Annual Report for Period: 10/2009 - 09/2010 **Submitted on:** 09/03/2010

Principal Investigator: Sparks, Donald L. **Award ID:** 0724971

Organization: University of Delaware

Submitted By:

Sparks, Donald - Principal Investigator

Title:

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

Project Participants

Senior Personnel

Name: Sparks, Donald

Worked for more than 160 Hours: Yes

Contribution to Project:

Pi - managing overall project with emphasis on ensuring science in being conducted and objectives are being met in each of the hypotheses presented in project.

Name: Pizzuto, James

Worked for more than 160 Hours: Yes

Contribution to Project:

Pizzuto has participated in overall project coordination and planning, including the hiring of research technicians and post doctoral scientists. His major areas of involvement have been in managing research under Objective 3 - Fluvial Network Controls on Complex Formation & Preservation. He has also been our CZO's primary contact with NCALM regarding LIDAR data collection and analyses.

Name: Kaplan, Louis

Worked for more than 160 Hours: Yes

Contribution to Project:

Kaplan has participated in overall project coordination and planning, including the hiring of research technicians and post doctoral scientists. His major areas of involvement have been on the development of continuous of organic carbon sensors, site selection, and development of work plans for research questions concerning the stability of organo-mineral complexes and organic carbon bioavailability.

Name: Aufdenkampe, Anthony

Worked for more than 160 Hours: Yes

Contribution to Project:

Aufdenkampe has helped lead overall project coordination and planning, including the hiring of research technicians and post doctoral scientists. His major areas of involvement have been on overall project design and integration of all research activities and objectives, data management at both local and national levels, sensor network development, site selection, and development of work plans for research questions concerning all components of the research tasks. Aufdenkampe also manages research under Objective 1 - Properties of Carbon-Mineral Complexes. Additionally, Aufdenkampe participates in the montly
teleconferences for all PIs and has been involved in the data management group for the CZOs.

Name: Yoo, Kyungsoo

Worked for more than 160 Hours: Yes

Contribution to Project:

Co-Pi managing research under Objective 2 - Weathering and Erosion Controls on Carbon-Mineral Complex Formation by exploring the mechanisms by which weathering and erosion

determine spatial distributions and fluxes of complexation potential, with the goal of providing a means to extrapolate these processes over a landscape of differing topography and land use.

Name: Newbold, J. Denis

Worked for more than 160 Hours: Yes

Contribution to Project:

Newbold manages, along with Aufdenkampe and Hornberger, research and modeling efforts under Objective 4 - Watershed Integration of Erosion-Driven Carbon Sequestration.

Name: Gill, Susan

Worked for more than 160 Hours: Yes

Contribution to Project:

Gill is the Director of Education at the Stroud Water Research Center. She was the lead PI on a proposal for a 'distributed' REU-RET program to integrate all CZO sites that will be resubmitted in autumn 2010.

Name: Dow, Charles

Worked for more than 160 Hours: Yes

Contribution to Project:

Charles Dow will provide support for all data management activities related to the Christina River Basin CZO (CRB/CZO). He has participated in the CZO data management workshop and will be responsible for implementing the data management procedures within the CRB/CZO.
Dow also participated in a national CZO data management meeting in Boulder Co, May 19-20, 2010. The meeting, attended by principle investigators and data managers from most of the CZOs, was a continuation of the effort towards an integrated data management system across all CZOs. This effort builds upon the creation and implementation of the Consortium of Universities for Advancement of Hyrdologic Science (CUASHI) Hydrologic Information System (HIS).

Name: Hornberger, George

Worked for more than 160 Hours: Yes

Contribution to Project:

Hornberger is advising Ph.D. student Mei as they develop several approaches for modeling the flux of Dissolved Organic Matter from hillslopes to streams and testing them against measurements made at the CRB/CZO. Work for the past six months has included development of a two-dimensional hillslope model and associated data collection on a hillslope at White Clay Creek. Hornberger willcontinue to focus on testing models of DOM fate and transport and on extending the PIHM framework to include carbon transport modeling at the whole-catchment scale.

Name: Michael, Holly

Worked for more than 160 Hours: Yes

Contribution to Project:

Working on Objective 2 - Weathering and Erosion Controls on Carbon-Mineral Complex Formation and advising post-doc.

Name: Levia, Delphis

Worked for more than 160 Hours: Yes

Contribution to Project:

Working on objective two and managing LIDAR and advising undergradaute students.

Name: Inamdar, Shreeram

Worked for more than 160 Hours: Yes

Contribution to Project:

Advising graduate students and working on objective 2 - Weathering and Erosion Controls on Carbon-Mineral Complex Formation

Post-doc

Name: Rosier, Carl

Worked for more than 160 Hours: Yes

Contribution to Project:

Carl Rosier received his PhD from the University of Montana in soil microbiology. He was recently hired to carry out research under Objectives 1 and 3, and will study organo-mineral aggregates within both erosional 'source' locations and depositional locations in floodplains and wetlands.

Name: Lazareva, Olesya

Worked for more than 160 Hours: No

Contribution to Project:

Recently hired to carry out research under Objective 2 - Weathering and Erosion Controls on Carbon-Mineral Complex Formation.

Name: Tsang, Yinphan

Worked for more than 160 Hours: Yes

Contribution to Project:

Tsang worked on extending and incorporating previous watershed hydrological modeling research (funded by NSF award EAR-0450331) within our CZO watersheds to new efforts to use the Penn State Integrated Hydrological Model (PIHM) within these same watersheds. She helped mentor graduate student Yi Mei in his early modeling efforts for several months, before accepting another job elsewhere

Name: Karwan, Diana

Worked for more than 160 Hours: No

Contribution to Project:

Dr. Karwan received her degree from Yale University in forest hydrology and sediment transport. She was recently hired to carry out research on Objective 3 - Fluvial Network Controls on Complex Formation & Preservation.

Graduate Student

Name: McLaughlin, Christine

Worked for more than 160 Hours: Yes

Contribution to Project:

Christine McLaughlin, a PhD. Candidate at the University Pennsylvania, is investigating water flow paths that deliver carbon to stream ecosystems. The goal of her research is to understand the controls on material export from the landscape by explicitly considering how streams connect with the rest of the land-based environment.

Name: Mei, Yi

Worked for more than 160 Hours: Yes

Contribution to Project:

Mei is a Ph.D. candidate at Vanderbilt University and is developing several approaches for modeling the flux of DOM from hillslopes to streams and testing them against measurements made at the CZO. Work for the past six months has included development of a two-dimensional hillslope model and associated data collection on a hillslope at White Clay Creek. Yi Mei participated in a PIHM Workshop sponsored by the Penn State CZO and, along with other investigators on the Christina CZO, did a preliminary calibration of the hydrological model to White Clay Creek. His work, with mentoring from George Hornberger, will continue to focus on testing models of DOM fate and transport and on extending the PIHM framework to include carbon transport modeling at the whole-catchment scale.

Name: Chen, Chunmei

Worked for more than 160 Hours: Yes

Contribution to Project:

Conducting research under objective 2 - Weathering and Erosion Controls on Carbon-Mineral Complex Formation

Name: Pearson, Adam

Worked for more than 160 Hours: Yes

Contribution to Project:

Graduate student working on objective three - Fluvial Network Controls on Complex Formation & Preservation

Undergraduate Student

Technician, Programmer

Name: Montgomery, David

Worked for more than 160 Hours: Yes

Contribution to Project:

David Montgomery is the watershed manager for the Stroud Water Research Center experimental watershed. He will provide logistical support and coordination for monitoring installations and research use within the watershed.

Name: Hicks, Steven

Worked for more than 160 Hours: Yes

Contribution to Project:

The main responsibilities for Steven Hicks on the CZO are to design and implement a network of environmental sensors throughout the study watersheds. He will use existing sensor and wireless technologies as well as develop custom sensor devices to record a variety of environmental measurements and then aggregate all of the data for processing by the data management group.

Other Participant

Name: Doremus, Kelly

Worked for more than 160 Hours: Yes

Contribution to Project:

Administering and monitoring financial accounts for CZO, scheduling conferences, meetings and calls.

Research Experience for Undergraduates

Organizational Partners

Other Collaborators or Contacts

The University of Delaware and the Stroud Water Research Center co-lead this project as equal partners. In addition, several senior staff are funded at other institutions via subcontracts:

George Hornberger at Vanderbilt University. See description under senior personel.

Ilya Zaslavsky at San Diego Super Computing Center. See description under senior personnel.

Rolf Aalto, Associate Professor at the Univ. of Exeter in the United Kingdom and Adjunct Associate Professor at the University of Washington, has been an important collaborator on this project. He will oversee the preparation of samples for cosmogenic radio isotopes at the Univ. of Washington, and is actively participating in Objective 3 - Fluvial Network Controls on Complex Formation & Preservation. A subcontract to Univ. of Washington covers laboratory supplies and materials. Aalto's salary, and that of his student, are covered by UK funds.

In addition, we are actively collaborating with a number of other CZO researchers funded by one of the other CZO projects. These include:

Alain Plante, at the University of Pennsylvania, and his graduate student, Wenting Feng, on

organo-mineral complexation.

Beth Boyer, at Penn State University, and Diane McKnight at Univ. of Boulder, on Dissolved Organic Matter characterization.

Chris Duffy and his students Gopal Bhatt and Lorne Leonard, at Penn State Univ., on modeling with the Penn State Integrated Hydrological Model (PIHM).

Mark Williams, from Univ. of Boulder, and a long list of other colloaborators from various institutions, on the national CZO data management system.

We are actively developing collaborations with a wide range of local partners who either produce or need/use data on the Christina River Basin (CRB). These include: federal (EPA, USGS), interstate (CRB Watershed Management Committee, Delaware River Basin Commission), state (DE Dept. of Natural Resources, DE Geological Survey, DE Water Resources Agency), and local (Chester County Water Resources Agency, Chester County Conservation District, White Clay Creek Watershed Management Committee (CCWRA), Red Clay Valley Association) agencies in addition to several non-profit non-governmental organizations (Brandywine Conservancy, Natural Lands Trust). Representatives from most of these groups have been meeting quarterly for several years under the name 'Christina River Basin Task Force'. We have attended many of these meetings are are beginning discussions for data sharing efforts.

Last, we are initiating collaborations with the Delaware Environmental Observing System (DEOS, http://www.deos.udel.edu/) , with whom we expect substantial collaboration and data sharing efforts in coming years.

Activities and Findings

Research and Education Activities:

1.1. Project Management and Coordination
In the first several months of funding, 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. Each team met separately to work on details of the work plan and then reported back to the entire group. Scientists from outside of the University of Delaware and the Stroud Water Research Center have joined these discussions via conference calls. 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 beginning to provide strong intellectual payoffs.

1.2. New Hires
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. 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. We also successfully recruited five outstanding graduate students to conduct research on the project.
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 a completely forested watershed that is protected in perpetuity within the Laurels Preserve, managed by the Brandywine Conservancy, an agricultural watershed that is held under an agricultural easement and dominated by row crops of soybeans and corn, and a watershed impacted by the Southeastern Chester County Refuge 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. 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: 3rd -order White Clay Creek Experimental Watershed gauging station at the Stroud Water Research Center, the mouth of the White Clay Creek near Newark DE at USGS gauging station 01479000, and the mouth of Brandywine Creek at the Wilmington Public Water Authority?s water intake.

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.
The core of our Sensor Network will be built around a field computer networked to the internet (via continuous bidirectional 3G broadband ?mobile? wireless). The field computer will control a number of advanced commercial geochemical sensors (below) in addition to a basic suite of hydrological and climate sensors. In addition, the 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, the field computer will serve as a data and web-services hub for a wireless sensor network.
The remote wireless sensor network will be built with sensor nodes connected to Memsic eKo (formerly owned by Crossbow) wireless data logging and sensor control platforms. The eKo system is a robust wireless data system built on open source protocols that are

being widely adopted throughout the world. The eKo system has been used successfully by the Shale Hills CZO and we have successfully deployed a test system within our watershed.
The centerpiece of our stream sensor cluster is a submersible UV-Vis diode array spectrophotometer (a spectro::lyser by s::can, http://www.s-can.at). For the last 6 months we have been putting a spectro::lyser to the test. 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 and pH ? will soon be deployed. In addition to sensors submersed in stream water, 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 matrix potential, soil temperature, 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 Geoinformatics for Geochemistry project (http://www.ldeo.columbia.edu/research/geochemistry/geoinformatics-geochemistry).
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 GfC 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 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.

1.6. Ground Truthing Lidar Imaging
In conjunction with all sites within the CZO network, we obtained and followed procedures for the ground truthing of Lidar images obtained under full-canopy conditions. Aerial photographs and historic knowledge of landscapes within the Christina River Basin were used to identify potential forested plots and provide directions and landowner approvals to assist two University of Delaware students hired for this project. The students performed a vegetation survey with documentation of species identification and measurement of individual tree sizes as well as measurements of forest canopy condition.

1.7. Adoption of the Penn State Integrated Hydrologic Model (PIHM)
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.

1.8 Participation in Cross CZO Comparisons of Dissolved Organic Matter (DOM)

Beth Boyer of the Shale Hills CZO has organized a DOM working group that is collecting and analyzing samples from all CZO sites. These analyses include the measurement of dissolved organic carbon (DOC) concentrations and analysis of the excitation-emission matrix associated with each sample. We have worked with Boyer on the standardization of sample handling protocols and have analyzed approximately 300 samples for the natural abundance of 13C DOC. In carrying out these analyses we have developed a novel application of a cryotrapping system in the interface between our carbon analyzer and isotope ratio mass spectrometer that has significantly increased our analytical sensitivity. This advance has made it possible to work with samples that have DOC concentrations that are less than 0.5 mg C/L.

Findings:

One of our CZO doctoral graduate students, Chunmei Chen who is advised by PI Don Sparks, with input from other CZO participants, has been conducting studies at the Stanford Synchrotron Radiation Laboratory (SSRL) and the Canadian Light Source (CLS) to directly determine the distribution, speciation, and elemental associations of soil organic carbon under varying landscape topographic positions at the molecular scale. This research deals with Objective 1 of our proposal.

The role of organic matter-mineral interactions in the long-term protection of soil organic matter against decomposition is increasingly recognized as a key process for soil carbon (C) stabilization. In a preliminary study, we examined the structural composition of organic matter and its interaction with soil minerals along a pasture hillslope transect within the Christina River Basin Critical Zone Observatory (CRB-CZO). The CRB-CZO is underlain by metamorphosed sedimentary bedrock and is located in the Piedmont Region of southeastern Pennsylvania. Soil samples were collected from A and B horizons at the ridge and the base of a hillslope. Humic acids were extracted from the bulk samples as well as from the clay fractions and characterized by attenuated total reflectance-Fourier transform infrared spectroscopy (ATR-FTIR). Scanning transmission X-ray microscopy (STXM) and C-ls near-edge X-ray absorption fine structure (NEXAFS) spectroscopy at the Canadian Light Source were used to assess soil organic matter distribution, speciation and elemental associations at the nm scale. Based on the ATR-FTIR spectra, humic acids at the hillslope base, compared to those at the summit, have greater proportions of more recalcitrant aromatic-C and smaller proportions of more labile polysaccharides in the bulk soils and the clay fractions. The C NEXAFS analysis of the clay fractions from A horizons indicated that: (1) aromatic-C, O-alkyl-C and carbonyl-C were present at both the ridge and base of the hillslope; (2) the more labile aliphatic-C, which was present at the ridge of the hillslope , was not found at the base of the hillslope; (3) the more recalcitrant aromatic C was enriched at the base of the hillslope (compared to the ridge of the hillslope). These results suggest that the stability of soil organic matter is greater at the base of the hillslope than at the ridge of the hillslope and could be ascribed to the selective preservation of recalcitrant carbon forms by the soil mineral matrix. STXM- NEXAFS results demonstrated that organic matter (especially aromatic-C and aliphatic-C) associated with clay particles exhibited a larger variability at the ridge of the hillslope than at the base of the hillslope from the nm to the ?m scale. In this work we were also able to determine the major mineral elemental (Si, Al, Ca, Fe, K) compositions simultaneously with C distribution and speciation. Future CZO research to constrain the physical and chemical weathering history of the hillslope will be integrated with this study to understand how such topography-dependent C-mineral interactions have emerged, eventually helping efforts to scale up organic matter?mineral associations to landscapes and to land-atmosphere carbon exchange processes.

Posters and oral presentations, based on this research, will be presented at the National CZO meeting in Boulder, CO, and at the American Geophysical Union (AGU) and Soil Science Society of America (SSSA) meetings.

Training and Development:
Nothing yet to report

Outreach Activities:
Presentations on the science and outreach elements of the CRB-CZO have been presented by PI Sparks and Co-PI Aufdenkampe at the following venues in the last year to policymakers and laypersons: the environmental section of the Delaware Bar Association, the Brandywine and Christina Conservancies, the PA State Water Symposium and the UD Academy of Lifelong Learning. Presentations are planned later this year to retired UD faculty.

Journal Publications

Books or Other One-time Publications

Web/Internet Site

URL(s):
http://www.udel.edu/czo/
Description:
This is a temporary website that provides basic information on our activities. Active development of this web site has been limited in anticipation of of a complete redesign of an integrated national CZO website built upon a modern content management system (CMS) framework. This national website is currently under development and should be unveiled by the end of 2010.

Other Specific Products

Contributions

Contributions within Discipline:
Although our project was only initiated less than one year ago, our stated hypotheses have already begun to contribute to critical zone research. Our hypotheses, if shown to be correct, have the potential to substantially transform perceptions on landscape scale controls on carbon sequestration. Aufdenkampe, Yoo, and Aalto have all given several invited presentations describing our core CZO hypotheses, which have been well received. Preliminary data, collected for this and previous projects are already supporting our hypotheses.

Contributions to Other Disciplines:
The science we have conducted so far will contribute to a number of disciplines including geochemistry, soil science, and environmental chemistry.

Contributions to Human Resource Development:
We have been successful in recruiting some highly talented postdoctoral researchers to conduct research on the CZO project including Olesya Lazavera, Carl Rosier, and Diana Karwan; excellent graduate students Chunmei Chen, Weinan Pan, Christine McLaughlin, Yi Mei, and Weinan Pan; Kelly Doremus as Financial Manager; Steve Hicks to develop and manage sensor technology; and David Montgomery as watershed manager. The students and postdoctoral researchers will obtain excellent training with new instrumentation and be involved in research that serves to link spatial and temporal scales that address C cycling and impacts on climate change. They will also benefit by having opportunities to communicate

their research to scientists and the public, enhancing their verbal and written communication skills.

Contributions to Resources for Research and Education:

Dr. Susan Gill, director of education at the Stroud submitted a proposal to NSF entitled: Introducing the Principles and Processes of Earth?s Critical Zone to Teachers, Informal Educators and Academically At-Risk Youth. award on CZO education. The proposal, which is still pending, would include a 1 week summer workshop and graduate courses for teachers and informal educators and an after-school and summer activities for children of local migrant agricultural workers.

In an effort to promote the CRB-CZO as a community resource Professor Francois Morel and coworkers at Princeton University will conduct research at our CZO associated with a NSF funded project entitled, 'Acquisition of nitrogenase metal cofactors in soils: Role of metallophores and limitation of nitrogen fixation'.

Contributions Beyond Science and Engineering:

The talks that have been given have assisted in educating the public about the importance of understanding carbon cycling as impacted by land use and mineral complexation and their impact on climate change.

Conference Proceedings

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Organizational Partners

Any Journal

Any Book

Any Product

Any Conference