Environment and Natural Resources Trust Fund

Research Addendum for Peer Review

Project Manager Name: **Mark Lindquist**

Project Manager Email address: **mark.lindquist@state.mn.us**

Project Title: **Establish scientific foundation for peatland carbon sequestration projects**

Project number: **134-F1+2+5**

The research addendum should provide concise but also comprehensive information so that peer reviewers have the appropriate level of information to provide helpful comments. Each project should include the following information:

1. **Abstract** - Summarize the research and its essential qualities including a clear statement on the purpose of the research.

The project will seek to establish total carbon balances (CO_2 + CH_4) in both pristine and a partially drained portions of the Red Lake Peatlands. The data will be collected through the use of open path eddy covariance units to measure CO_2, H_2O and energy flux. The project will utilize two such units already established at the Red lake Peatlands Observatory as well as install two new units in a disturbed location of the peatlands. Further data will be collected by equipping the towers with Li- Cor open path CH4 analyzer kits. The analysis of the data collected will provide a defensible estimate of the changes in net carbon balance that can be anticipated with the restoration of peatland restoration.

2. **Background** - Provide the basic information and other relevant work that are the context for this research.

The Glacial Lake Agassiz peatlands (GLAP) cover 56% of the regional landscape in northwestern Minnesota. This 7600 km^2 area contains some of the largest raised bog complexes and patterned water tracks in existence as well as the largest expanse of boreal peatland in the contiguous United States. The growth of these peatlands over the past 5000 years represents an enormous transfer of carbon dioxide from the atmosphere to a terrestrial sink since peat has now accumulated to an average depth of 2.5 m throughout the GLAP with maximum depths approaching 6 m. Peat profiles largely consist of water and dead organic matter with organic carbon representing 45-55% of the dry mass. Unlike most terrestrial soils, dead organic matter accumulates into thick peat deposits because of a high water table, which maintains an anoxic soil profile and limits decomposition to the least efficient anaerobic pathways. Since methane is the terminal end product of most anaerobic-decomposition pathways in freshwater wetlands, peatlands also serve as important sources for this potent greenhouse gas, which has 20 times the Global Warming Potential of CO_2 on a per molecule basis.

Peatlands are therefore considered to be key components of the Global Carbon Cycle that are especially sensitive to Global Warming. A shift to a warmer drier climate, for example could lead to the rapid conversion of peat into carbon dioxide and methane as a consequence of lower water tables, more rapid rates of decomposition, and widespread peat fires. These processes could inject massive amounts of greenhouse gases into the atmosphere and further amplify warming given the large mass of carbon stored in northern peatlands (e.g. 200-455 Pg C). Despite this potential threat for accelerating Global Warming, considerable uncertainty still exists with respect to the current carbon balance of boreal peatlands and their response to climate change. Current research initiatives have therefore focused on quantifying carbon fluxes in peatlands and resolving their relation to climatic and hydrologic drivers. Two approaches can be used to investigate these important problems.

One approach followed by Paul Glaser and his colleagues in northern Minnesota involves a continuing 30-year study in the GLAP, which has developed within a relatively dry climate punctuated by periodic droughts. The seasonal and multi-year droughts of this region simulate the effect of an experimental manipulation of this ecosystem at the regional scale that is free from unintended artifacts. The other approach utilized by scientists elsewhere simulates the effect of climatic drying by constructing drainage ditches in small peatlands and monitoring the difference in carbon fluxes between these experimental sites and nearby control sites. This later approach has never been utilized in large peatlands because of their great size and inaccessibility. However, such studies would be very timely since the largest peat basins contain a significant fraction of the total carbon mass stored as peat. In addition, reversing the effect of the extensive drainage networks across the GLAP could provide sufficient carbon credits to offset the net carbon emissions from current anthropogenic sources across Minnesota as a whole. Unfortunately, the actual impact of these ditches on the local peat landforms must first be established and quantified.

Drainage Ditches

Prior to World War I several counties in northwestern Minnesota financed an ambitious program to drain the GLAP and convert the peatlands into arable farmland. This drainage program, however, was a failure because the regional relief is too low, the river network is too sparse, and most ditches were restricted to the section lines of the original land survey. Although the drainage program was a failure, the ditches did produce noticeable changes to the surface vegetation patterns in many places. Lower water tables favored the spread of shrubs and trees across areas formerly dominated by sedges and also increased the frequency and spread of peat fires. The impact of drainage operations on the carbon balance of these sites is not known at present since basic research over the past 30 years was focused on more pristine portions of these peatlands. However, judging from the abundance of fire scars near ditches and roadways across northern Minnesota, drainage operations must have produced substantial losses of carbon as a result of lower water tables, deeper aerobic layers, and more rapid conversion of peat into greenhouse gases. The altered peatlands of the GLAP therefore provide an exceptional opportunity to provide carbon credits for the State of Minnesota if it can be shown that 1) the drainage ditches have significantly altered the carbon balance of these areas by 1) lowering their present capacity to sequester atmospheric carbon dioxide and 2) depleting their carbon stocks amassed over several millennia. Plugging the ditches could then restore the capacity of these disturbed peatlands to again rapidly sequester atmospheric carbon dioxide (i.e. enhance more rapid rates of peat accumulation).

Red Lake Peatland Observatory

Over the past 30 years Paul Glaser and his colleagues have shown that the development of the Glacial Lake Agassiz peatlands in Minnesota was closely coupled to climatically-driven flow systems. The most recent phase of this on-going research program culminated in the construction of the Red Lake Peatland Observatory (RLPO), a multi-sensor array for monitoring fluxes of carbon, water, and energy through the central bog complex of the 1200 km^2 Red Lake Peatland in northwestern Minnesota. The Red Lake Peatland contains 4 major watersheds (Glaser et al. 1981). The westernmost watershed (RLI) comprises the largest patterned watertrack in North America characterized by striking Aapamoor patterns of sinuous networks of sinuous peat ridges and pools oriented perpendicular to the slope and streamlined tree islands. The 3 watersheds to the east (RLII, RLIII, and RLIV), in contrast contain bog complexes comparable in area to the largest bog complexes in North America. Each of these large bog complexes has 1) a forested bog crest that grades downslope into 2) gently sloping *Sphagnum* lawns and 3) fen water tracks that divide the lower flanks of the bog into ovoid-shaped "islands." The water tracks converge farther downslope widening to form a major portion of the peatland watershed. Building upon past work we installed 20 new instrument stations in the west-central RLII watershed to monitor fluxes of carbon, water, and heat continuously within the 4m-thick peat profile and also the atmospheric boundary layer on scales of meters to kilometers. This integrated array of stations comprise the Red Lake Peatland Observatory (RLPO), which now collects data from a) 14 dual-frequency GPS units arranged in a nested triangular network measuring vertical and lateral deformations of the peat mass caused by changes in water and gas storage, b) 2 eddy covariance units that monitor fluxes in heat, momentum, carbon dioxide, and water vapor across the atmospheric boundary layer, and c) 4 stations equipped with instrumented piezometers and meteorological sensors for measuring changes in water and gas storage within the entire peat profile. All remote stations communicate by radio to a base station and through the internet to a centralized database at the University of Minnesota that automatically downloads and stores sensor data on a daily basis.

These instrument stations detected the presence of large overpressured pockets of methane gas within the deeper peat of the bog crest, bog lawn, and internal fens (water tracks. The gas bubbles become trapped under confining layers within the deeper peat that episodically rupture in response to the arrival of low atmospheric pressure systems, steep declines in the water table, or the accumulation of excess gas. The rupture of these confining layers produces sharp depressuring cycles at depth that occur synchronously with topographic oscillations of the peat surface that exceed 36 cm (both laterally and vertically). On the basis of the measured changes in pore pressures, peat volume, and temperature profiles we calculated that each ebullition event released over 35 g CH_4 per square meter and that 3 out of 10 events alone in August 1997 exceeded by an order of magnitude the annual methane emissions measured by chambers from this same site. Free--phase gas appears to accumulate throughout the peat profile in winter after the surface layers freeze, but pockets of gas also persist during the frost-free season at deeper depths. The production, storage, and degassing of free-phase methane and carbon dioxide therefore seem to be an important component of carbon fluxes in this large northern peatland.

The stage is now set to expand the RLPO to disturbed portions of the Red Lake Peatland to determine the impact of past drainage operations on the carbon balance of this peatland. The most important needs at present are first to upgrade the existing OPEC stations with an open-path methane analyzer that is capable of running on solar power so the instrument can be operated in this very large remote peatland. The addition of this instrument, which has just become available will enable us to monitor the complete carbon balance at this site. The second objective will be to install an OPEC station with a open-path methane analyzer at a comparable site within a disturbed portion of the Red Lake Peatland, most likely in the RLIII watershed (of Glaser et al. 1981). The occurrence of these striking landform patterns, which are characterized by discrete vegetation assemblages, ranges in surface water chemistry, and hydrology (see Glaser et al. 1981, 1990, 1997; Glaser 1987, 1992a,b,c) greatly simplifies sampling strategies and scaling-up local site measurements to regional averages. At present levels of funding it has not been possible to sample all the principal types of major peat landforms in the Red Lake peatland, which are closely comparable to those found across the major peat basins of North America south of the zone of continuous permafrost. However, past funding from the National Science Foundation and the LCCMR recommended funding from the Minnesota Environment and Natural Resource Trust Fund provides an important basis for more comprehensive coverage of the entire peatland. Third, we will also begin a program of recovering long cores from the peat surface to the mineral substratum in the RLIII watershed to quantify the effect of past drainage operations on long-term rates of carbon accumulation.

3. Hypothesis - State the premise or propositions set forth to explain and achieve the described outcome of the research.

Healthy peatlands represent an ongoing sink for atmospheric carbon dioxide and altered peatlands, where water tables have been lowered, have become a source of atmospheric carbon dioxide as the underlying peat is exposed to oxygen and degrades at rates faster than accumulation.

4. Methodology - Describe the methodology to be employed to carry out the proposed research. Including descriptions of the sample design(s), if applicable.

1. Short-term monitoring of carbon budgets

We propose to add 2 new open-path eddy covariance stations to the RLPO so it will now be capable of monitoring fluxes of energy, water vapor, carbon dioxide, and also methane from comparable peatland sites in both the drained and relatively pristine portions of the Red Lake Peatland. The core stations will consist of a CSAT3 sonic anemometer (which measures wind speed and direction in the 3 orthogonal directions at 10MHz sampling interval), a Li-cor 7500 open path infrared gas analyzer for measuring fluxes of carbon dioxide and water vapor), the new Lic-cor 8500 open path methane analyzer, rain gauge, water table sensor, and a group of sensors needed to measure the complete energy balance at these sites (e.g. radiometer, temperature and humidity probes, soil heat flux plates, and time-delay refractormeters). These stations will collect data needed to determine the current carbon balance at these peatland sites and its coupling to the local water balance.

The sensors will be mounted on a tripod (e.g. CSAT3, Li-cor 7500 and 8500), radiometer, temperature, and humidity probes) or inserted into the upper layers of peat (soil heat flux plates and time-delay refractometers) and powered by banks of deep cycle 100 amph gell-cell batteries recharged by solar panels. The sensors will be connected to a Campbell Scientific CR3000 datalogger equipped with compact flash card storage for downloading the high frequency (10 MHz) data and radios for automated downloads of the flux data. The solar panels and tripod will be mounted on 1 and a half inch pipe driven through the peat profile into the mineral substratum. We will utilize an assembly of bushings, nipples, and wide diameter washers to attach the feet of the tripod to the pipe providing a very stable platform for the aboveground sensors. The solar panels in contrast will be mounted to an assembly of pipe driven into the mineral substratum and stabilized by means of guy lines.. All exposed cables and wires will be armored by conduit or hardware cloth to protect them from gnawing rodents. The OPEC stations acquire more than a gigabyte of data a month and currently need to be manually downloaded (by swapping out the cards) once every 2 months to retain the high frequency (10 MHz) data. Unless Campbell offers an alternative means of storing larger data files, we anticipate re-visiting the sites every 2 months to swap out the cards and service the sites for routine problems. The IRGAs will be re-calibrated once a year at which time we will replace the chemicals scrubbing the internal instrument chamber for CO_2 and water vapor.

The new instrument stations will be incorporated into the automated data-management system of the RLPO to streamline the acquisition, storage, and analysis of all field data. All stations communicate via radio with a base station located in the Minnesota DNR Hatcheries building. This base station in turn is connected to the internet by a DSL line allowing direct communication to each station from any location in the world that has internet access. The main data repository for the RLPO is located in the VMWare cluster at the WBOB building at the University of Minnesota in Minneapolis. Each day data from all the stations is automatically downloaded using the LoggerNet software and stored in the VMWare cluster. Data is then processes and displayed in Vista Data Vision (VDV) that allows us to control access and also visualize data on the web, while also allowing data to be downloaded in tabular form for further processing. Data protection is enhanced by the configuration of the VMWare cluster, which has 3 nodes loaded at 2/3 with one node acting as a failover. The data is written to our storage servers, which have RAID-6 redundancy and are backed up hourly to a backup server. The cluster is housed in a secure, climatically controlled room in WBOB, which has dedicated backup power in case of an outage. This robust data management system provides access to our instrument stations and database from any location in the world equipped with internet access.

2. Peat Cores-Long-term rates of carbon accumulation.

A series of long cores will be collected from the peat surface to the mineral substratum to determine long-term rates of carbon accumulation. Large diameter (10 cm) cores will be collected with a piston sampler equipped with a steel barrel that has a serrated cutting edge designed to cut through large pieces of wood and peat fibers. The cores will extruded in the field, wrapped in plastic, and sealed in longitudinally cut sections of PVC for shipment to cold rooms in the LRC core lab of the University of Minnesota. At the lab the cores will first be logged at 1 cm intervals with a Geotek multi-sensor core logger to determine the wet bulk density (by gamma ray attenuation), occurrence of possible ash layers (by magnetic susceptibility), and other physical parameters. The cores will then be cut into longitudinal sections and imaged with a digital-color line scanner at 300 dpi. One set of longitudinal sections will be preserved as an archive and the other subsampled for elemental analysis (C,N,S), the ratio of wet-to-dry weight, and ash content (loss on ignition). Both core sections will be stored in cold rooms when not in use.

If funding allows, or if additional funding can be secured, an age model for the cores will be constructed using calibrated radiocarbon dates in conjunction with one of several types of age-model programs currently available based on either Bayesian statistics (e.g. BCal, Bacon) or other types of curve-fitting methods (e.g. least squares regression, splines, TGA view). Results from these different methods will be compared for agreement to provide the most reliable age model for these cores. Long-term accumulation rates for carbon and nitrogen will be calculated using the age model for the cores in conjunction with the dry bulk density and elemental carbon profiles.

3. Quantify rates of carbon storage or loss associated with drainage operations in the Red Lake peatland

The effect of drainage operations on the carbon balance of specific peat landforms will be quantified by comparing the results obtained from areas most noticeably impacted by drainage operations (RLIII) to the more pristine portions of the Red Lake peatland (RLI, II, and IV) and adjacent areas of the GLAP sampled by Glaser and his colleagues over the past 30 years. Specifically data on short term fluxes of water, carbon dioxide, and methane will be compared between the OPEC towers of the NSF-funded RLPO in the relatively undisturbed RLII watershed of the Red Lake peatland with the new tower(s) to be installed in disturbed portions of the RLIII watershed of the Red Lake Peatland. Although it is not possible at the present funding level to obtain flux data for all the principal types of peat landforms, this proposal will provide an important base on which to build a more comprehensive monitoring network. We also propose to determine if the drainage ditches altered the rate of carbon accumulation averaged over much longer (e.g. millennial) time scales by comparing accumulation rates based on the analysis of long cores from drained portions of the Red Lake Peatland to those that show less visible evidence of disturbance, this element may be dependent upon securing funding needed for radio carbon dating. The new stations can then be expanded in the near future to include sensors capable of monitoring changes in hydraulic head (i.e. pore-pressure profiles), temperature profiles, and peat volume (e.g. with

GPS stations) as additional funding becomes available to quantify ebullition fluxes at these new sites.

5. Results and Deliverables - Describe in detail the expected outcomes of each of the results and deliverables.

1) install 2 new permanent OPEC stations in the Red Lake peatland

2) collect continuous data (at 10 MHz sampling interval) on short-term fluxes of carbon, water, energy at disturbed and undisturbed peatland. All data will be stored in the RLPO database located in the WBOB buliding of the University of Minnesota in Minneapolis.

3) collect large diameter peat cores from drained portions of the Red Lake peatland. All cores will be stored in cold rooms located in the core repository of the Limnological Research Center of the University of Minnesota.

4) As resources allow, analyze core samples for rates of carbon and dry mass accumulation. These data will provide insights on the impact of drainage ditches on long-term rates of carbon storage.

5) Preliminary total carbon balance (CO_2+CH_4) based on 1 year data collection

6) Preliminary report and recommendations to the Minnesota DNR and other agencies for managing drained portions of the GLAP with special reference to existing drainage ditches.

6. Timetable - Layout the proposed times for completing the proposed research including proposed dates for individual results and deliverables.

August, 2011, Complete contracts between DNR and U of MN

August, 2011, order equipment

October, 2011, Install Equipment (Deliverable 1) and initiate data collection secure core samples (De

October, 2011 – July, 2013 On-going Data collection and management, equipment maintenance (Deliverable 2)

November, - 2011 – March 2013 Core sample analysis (Deliverable 4)

October, 2012 – July 2013 Data analysis and carbon balance estimate (Deliverable 5)

January, 2013 – June 2013 Report on preliminary analyses of one year carbon balance (Deliverable 6)

7. Budget –

IV. TOTAL TRUST FUND REQUEST BUDGET *[Insert # of years for project]* years

	AMOUNT
Salary: , Project Management and Contract Management (8% time each of two years). This is new work for the department. (Assumed $95,253 salary and fringe)	$ 15,240
Contracts: University of Minnesota, Department of Geology and Geophysics (Dr. Paul Glaser, principal investigatory) The contract elements will be outlined below as separate line items.	See below
Contract (U of MN): Staffing: Dr. Paul Glaser salary and fringe 46% time for 2 years (31,000 salary per year + 32% fringe). Dr. Glaser will be responsible for procurement, installation, maintenance of eddy current flux towers, core sampling, and procurement of core sample carbon dating, as well as data analysis and reporting of GHG fluxes produced on pristine and restored peatlands.	$ 74,780
Contract (U of MN) Equipment/Tools/Supplies: Open path eddy covariance units to measure CO2, H2O and energy flux 2 @ 37,500 (procurement, operation and maintenance by U of MN in accordance with ENRTF requirements)	$ 75,000
Contract (U of MN) Equipment /Tools and / Supplies: Li Cor open path CH4 analyzer kit 4@ 40,000 (procurement, operation and maintenance by U of MN in accordance with ENRTF requirements)	$ 160,000
Contract (U of MN) Equipment/Tools/Supplies: Balance of plant equipment/supplies for covariance and CH4 analyzer units (procurement, operation and maintenance by U of MN in accordance with ENRTF requirements)	$ 10,000
Contract (U of MN): Carbon dating and lab analysis of peat cores. 80 carbon dates @$350 + $5,000	
Contract (U of MN) Travel: Helicopter Trips to Red Lake Peatlands 12 trips @ $5,000 (site is otherwise inaccessible)	$ 60,000
Contract (U of MN) Travel: 12 Trips to Red Lake Peatland (Baudette) @670 mile/trip x .50 per mile + 12 hotels @ $80 per night	$ 4,980
Additional Budget Items: Internal services agreement with DNR, Grand Rapids Resource Assessment program (operates on internal fee for service contract basis) 100 hours @ $85 per hour professional services cost.	
TOTAL ENVIRONMENT & NATURAL RESOURCES TRUST FUND $ REQUEST	$ 400,000

V. OTHER FUNDS

SOURCE OF FUNDS	**AMOUNT**	**Status**
Other Non-State $ National Science Foundation will continue to be sought for supporting the broader Red Lake Peatland Observatory project as opportunities arise.	TBD	Indicate: Secured or Pending

Other State $ Being Applied to Project During Project Period: *.MN DNR Minnesota DNR Shared Services*	$ 8,906	*Indicate: Secured or Pending*
In-kind Services During Project Period:		
Specify $ and year of appropriation from any current ENRTF appropriation for any directly related project of the project manager or organization that remains unspent or not yet legally obligated at the time of proposal submission. Be as specific as possible. Describe the status of $ in the right-most column.	$ -	*Indicate: Unspent? Not Legally Obligated? Other?*
Funding History: NSF Funding (approximately 300,000 for equipment, 75,000 for helicopter site access, and 125,000 for .5 FTE staffing over three years)	500,000	
Funding History: Legislative appropriation for U of MN study: Potential for Terrestrial Carbon Sequestration in Minnesota (legal citation)	$ 385,000	

8. **Credentials** - Provide brief background of the principal investigators and cooperators who will carry out the proposed research and selected publications

Dr. Paul Glaser is the principal investigator who will lead and conduct the research program and author appropriate scientific papers and reports. His CV is attached at the end of this document. Mark Lindquist is the project manager he will oversee contracts, budgets, accept deliverables, coordination between DNR managers and the University as well as ensure that the research output is utilized to inform peat land and carbon management within Minnesota. His resume is attached.

9. **Dissemination and Use** – Describe how the findings of the research will be disseminated and describe the expected audience and potential use.

Data will be disseminated and used through dual tracks**.**

Dr. Glaser and RLO collaborators will lead the dissemination in the scientific community as follows. The results of this research project will be disseminated as 1) scientific papers published in peer-reviewed scientific journals, 2) oral presentations at local, national, and international meetings of governmental agencies and professional scientific societies, and informal contacts with all interested parties, A web site is being prepared for the RLPO, which will also present the salient results from this study.

DNR will also actively use and disseminate the data. 1) The increased understanding of peatland carbon balances will be used to inform DNR management of peatlands throughout the Glacial Lake Agassiz basin. 2) The DNR and the Interagency Carbon Sequestration Team will work with a wide range of stakeholders and interests, including policy makers and local drainage authorities, to share information and opportunities related to carbon management in peatlands. 3) DNR will post reports and relevant documents on its website. 4) DNR will provide oral presentations as opportunities arise.

Project Title: **Establish scientific foundation for peatland carbon sequestration projects**
Project number: **134-F1+2+5**

CURRICULUM VITAE

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Education

A.B., (Botany), Rutgers-The State University, Newark, NJ, 1968.
M.S., (Botany), University of Minnesota, Minneapolis, MN, 1971.
Ph. D., (Botany), University of Minnesota, Minneapolis, MN, 1978.

Appointments

Research Professor (Graduate faculty) Department of Geology & Geophysics, University of Minnesota, Minneapolis, MN 2009-present
Graduate faculty, Conservation Biology, University of Minnesota, Saint Paul, MN 2008-present
External Faculty, Department of Earth Sciences, University of Maine Orono, Orono, Maine 2007-present.
Senior Research Associate, (Graduate faculty) Department of Geology & Geophysics, University of Minnesota, Minneapolis, MN 55455: 1994-2009
Research Associate, Limnological Research Center, University of Minnesota: 1979 -1994.
Visiting Scientist, Trinity College, University of Dublin, Dublin 2, Ireland: 1985-1990.

Awards

Fellow, Geological Society of America (2007-present).

Field Leader

Helicopter expeditions to Glacial Lake Agassiz peatlands, Minnesota: 1978, 1980, 1981-1984, 1990-1994, 1997-2000; 2007-2112 (NSF, NASA, DOE and Minnesota DNR)
Helicopter/float plane expedition to Hudson Bay Lowland, northern Ontario, Canada: 1985; 1992 (NSF and NASA)
Helicopter/float plane expedition to Great Slave Lake lowlands, N.W.T. Canada: 1986 (NASA)
NSF sponsored expeditions to study raised bogs in Canada (Newfoundland, SE Labrador, New Brunswick, Nova Scotia, Prince Edward Island, Quebec, Ontario, and Manitoba) and the United States (Maine, Minnesota, and New York), 1981-1983.
NSF sponsored expeditions to western Ireland: 1985-1987; 1990.

Also field experience on Isle Royale, Michigan (1967), the Alaska Range, south-central Alaska (1968-1970, 1972, 1974-1975), SE Alaska (1986, 1995, 1998), Iceland 1985-1986), parts of western Europe (1985-1987, 1990; 2001), New Zealand (1995), SE Australia (1995), Everglades, Florida (2002-2006). Big Cypress Swamp, SW Florida (2005), Kenai Peninsula, Alaska (1997, 2009); lower Nelson River and adjacent areas of Hudson Bay, northern Manitoba, (2006-2010).

Graduate Student Committees /External Examiner

Gracz, M. (Ph.D.) Conservation Biology, University of Minnesota, Saint Paul, MN. (advisor).
Sarkar, S. 2010 (Ph.D.) Dept. of Earth Sciences, Syracuse University, Syracuse, New York.
Fassbinder, J. 2010 (M.S.) Dept. Soil, Water, & Climate, University of Minnesota, Saint Paul, MN.
Rhoades, J. 2009. (M.S.) Dept. Earth Sciences, University of Maine Orono, Orono, Maine.
Lusteck, R. 2008 (Ph.D.) Department of Anthropology, University of Minnesota, Minneapolis, Minnesota.

Dommaine, R. 2006 (Diploma-MS) Ernst-Moritz-Arndt Universität, Greifswald, Greifswald, Germany (co-advisor).
Korth, P. 2006 (M.S.), Department of Earth Sciences, Syracuse University, Syracuse, New York.
Locky, D. 2005 (Ph.D.) Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada.
Myrbo, A. 2005 (Ph.D.) Department of Earth Sciences, University of Minnesota, Minneapolis, Minnesota.
Poulin, M. 2002 (Ph.D.) Centre d'études nordiques, Université of Laval, Sainte-Foy, Québec City, Québec, Canada.
Mckenzie, J. 2005 (Ph.D.) Department of Earth Sciences, Syracuse University, Syracuse, New York.
Goa, Y. 2003 (Ph.D.) Department of Geology and Geophysics, University of Minnesota, Minneaplois, Minnesota.
Urbano, L. 2001 (Ph.D.) Department of Geology and Geophysics, University of Minnesota, Minneaplois, Minnesota.
Robinson, S. 2000 (Ph.D.) Department of Geography, McGill University, Montreal, Quebec, Canada.
Rivers, J. 1999 (Ph.D.) Department of Earth Sciences, Syracuse University, Syracuse, New York.
Reeve, A. 1996 (Ph.D.), Department of Geology, Syracuse University, Syracuse, New York.
Stimson, T. 1996 (M.S.) Department of Computer Science, University of Minnesota, Minneapolis, Minnesota.
So, J. 1996 (M.S.) Department of Earth Sciences, Syracuse University, Syracuse, New York.
Waddington, M. 1995 (Ph.D.), Geography Department, York University, Toronto, Ontario, Canada.
Jansen, R., 1994 (M.S.), University of Utrecht, Utrecht, The Netherlands.
Rutkowski, N., 1993 (M.S), State University of New York, College of Environmental Science and Forestry, Syracuse, New York.
Romanowicz, E.A., 1993 (Ph.D.), Department of Geology, Syracuse University, Syracuse, New York.
Ours, D.P. 1993 (M.S.), Department of Geology, Syracuse University, Syracuse, New York.
Shen, Y.1993 (M.S.), Department of Geology, Syracuse University, Syracuse, New York.
Nicholson, B. 1992 (Ph.D.), University of Alberta, Edmonton, Alberta, Canada.

Other Professional Experience

Project leader and lead PI for the Red Lake Peatland Observatory (2007-present). The RLPO is the only integrated instrument installation for monitoring groundwater-carbon coupling at multiple scales within a large (>1000 km^2) boreal peatland. Over 40 senior scientists and graduate students from 9 different universities or government agencies are currently participating in this project.

Coordinator and lead PI for Glacial Lake Agassiz Peatlands Project (1990-2006). This interdisciplinary project involved 67 participants (including 39 students) from 22 different institutions. It produced 6 Ph.D. dissertations, 10 M.S. theses, 35 peer-reviewed journal articles or book chapters, and 48 published abstracts between 1990 to 2006. Over the entire 30 year lifespan of this ongoing project, more than 20 book chapters and 50 journal articles have been published, which received over 1700 citations according to the ISI Web of Science.
Canada Research Chair (College of Reviewers) 2010
NSERC (National Science and Engineering Research Council of Canada) site visit committee member for proposal CRDPJ-360525-07, University of Waterloo, (2008)
NSF: Integrated Carbon Cycle Research Panel (2002)
Executive Committee for AEGIS (Atmosphere/Ecosystem Gas Interchange Study), NCAR (National Center for Atmospheric Research), Boulder CO, 1990-1991.
Associate Editor for *Wetlands*, the Journal of the Society of Wetland Scientists: 1987-1992.

Publications

Glaser, P.H. (*in prep.*) Wetlands and Environmental Change. Arnold, London

D'Andrilli, J. J.P. Chanton, P. H. Glaser, and W.T. Cooper (*in press*). Characterization of dissolved organic matter in northern peatland soil porewaters using Ultrahigh Resolution Mass Spectrometry. Organic Geochemistry.
Parsekian, A., L. Slater , X. Comas , and P. Glaser. (2010*).* Non-invasive comparison of biogenic free

phase gas accumulation between forested crest and mid-slope lawn of a large raised bog complex: variations in the vertical distribution of gas. Journal of Geophysical Research-Biogeosciences. 115, G02002, doi:10.1029/2009JG001086.

Glaser. P.H. and J.P. Chanton (2009). Methane accumulation and release from deep peat: measurements, conceptual models, and biogeochemical significance. In Northern Peatlands and Carbon Cycling, Baird, A., L Beyla, X. Comas, A. Reeve, and L. Slater (eds). American Geophysical Union Books.

Chanton, J. P., P. H. Glaser, L. S. Chasar, D. J. Burdige, M. E. Hines, D. I. Siegel, L. B. Tremblay, and W. T. Cooper. 2008. Radiocarbon evidence for the importance of surface vegetation on fermentation and methanogenesis in contrasting types of boreal peatlands, Global Biogeochemical Cycles, 22: GB4022, doi:10.1029/2008GB003274.

Givnish, T.J., J.C. Volin, V.D. Owen, V.C. Volin, J.D. Muss and P.H. Glaser 2008. Vegetation differentiation in the patterned landscape of the central Everglades: importance of local and landscape drivers. Global Ecology and Biogeography 17: 384-402.

Glaser, P.H. and M. Griffith. 2007. A field extruder for rapidly sectioning near-surface cores from lakes and wetlands. Journall of Paleolimnology 38: 459–466.

McKenzie, J.M., Siegel, D.I., D.O. Rosenberry, Glaser, P.H., and C. Voss. 2006. Heat transport in the Red Lake Bog, Glacial Lake Agassiz Peatlands. Hydrological Processes 21: 369–378.

Glaser, P.H., D.I. Siegel, A.S. Reeve, and J.P. Chanton. 2006. The hydrology of large peat basins in North America, *In* Peatlands: Basin Evolution and Depository of Records on Global Environmental and Climatic Changes Martini, I.P., Matinez Cortizas, A., and Chesworth, W. (eds.) Elsevier, Amsterdam.

Siegel, D. I., P. H. Glaser, J. So, and D. R. Janecky 2006, The dynamic balance between organic acids and circumneutral groundwater in a large boreal peat basin. Journal of Hydrology 320: 421–431.

Siegel, D.I. and P.H. Glaser. 2006. The hydrology of mires. *In Peatland Ecosystems* K. Weider and D.H. Vitt (eds). Springer-Verlag, Heidelberg, pp. 289-311.

Reeve, A.S., Evensen, R., Glaser, P.H., Siegel, D.I., Rosenberry, D.O. 2006. Flow path oscillations in transient ground-water simulations of large peatland systems. Journal of Hydrology 316: 313-324.

Bleuten, W., Borren, W. Glaser, P.H., Tsuchihara, T., Lapshina, E., Mäkilä, M, Siegel, D., Joosten, H., Wassen, M.J.. 2006. Hydrological processes, nutrient flows, and patterns of fens and bogs. In Wetlands and Natural Resource Management. Ecological Studies Vol. 190. J.T.A. Verhoeven, B. Beltman, R. Bobbink, and D.E. Whigman (Eds.) Springer-Verlag Berlin-Heidelberg. pp. 183-204.

Rosenberry, D.O., P.H. Glaser, and D.I. Siegel. 2005. The hydrology of northern peatlands as affected by biogenic gas: current developments and research needs. Hydrological Pocesses. 20:3601-3610.

Glaser, P.H., D.I. Siegel, A.S. Reeve, J.A. Janssens, and D.R. Janecky 2004. Tectonic drivers for vegetation patterning and landscape evolution in the Albany River region of the Hudson Bay Lowlands. Journal of Ecology 92: 1054-1070.

Glaser, P.H., B.C.S. Hansen, D.I. Siegel, A.S. Reeve, and Morin P.J. 2004. Rates, pathways, and drivers for peatland development in the Hudson Bay Lowlands, northern Ontario. Journal of Ecology.92: 1036-1053.

Glaser. P.H., J.P. Chanton, P. Morin, D.O. Rosenberry, D.I. Siegel, O. Ruud, L.I. Chasar, A.S. Reeve 2004. Surface deformations as indicators of deep ebullition fluxes in a large northern peatland. Global Biogeochemical Cycles, 18, GB1003, doi:10.1029/2003GB002069.

Chanton J.P., L.C. Chasar P. Glaser, and D. Siegel 2005. Carbon and hydrogen isotopic effects in microbial methane from terrestrial environments. *In* Stable Isotopes and Biosphere-Atmosphere Interactions. Edited by L.B. Flanagan, J.R. Ehleringer, D.E. Pataki, pp. 85-105, Elsevier-Academic Press, Physiological Ecology Series.

Gorham, E., J.A. Janssens, and P.H. Glaser. 2003. Rates of peat accumulation during the postglacial period in 32 sites from Alaska to Newfoundland, with special emphasis on northern Minnesota. Canadian Journal of Botany 81: 429-438

Rosenberry, D.O., P. H. Glaser, and D.I. Siegel, E.D. Weeks. 2003. Use of hydraulic head to estimate volumetric gas content and ebullition flux in northern peatlands. Water Resources Research 39, NO. 3, 1066, doi:10.1029/2002WR001377,

Glaser, P.H. 2002. C.A. Weber's benchmark treatise on the Augstumal bog: reflections on its impact and significance to peatland ecology. *In* J. Couwenberg and H. Joosten *(eds.) C.A. Weber and the Raised Bog of Augstmal* IMCG and Grif & K, Tula, Russia

Siegel, D.I., J.P. Chanton, P.H. Glaser, L.S. Chasar, and D.O. Rosenberry 2001. Estimating methane production rates in bogs and landfills by deuterium enrichment of pore-water. Global Biogeochemical Cycles, 15: 967-975.

Reeve, A.S., J. Warzocha, P.H. Glaser, and D.I. Siegel 2001. Regional ground-water flow modeling of the Glacial Lake Agassiz peatlands, Minnesota. Journal of Hydrology 243: 91-100.

Reeve, A.S., D.I. Siegel, and P.H. Glaser. 2001. Simulating dispersive mixing in large peatlands. Journal of Hydrology 242: 103-114.

Chasar, L. S., J. P. Chanton, P. H. Glaser, D. I. Siegel, and J. S. Rivers. 2001. Radiocarbon and stable carbon isotopic evidence for transport and transformation of dissolved organic carbon, dissolved inorganic carbon, and CH_4 in a northern Minnesota peatland. Global Biogeochemical Cycles 14:1095-1108.

Chasar, L. S., J. P. Chanton, P. H. Glaser, and D. I. Siegel, 2000, Methane concentration and stable isotope distribution as evidence of rhizospheric processes: comparison of a fen and bog in the Glacial Lake Agassiz peatland complex. Annals of Botany 86: 655-663.

Reeve, A.S., D.I. Siegel, and P.H. Glaser. 2000. Simulating vertical flow in large peatlands. Journal of Hydrology 227: 207-217.

Hogan, J.F., J.D. Blum, D.I. Siegel, and P.H. Glaser 2000. $^{87}Sr/^{86}Sr$ as a tracer of groundwater discharge and precipitation recharge in the Glacial Lake Agassiz Peatlands, northern Minnesota. Water Resources Research 36: 3701-3710.

Glaser, P.H. 1999. The distribution and origin of mire pools. *In* Patterned Mires and Mire Pools, Proceedings University of Durham, 6-7 April 1998, Edited by V.Standen, J.H.Tallis and R.Meade, Special Symposium British Ecological Society

Rivers, J.S., Siegel, D.I., Glaser, P.H., Chanton, J.P. and Stalder, L. and N. Roulet 1998. A stochastic appraisal of the annual inorganic and organic carbon budget of a large circumboreal peatland, Rapid River Watershed, northern Minnesota. Global Biogeochemical Cycles 12: 715-728.

Glaser, P.H., Siegel, D.I., Romanowicz, E.A., and Shen, Y.P. 1997. Regional linkages between raised bogs and the climate, groundwater, and landscape features of northwestern Minnesota. Journal of Ecology 85: 3-16.

Ours, D.P., D.I. Siegel, and P. H. Glaser. 1997. Chemical dilation and the dual porosity of humified bog peat. Journal of Hydrology 196: 348-360

Glaser, P.H., Bennett, P.C., Siegel, D.I., and E.A. Romanowicz. 1996. Paleo-reversals in groundwater flow and peatland development in the Lost River peatland, northern Minnesota, USA. Holocene 6: 413-421.

Reeve, A. S.., D. I. Siegel, and P. H. Glaser. 1996. Geochemical controls on peatland pore-water from the Hudson bay lowlands: a multivariate and statistical approach. Journal of Hydrology 181: 285-304.

Chanton, J.P. , Bauer, J. Glaser, P.H., Siegel, D.I., Kelley, C., Tyler, S.C. Romanowicz, E.A., Lazrus, A. 1995. Radiocarbon evidence for the substrates supporting methane formation within northern Minnesota peatlands. Geochimica et Cosmochimica Acta 59: 3663-3688.

Siegel, D.I., A.S. Reeve, P.H. Glaser and E. Romanowicz. 1995. Climate-driven flushing of pore water in humified peat . Nature 374: 531-533

Romanowicz, E.A., D.I. Siegel, J.P. Chanton, and P.H. Glaser 1995 Temporal variations in dissolved methane deep in the Lake Agassiz peatlands, Minnesota (USA). Global Biogeochemical Cycles 9: 197-212.

Romanowicz, E.A., D.I. Siegel, and P.H. Glaser. 1993. Hydraulic reversals and episodic methane emissions during drought cycles in mires. Geology 21: 231-234.

Glaser, P.H. 1992. Peat landforms. *In* H.E. Wright, Jr. and B.A. Coffin (eds.), Patterned Peatlands of Northern Minnesota, University of Minnesota Press, Minneapolis, pp. 3-14.

Glaser, P.H. 1992. Vegetation and water chemistry. *In* H.E. Wright, Jr. and B.A. Coffin (eds.), Patterned Peatlands of Northern Minnesota, University of Minnesota Press, Minneapolis, pp. 15-26.

Glaser, P.H. 1992. Development of patterned peatlands. *In* H.E. Wright, Jr. and B.A. Coffin (eds.), Patterned Peatlands of Northern Minnesota, University of Minnesota Press, Minneapolis, pp. 27-42.

Glaser, P.H. 1992. Rare vascular plants in the patterned peatlands of northern Minnesota. *In* H.E. Wright, Jr. and B.A. Coffin (eds.), Patterned Peatlands of Northern Minnesota, University of Minnesota Press, Minneapolis, pp. 59-69.

Janssens, J.A., B.C.S. Hansen, P.H. Glaser, and C.W. Barnosky 1992. Development of a raised-bog complex in northern Minnesota. *In* H.E. Wright, Jr. and B.A. Coffin (eds.), Patterned Peatlands of Northern Minnesota, University of Minnesota Press, Minneapolis, pp. 189-221.

Glaser, P.H. 1992. Raised bogs in eastern North America: regional controls on species richness and floristic assemblages. Journal of Ecology 80: 535-554.

McNamara, J.P., D.I. Siegel, Glaser, P.H., and R.M. Beck 1992. Hydrologic controls on peatland development in the Malloryville wetland, New York (USA). Journal of Hydrology 140: 279-296.

Glaser, P.H., J.A. Janssens, and D.I. Siegel 1990. The response of vegetation to hydrological and chemical gradients in the Lost River Peatland, northern Minnesota. Journal of Ecology 78: 1021-1048.

Bennet, P. C., D.I. Siegel, B. Hill, and P.H. Glaser 1990. The fate of silica in a peat bog. Geology 19: 328-331.

Glaser, P.H. 1989. Detecting ecologic and hydrogeochemical processes in large peat basins with Landsat TM imagery. Remote Sensing of Environment 28: 109-119.

Mooers, H.D. and P.H. Glaser 1989. Active patterned ground at sea level, Forchu, Nova Scotia. Arctic and Alpine Research 21: 425-432.

Glaser, P.H. 1987. The development of streamlined bog islands in the interior of North America. Arctic and Alpine Research 19: 402-413.

Glaser, P.H. 1987. The ecology of patterned boreal peatlands of northern Minnesota: A community profile. U.S. Fish & Wildlife Service Biological Report 85(7.14), 98 pp.

Siegel, D.I. and P.H. Glaser 1987. Groundwater flow in a bog-fen complex, Lost River peatland, northern Minnesota. Journal of Ecology 75: 743-754.

Gorham, E., J.A. Janssens, G.A. Wheeler, and P.H. Glaser 1987. The natural and anthropogenic acidification of peatlands. In T.C. Hutchinson (ed.), The Effects of Acid Deposition on Forest, Wetland, and Agricultural Ecosystems. Springer-Verlag, Heidelberg, pp. 493-512.

Glaser, P.H. and J.A. Janssens 1986. Raised bogs in eastern North America: transitions in landforms and gross stratigraphy. Canadian Journal of Botany 64: 395-415.

Almendinger, J.C., J.E. Almendinger, and P.H. Glaser 1986. Topographic fluctuations across a spring-fen and raised bog in the Lost River peatland, northern Minnesota. Journal of Ecology 74: 393-401.

Janssens, J.A. and P.H. Glaser 1986. The bryophyte flora and major peat-forming mosses at the Red Lake peatland, Minnesota. Canadian Journal of Botany 64: 427-442.

Foster, D.R. and P.H. Glaser 1986. Raised bogs of southeastern Labrador, Canada: Classification, vegetation, and recent dynamics. Journal of Ecology 74: 47-71.

Glaser, P.H. and D.R. Foster 1984. The vascular flora of ombrotrophic bogs in southeastern Labrador and its phytogeographic significance. Canadian Journal of Botany 62: 1361-1364.

Wright, H.E., Jr., D.H. Mann, and P.H. Glaser 1984. Piston corers for peat and lake sediment. Ecology 65: 657-659.

Glaser, P.H. 1983. Vegetation patterns in the north Black River peatland, northern Minnesota. Canadian Journal of Botany 61: 2085-2104.

Glaser, P.H. 1983. *Carex exilis* and *Scirpus cespitosus* var. *callosus* in patterned fens in northern Minnesota. Michigan Botanist 22: 22-26.

Glaser, P.H. l983. A patterned fen on the north shore of Lake Superior. Canadian Field-Naturalist 97: 194-199.

Glaser, P.H. l983. *Eleocharis rostellata* and its relation to spring fens in Minnesota. Michigan Botanist 22: 19-21.

Wright, H.E., Jr. and P.H. Glaser 1983. Post-glacial peatlands of the lake Agassiz plain, northern Minnesota. In J.T. Teller and L. Clayton (eds.), Glacial Lake Agassiz, Geological Association of Canada, Special Paper No. 26, pp. 375-389.

Janssens, J.A. and P.H. Glaser 1983. *Cynclidium stygium* Sw (Bryopsida: Mniaceae) in Minnesota. Michigan Botanist 23: 19-20.

Janssens, J.A. and P.H. Glaser 1983. *Rhizomnium gracile* a new moss to Minnesota and the distribution of *Rhizomnium* in the State. Michigan Botanist 23: 89-92.

Foster, D.R., G.A. King, P.H. Glaser, and H.E. Wright, Jr. 1983. Origin of string patterns in boreal peatlands. Nature 306: 256-258.

Wheeler, G.A., P.H. Glaser, E. Gorham, C.M. Whetmore, F.D. Bowers, and J.A. Janssens 1983. Contributions to the flora of the Red Lake peatland, northern Minnesota with special reference to *Carex.* American Midland Naturalist 110: 62-96.

Wheeler, G.A. and P.H. Glaser 1982. *Tomenthypnum falcifolium* in Minnesota. Michigan Botanist 21: 66.

Wheeler, G.A. and P.H. Glaser 1982. Vascular plants of the Red Lake peatland, northern Minnesota. Michigan Botanist 21: 89-92.

Glaser, P.H. 1981. Transport and deposition of leaves and seeds on tundra - a late-glacial analog? Arctic and Alpine Research 13: 173-182.

Glaser, P.H., G.A. Wheeler, E. Gorham, and H.E. Wright, Jr. 1981. The patterned peatlands of the Red Lake peatland, northern Minnesota: vegetation, water chemistry, and landforms. Journal of Ecology 69: 575-599.

Glaser, P.H. and G.A. Wheeler 1980. The development of surface patterns in the Red Lake peatland, northern Minnesota. In Proceedings of the 6th International Peat Congress, Duluth, MN, pp. 31-35.

Wheeler, G.A. and P.H. Glaser 1979. Notable vascular plants of the Red Lake peatland, northern Minnesota. Michigan Botanist 18: 137-142.

Glaser, P.H. 1978. Recent plant macrofossils from the Alaska interior and their relation to late-glacial landscapes in northern Minnesota. Ph.D. thesis, University of Minnesota, Minneapolis, MN.

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December 2008

Anderson, Jim et al, The Potential for Terrestrial Carbon Sequestration in Minnesota: A Report to the Department of Natural Resources from the Minnesota Terrestrial Carbon Sequestration Initiative February 2008

Mishra, N., Corn Stover Utilization and Soil Health University of Minnesota, Center for Regional and Urban Affairs July 2008

DanMar and Associates Economic Impact Analysis of Windpower Development in Southwest Minnesota Southwest Regional Development Commission, September, 1996