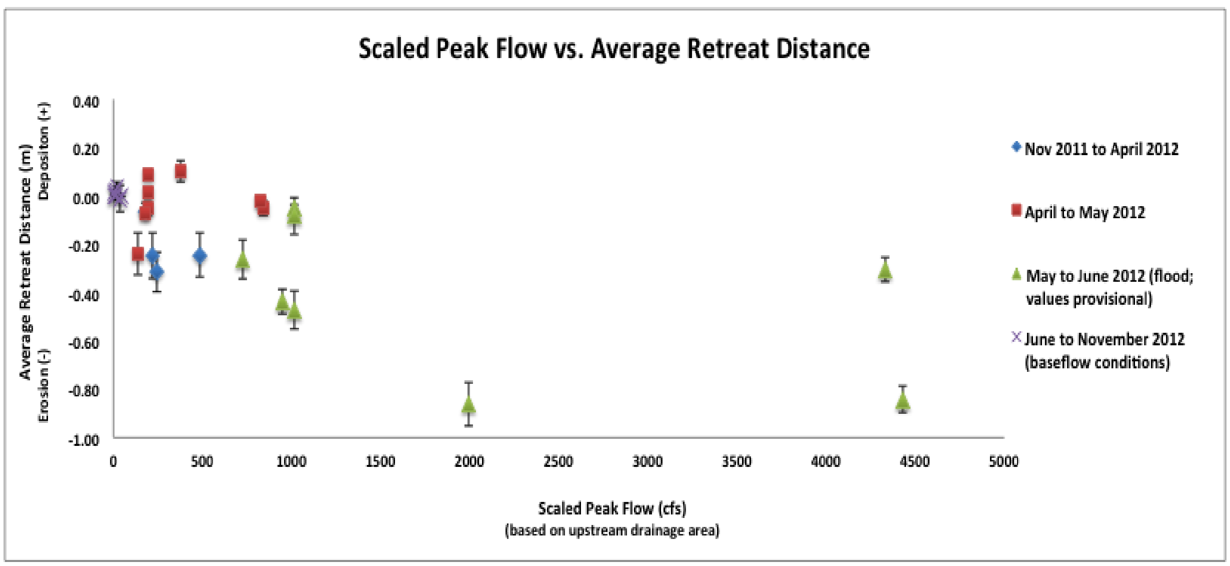

Figure 4. Bluff retreat rates (Volume/Area) for storm events (April-May 2012; May-June 2012), snowmelt (Nov 2011-April 2012), and summer low flow (June-Nov 2012). The peak discharge for the June 2012 event is provisional, since the gage on Amity Creek was destroyed during the June 2012 event.

3. Basin-wide hydrologic changes through time (Mitchell, M.S.; Targos, M.S.)

As hydrologic change is a major driver of geomorphic change (with ensuing effects on aquatic ecosystems), this project seeks to understand both past hydrologic changes (over Holocene time scales) and potential future hydrologic changes, given different management strategies. We are just starting work mapping out paleomeanders stranded on terrace treads throughout the Greater Blue Earth basin. These terraces record fluvial incision history over the past 13,400 years. We were able to develop a model for river incision in the Le Sueur River using dated terraces [*Gran et al.*, 2013], and the next phase is to actually measure geometry of paleochannels to develop a history of paleodischarge. Paleogeometry data are being obtained through a combination of GPR (ground-penetrating radar) and augering, with depositional ages obtained by OSL (optically-stimulated luminescence).

We are also investigating how flows might change with future management decisions and how those hydrologic alterations could affect both geomorphic response in the channels and ultimately, aquatic habitat and ecosystem integrity. Our research group is focusing on the hydrologic implications of specific management actions. To date, we have focused on wetland installation as a management option to lower flood peaks. N. Mitchell is developing a reduced complexity model at the subbasin scale in the Greater Blue Earth River basin (GBERB) relating differing amounts of wetland installation to changes in peak discharge. Work by colleagues at Johns Hopkins (Wilcock and Cho) has found a strong link between peak flows and near-channel erosion in the incised zone, thus linking hydrologic change upstream to geomorphic change downstream. We are developing techniques to better simulate wetlands in the SWAT (Soil-Water Assessment Tool) model and then using the model to run scenarios, building up a series of hydrologic response curves at the sub-basin level. The hydrologic response curves will be used in a reduced complexity model of near-channel erosion in the incised knick zone. Care is being taken to relate hydrologic response curves to geomorphic regime allowing for better transferability of findings. This simulation model will be run with stakeholders in real-time as an iterative approach to developing a consensus management strategy for sediment reduction in the GBERB.

4. Riparian vegetation effects on modern channel geomorphology (Triplett, M.S.; Batts, M.S.)

As flows increase, there are repercussions on channel morphology and riparian vegetation. On the lower Minnesota River, there have been significant changes in flow magnitudes [*Novotny and Stefan*, 2007] leading to channel widening [*Belmont et al.*, 2011; *Schottler et al.*, 2014], and potentially to changes in point bar vegetation communities [*Lenhart et al*., 2013]. An on-going collaborative project with Dr. Lenhart’s group at UMN is investigating relationships between timing and magnitude of peak flows and riparian vegetation establishment; specifically the impact of changes in hydrology on the colonization of riparian vegetation. M.S. student Laura Triplett is investigating how changes in hydrology, such as the timing and duration of base and peak flow events, affect the recruitment, germination, and establishment of vegetation on point bars. Over recent decades, increases in low and median flows have been observed across the study area. These increases have been shown to inhibit the establishment of woody riparian vegetation through decreased point bar exposure time and scouring processes.

In order to investigate this relationship, riparian vegetation surveys documenting occurrence of seedlings and saplings on Minnesota River point bars were completed and compared to current and historical streamflow data. The percent of sandbar submergence during peak seed dispersal windows was determined using available cross-sectional data and historical aerial photography. As shown in Table 1, sandbar submergence is significantly higher in recent years, particularly during later seed dispersal windows. In comparing current and historical hydrographs we also see more extreme flood peaks that occur later in the growing season for recent years (Fig. 5). Flood peaks for current decades also have more extreme recession rates than historically, contributing to rapid loss of soil moisture required for seedling establishment and survival. Within the vegetation survey data we see higher relative frequencies of plants with early seed dispersal windows occurring before peak floods, such as silver maple and American elm. We also see higher occurrence of seedlings as compared to older, established saplings (Fig. 6). High frequencies of sandbar willow were also observed, which is capable of alternation propagation and forms large colonies that can shade out young seedlings. The trends in these vegetation data could be attributed to recent flow increases leading to longer sandbar submergence duration, increased scouring at high flow, and rapid loss of soil moisture.

The next phase in this project is to investigate how reduced seedling recruitment may be affecting deposition rates on point bars. M.S. student Virginia Batts is currently designing a physical experiment to link vegetation cover to suspended sediment deposition. The results of her investigation will help understand some of the implications of reduced seedling recruitment on Lower Minnesota River point bars. Preliminary experiments have been conducted, with the main experiments planned for summer 2014.

Table 1. Woody Riparian Vegetation Peak Seed Dispersal Windows, preliminary data.

Species	Date	2013 Submergence	1955 Submergence
Silver Maple	April 15 - June 15	58%	0%
American Elm	May 15 - June 15	46%	0%
Peach-Leaved Willow	May 15 - July 10	71%	0%
Sandbar Willow	May 15 - August 15	51%	13%
Cottonwood	May 20 - July 15	81%	7%
Black Willow	June 1 - July 10	86%	0%
Green Ash	July 1 - September 10	25%	14%
Box Elder	August 1 - September 20	0%	0%
Total Growing Season Submergence		**52%**	**8%**

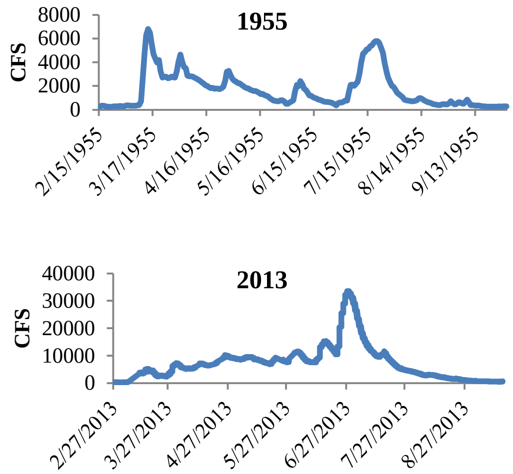

Figure 5. 1955 and 2013 hydrographs obtained from USGS gauge data at Mankato, MN.

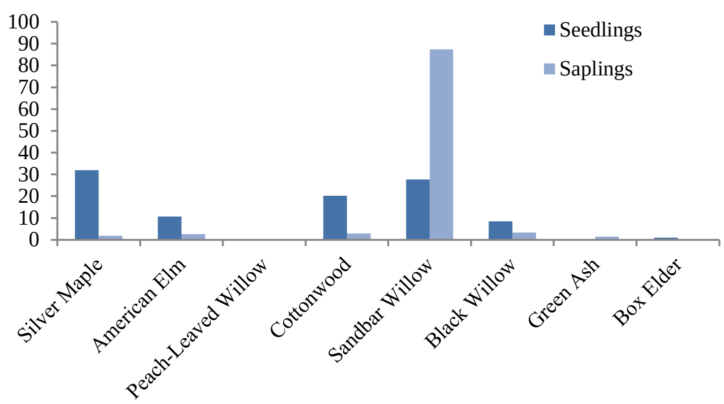

Figure 6. Relative frequency of riparian seedlings and saplings.

Future Research Plans (2014-2015)

1. Sediment budgeting and scaling of modern erosion rates across watersheds

- Finalize sediment budgets for Blue Earth River and Watonwan River, pending sediment fingerprinting data.
- Complete statistical analysis of relationships between channel migration rates, bluff erosion rates, and upland yields with surficial geology, topographic relief, vegetation cover, and geomorphic location.
- Utilize sediment budget information to help constrain a sediment delivery model and use it with stakeholder groups to make decisions about management options for managing both peak flows and excess fine sediment loading within the watershed.

2. High-resolution bluff erosion monitoring

- Continue monitoring study bluffs in Le Sueur River & North Shore streams.
- Compare TLS and aerial LiDAR erosion data on study bluffs in Le Sueur River once aerial lidar analyses are complete.

3. Basin-wide hydrologic changes through time

- Complete reduced complexity model for sub-basin hydrologic response to wetland installation. Analyze sub-basin response by geomorphic regime. Merge reduced complexity hydrologic response model with sediment simulation model to connect land use decision with hydrologic response with geomorphic response.
- Complete field data collection and OSL analyses on relict channels preserved on terraces throughout lower Minnesota River basin to determine paleogeometry and paleodischarge throughout the Holocene.
- Reconstruct history of channel incision on Blue Earth and Watonwan Rivers.

4. Riparian vegetation effects on modern channel geomorphology

- Finish analyses of hydrologic changes during seedling recruitment windows through time on the lower Minnesota River.
- Conduct series of physical experiments to investigate the fine sediment trapping efficiency of emergent vegetation.
- Relate how changing germination and growth patterns may feedback on overbank deposition rates in lower Minnesota River.

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Overview

Year two of: "The River Run: Professional Development with a Splash of Technology", has continued to see progress towards the project's previously identified areas of continued research and development. This progress report will focus on five aspects of the collaboration and research: (1) Continued teacher collaboration, (2) Curriculum development and classroom implementation, (3) Collaboration and collection of digital artifacts via the developed online space, (4) Socio-scientific and technology integration educational research, (5) Research presentations, articles, proposals.

The summer of 2013 and the four consecutive days of teacher professional development (PD) have served as the foundation and jumping off point for the River Run. As teachers were immersed in the scientific and socioscientific issues contained within the Minnesota River Basin (MRB), conversations and efforts began to emerge as the research team and participating teachers began exploring ways of implementing curriculum into their secondary science classrooms. The remainder of this report will describe these efforts.

1. Continued Teacher Collaboration

The following section will outline and summarize the collaborative efforts that have been implemented and executed by the River Run team throughout the year. Table 1 contains an overview and summary of these activities.

Table 1. Professional development experiences for the River Run (2013-14).

Date	Event	Description
Aug. 16, 2013	Pre-School Meeting	Prior to the start of the school year the River Run team met with teachers in Shakopee, MN to assess the group's needs and plan for the upcoming school year.
Oct. 2013 to June 2014	Site Visits	The research team tracked approximately 2200 miles and 30 hours of classroom observations in each of the 4 high school classrooms of participating teachers. Research objectives included some of the following: gaining knowledge of the specific contexts of the teachers' environments, learning about the communities in which their school existed, getting to know the students they worked with, and gaining familiarity with the structure and flexibility of their different courses.
Fall 2013	Google Hangouts – (Sept. 29, & Oct. 27)	These were used in lieu of face-to-face meetings given the large distances between the team and the challenging logistics of scheduling with 6 teachers during the school year. Discussions primarily revolved around the discussion of teacher progress and implementation of lessons involving the MRB and the use of data collection technologies with students.
Spring 2014	Google Hangouts – (Feb. 15 & May 29)	Google Hangouts in the spring were used to discuss and plan two events. The February 15th meeting was primarily used to discuss the logistics of the upcoming spring symposium in April and the May 29th meeting was primarily used to discuss the logistics of the forthcoming 2014 summer professional development experience.
Mar. 15, 2014	Mankato Meeting	Meeting in Mankato after not seeing the entire group in person since August provided the group with a chance to reconnect and discuss upcoming plans for the spring and summer. Teachers were also able to discuss their current successes and challenges revolving around the implemented lesson about the MRB thus far.

Apr. 16, 2014	Student Symposium	Approximately 200 individuals participated in a Spring Symposium on the St. Paul campus of the University of Minnesota. Twelve breakout sessions and keynote speaker highlighted the day as students and teachers for the schools working with the River Run were all in attendance.
Aug. 4-8, 2014	Year 2 Summer PD (forthcoming)	Year 2 of the River Run's PD experience will be based out of the Twin Cities metro with activities planned around and on the Mississippi and Minnesota River. Teachers from St. Paul Public Schools will also be participating in the espoused PD. Faculty from Wilderness Inquiry will also be involved in leading the group on water-based outings.

Pre-School Meeting. On August 16, 2013 the entire group of River Run teachers met at the Environmental Learning Center in Shakopee, Minnesota at Shakopee High School. The meeting's purpose was to assess the needs for the upcoming year, discuss next steps for curriculum development, assess the technology needs of the teachers, and plan events and meetings that would occur throughout the rest of the year. Prior to the meeting, teachers were asked to provide feedback to the team about their thoughts for the upcoming year. The following questions were posed to the group: (1) What do you envision/hope to implement in your class this year? (2) How, if at all in the initial year, do you envision this curriculum unit being connected to your colleagues' and their students? (3) What are the logistics that need to be considered when implementing this unit in your classroom? (4) What work needs to be done before the unit can be implemented? and (5) What help can the River Run team provide you to facilitate this process initially and/or throughout the year? These questions helped guide the agenda for the meeting. One of the espoused goals of the meeting was to create a statement that would encompass the coordinated efforts of the River Run. The slogan that emerged was, "The River Run is an effort to promote awareness in secondary science classrooms about issues related to the Minnesota River and its watershed for the communities in which the classrooms exist."

Site Visits (2013-14). The team logged over 2200 miles and nearly 30 classroom hours of observation between October 2013 and June 2014. Team members worked closely with participating teachers to support their classroom activities and instruction on content related to pedagogy pertinent to the MRB. Each classroom visit entailed an observation of the teachers planned activity and instruction, observation of student's engagement in a learning experience, and a post instruction debrief with the teachers of that day's activity along with placing the entire experience within the context of the greater project. The teacher's profiles can be viewed in Table 2.

The team focused their efforts in the fall becoming familiar with the specific contexts of the teachers environments, the communities in which their school existed, the students they worked with, the structure and flexibility of their different courses and learning environments, and lastly the specific needs teachers might have for us to be able to meaningfully support their teaching about the Minnesota River Basin. This ground level research allowed the team to design specific objectives for our work with each teacher while allowing for the design of specific research projects that would illuminate the teaching and learning of socioscientific issues surrounding the MRB.

Table 2. River Run teacher profiles and demographic information.

Teacher Name	Age Range	High School	Experience (Years)	Subject(s)/Unit
Jake	27-30	Yellow Medicine East	7	biology - environmental science (Minnesota River water quality, ecological interactions)
Julia	24-26	Mankato East	3	biology and ecology - ecosystems, nutrient cycles, biological interactions, environmental issues, run off, water cycle
Harrison	20-23	Montevideo	2	biology - ecology unit
Ed		Shakopee	15	social studies - social issues of the Minnesota River Basin
Billy	31-35	Shakopee	10	biology and ecology - run off, sediment, pollution

Google Hangouts (2013-14). Given the vast geographical range the 4 schools are located in (~300 miles), virtual meetings were planned and orchestrated throughout the year. Google Hangouts (Fig. 1) were used on 4 occasions throughout the year, when teachers would be implementing and thinking about lesson plans involving the MRB. Two occurred in the fall of 2013 (09/29/2013, 10/27/2013), and two in the spring of 2014 (02/15/2014, 05/29/2014). Agenda items for these online meetings consisted of discussing teacher progress and implementation of lessons involving the MRB, the use of data collection technologies, and logistical planning for upcoming events and classroom visits.

Figure 1. Screenshot of a Google Hangout meeting with teachers and members of the River Run.

March Mankato Meet-up. On March 15, 2014, the entire River Run team and collaborating teachers met in Mankato, Minnesota to discuss the upcoming spring symposium and check-in with teachers regarding their current classroom progress. Curriculum design efforts were also re-introduced to the group with the consensus of the group being that in the upcoming summer, curriculum development of a single cohesive unit that could be shared amongst the group and teachers located in river basins throughout the country would be of primary interest.

River Run Spring Symposium. The group has from its conception expressed an interest in bringing their students together on the campus at the University of Minnesota for an event where they could meet students and teachers from collaborating school districts and learn more about environmental science topics (and science topics in general) that may be related to the work they are carrying out in their respective science courses. On April 16, 2014 the River Run team planned and executed a "Spring Symposium" on the St. Paul campus of the University of Minnesota. The event hosted approximately 200 participants. Teachers, students, scientists, activists, and the River Run team participated in an all-day event that included 12 breakout sessions, lunch, and keynote speaker. The schedule of the day's events can be found at (http://riverschedule.weebly.com/). The keynote speaker, Natalie Warren, gave a riveting talk/presentation describing her canoe journey from Minneapolis, Minnesota to the Hudson Bay via the Minnesota and Red Rivers.

August 4-8, 2014 Summer Professional Development. The forthcoming summer is slated for 4-5 days of teacher PD. The PD will be based out of the Twin Cities metro area and will be in conjunction with faculty from the Wilderness Academy (http://www.wildernessinquiry.org/) and St. Paul Public Schools. Wilderness Inquiry is a national organization that reached out to River Run leadership via St. Paul Public Schools with the vested interest of working with teachers interested in giving students access to a placed-based learning experience revolving around river systems. St. Paul Public schools also expressed an interest in combing PD efforts with the River Run and has put forth ~9 teachers thus far who are planning on working with the existing group of River Run teachers in the summer of 2014.

2. Curriculum Development and Classroom Implementation

Classroom observations of teachers in the fall of 2013 quickly revealed that individual teaching styles, varying teaching contexts, and various pedagogical affordances and constraints were going to impact the nature in which individual students in their respective schools were going to experience lesson plans designed and conceptualized from the summer PD experience. This was an anticipated phenomenon. *Clements* [2007] identifies that research on enacted curriculums aligns with one of the phases of the *Curriculum Research Framework* (CRF). Data collected to confirm the varying teacher enactments aligns with the CRF. *Clements* [2007] states that during classroom observations, "the focus is on how the materials are used, how the teacher guides students through the activities, what characteristics emerge in various instantiations of the curriculum…how these processes are connected to both intended and unintended student outcomes" (p. 49). Teachers were considering how their students should experience and learn about the MRB in this inaugural year. The forthcoming summer and academic year will include conversations and curriculum writing that takes into account these experiences and lesson plans as the group joins efforts to design a single cohesive unit that highlights the issues surrounding the MRB.

An example of three student projects from one of the participating high schools will highlight some of what was accomplished in participating classrooms in the 2012-13 academic year. During an open-ended, project-based environmental student project, the following three projects emerge:

1. Storm Water Management: The Establishment of a Rain Garden at a Participating School.
2. Loon Habitats: The Creation of Artificial Loon Habits via Floating Islands.
3. RipRap: The Creation of Stone Barriers to Slow the Erosion of Sediment in the MRB.

Each of these projects will be passed on to the next class of students from the current environmental science class.

Prior to the start of the 2014 PD, efforts will be made to coordinate and align participating teachers' work thus far to further enhance the time together in August. A project-based learning model ("Project-Based Learning: Relevant Learning for the 21st Century") created by the *Pacific Education Institute* will provide a starting point to guide the curriculum development efforts. A curriculum reference model created by *Lee and Kolonder* [2011] will also be instituted to guide the curriculum development of the team's joint efforts. Figure 2 outlines the major components that will be further developed in the curricular unit.

The final curriculum-related area of interest lies in the creation of a drain tile model that accurately depicts the science and engineering detailing the technology. The need to create a working model of a drain tile system came to realization after the summer PD experience and subsequent classroom observations. There were identified misunderstandings involving drain tile systems and given its prevalence in the MRB, a working model was deemed suitable. This effort is being coordinated with faculty at the St. Anthony Falls Laboratory at the University of Minnesota.

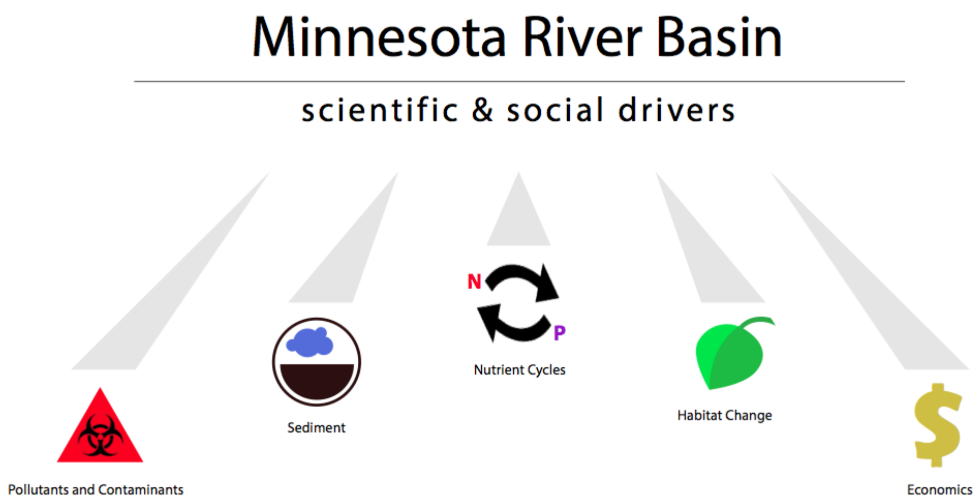

Figure 2. Curriculum model major drivers for the Minnesota River Basin

3. Collaboration and Collection of Digital Artifacts: Online Space

The River Run team has created, supported, and maintained a publicly viewable Word Press website since September 2013. The website can be found at (http://stem-projects.umn.edu/riverrun/). The website contains information that outlines the project's purpose, researcher bios, and location of participating schools and teachers. The primary use of the website thus far has been the accumulation of curriculum, resources, and data collection protocol for participating teachers. The site serves as a central hub for the dissemination of digital media to teachers and students (as well as the public) involved in the River Run. This site also contains updated information and articles pertinent to the project.

Future developments will focus on creating a digital space for student-created digital media (videos, projects, etc.) along with providing a virtual space for teachers to communicate. The goal is to give students a platform to showcase projects they've worked on in science classrooms located within the MRB while also getting participating teachers to use the website as a more central aspect of their teaching when teaching units involving the MRB. These efforts will be a major focus of interest for the research team and participating teachers/students in the upcoming year.

4. Socioscientific and Technology Integration Educational Research

Socioscientific issues are ill-structured problems having "conceptual and/or procedural links to science" and "a social significance as identified by society" [*Fleming*, 1986; *Kolstø*, 2001; *Patronis, Potari, & Spiliotopoulou*, 1999; *Sadler*, 2004; *Sadler*, 2009; *Sadler & Zeidler*, 2003; *Zeidler, Walker, Ackett, & Simmons*, 2002]. The context of socioscientific issues which serves as a joining thread through the research fits well with the intentions of the educational outreach component of the River Run and the WSC project. Based on the classroom observations and the interviews with participant teachers and their students, the research projects focused on (1) teachers' ways of designing technology-rich learning experiences to teach content related to the socioscientific issues around MRB and (2) students' understanding and reasoning about the socioscientific issues around Minnesota River basin[1].

The group of River Run teachers is continually working to meet their students' needs. They are also interested in providing their students with a technology-rich learning experience. Understanding how teachers actively engage learners with content relevant to their immediate communities is important to making science real and personal for learners. We developed and engaged teachers in an interview protocol based on *Mishra and Koehler's* [2005; 2006] framework of technological pedagogical content knowledge. Our goal is to gain a deeper understanding from each of the participating teachers. Within the context of their communities, our questions focused on their past experiences teaching about the issues, what content they have taught this year in their courses, what strategies they use to teach about the MRB issues, what kinds of instructional strategies they have used to make MRB content accessible to students, how they have integrated students interests into lessons plans, and what kinds of things they would like to do going forward. Working with and observing these teachers will inform instruction and curriculum development in environmental science, teaching and learning about environmental issues in real world and social contexts, and about the implication of human actions on the environment. In addition, student data is collected in order to have some understanding as to what students know and learn about a significant socioscientific issue situated in their community, how they collect data about the issue(s), analyze and interpret that data, draw connections between classroom instruction, local knowledge, and information provided by expert sources and ultimately how students make meaning of the issue.

5. Research Presentations, Articles, Proposals

The educational outreach team has, thus far, presented or had the following papers accepted pending presentation at international and regional conferences:

Karahan, E., Andzenge, S.T., Bhattacharya, D., Roehrig, G. (November 2014). A Technology Rich Professional Development Program and Its Influence on Participant Teachers' Practices. *Paper accepted for presentation at the annual meeting of the Association for Educational Communications and Technology (AECT), Jacksonville, FL.*

Andzenge, S.T., Karahan, E., Bhattacharya, D., Roehrig, G. (November 2014). Technology Integration and Water Sustainability in STEM Education: a Professional Development Experience. *Paper accepted for presentation at the annual meeting of the Association for Educational Communications and Technology (AECT), Jacksonville, FL.*

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[1] A large amount of the data collected thus far is very specific to a thesis project currently in progress.

McFadden, J., Roehrig, G. (April 2014). A place-based approach for technically integrated science instruction: The river run experience. National Science Teachers Association (NSTA) Conference, Boston, MA.

McFadden, J. (March 2014). Designing science teacher professional development from small to large: Educational design research and the river run experience. Graduate Student Research Day (Curriculum and Instruction), Minneapolis, MN.

Karahan, E., Bhattacharya, D., Andzenge, S.T., McFadden, Roehrig, G. (January 2014). Secondary science teachers' understanding of socioscientific issues and its effects on their curriculum implementation plans. *Paper presented at the annual meeting of the International Conference of Association of Science Teacher Education (ASTE), San Antonio, TX.*

Future Research

In 2014-15, research and resources will be focused around the following areas:

1. Teacher Continued Collaboration

- Co-designed curricular unit bringing together the many facets that influence the MRB.
- Continue working with and providing support (educational, scientific, technological, etc.) for the implementation of the forthcoming SSI-focused curriculum with the current group of teachers.
- Continued collaboration with incoming teachers from St. Paul Public Schools.

2. Curriculum Development and Classroom Implementation

- Continue phase two and three of *Clements* [2007] Curriculum Research Framework:
  - Revise curricular modules in accordance with models of children's thinking and learning within the specific content domain.
  - Conduct formative and summative evaluations in classroom settings.
- Curricular revisions of the espoused curriculum throughout the year as classroom implementations occur.

3. Collaboration and Collection of Digital Artifacts via the Developed Online Space

- Continue familiarizing participating teachers with the online space while creating a social aspect of the site for communication and collaboration.
- Continue the development of a Community of Practice (CoP) [*Barab et al.*, 2003] with the participating teachers by providing updated, relevant content that the teachers can utilize in their own classrooms.
- Collect and display, student-created digital media related to the socioscientific issues explored within the MRB for the public.

4. Socioscientific and Technology Integration Educational Research

- Continue data collection from teacher classrooms (classroom observations, teacher interviews, classroom artifacts, student interviews).
- Continue the collection of data related to the integration of technology by teachers in selected classrooms to reveal teachers technological pedagogical content knowledge (TPACK) [*Mishra and Koehler*, 2006].

Selected References

Barab, S. A., MaKinster, J. G., & Scheckler, R. (2003). Designing system dualities: Characterizing a web-supported professional development community. Information Society, 19(3), 237.

Clements, D. H. (2007). Curriculum research: Toward a framework for 'research-based curricula'. Journal for Research in Mathematics Education, 38, 35-70.

Kirschner, P., Strijbos, J., Kreijn, K., & Jelle Beers, P. (2004). Designing electronic collaborative learning environments. Educational Technology Research and Development, 52(3), 44-66.

Lee, C.-S., & Kolodner, J. L. (2011). Scaffolding Students' Development of Creative Design Skills: A Curriculum Reference Model. *Educational Technology & Society*, *14* (1), 3–15.