2010 Annual Report – Oct. 2009 to Sep. 2010

NSF Award 0724971
Christina River Basin Critical Zone Observatory (CRB-CZO)

Spatial and temporal integration of carbon and mineral fluxes: a whole watershed approach to quantifying anthropogenic modification of critical zone carbon sequestration.

1. Research and Education Activities

1.1. Project Management and Coordination

In the first seventeen months of the project, our research team thoroughly re-evaluated and reaffirmed project hypotheses, objectives and tasks. Integration of all research activities in this project toward our overall goal – to integrate the net carbon balance (sink or source) due to mineral production, weathering, erosion and deposition over landscapes of contrasting land use – has been a high priority to project PIs. Coordination of the project during the initial period was through monthly PI and all-scientist meetings, and included the selection of team leaders for our 4 primary research objectives.

Our research team grew substantially at the end of our first year, with the arrival of three Post-Docs (all starting in early Fall 2010) and six graduate students (3 continuing from other projects and 3 starting fresh in Fall 2011). This required a continuation and intensification of coordination activities, including a weekly 2-hour meeting primarily focused on developing post-doctoral and graduate student projects and recently culminating in a 1-day project retreat (Feb. 18, 2011).

Scientists from outside of the University of Delaware and the Stroud Water Research Center have joined these discussions via conference calls. Weekly meetings have occurred with PI's and postdoctoral researchers as well as meetings with the entire team. In February, we held a retreat where work plans were discussed and presentations were made by postdoctoral researchers and graduate students. This thoughtful coordination has been required because water, carbon and minerals are transported and transformed across geophysical boundaries that also traditionally separate scientific disciplines. We believe that these coordination efforts are already providing strong intellectual payoffs.

1.2. New Hires

In year 1, the Christina River Basin CZO advertised for new positions, interviewed candidates, and hired new personnel for the project, including three post-doctoral scientists, an installations engineer, and a watershed manager. In year 2, we are in the process of hiring a fourth post-doctoral scientist

Our new post-doctoral scientists are Dr. Diana Karwan, Olesya Lazareva, and Carl Rosier. Dr. Karwan received her degree from Yale University in forest hydrology and sediment transport, Dr. Lazareva received her degree from University of South Florida in environmental geochemistry, and Dr. Rosier received his degree from University of Montana in soil microbiology. Our fourth post-doctoral position will be filled by one of the many excellent candidates we are interviewing this month, all with expertise in groundwater-surface water interactions.

In year 1, we also successfully recruited six outstanding graduate students to conduct research on the project. Three – Chunmei Chen, .Chris McLaughlin and Yi Mei – were top students recruited from other projects, and three – Weinan Pan, Adam Pearson and Jing Yan – are new students, all arriving with Master's degrees and strong previous research experience.

Our CZO has placed a strong emphasis on the development and deployment of sensor technology and wireless transmission of data from remote sensor platforms. To assist with this process we have hired Steve Hicks, an electrical engineer with a background in hillslope hydrology. Steve is being joined by David Montgomery, a long-term Stroud Water Research Center employee who has been hired to fill a newly created position of watershed manager. The primary responsibilities for Montgomery are to facilitate watershed access and manage watershed installations. Both Hicks and Montgomery will closely interface with our data management team to assure the continuous flow of data from sensor platforms.

1.3. Site Selection

To understand the impact of natural versus human-accelerated mineral cycling on the carbon flux between lands and the atmosphere, we have chosen to instrument three headwater streams that differ in their land uses: forested; agriculture; and construction. We used aerial photographs and ground-truthing to identify the appropriate sites. These include: (1) a completely forested watershed that is protected in perpetuity within the Laurels Preserve, managed by the Brandywine Conservancy; (2) an agricultural watershed that is held under an agricultural conservation easement and dominated by row crops of soybeans and corn; and (3) a watershed impacted by the Southeastern Chester County Refuse Authority landfill. The landfill, which is active and has capacity for at least the next decade, moves soil almost on a continuous basis, so it represents an appropriate surrogate for a major construction site. We have been in active contact with landowners for each of these sites, and all are very open to working with our CZO project into the future. We are currently finalizing our proposed infrastructure plans for each site, which includes a stream discharge flume and a suite of sensors (see 1.4 below).

In addition to these three contrasting headwater streams, we will place sensors hubs and other research infrastructure at three downstream locations in order to integrate the larger watershed-scale and coastal processes within our Objectives 3 and 4. These include: (1) the 3rd -order White Clay Creek Experimental Watershed gauging station at the Stroud Water Research Center; (2) the mouth of the White Clay Creek near Newark DE at USGS gauging station 01479000; and (3) the mouth of Brandywine Creek in Wilminton DE at USGS gauging station 01481500.

1.4. Development of an Advanced Sensor Network.

The search for hydrological and geochemical "hot spots" and "hot moments" that control landscape and ecosystem level processes requires a rethinking of how we measure critical zone properties. Despite increasingly automated and rapid laboratory-based analytical methods, these improvements can not hope to meet the increase in frequency of spatial and temporal measurement required to realize the two, three or four dimensional maps necessary to identify important physical locations and the timing of these processes. The Critical Zone Observatory program was in part founded on the need for data with high spatial and temporal frequency, and we envision an advanced, real-time, environmental sensor network as a central component of our CRB-CZO project. To that end, we have hired an electrical engineer with extensive experience designing, deploying and maintaining hydrological sensors and using wireless data communication strategies. We have begun the testing and deployment of several novel technologies that will both meet our immediate needs very well and also serve as a strong foundation for rapid and limitless future expansion. Where possible, we will leverage the revolution in micro-manufacturing and open-source hardware projects to maximize the number and diversity of deployed sensors.

The core of our sensor network will be built around six field computers, which will serve as sensor hubs at each of our six primary stream gauging sites (see 1.3 above). Each field computer will be networked to the internet via continuous bidirectional 3G broadband "mobile" wireless and will control a number of advanced commercial geochemical sensors (below) in addition to a basic suite of hydrological and climate sensors. In addition, each field computer will be able to control any chosen assortment of relay switches that will enable logical triggers for sample collection and nearly limitless possibilities for home-engineered instrumentation. Last, each field computer will serve as a data and web-services hub for a broader ranging wireless sensor network that will extend as much as several kilometers throughout the gauged watershed.

Given the importance of quantifying mineral and carbon mass fluxes to our CZO's objectives, we will invest in a number of advanced hydrological and geochemical sensors at each stream gauging station. The centerpiece of each of our stream sensor clusters is a submersible UV-Vis diode array spectrophotometer (a spectro::lyser by s::can, http://www.s-can.at). For the last 14 months we have been putting a spectro::lyser to the test at the 3rd order White Clay Creek site adjacent to the Stroud Water Research Center. Every 3 minutes it has been collecting absorbance values at 256 wavelengths at ~2 nm resolution from 220 to 720 nm. This wide range allows for the calculation of turbidity-compensated spectra of dissolved species, and highly accurate multivariate parameterization of dissolved organic carbon, biochemical oxygen demand, nitrate, total suspended solids and other parameters (Langergraber et al. 2003; Aufdenkampe & Kaplan, unpublished data). In addition, the raw and turbidity-compensated full-spectrum data from the Spectrolyzer can be exported for external parameterizations, such as calculation of spectral slopes, which are correlated to molecular weight (Helms et al. 2008). All of these parameters will contribute substantially to our understanding of dynamics of carbon transport and processing in our observatory. Other water chemistry sensors – for temperature, conductivity, dissolved oxygen, dissolved carbon dioxide and pH – have been or will soon be deployed at our test site. We plan to deploy this stream sensor station at our 5 other sites within the next 6 months.

Understanding critical zone processes within the gauged watersheds requires a large array of other sensors on hillslopes, in soils, in the groundwater and in the canopy. We will wirelessly network these sensors for near-real-time data collection using the open source electronics "Arduino" platform that now has over half a million users worldwide (http://www.arduino.cc/) in combination with SNAP wireless modules widely used in industry (http://www.synapse-wireless.com/). The advantages of this combination are numerous. First is cost. For $50-$100, we can replicate and even exceed the capabilities of a $3000-$4000 wireless data-logger from Campbell Scientific. Thus, we can invest our money in sensor hardware, rather than data collection hardware. Second is ease of use. The Arduino electronics prototyping platform was initially designed "for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments." As such, the Arduino family of electronics hardware is exceptionally easy to snap together and program, yet it is also capable of nearly any task we might imagine. Thus, the sensor network system that we are developing on this platform will be easy to disseminate to graduate students and other researchers. We are successfully testing a large system within the 3rd order White Clay Creek research watershed. Using this system, each of the watersheds feeding our three headwater study streams will be instrumented with hillslope sensor nodes that will all include at a minimum: water table elevation, soil moisture, soil temperature, soil matrix potential, soil and groundwater redox potential, soil oxygen and carbon dioxide concentration profiles, soil pH, air temperature, air moisture and precipitation.

1.5. Cyber-infrastructure for Data Management
In the last year, we have made large strides migrating our data management approaches toward a modern relational database management system that is a hybrid of those developed by CUAHSI's Hydrological Information System team (http://his.cuahsi.org/) and by the EarthChem project (http://www.earthchem.org/).

The Stroud Water Research Center is an institution with a long history of managing continuous hydrological data and more complex geochemical data based on laboratory analyses of sample fractions and subsamples. Because of this, our group has played an integral role in helping form a national CZO data system that merges the best of both the CUAHSI and EarthChem data models, and we have played a leadership role in all cross-site data management efforts over the last year including a 2-day meeting in Boulder in May 2010, a 2-day meeting in Logan Utah in Feb. 2011 and numerous (at least 2 per month) conference calls since September 2009.

At present, we are actively working with Ilya Zaslavski's team at the San Diego Supercomputing Center to load historical data onto a local CUAHSI "Hydro-Server" and to develop web services to automatically load this data to the central CZO data repository.

We are also collaborating with Emilio Mayorga at the University of Washington's Applied Physics Laboratory to implement a map-based data browser, similar to one that Emilio and collegues have developed for the Northwest (http://www.nanoos.org/nvs/nvs.php?section=NVS-Assets). A prototype should be available by late March at our website (http://www.udel.edu/czo/data.html).

1.6. Ground Truthing of Airborne Lidar Imagery
In conjunction with all sites within the CZO network, we conducted a field campaign last summer to ground truth the airborne LiDAR imagery. We followed the sampling protocol established for all CZO sites for the full-leafed canopy. Prior to the field work, aerial photographs and historic knowledge of landscapes within the Christina River Basin were used to identify potential forested plots for the ground truth work. Two University of Delaware graduate students hired for this project conducted the fieldwork under the supervision of the PIs. The vegetation survey yielded the acquisition of the necessary data, including tree dbh, LAI, and canopy closure. All the field data have been sent to UC, Merced for development of algorithms per the standard protocol. The data collected from our field campaign was presented at the National CZO meeting in Boulder, Colorado in September 2010.

1.7. Adoption of the Penn State Integrated Hydrologic Model (PIHM) and other models.
We have been actively collaborating with Chris Duffy and his research group at the Penn State Shale Hills CZO over the past year to learn PIHM and get it to run for our watersheds. This collaboration has included three visits by Chris Duffy and his graduate students between January and July of 2010, and attendance at a PIHM workshop at Penn State by five CRB-CZO project members. We now have PIHM running for our 3rd - order research watershed for which we have extensive data, and with five of us conversant in PIHM, we are now designing our sensor network in such a way as to optimally calibrate and validate 3-D watershed models such as PIHM.

This work with PIHM builds upon efforts by Newbold, Hornberger, Mei and others to calibrate TOPMODEL for White Clay Creek, and also to calibrate a 2-D hillslope model, based on groundwater depth and soil moisture data collected during the summer of 2010.

Luc Claessens joined the faculty at UD in Sept. 2010 and has made concerted efforts to integrate his research with our CZO. One of these efforts includes implementing the RHESSys eco-hydrology model for our CZO.

1.8. Sample Collection
In 2010 we kicked off what will eventually be a substantial soil and sediment sample collection effort. Graduate students Chunmei Chen and Chris McLaughlin collected a large number of soil and groundwater samples from our “Transect A” hillslope for their respective PhD projects (see findings). Our biggest sampling efforts, however, will be in sediment source and depositional zones throughout the basin. To train grad students and post-docs in our sampling approaches, in early Nov. 2011 Rolf Aalto, Kyungsoo Yoo and Anthony Aufdenkampe conducted an intensive “field camp” for nearly 2 weeks, coring floodplains and hillslopes and digging soil pits. In 2011-2012, students and post-docs will use this training to collect a wide variety of samples in erosion and depositional zones throughout the CZO watersheds using similar techniques. This will eventually allow for integrated “fingerprinting” and determination of sediment sources.

In Fall 2011 we also began the collection of a large volume (>200 L) suspended sediments samples, in order to quantify meteoric radio-isotope signatures for “Fingerprinting”.

1.9. Laboratory Experiments
We have begun a series of organo-mineral complexation and incubation experiments, to provide a “smoking gun” test of whether organic carbon stability is determined by the degree of mineral complexation.

2. Planned Activities and Future Vision

In each section above, we have described both completed and planned activities.

Our future vision for our CZO is to create:

- A spatially and temporally rich sensor dataset from which our team and others can calculate water, mineral and carbon fluxes and balances for our research watersheds, and explore processes
- An easy to use data system for exploring, obtaining and integrating our many sensor and sample based datasets into models or other data analyses

- A highly integrated team of researchers, who tackle questions and research problems that none would attempt alone, by maximizing synergisms and group capabilities
- A body of evidence to test each of the hypotheses poised in our proposal
- A watershed, sensor and data infrastructure to support new projects to answer new questions within our CZO watersheds