McMurdo Dry Valleys Long Term Ecological Research

MCM-LTER PIs: *(inset) - Peter Doran (back, left to right) - John Priscu, Berry Lyons, Diane McKnight, Diana Wall (front, left to right) - Ross Virginia and Andrew Fountain.*

Site Review
January 2008

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1. Science Narrative

Publications and Data

- MCM LTER publications and student theses and dissertations from the current funding period are located in Appendix C. A searchable publications database is also available at www.mcmlter.org/publications_home.htm
- All MCM datasets are available electronically at www.mcmlter.org/data_home.htm

Conceptual Background

The central tenet of MCM-III is that biodiversity and ecosystem structure and function are dictated by the interactions of climatic legacies with contemporary biotic and physical processes. Although some recent results are presented below, details will primarily be presented at the site visit. Our earlier research demonstrated that subtle changes in the climate system, such as the temperature and albedo, greatly influence the MCM hydrologic system, which in turn drives the biogeochemistry and productivity. In addition, we realized that past climatic events going back tens to hundreds of thousands of years have acted as a major regulatory force on the MCM landscape and its ecological dynamics. MCM-III activities have sought to combine these two ideas, contemporary change and "legacy" of the past, in order to better describe and quantify ecosystem status and response in our system. The MCM hydrologic system is poised in an extremely important climatic threshold – subtle change in temperature can release large amounts of liquid water from the glaciers, which in turn leads to significant ecosystem changes. Our conceptual model (**Figure 1**) built upon our MCM-I and MCM-II models and emphasizes the role of resource legacy on the on-going contemporary linkages between resources, biodiversity and processes. We now address biodiversity issues in both the context of physical dispersion and habitat suitability. In addition, as suggested by the 2002 site review, we have included a stoichiometric approach in our research plan to define the functional aspects of the ecosystem and have recently summarized this work in a publication (Barrett et al., 2007).

A cooling trend both annually (0.7^{o}C per decade) and during the summer (DFJ) months (1.2^{o}C per decade) was reported by Doran et al. (2002) in the McMurdo Dry Valleys from 1986 to 2000. This cooling reduced stream flow, increased lake ice thickness and decreased soil moisture content, thereby affecting ecosystem processes at all landscape levels. Cooling continued through the end of 2006 with the same 0.7^{o}C per decade annual trend and a 0.7^{o}C trend in summer temperatures. However, during this period of cooling we have also experienced a "flood year" in 2001-02, where extreme melting occurred (an order of magnitude greater than normal) over a two-week period, resulting in stream flooding and elevated water flux throughout the system (Gooseff et al., 2007), including rapid melt of buried ice bodies in the soils (Harris et al., 2007). This event increased stream scour, resulting in increased nutrient flux to the lakes and elevated moisture in soil patches, to which the ecosystem responded (Foreman et al., 2004; **Figure 2**). Lake levels rose between 0.54 and 1.01 m during these few weeks and rapidly countered lake level lowering over the previous decade due to net water lost to evaporation and sublimation (**Figure 3**). Lake levels continue to rise since the flood year even though the annual and summer temperatures continue to decrease on average. Thus over the 15 year period of MCM, we have been able to evaluate ecosystem change during both a long-term cold/dry period where water input is small and rapid influxes of water driven by short-term pulses that may mimic longer term climate warming. We are therefore beginning to address the ecological impact of pulse events (weeks), against the backdrop of decadal trends. And because of our detection of long term legacy effects (centuries-millenia) of past climate variations, we can define the ecological response of climate over many time scales in this polar environment.

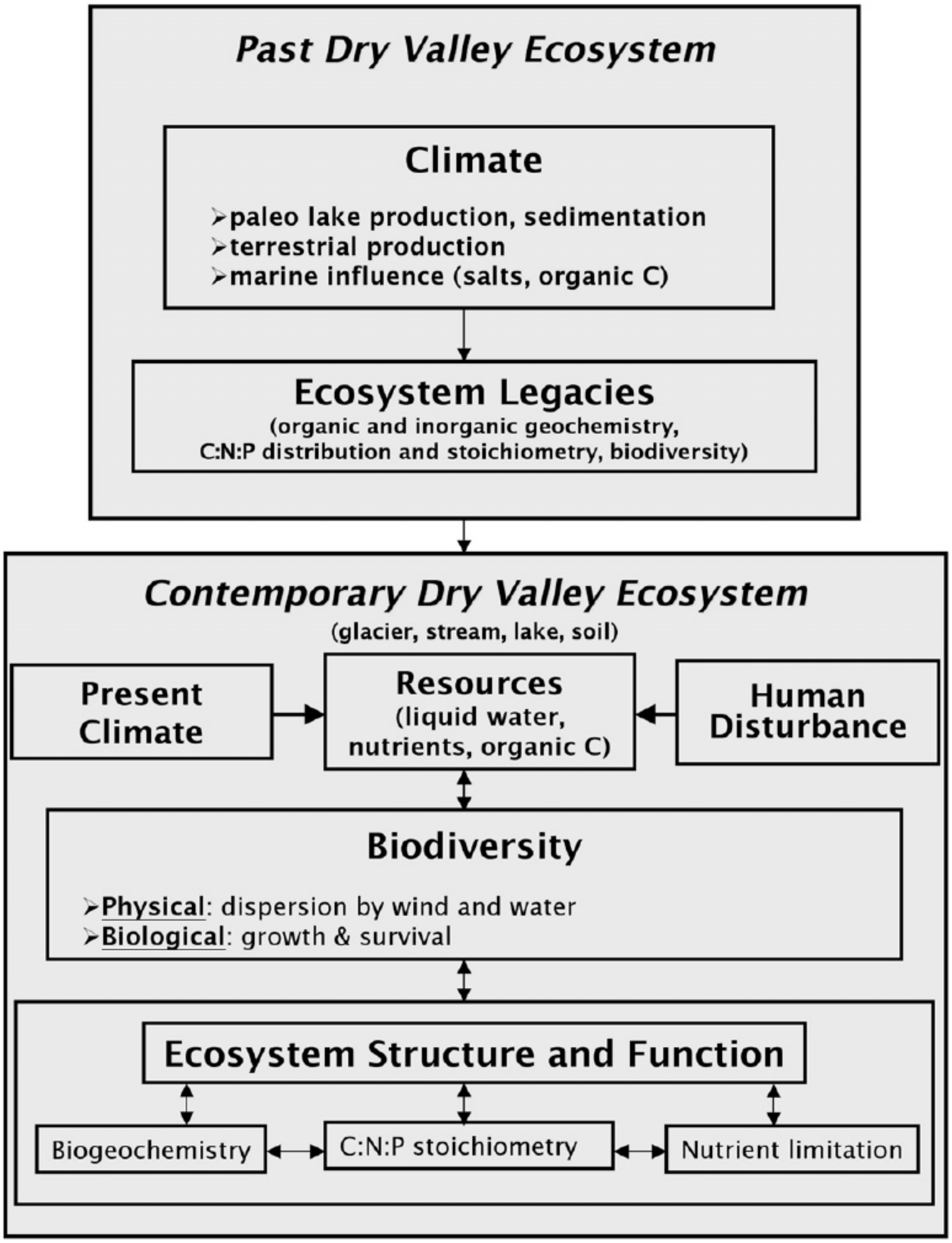


Figure 1. Conceptual Model for MCM-III

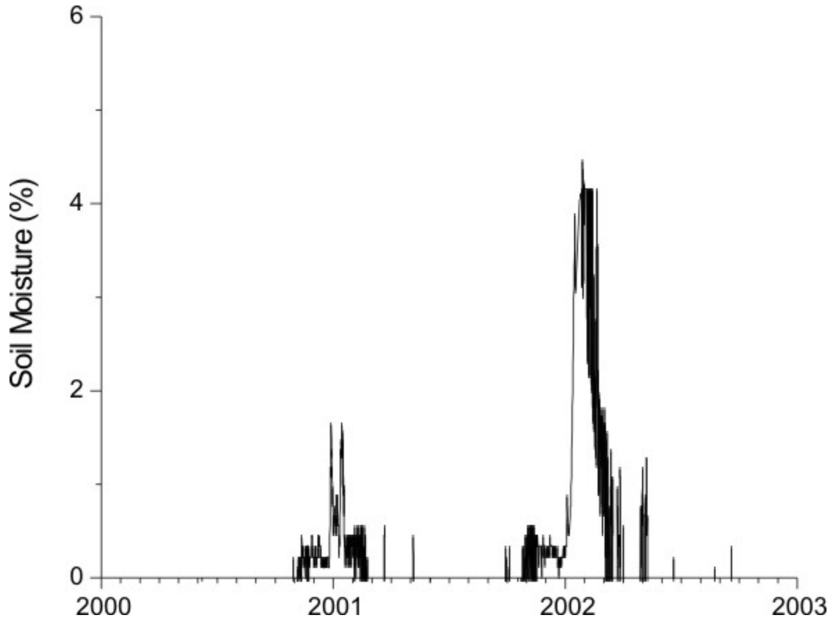


Figure 2. Water content in a long term monitoring site on the south side of Lake Hoare, Taylor Valley estimated using Delta-T Soil Reflectometers

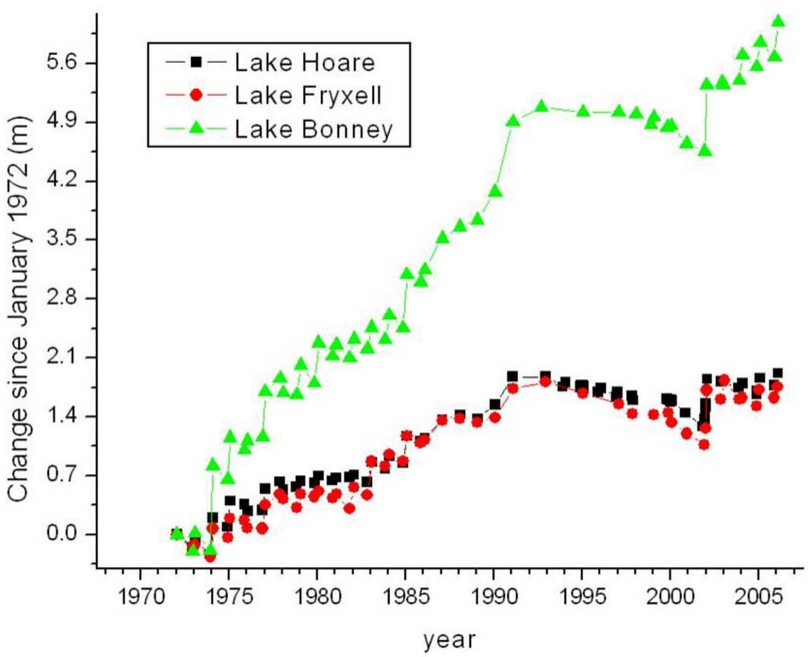


Figure 3. Long term lake level changes for Taylor Valley lakes measured by optical survey instruments

Organization

Our proposed work for MCM-III is organized into three portfolios: hydrology, biodiversity and ecosystem structure and function. Specific hypotheses within each portfolio are detailed in our proposal (www.mcmlter.org/research_home.htm). These various portfolios contain a series of hypotheses that are integrated across landscape units and disciplines. For example, an emphasis in MCM-III has been on the aeolian transport of inorganic and organic material by both wind and water across and between landscape units, and the influence of these transfer processes on both the biodiversity and stoichiometric (C:N:P) composition with the landscape units. We have established aeolian material collectors and have begun to quantify aeolian transport and associated biodiversity throughout Taylor Valley using acoustic particle sensors (in addition to collectors quantifying invertebrate dispersal). We are also investigating the transition zones between "dry" soils and "wet" stream channels as well as develop a more comprehensive habitat suitability model for the soils by investigating other terrains. All these exercises incorporate integrated physical, chemical and ecological measurements. As the previous site review team commented in 2002, "We believe there is no other LTER – that integrates the biogeochemical sciences as effectively as does the MCM." We continue to integrate physical, chemical and biological properties of the MCM in an effort to understand long-term changes in ecosystem processes.

MCM Study Area and Sampling Program

MCM is the largest ice-free area in the Antarctic (~4800 km^2) and contains glaciers, soils, ephemeral streams and ice-covered lakes as its landscape units. Taylor Valley (**Figure 4**), (77°40'S and 163°W) is the primary focus of the long term MCM data record. We also collect intermittent data on the meteorology, ecological, chemical and physical properties in the Wright, Victoria, Beacon, Arena and Garwood Valleys. Taylor Valley is ~33 km long and 12 km wide and contains three major lakes: Fryxell, Hoare and Bonney. The MCM is a polar desert with a mean annual temperature of ~-20°C and less than 10 cm of water equivalent precipitation per year (Fountain et al., 1999) and is an extreme end member of the 26 LTER sites (**Figure 5**). Water is generated in the austral summer from the melting of glacier ice, which forms streams that flow from 4 to 12 weeks per year (McKnight et al., 1999). The soils are poorly developed and consist of a mosaic of glacial tills of differing age (from a few thousands to ~2.5 million) and lacustrine sediments deposited when lake levels were higher (Virginia and Wall, 1999). The soils are derived from a number of rock types within the Victoria Land region, including Precambrian crystalline basement rocks, early Paleozoic intrusive rocks, sedimentary rocks (Beacon supergroup), Jurassic age dolerites and more recent volcanic rocks. The soils contain little organic carbon compared to temperate environments and can contain high amounts of soluble salts (Fritsen et al., 2000). Permafrost underlies all the valleys and the active layer at the surface can be as shallow as 10-30 cm. Although all Taylor Valley lakes are relatively close (<10 km between lakes) each has a distinct geochemical profile that reflects their unique age and evolution (Priscu, 1997; Lyons et al., 2000; Lyons et al., 2005).

Monitoring

Our core monitoring program includes the following:

- 8 meteorological stations in Taylor Valley (including aeolian samplers) and another 5 in adjacent valleys;
- Glacier mass balance is measured on 4 glaciers (Commonwealth, Canada, Howard and Taylor);
- Stream flow is gauged on 15 streams within Taylor Valley and 2 sites on the Onyx River in Wright Valley (the longest river on the continent); biogeochemical measurements are taken at 37 stream sites;
- Cyanobacteria and diatom transects at 13 streams;

- Soil biota and soil physical/chemical properties in monitoring experiments in Taylor Valley;
- Biological, physical and biogeochemical properties of the Taylor Valley lakes at least twice an austral summer; Measurement of benthic lake algal mats, especially in Lake Hoare;

Our core monitoring program was expanded to include new lake measurements, under ice PAR sensors, and stoichiometric measurements of sediment trap materials. For the benthic algal mats, measurements of bacterial biomass and productivity, biodiversity and stoichiometry have been added.

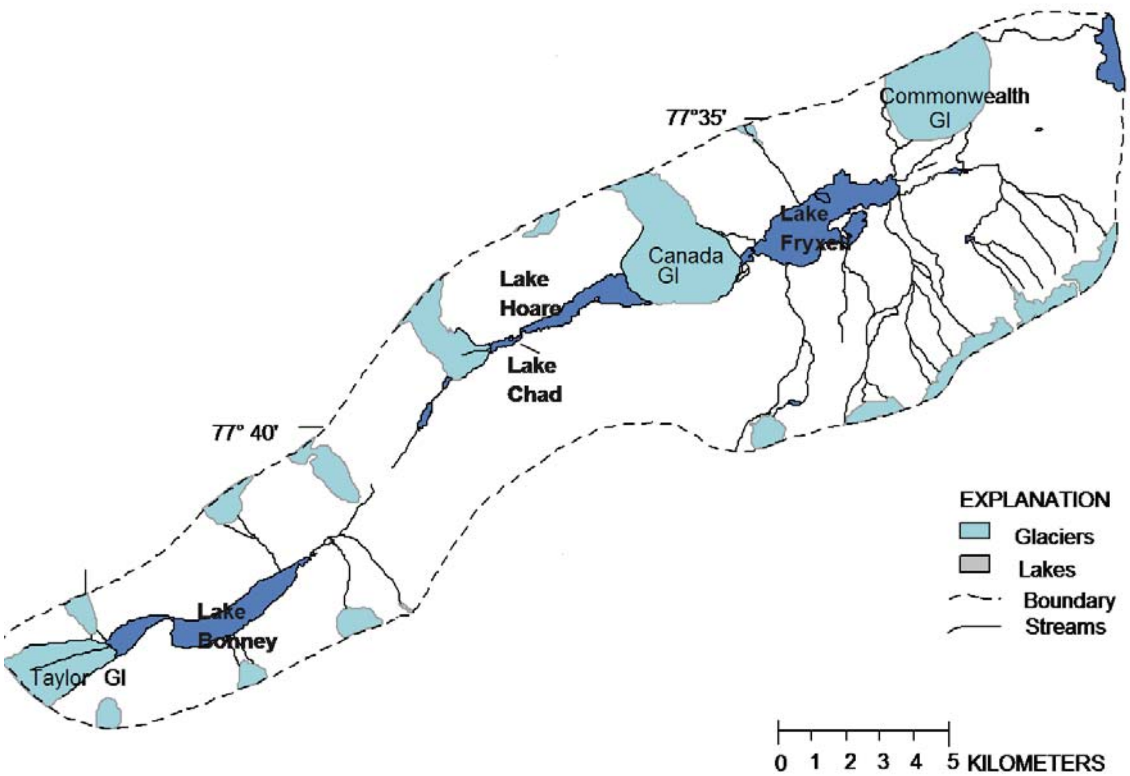


Figure 4. Taylor Valley

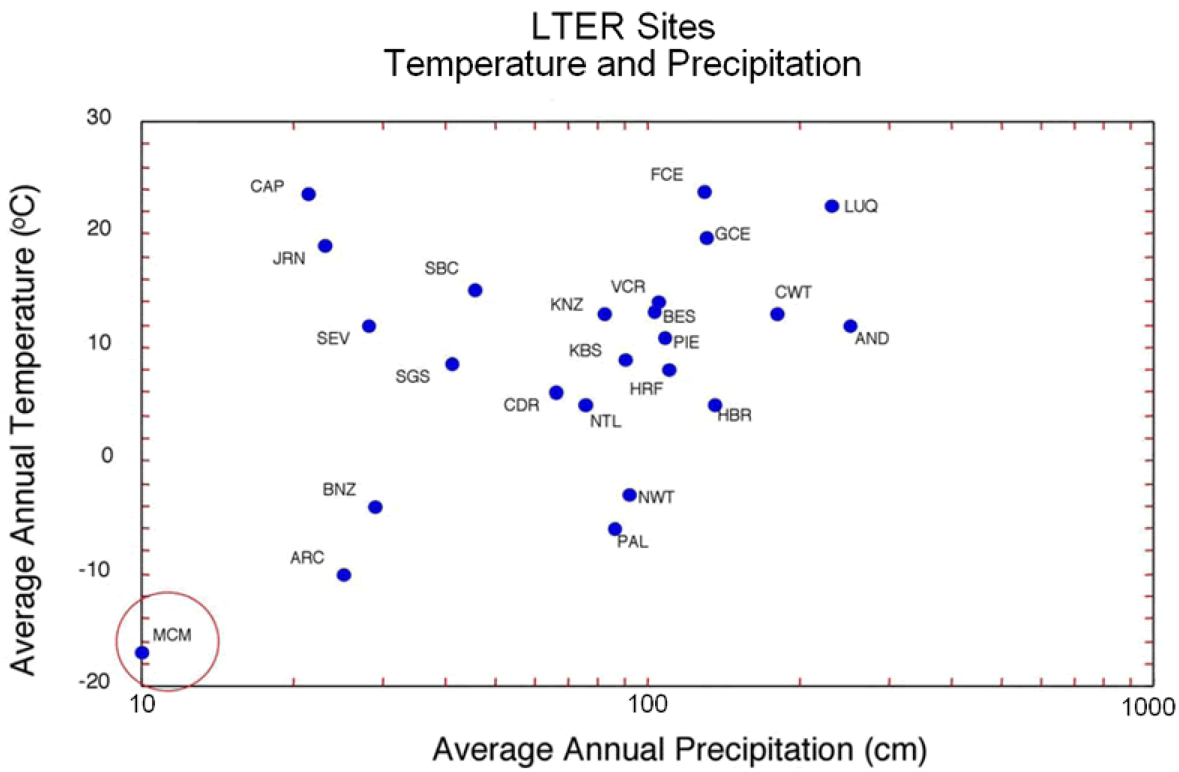


Figure 5. Average annual temperature and average annual precipitation at the 26 site in the LTER Network

Long-Term Soil Plot Studies and Experiments

The soil plot investigations now include C and N uptake experiments and soil respiration measurements to better quantify C and N budgets. These studies will help define the role of legacy versus contemporary C pools in the soils and how each affects the functioning of soil biological communities. Lake and soil studies have added a molecular pigment diversity component to define phylogenetic, phylogeographic and functional aspects of biodiversity.

On-going soil experiments include an elevational transect (established in 1993), a long-term manipulation experiment (established in 1992) and a biotic effects experiment (established in 1998). The latter two utilized ITEX chambers to manipulate the soils via additions of water, carbon and geographic variations on soil biodiversity and function. In the second experiment, the treatments have been discontinued in order to see how these plots "recover" from disturbance. Our long-term snowfence experiment that began in 2000-01 will be discontinued during MCM-III. Results observed from another snow pack study in the valley indicated that snow covered soils were colder, had higher moisture content and higher invertebrate populations and species richness than exposed soils (Gooseff et al., 2003). Because other LTER sites have conducted similar experiments, the information gathered from this experiment can be compared as a cross-site experiment.

Continued long-term experiments include the relict stream reactivation, where water was diverted to a stream channel that had not seen flow for approximately two decades. This experiment seeks to explore the relationships between habitat and dispersal controls on biodiversity and ecosystem function. Tracer experiments in streams will continue to be utilized to understand the relationship between algal abundance and biogeochemical processing in the streams as well as the role of the hyporheic zones and their microbial and faunal communities play in nutrient dynamics within the system. The initial results of the relict stream experiment were recently published (McKnight et al., 2007).

In addition to these pre-MCM-III experiments that are on-going, we have also added three new experiments to our activities. The aeolian traps along with particle flux monitors have been mentioned previously. Materials have been collected in traps placed in 3 transects perpendicular to the 3 lakes, on the lakes themselves, and on the 4 glaciers where cryoconite hole studies are on-going. Materials are being analyzed for grain size, C-N-P and molecular diversity. In addition to other landscape transects to understand stoichiometry (Barrett et al., 2007), samples for molecular biodiversity have also been added. These measurements, together with ongoing molecular phylogeographic studies, will provide insight into the mode of transport across the MCM landscape and historical patterns of biodiversity and ecosystem assembly.

Response to the Panel Review of the MCM-III Proposal
When the MCM-III proposal was reviewed in 2004, there were eight areas where the panel thought improvements could be made. We discuss how we have addressed those criticisms below:

1) *Need for automated sampling within the lakes* – We have made numerous attempts to obtain funds for automatic in-lake system measurement devices. Towards the end of MCM-II Doran and McKnight submitted an ~ $1 M proposal to the Cyberinfrastructure and Sensors program at NSF to install a network of physical and biogeochemical sensors in the Dry Valleys and telemetry network for all existing data loggers (meteorological stations, stream gages and lake stations). The responsible program officer at the Office of Polar Programs encouraged us to apply to this program and assured us that our proposal was a good fit for the program. We were well-reviewed (4 Excellent, 4 V. Good, 1 Good, 2 Fair) but in the end declined, and told we were a bad fit for the program. In MCM-III, Doran submitted an MRI that focused on developing lake water column and benthic sensors, and telemetering of all Dry Valley data. The MRI was also well-reviewed (2 Excellent, 1 V. Good), but ultimately was not funded. Doran tried a repeat MRI submission in 2006, but was not selected to be one of the three MRI's from his institute. Doran's university felt that if NSF had declined the proposal previously, the proposal was flawed and unlikely to be successful. Roberta Marinelli submitted a letter to Peter, which was conveyed to his university, describing the intense competition and year-to-year variability in MRI submissions and decisions, and suggesting that proposals declined in one year may be successful in subsequent years. A third MRI was submitted in January 2007 was selected as one of UICs three MRI's that year. Unfortunately the day before the NSF deadline, a major industry partner pulled out of the collaboration and the proposal had to be completely rewritten in 24 hours. That proposal was not well-reviewed (2 V. Good, 2 Fair). Doran is not in a position to submit anymore MRI's for dry valley sensors and telemetry.

We did have some success in securing external funds for sensor work. Doran (with Priscu as co-PI) has been awarded funds from NASA to construct and deploy an autonomous underwater vehicle (ENDURANCE) in West Lake Bonney during the 2008/2009 and 2009/2010 season. The vehicle will generate a high resolution bathymetric map of the lake and measure temperature, conductivity, pH. redox, chl-a, DOC, and PAR through the entire lake. The density of the biogeochemical survey will be 100x100m on the horizontal plane and 0.5 m vertical. Digital imagery will be obtained from across the bottom of the lake and an attempt to image the entire Taylor Glacier face underwater will be made. The biogeochemical measurements will be made in two consecutive seasons to tract inter-annual changes of the lake in the third dimension. The vehicle is being tested in Lake Mendota in February 2008 in collaboration with NTL personnel at University of Wisconsin Madison

We have continued to attempt to compete for both NSF and NASA funds to help supplement our field operations and our MCM-LTER related work. Priscu's Microbial Observatory work and Doran's and Priscu's NASA related work, and the Latitudinal Gradient Project (LGP) grant to PIs Virginia, Wall, Lyons and Fountain are excellent examples of this. We (primarily through the efforts of Doran and Priscu) will continue to pursue MRI funds to purchase and deploy these automated systems. In addition, the PIs continue to apply for funds related to LGP activities.

2) *Need for sediment coring to supplement sediment trap data* – A coring program in the three Taylor Valley lakes was undertaken by Doran on a separate OPP-NSF grant. Other MCM-PIs have been involved in the analysis of the core materials. Although an initial paper has been published on the results from Lake Fryxell (Wagner et al., 2006), data analysis continues. This information will allow us to place the on-going sediment trap collections into a longer-term perspective, and add important new information on how the biodiversity and biogeochemical processes changed in the lakes as the climate changed in the past, thus complementing our legacy concept. Results from Wagner et al. (2006) have supported our previously reported ideas (Lyons et al. 1998) on lake level history, and have also provided a longer record of lake hydrologic variation going back ~ 48,000 years.

3) *Use the isotope signature of C to investigate benthic mats in the lakes* – We have begun these approaches, with the first data published in Lawson et al. (2004). The analyses demonstrate that the isotopic composition of the benthic material is different than the OC produced in the water column of the lakes. In general, the benthic OC is heavier due to what we believe is CO_2 limitation. These initial measurements suggest that in Lakes Fryxell and Hoare, benthic production rivals pelagic production.

4) The panel asked us to consider this question – *Do the physical environment and ecological legacies drive differences in diversity?* – We have clearly shown by our recent work (Ayres et al., 2007; Barrett et al., 2007) that landscape form as well as the legacy of C, salinity and water are greater drivers in the MCM soil ecosystem than biotic competition. Our soil resource legacy model is supported by the strong relationships between soil biota distribution and diversity with these soil properties, which are established by past climatic events. However, we also have indicated in our conceptual model that it is not one or the other (physical vs. biological control), but their interaction and response to climate change that is important to MCM-LTER. In contrast, we have shown that for the diatom assemblages growing in the benthic mats of the streams, diversity and the importance of endemic species are strongly controlled by the harshness of the flow regime during the summer, with diversity decreasing and dominance by endemic species during cold summers with low and intermittent stream flow (Esposito et al., 2006).

5) *How will our various models be connected and integrated across landscape components?* As noted below, we are currently in the process of changing the focus of our modeling efforts. This has been driven in part by this question posed by the panel. Please note Appendix B where we outline the beginning of an integrated cross-landscape modeling effort under the leadership of Mike Gooseff, a current young investigator associated with MCM.

6) *Need for update of IM, especially GIS functions and databases* – We think we have addressed these issues over the ensuing three years under the hard work of Chris Gardner, who took over the IM during MCM-III. We refer you to the IM section of this document for details on what has been accomplished over the past three years.

7) *Extension of the field season* – This year Priscu will lead a group of 17 scientists and students to sample the lakes and streams during the transition from 24 h sunlight to the polar night (mid-February through late April). This project was funded under the International Polar Year (IPY) solicitation by OPP-NSF. For the first time, we will have information on phytoplankton, bacterioplankton and virioplankton and their associated biogeochemical relationships during the transition from phototrophy to heterotrophy. The plan of this unique field operation will be discussed during the site visit. This Polar Night project also includes a videographer and artist who will document the science being conducted during this unique part of the season.

8) *Molecular studies that link genetic diversity to ecosystem function* were started during MCM-III in coordination with the Microbial Observatory project under Priscu's leadership, with similar approaches for metazoans underway by Wall and Adams. Important new insights into the significance of legacy effects and the past histories of the lakes on microbial diversity between the lakes have been established. Similarly, molecular genetic data are being used to elucidate species boundaries and phylogeographic patterns of invertebrates, providing insight on the relationship between biodiversity, foodweb assembly, and ecosystem functioning. On-going work on the importance of aeolian and water transport to the distribution of metazoans and microbes will be presented during the site visit.

2. Site Management

Lyons will step down as lead PI after the site review, with Fountain taking his place. This has been planned for approximately two years, and the transition has gone very well. MCM is managed with a three person rotating Executive Committee (EC) which has worked well. It is anticipated that Fountain will appoint his own EC in March 2008.

Ms Kathy Welch (Senior Research Associate) at OSU coordinates 1) field logistics, 2) preparation of the required field planning documents (SIP) that are due to the NSF by mid-April, and 3) serves as the fieldwork coordinator during the four month field season. OSU and the Byrd Polar Research Center (BPRC) cost-share a portion of Welch's salary. Welch will continue to perform tasks 1 and 3 after the transition to Fountain's leadership and will assist with task 2 in March 2008.

The PIs meet twice per year, first in February/March to review the activities of the past field season and to plan for the next one, and again in the summer for a science meeting. The science meeting includes PI's, all collaborators, students, post-docs, outreach coordinators and technical staff, and the location is rotated among the PI's institutions. Scientists from outside the MCM are invited as well. The 2007 science meeting was in August in Boulder, CO; the 2006 meeting was held as a joint MCM-PAL meeting directly after the LTER ASM in Fort Collins, CO. MCM-III continues to convene workshops on specific science topics with the latest one in June of 2006 in Hanover, NH on dry valleys hydrology and soil moisture.

The MCM-III proposal reviewers were quite positive regarding site management: "Lyons is clearly providing excellent leadership, and the 3-member EC management model seems to work well"; and "it is good that the EC membership is rotated." Criticisms were minor but included a suggestion to rotate the EC more frequently. The PIs will do this when Fountain takes leadership – EC terms will be 2 years. In addition to the 3 PIs, both formal collaborators and young investigators will be eligible for a fourth membership slot on the EC.

Two major changes of MCM-III occurred; (1) Lyons took over the information management (IM) operation in the summer of 2004, and a full time information manager, Mr. Chris Gardner, was hired; and (2) Bill Hunt became a PI for ecosystem modeling. At the MCM Science meeting in August, 2007 Bill requested he become a formal collaborator rather than a PI because of family reasons, and the PIs agreed. Both Dr. Roberta Marinelli and Dr. Henry Gholz were notified of this decision in September. Details of our future modeling directions are provided in Appendix B.

Another new development during MCM-III has been the additional responsibility of MCM-LTER (by Priscu and Lyons) of administering, staffing and running the analytical chemistry laboratory in the Crary facility at McMurdo Station for the 4-month field season. This began in 2004. This new arrangement/organization was formalized through MCM-III by the addition of funds through NSF-OPP to hire a full-time analyst and two hourly seasonal personnel. Welch, in addition to her other duties, is the lab oversight manager, and Rob VanTreese was hired through Montana State University as the analytical chemist. Welch also analyses major ion samples and VanTreese is responsible for nutrient analyses, both based in McMurdo. The two hourly MCM seasonal hires change yearly based on personnel available and are responsible for TOC and chlorophyll-a analysis. Over the past three years seasonal hires were from Lyons, Priscu and McKnight's groups. Rather than measuring C/N on solids in McMurdo, these samples are now shipped back to Montana State where they are analyzed during the non-field season portion of the year. After a transition period, the new organization has worked quite well.

Currently the field season is limited to 30 field scientists and 3 lab scientists due to logistical constraints, which restricts our flexibility. This was clearly noted by both the site review team in 2002 and the reviewers of our MCM-III proposal. Before the last proposal submission, we designated a new category of scientist termed "investigator" to go with our "formal collaborator" designation (**Table 1 -** collaborators and investigators). Investigators are generally young scientists who either had graduate student or post doctoral experience working with MCM-LTER PIs. We think this category will allow us to develop young scientists for MCM leadership roles. The investigators and formal collaborators have contributed greatly to MCM (see publication list). They attend our annual science meetings and interact with the PIs and students on a range of activities. For example, Lyons spent August 2007 in England on a Royal Society Travel Grant visiting Laybourn-Parry and Tranter in order to coordinate future science efforts, synthesize data, and prepare manuscripts. Fountain traveled previously to work with Tranter resulting in a special forth coming issue of JGR-Biogeosciences on cryoconites.

We continue to encourage and promote diversity with MCM. Two of the seven PIs are women, 40% of the investigators and 33% of the formal collaborators are women. Currently, 42% of the undergraduate and graduate students are women.

Based on our international activities and scientific visibility, we believe the MCM is a leader within the LTER Network. MCM continue to maintain strong ties to the New Zealand Antarctic program through collaborations through the Latitudinal Gradient Project (LGP) and close collaboration with NIWA in order to carry out the lake benthic studies every other year. During MCM-III we have had Russian, Japanese and Czech Republic scientists on our field teams. Most of the PIs are invited on a regular basis to attend international and/or foreign national Antarctic related meetings. In 2007 alone, Wall and Lyons were invited speakers at the Italian Antarctic Biological Program's meeting and the 50^{th} Anniversary of the New Zealand Antarctic program; Lyons was asked to be a keynote speaker at the International Environmental Biogeochemistry Symposium in NZ to synthesize MCM-LTER research. In Madrid, Priscu presented a keynote lecture on biodiversity, sponsored by the Spanish Antarctic Program, and he spoke on pole-to-pole climate change in Edmonton, Canada, sponsored by the Canadian polar program. For other important activities see Outreach (Section 4).

The LTER Network recently introduced the ISSE (Integrative Science for Society and Environment) plan, which recognizes the importance of human imprints on ecosystems. MCM and Palmer (the other Antarctic LTER site) have been funded for a workshop in the spring of 2008 entitled "Antarctic Socioecology: Climate Change and Human Decisions" in order to begin a discussion of how the Antarctic LTER sites might better integrate into this program.

Formal Collaborators		
Dr. Byron J. Adams	Brigham Young University	Molecular Biology
Dr. Gayle Dana	Desert Research Institute	Energy Balance, Radiative Balance, Remote Sensing
Dr. Ian Hawes	National Institute of Water and Atmosphere, New Zealand	Algal Mat Ecology and Physiology, Aquatic Ecology
Dr. Fabien Kenig	University of Illinois, Chicago	Organic Geochemistry, Isotope Studies
Dr. Johanna Laybourn-Parry	University of Tasmania, Autralia	Protozoan Ecology, Microbial Loop Dynamics
Dr. Martyn Tranter	University of Bristol, England	Glaciochemistry, Glacial Hydrology, Glaciology
Investigators		
Dr. J. E. Barrett	Virginia Tech	Soil Biogeochemistry
Dr. Brent C. Christner	Louisiana State University	Microbiology
Dr. Christine Foreman	Montana State University	Microbial Ecology
Dr. Michael N. Gooseff	Pennsylvania State University	Hydrology
Dr. Cristina Takacs-Vesbach	University of New Mexico	Microbial Ecology

Table 1. Formal Collaborators and Investigators

3. Information Management

Organization

The MCM information management (IM) system is housed at the BPRC at OSU. At the onset of MCM-III, the IM position transitioned from a part-time graduate student to a full time employee. The current information manager is Chris Gardner, who is responsible for systems administration and the entire database, webpage and GIS. Communication with PIs is frequent, and additionally an IM subgroup was formed that includes a representative for each PI. Gardner communicates regularly with group members regarding data submittal, data and metadata protocols, and various site management tasks. IM is also an important component at annual MCM science meetings. Gardner represents MCM at the annual LTER IM meetings and attends various workshops, including informatics and GIS training, to ensure MCM is consistently state-of-the-art. Comprehensive IM protocols are constantly updated to ensure a smooth transition after a turnover of personnel as recommended by the LTER IM committee.

Computing hardware consists of a Sun Microsystems SunFire V480 server running an Oracle relational database, which holds all data and GIS layers. The server runs the dynamic website and serves GIS layers to the online map and remote ArcGIS users through ArcSDE. A secondary SunBlade 1500 system automatically replicates and updates the entire Oracle database and entire contents of the primary system, and operates ArcGIS Server, the online mapping application. Monthly backups are also transferred to external hard drives, which go offsite for further data redundancy. A SunBlade 1000 server continues to be maintained at INSTAAR for stream data and additional storage space.

Strategy

A distinguishing feature of MCM is the high degree of coordination needed for planning field seasons. The MCM IM system facilitates timely access to data and metadata, participates in cross-site IM activities, and improves MCM site organization. Gardner works closely with the IM subgroup to ensure data and metadata are made publicly available online as quickly as possible. Data accessibility is driven by the timing of the annual field season and completion of data analyses. Some data products, including meteorology measurements and stream flow, are submitted within 4 months of the season, and made public *immediately* after they have been worked up by PIs and checked over by the IM. Slower-acquisition data where analysis time consuming or costly (e.g. chemistry, soil biota species abundance) may be unavailable for 6-12 months or more and will be on the web in a minimum of 2 years. Some datasets are restricted to the MCM LTER until after 2 years of collection so MCM personnel can perform final QA/QC. These datasets are automatically made public after the 2 year restriction period has passed.

Our website (www.mcmlter.org) was redesigned in 2006 to be more user-friendly, dynamic, up-to-date and attractive to public visitors. Users can access data quickly and easily – core data are downloaded with 3 clicks on our webpage. Core data are kept entirely in the Oracle relational database and web output includes the MCM data use agreement and metadata URLs with data in a comma-delimited format. Users may browse data by season, perform a custom data query, or retrieve the entire dataset directly though the metadata. Many useful derived datasets are also available through custom tools. Statistics for continuously measured data (i.e. stream flow and meteorology), table joins and unit conversions are all done automatically by the database and available on the web.

During MCM-III, all metadata were converted to the Ecological Metadata Language (EML) used by the LTER Network at “level 5.” Metadata are harvested daily by the LTER Network servers for inclusion in global metadata searches. These metadata are updated to keep pace with seasonal variances in instrument status and measurement practices. Our system contributes to the LTER Network-level databases ClimDB and HydroDB, which are automatically kept up-to-date, thanks to data transformation scripts. The LTER-level site bibliography, personnel list, and SiteDB are always kept up-to-date.

Site management tools on the web

The website also features many new enhanced tools related to website management. The site has a fully searchable database of publications and student theses/dissertations, a personnel list, MCM news (distributed across the web through RSS), outreach events, website and data usage statistics and a database of ancillary field projects. MCM personnel may make their own additions to all of these databases online through the restricted portion of the website.

Incorporation with Field Sampling and Analytical Services

After MCM took over responsibility of the analytical chemistry lab at the Crary facility at McMurdo station, Gardner developed a new system to ensure data integrity throughout the life cycle of submitted samples. Each team has access to a comprehensive web page outlining protocols to be followed from field to data submission. Downloadable chain of custody (COC) forms ensure that sample names and date/times entered will be consistent with constraints in the existing database. These forms are entered into a web-accessible database that allows analysts to copy and paste sample names into their instrument software, allows the IM to ensure all expected data are received after the field season, and allows the IM to incorporate field notes from the COCs into data tables. Data format templates, protocols, and guidelines for submitting data to the IM are also available here.

GIS and Mapping

The original GIS of Taylor Valley was developed at the Desert Research Institute, which was later replaced by VALMAP, developed by Dr. Michael Prentice at the University of New Hampshire. The VALMAP team was instrumental in rectifying the previously established benchmarks and in creating many spatial datasets. In 2003, the VALMAP layers were transferred to INSTAAR and held in the Oracle relational database, which was transferred to BPRC at the onset of MCM-III.

A previous reviewer observed that “it is critical that MCM revive their GIS solution and make it more available to researchers. It is also advised that MCM come up with a plan for how to maintain and enhance their GIS, while better integrating it with their other data collection efforts.” We have responded to this criticism in the five areas below:

1. *System Architecture*. Spatial layers are stored in Oracle and managed through ArcSDE with multiple levels of access. Edits are made directly to the database using a database connection in ArcMap on PC by a user with editing privileges, while most researchers have read-only privileges. All edited layers are replicated to our secondary server as changes are made.

2. *Improvement of GIS Layers*. Gardner organized, attributed layer features, performed QA/QC on VALMAP layers and created new spatial layers (e.g. glacier stake, meteorology station, and stream gauge locations, DEMs, and vector bathymetric contour maps). Additional metadata have been associated with existing VALMAP layers.
3. *Integration with Other Data*. Many GIS layer features are now encoded with parameterized URLs to related up-to-date data through the web, which allows users to directly access data through the GIS, regardless of how the layer was obtained. New datasets with a fundamental spatial component are being developed, which will be joined with existing data entirely within the relational database so spatially-referenced data can be utilized directly within the GIS.
4. *Improved Access to Researchers.* We provide three methods for accessing GIS data:
    a. *Online Interactive Map.* This option allows interested researchers and the general public to utilize basic GIS resources directly through our website. In addition to navigation, identification and measurement tools, the site acts as a data portal, allowing users to download data by clicking on various features.
    b. *Direct Connection to the Spatial Database.* MCM personnel and other researchers may connect directly to our Oracle spatial database through ArcGIS 9.2 as a read-only user. This option allows users to add all available MCM spatial layers to their map across the internet. Instructions are found in the restricted access portion of our website.
    c. *Download Exported Layers.* Many layers have been exported from our database and made available for download. These layers are pre-symbolized, allowing users to create quality maps quickly and easily for publication or incorporation with their own spatial data.
5. *Future Plans*. In addition to incorporating new spatial layers into the database, we will begin creating metadata for all layers through ArcCatalog, and a script will convert the metadata to EML to be harvested by the LTER Network. We also plan to create layers in Google Earth with links to data and photos taken by MCM team members as part of our outreach, and add additional functionality to the online map.

Concluding Remarks and Future Goals

Our IM system is now functioning at a level equivalent to the best in the LTER Network. In the future, our goal is to better capture ancillary data produced by graduate students and make theses and dissertations available online. Our metadata strategy will expand to a more database-oriented approach and our GIS will continue to evolve. A system for better tracking data usage through the web will also be implemented.

4. Outreach

MCM LTER continues to actively engage in education and outreach activities. Dr. Carol Landis began coordinating the collective MCM outreach/education activities at BPRC in 2005. Outreach activities are summarized under the seven categories below.

1. The Lost Seal. As part of the LTER children's book series, *The Lost Seal* written by McKnight, was published by Moonlight Publishing in 2006, and is available from Amazon and Barnes & Noble. This true story tells of one seal's travels in the Antarctic desert and provides an engaging framework for conveying how different Antarctica and the Dry Valleys are from the environments with which children are familiar. It contains original artwork from children in grades 2-4 from 19 different elementary schools throughout the world. The book has received considerable attention from the press, the LTER Network and NSF. For the 2nd Edition in 2008, a teachers' guide with extra digital material and classroom activities will be included. The book's success led to NSF seed money for other proposals for the LTER children's book series.

2. Website and Online Resources. Previous reviewers suggested we focus on online interactive resources to strengthen our outreach program. Our newly-designed website continues to be an important source of outreach and education materials, including a searchable photo gallery, an interactive MCM map, and field blogs by MCM field team members that are associated with educators in the U.S. The site also hosts *77 Degrees South*, McKnight's group's online journal and resources for K-12, which has continued since 2002. A highly visited site is *The Lost Seal* (www.mcmlter.org/lostseal), where children browse through 490 pieces of original artwork and associated captions about MCM and the dry valleys created by students around the world. They may also explore the dry valleys through photos of MCM and video of the real life lost seal.

3. Interactive CD. In 2006, Landis and her students produced a set of interactive CDs about MCM research for middle/high school science education. The CD set includes a student CD with a primer about basic ecological principles, accompanied by a teachers' guide. The student CD is rich with images, including student-drawn illustrations. The CD set has been showcased by Landis at science teacher conferences and teacher workshops, and over 900 sets have been distributed. The teachers' guide includes cross-references to the National Science Education Standards, video interviews with scientists, and a selection of activities that teachers can use for engagement and enrichment. Images and explanations from the CD set contributed to the development of the Teachers' Guide for the second edition of *The Lost Seal*.

4. SLTER. Our Schoolyard program continues to focus on the Columbus metro area and is based out of Linworth Alternative High School, part of Worthington Schools. Activities are primarily directed at water quality studies on the Olentangy River in Columbus, where students sample at various locations. The SLTER website (www.mcmlter.org/SLTER) was recently updated to accommodate the increasing datasets from new relationships with additional schools. New features include an interactive Google map of sampling locations with videos, and a custom searchable database of student-collected data. An OSU undergraduate also synthesized the data and presented at the North Central Geological Society of America meeting in 2006.

5. Presentations at Professional Education Meetings. Landis's presentations on MCM-LTER activities include the national-level National Science Teachers Association (NSTA) meeting in St. Louis in 2007; the Science Education Council of Ohio (SECO) meetings in 2006 and 2007; the North Central Geological Society of America (GSA) meeting in 2007; and the Society for Information Technology and Teacher Education (SITE) in 2006.

6. Outreach to Schools, Other Groups and the National Media. MCM members frequently present their research at a variety of schools, community groups and public forums. These numerous outreach events highlight not only MCM activities, but also the importance of long-term ecological data and the multidisciplinary approach taken by the LTER. Highlights include the following (a more complete list can be found at www.mcmlter.org/outreach.htm):

- Wall helped establish an ongoing public lecture series in Ft. Collins that features Antarctic speakers, including Wall and McKnight.
- Lyons continues to be involved with COSI (Center of Science and Industry) in Columbus, where he presents via distance learning TV to middle/high school students from New England to Texas about polar science, climate change and LTER activities
- Doran wrote an Op-Ed piece for the *New York Times* entitled "Cold, Hard Facts," written to try to combat the spread of misinformation over Antarctic climate trends. Numerous web articles covered the piece, which led to his appearance on several radio shows and more print interviews.
- Byron Adams, a formal collaborator, established a module for grades 7-12 science teachers for the Utah state biology core curriculum that features Antarctic soil biology and MCM-LTER activities (www.schools.utah.gov/curr/sci/Evolution.htm).
- A television piece about *The Lost Seal* on Denver's CBS affiliate led to McKnight speaking to neighborhood groups about earth science education for children and a lecture to the city of Boulder, CO during a climate change action rally in 2007.
- Numerous groups visit the Byrd Polar Research Center every year (1200 visitors during the 2005-2006 academic year), where MCM research activities are featured.
- Students and other field team members frequently speak to school groups or answer children's questions from the field through blogs. Holly Zedah, John Chaston, Chris Gardner, Breana Simmons, Robin Elwood and Sarah Fortner all participated in these activities.
- Priscu is working with videographers from POLARPALOOZA to develop podcasts of late season research that will occur in 2008 and will be taking a professional artist (as part of NSF's artist and writers program) with him during this same period.

7. Distinguished Visitors and Media Visits to the Site. Because of our unique location, our site is visited by both media and political figures every field season; the last site review team made an important note of this. For example, during the 2005-2006 season, Lyons and other MCM team members interacted with Senators McCain and Collins, as well as Congressman Boehlert, then chair of the Science Committee in the House of Representatives, and much of his committee members. During the 2006-2007 season, Fountain and MCM students hosted NSF Director Dr. Arden Bement and Helen Clark, Prime Minister of New Zealand, at the site. This season the MCM field team will host British film makers working on a documentary on climate change. During these important interactions, MCM scientists and students play a vital role in highlighting the importance of LTER-type research and serve as a significant conduit of LTER and Antarctic science to these important visitors and the public media.

Appendix A. Research Components

Limnology

The limnology team has made continuous measurements of selected physical, chemical and biological parameters on 4 lake basins (Fryxell, Hoare, east lobe Bonney, west lobe Bonney) at approximately monthly intervals during the austal summer since the inception of the MCM-LTER. All of these lake basins are hydrologically terminal (i.e. there are no outflows) and integrate environmental change in the region. They are also the only landscape unit that contains bulk liquid water throughout the year. Our long term data on phytoplankton dynamics reveal that summer rates of primary productivity (PPR) and chlorophyll-a (CHL) react dramatically to changes in temperature-induced stream flow. This response is supported by the fluctuations recorded in east lobe Lake Bonney that followed the 2001-02 austral summer, which had the warmest air temperatures recorded by the MCM-LTER since its inception (**Figure 6**). The "flood" event that resulted from the warm air temperatures also changed the ice thickness in all of the lakes resulting in changes in the under-ice photosynthetically available radiation. The 10 years before the flood was a period of cooling, and phytoplankton production was in quasi-steady state with respect to time. These results have led us to develop a conceptual model of the lake ecosystem where we suggest that periods of relatively stable climate produces an oscillating system punctuated by decadal warming events. As climate continues to either warm or cool, a threshold is eventually reached where lake basins either coalesce or separate, resulting in a new level of biological activity and diversity (**Figure 7**). Only through continued long term research will the true dynamic nature of the ecosystems be known.

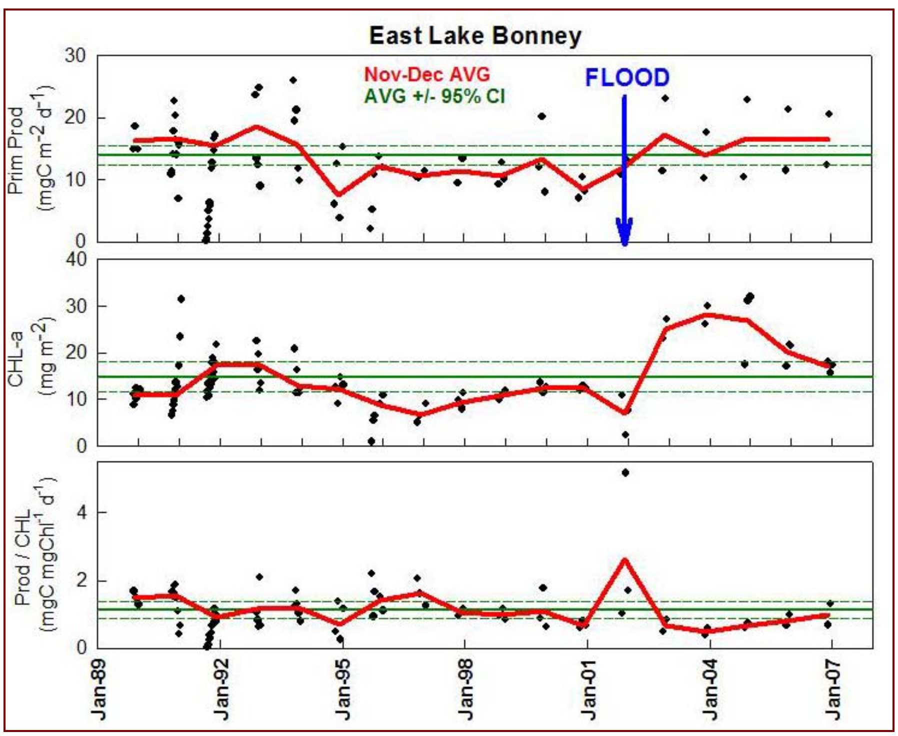


Figure 6. Long-term changes in depth-integrated primary productivity, chlorophyll-a, and primary production:chlorophyll-a in the east lobe of Lake Bonney. The dots indicate individual measurements; the solid red line is the Nov-Dec average for each year; the horizontal green line is the long term average from 1989-2007.

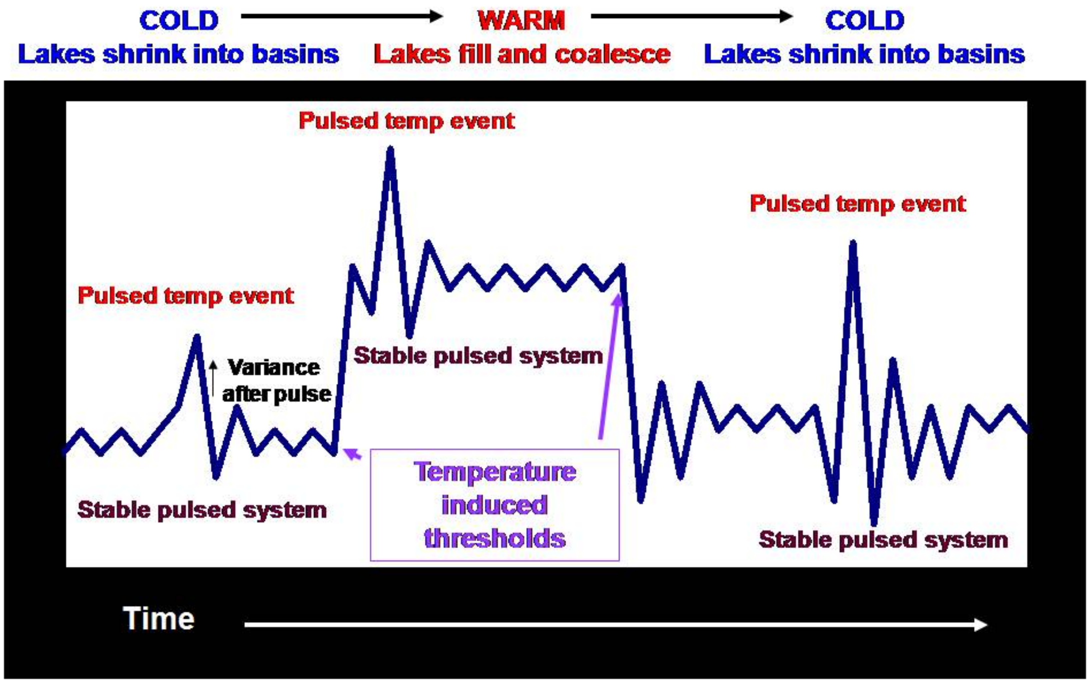


Figure 7. Climate induced conceptual model for MCM lakes

Long Sediment Cores

During the 2001-2002 field season, PI Doran, collaborator Fabien Kenig and German colleagues then from Alfred Wagner Institute, extracted long sediment cores from Lake Fryxell, Lake Hoare and both lobes of Lake Bonney. Analysis of these cores has been an ongoing process under the auspices of the MCM-LTER. The Lake Fryxell sediments have been the most thoroughly studied to date because this was our most complete sediment record we collected. The total sediment sequence was 9.14 m long with an estimated basal date of 48 k cal yr BP (Wagner et al., 2006). Our research on the Fryxell sediment core has provided the first direct evidence that Lake Fryxell has had a continuous presence back through the Last Glacial Maximum. Wagner et al. suggest that Glacial Lake Washburn was established at 42,000 cal. year BP, which is 10,000–14,000 years earlier than previously assumed. Although there is evidence of lake level fluctuation since then, there is no evidence of the lake desiccating during that time. This is significant for the MCM, in that it suggests the lake habitat in Fryxell have been continuous for several tens of thousands of years. Recent stable isotope work (Moore Topinka, 2007) has allowed us to refine the history of Lake Fryxell and hence the legacy left by these historical events (**Figure 8**). These data support the conclusions of Wagner et al., but further suggest that the most recent period has been marked by significant lake level fluctuations, which may have at least been partially driven by periodic drainage of Lake Hoare into Lake Fryxell. Analysis of the Lake Hoare sediments also suggests that Lake Hoare has gone through a number of draining events over the last 14,000 ^{14}C yrs (Burkemper, 2007). Both the Lake Fryxell and Lake Hoare sediment cores suggest the recent lake levels represent high stands for the late Holocene. Analysis of the Lake Bonney cores continues, but both cores are highly unusual and have required careful (slow) progress. The East Bonney core is about 3 m long and is composed mostly halite crystals. Our German colleagues have been working on this core, but have yet to report their results. One third of the west lobe Bonney core was comprised of an unknown volatile material which dissociated when brought to the surface. The material is most likely a CO_2 clathrate, but we have not yet ruled out the mineral ikaite. In either case, both of these substances are stable only at depth, and fluctuating lake levels over time will have significant implications for CO_2 flux and storage at the lake bottom.

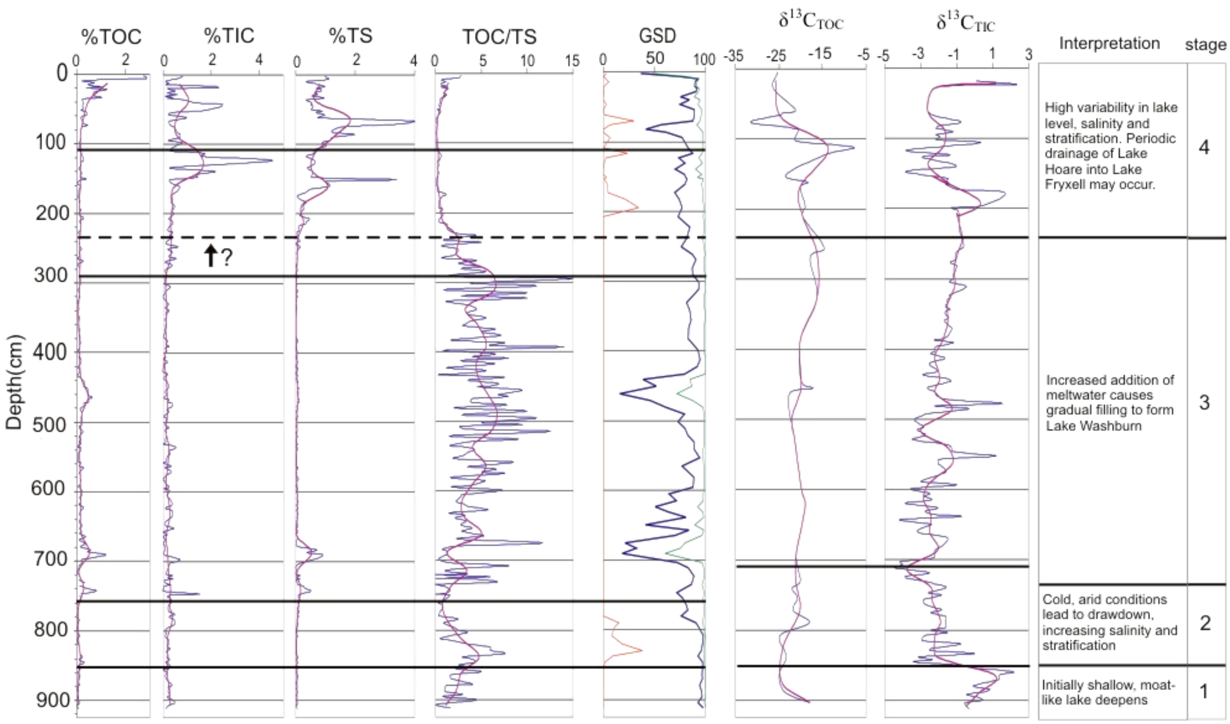


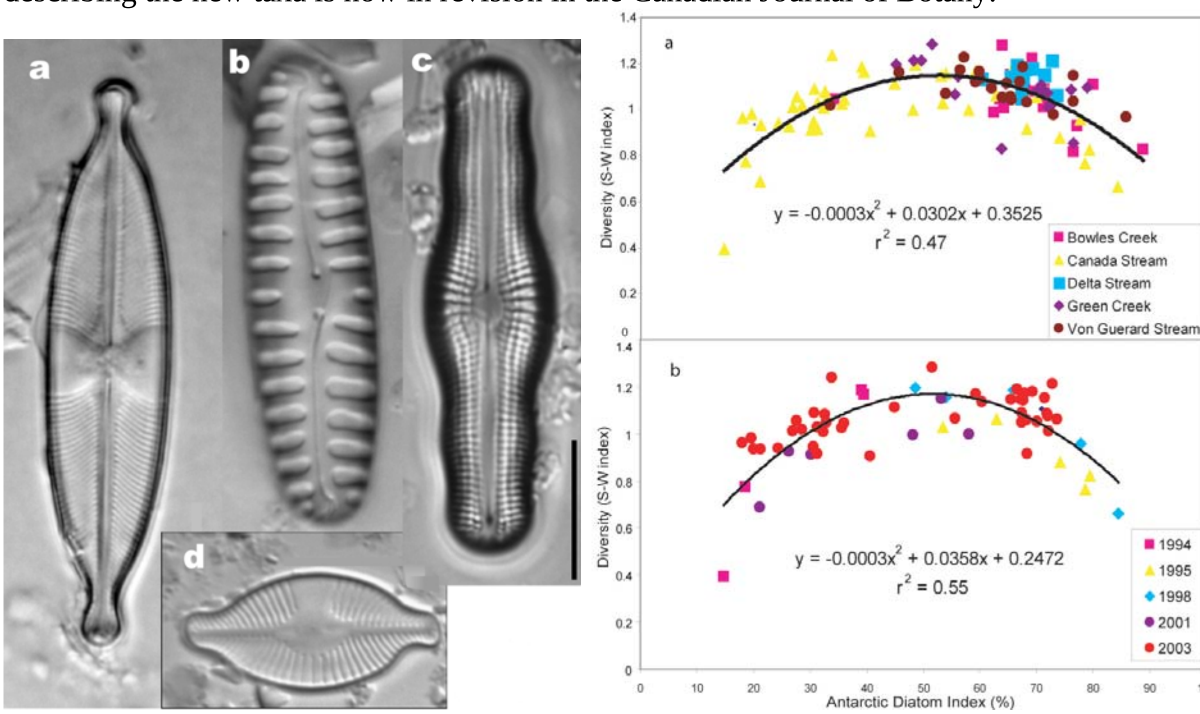
Figure 8. Comparison of Lake Fryxell sediment core Lz1021 data from Wagner et al. (2006) (TOC - total organic carbon, TIC – total inorganic carbon, TS – total sulfur, and GSD – grain size distribution: %gravel, sand, silt, clay) and $\delta^{13}C_{TOC}$ and $\delta^{13}C_{TIC}$ from this study, with interpretations. Smoothed lines indicate running averages. Thick horizontal lines indicate stage delineations from Wagner et al. (2006) and this study. Dashed line indicates proposed new position of stage III/IV boundary (from Moore Topinka 2007).

Stream Hydrology and Ecology

The McMurdo Dry Valleys contain many glacial meltwater streams that flow for 6 to 12 weeks during the austral summer and link the glaciers to the lakes on the valley floors. Dry valley streams gain solutes longitudinally through weathering reactions and microbial processes occurring in the hyporheic zone. Some streams have thriving cyanobacterial mats. In streams with regular summer flow, the mats are freeze-dried through the winter and begin photosynthesizing with the onset of flow.

One of the key habitat features of the dry valley streams is that water temperatures reach 15°C every day when the sun is directly overhead. These warm temperatures promote the growth of the algal mats during the brief summer. We have found that the maximum temperatures in the streams are controlled by the balance between the rates of warming by solar radiation and cooling by evaporation. An experimental "cooling" manipulation of a dry valley stream was conducted to quantify the rates of processes that control the warming of the stream. This experiment also confirmed that advection of the warm water into the hyporheic zone eroded the frozen boundary with the underlying permafrost, causing the hyporheic zone to expand during the summer (Cozzetto et al., 2006). Subsequent field experiments have been conducted to more fully resolve the thermal budget for the streams.

Diatom algae from our monitoring sites in the glacial meltwater streams that flow into Lake Fryxell were identified to elucidate biotic responses to the cooling trend. Diatoms are abundant in these streams, and 24 of 40 species have only been found in the Antarctic, predominantly in the South Victoria Land (Esposito et al., 2006) (**Figure 9**). We found that the percentage of these Antarctic diatom species increased with decreasing annual stream flow and increasing harshness of the stream habitat. Harshness was characterized using the stream flow record following an approach developed by the Konza LTER for intermittent prairie streams. The species diversity of assemblages reached a maximum when the Antarctic species accounted for 40–60% of relative diatom abundance. Decreased solar radiation and air-temperatures reduce annual stream flow, raising the dominance of these Antarctic species to levels above 60%. These results show that cooling favors the Antarctic species, and generally lowers diatom species diversity in this region. We created a relational database that presents the morphological information on the diatom species found in these streams, and this database is widely used by diatomists from other Antarctic research programs. Endemic diatoms have now been cultured and identified using morphometric and molecular techniques to assess their evolutionary relationships. A manuscript describing the new taxa is now in revision in the Canadian Journal of Botany.



A. **B.**

Figure 9. **(A)** Light micrographs of Dry Valley diatoms. (a*) Stauroneis cf. latistauros*, (b) *Pinnularia borealis*, (c) *Muelleria meridionalis var. #1*, (d) *Psammothidium germainii var. #1*. The scale bar is 10 microns, and applies to all images. **(B)** (a) Graph of Shannon-Wiener diversity index as a function of the Antarctic Diatom Index, measured as the relative abundance of endemic Antarctic diatoms. The equation and curve is significant at the $P < 0.0001$ level. Points for individual streams (a) or years (b) are coded according to the legend.

To evaluate the longer term persistence of cyanobacterial mats, we diverted flow to an abandoned channel, which had not received substantial flow for approximately two decades.

Monitoring of specific conductance showed that for the first 3 years after the diversion, the solute concentrations were greater in the reactivated channel than in most other dry valley streams. We observed that cyanobacterial mats became abundant in the reactivated channel within a week, indicating that the mats had been preserved in a cryptobiotic state in the channel. Over the next several years, these mats had high rates of productivity and nitrogen fixation compared to mats from other streams. Experiments in which mats from the reactivated channel and another stream were incubated in water from both of the streams indicated that the greater solute concentrations in the reactivated channel stimulated net primary productivity of mats from both streams. These stream-scale experimental results indicate that the cryptobiotic preservation of cyanobacterial mats in abandoned channels in the dry valleys allows for rapid response of these stream ecosystems to climatic and geomorphological change, similar to other arid zone stream ecosystems.

Soils

Despite an appearance of uniform sterility, Antarctic soils have a high degree of spatial and temporal heterogeneity in soil properties, hydrologic regimes, and biota. We are working to relate this variability to geological legacies and to the resulting complex distributions of invertebrate communities. To address the central hypothesis, *biodiversity and ecosystem structure and function in the MCM are dictated by climate legacies with contemporary biotic and physical processes*, the study of the dry valley terrestrial landscape is partitioned into two foci: the effect of climate legacy on soil biogeochemistry and terrestrial biodiversity. These research paths are integrated to provide a complex picture of the functioning of the soil ecosystem within the McMurdo Dry Valleys.

Biogeochemical controls on the distribution of biota were examined utilizing the natural gradient in geochemical conditions occurring at Bull Pass to quantitatively assess controls over the distribution and abundance of the dominant animal, the nematode *Scottnema lindsayae* (Poage et al., in press). Correlations suggest that progressive increases in anion concentrations (particularly nitrate), collectively reflected in the conductivity values, create progressively inhospitable soils for viable *S. lindsayae* communities along the Bull Pass transect. We proposed that the influence of soil salinity on invertebrate community structure is scale-independent over ranges of meters to tens of kilometers and should be considered a primary determining factor explaining nematode habitat suitability (Barrett et al., 2004; Courtwright, 2001). This dataset, compared with model results from previous literature, suggests that the large scale distribution of nematodes across the MCM may be reflected in small-scale chemical gradients.

Soils are the primary reservoir of phosphorus in the McMurdo Dry Valleys, a severely P-limited ecosystem. Quantification of the P content of chemically-defined fractions in soils indicates that landscape history and contemporary subsurface and stream hydrology are the primary controls over phosphorus cycling in the MCM. As with other terrestrial deserts, P dynamics are dominated by physicochemical factors, with little internal biological P cycling except in stream channels or biologically active upland soils. There is little evidence for spatial variation in P dynamics as a consequence of *in situ* processes, as has been suggested for the MCM, but for a larger role of geological legacies (Bate et al., in press, Blecker et al., 2006).

The MCM polar desert also provides an opportunity to evaluate stoichiometric approaches to understand nutrient cycling in an ecosystem where biologic diversity and activity are low and controls over the movement and mass balances of nutrients operate over $10\text{-}10^6$ years. The high variability in ecosystem stoichiometry was examined using contemporary C, N and P data from soils, glaciers (cryoconite holes), streams, and lakes, and a synthesis of recent literature to develop a conceptual model describing variation in element ratios and nutrient transformations among aquatic and terrestrial landscapes of the MCM (**Figure 10**). We conclude that contemporary ecosystem stoichiometry of Antarctic dry valley soils, glaciers, lakes and streams result from a combination of extant biological processes superimposed on a legacy of landscape processes and previous climates. Physical processes (e.g. weathering, landscape development, etc.) dominate the geochemical stoichiometry of soil and aquatic system weathering controls biota. When activated by the availability of liquid water, biota can alter the environment according to their strict biochemical requirements. Sources of nutrients (N and P) in the MCM are often decoupled from the biota that facilitate their transformation and the availability of liquid water that controls their transport (Barrett et al., 2007).

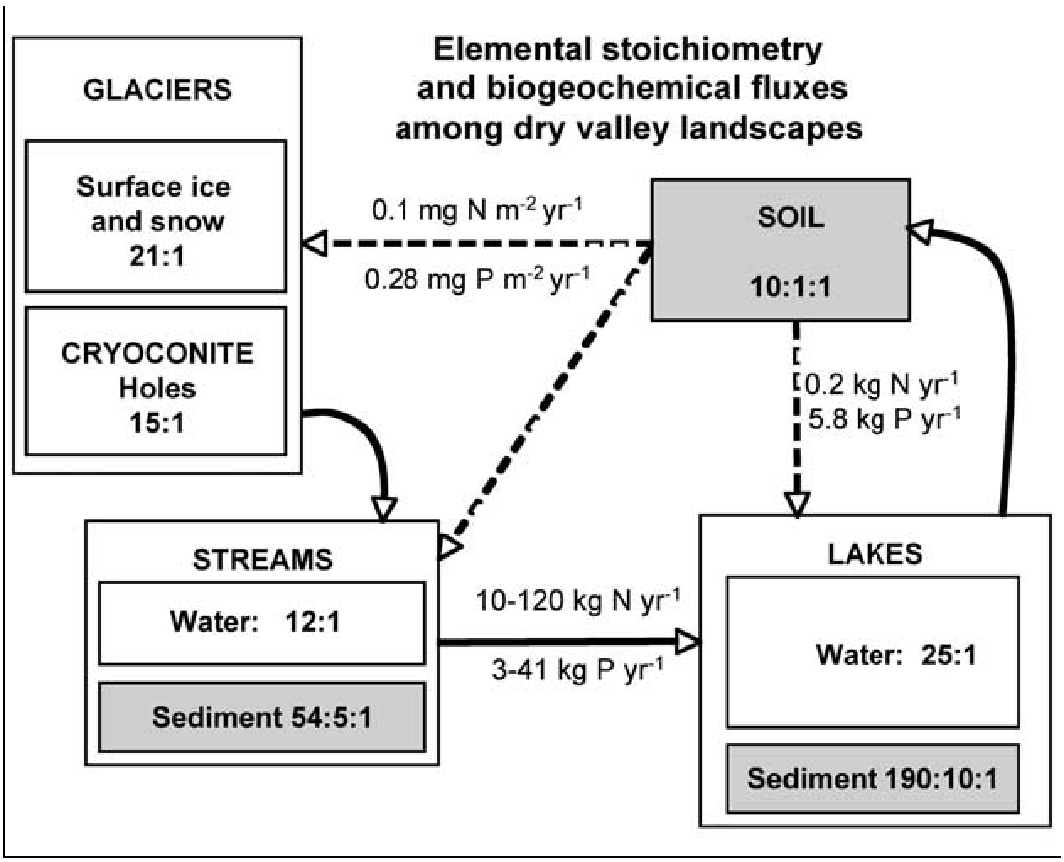


Figure 10. Average molar N:P or C:N:P ratios and biogeochemical fluxes among landscape units in eastern Taylor Valley, Antarctica. Estimated and theoretical aqueous fluxes are depicted by solid arrows, eolian fluxes by dashed arrows. A general narrowing of N:P ratios illustrates a biological modification of melt water along this hydrological continuum closer to the ratio of microbial biomass. Lakes, as the bottom of this hydrological continuum, integrate the legacies of geology and climate resulting in unique lake chemistries and stoichiometry in each basin contingent upon the chemistry of surface soils and tills and its climate history.

To understand how soil biodiversity mediates ecosystem processes within MCM we examine factors driving soil species biogeography, phylogeography, the direct and indirect effects of global change on soil biodiversity, and the connections between biodiversity and ecosystem components (glaciers, streams, lakes, geologic history, atmosphere, etc). Our understanding of the distribution of soil invertebrate diversity *at the species level* across the landscape, and how human-mediated disturbances will impact diversity within the ecosystem, has been significantly advanced through our integrated approach that ranges from genes to landscape.

Within the Taylor Valley, some nematode species are dispersed by wind in a survival state, anhyrobiosis, with no apparent geophysical barriers (Nkem et al., 2006a). Long term field studies have shown that soil factors such as salinity, pH, and nutrient status determine suitable habitats and structure species distributions (Nkem et al., 2006b, Adams et al., 2006, Blecker et al., 2006, Ayres et al., 2007, Poage et al., in press). Further study along elevation transects and long term manipulation plots show that faunal species have clearly defined niches in soils that are based on soil carbon, presence of algae, moisture, and salinity, and the structure of nematode genera (and rotifers and tardigrades) are similar in soils and sediments. This indicates that environmental conditions in Taylor Valley may select for groups with broad ecological niches (Ayres et al., 2007). However, molecular data shows both geographic (*E. antarcticus*) and ecological (*Plectus* spp) drivers of evolution (speciation) (Adams et al, in prep). Using molecular and morphological approaches we determined the southernmost distribution of Nematoda towards the pole and infer tremendous capacity for gene flow, but also high sensitivity to environmental perturbation (Adams et al., 2007).

Long term manipulation data from Taylor Valley indicate that direct (human trampling) and indirect (climate change) effects of global change can impact soil biodiversity. Even low levels of human traffic altered soil biotic composition (Ayres et al., submitted). A snow fence experiment suggests annual short-term water additions via snow melt changed community structure and species composition, while experimental warming and seasonal flooding reduced populations of the dominant nematode species (Simmons et al., in prep). Long term monitoring of Taylor Valley climate shows that cooling reduces populations of the dominant nematode species (Doran et al., 2002). The addition of labile carbon sources to soils over 13 years did not increase soil animals over the long term, indicating that climate effects such as temperature change and soil moisture may have a greater effect on species distribution than nutrient addition.

Modeling

We constructed a new model for soil water-release curves which is applicable to dry valley soils, and which also represents a fundamental advance in representing the effects of texture and bulk density on water potential (Hunt et al., 2007). A major conclusion was that soil texture is necessary for predicting matric potential and biological activity from observed gravimetric water, even though dry valley soils are very sandy, with clay contents generally below 7%.

The above model serves as the core of a new mechanistic heat and water flow model for dry valley soils. This model was developed using data for three sites in Taylor Valley, and predicts soil temperatures within 1 to 2 degrees in validation tests. The model (ms. in prep.) is being used to examine long-term trends in soil temperatures, a major control on the activity of soil organisms.

Glaciology

We hypothesized that subsurface glacier melting was ubiquitous, as is the case in other areas of Antarctica. While subsurface heating is ubiquitous, we now realize that melting is limited to zones of clear ice or ice with sediment. Thus subsurface melting is very localized (**Figure 11 - *Right***).

Our glacier-wide statistical models of seasonal melt have proved to be successful (Ebnet et al., 2005) and we plan on using these to estimate past and future lake level changes where only temperature change is known. We have also adapted physically-based models to investigate the specific controls on melt and to predict hourly to daily estimates of meltwater runoff. The modeling has shown good results for estimating total surface ablation (melt and sublimation) and for melt as well (Ebnet, 2008; Hoffman and Fountain, in prep). The modeling has shown that it is not glacier specific. That is, the characteristics of the ice appear to be fairly uniform in Taylor Valley. The large difference in the magnitude and timing of runoff has to be due to other factors discussed below.

The morphology of the glaciers changes dramatically from glacier to glacier with some glaciers as smooth as ice-skating rinks and others with large canyons. These differences are due to rock debris, either from rock avalanches, medial moraines, or aeolian transport of sediment, on the glacier surface that alter local energy balance conditions resulting in rough topography (Johnston, et al., 2005). This sets up a feedback process such that rough topography reduces the wind and that also shifts the energy balance at the ice surface from sublimation conditions to melting (runoff) conditions (Lewis et al., 1998). Melting is a more energy efficient ablative process and the roughness features develop further. The process is limited by the available solar radiation that can reach the bottom of the rough depressions and by the long winter night where the high points of the roughness ablate faster than the bottom of the depressions. The net result is that glaciers with a rough topography provide much more runoff than smooth glaciers (**Figure 11**). Future modeling will explicitly include the spatial pattern of glacier roughness in Taylor Valley for melt water flow (Ebnet, 2008).

Figure 11. *(Left)* The surface of lower Canada Glacier - the sediment melts into the ice creating large canyons on the glacier surface. Compare with the surface of Taylor glacier. *(Right)* Taylor Glacier - Despite the obviously cold temperatures, note that the crampons are not sinking into the ice, meltwater is found just below the surface.

Cryoconite holes are subsurface melt water habitats formed from ice melt around sediment patches on and in the glaciers (Fountain et al., 2003). Solar radiation preferentially heats the sediment compared to the surrounding ice, melting the sediment into the ice. We have shown that hole depth is in equilibrium with the local climate confirming theoretical studies. The holes host cyanobacteria, bacteria, and protists that incorporate nutrients from the sediments and the melting ice (Porazinska et al., 2004; Foreman et al., in press). The chemistry and physical evolution of the cryoconites varies from hole to hole depending on surface albedo and on subsurface hydrologic connections (Fountain et al., in press). The biology is fairly consistent on one glacier but varies from glacier to glacier. Cyclical precipitation/dissolution of carbonates reflects periods of summer photosynthesis and autumn net respiration prior to freezing (Tranter et al., 2004; Bagshaw et al., in press). Cryoconite holes represent an icy habitat and play a role as a way station in recycling sediment and biologic material transported from the valley bottom by winds and returned to the valley bottom by water. Periodically, as the cryconites are "flushed," they return organisms that have survived this environment back to the streams and lakes.

Glacier mass balance is measured because the growth or shrinkage of the glaciers is an important climate indicator and affects the ecology of the valley through landscape modification and water availability (**Figure 12)**. Our mass balance measurements over the past 10 years show that the glaciers are in equilibrium with the present environment, unlike the rapidly shrinking glaciers of the temperate or Arctic regions (Fountain et al., 2006). The meteorological measurements support this result, showing that the summer and annual air temperatures continue to cool with time as shown previously (Doran et al., 2002). We have also examined our precipitation data, after many difficulties in the field7 6 and can now show that yearly snow accumulation has not exceeded 10 cm water equivalent (weq) with minimum values of 0.3 cm weq. These values include both direct snowfall and wind redistribution of snow from the surrounding mountains. Direct snowfall is roughly 50% of the values stated (Fountain et al., in prep).

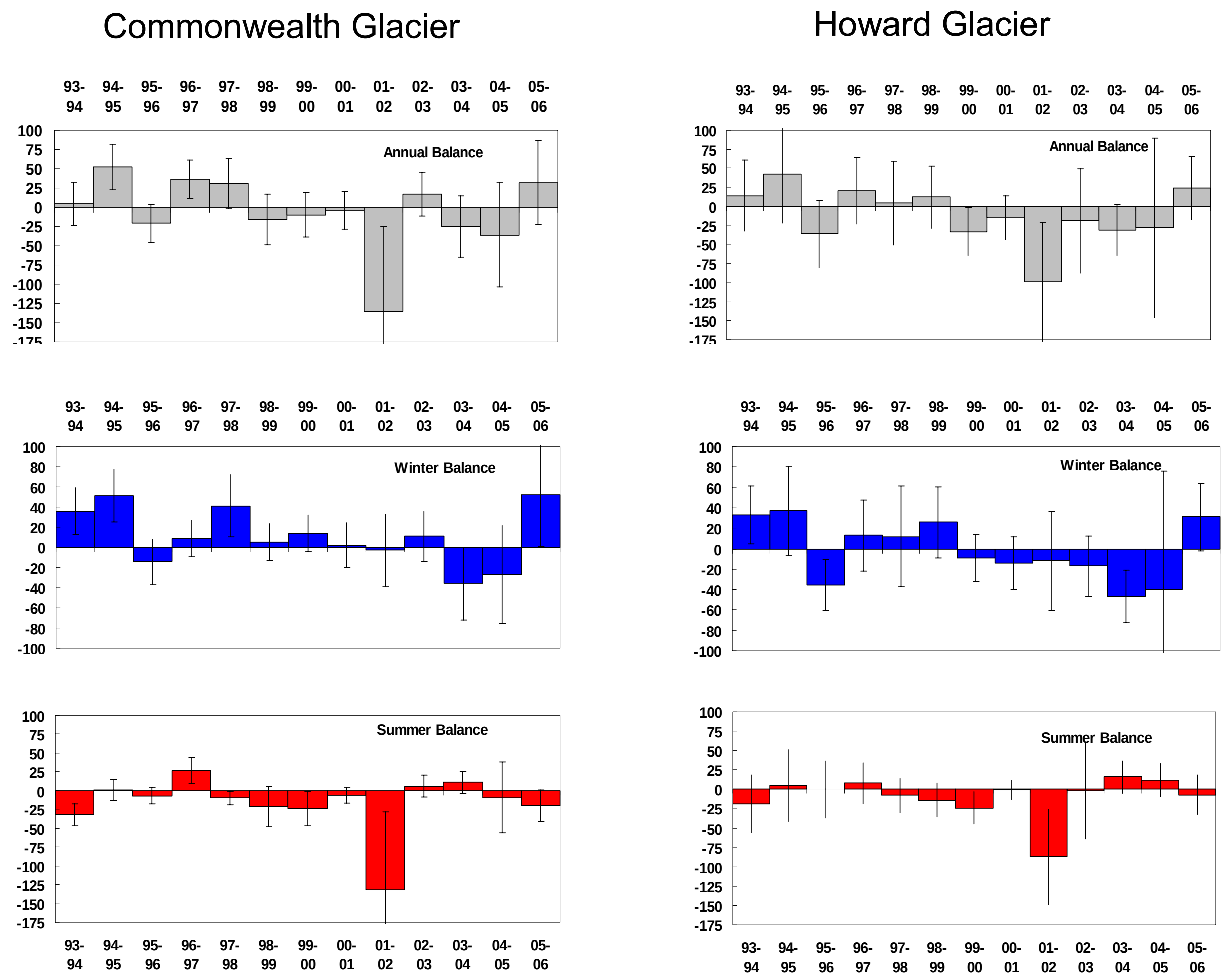


Figure 12. Mass balance data for the two glaciers measured. The 'big melt year' is obvious in the summer and annual balance of 2001-02.

Geochemistry

In addition to the ongoing monitoring programs where our geochemical measurements are used to track contemporary hydrological and biogeochemical processes, we have also used geochemical and isotopic distributions to describe past climate dynamics of MCM. For instance, we have used halogen geochemistry to understand the sources of solutes and evolutionary histories of the Taylor Valley lakes (Lyons et al., 2005). Recent work has also focused on the description of subsurface melt features within Taylor Valley and their potential contribution of solutes to the surface waters (Harris et al., 2007), and the processes involved in forming calcium carbonate in Taylor Valley soils (Foley et al., 2006). Review papers on the biogeochemistry of Antarctic and polar lakes have strongly relied on MCM geochemical data (Lyons et al., 2006; Lyons and Finley, in press). Geochemical investigations continue to be an important part of MCM synthetic activities, as evidenced by Barrett et al. (2007).

Appendix B. Modeling

We propose an integrated cross-landscape modeling effort to examine the impact of water/moisture variations on nutrient transport and biodiversity in MCM. Our understanding of the physical, chemical, and biological components of the ecosystem have matured significantly since the inception of the MCM, and we have developed a number of successful, but limited modeling efforts. Therefore, we are motivated to integrate our understanding and preliminary modeling efforts. We hope to engage the site review team in discussion relating to this new activity and receive feedback regarding its appropriateness. This effort would be led by Dr. Mike Gooseff, a current investigator with MCM.

Simulating Lake Hydro-Biogeochemical Fluxes

The first step in the development of this model will be to develop a valley-wide DEM/lake bathymetry landscape module which will output soil surface area, lake bottom area, and lake water column volume changes (i.e. at 1 m depth increments) for any change in lake level. Eventually the output from this module could be more finely subdivided (e.g. different soil elevational zones, light and oxygen zones in the lakes, etc.), in order to track how, for example, nutrient pools change with lake level change.

The levels of the closed-basin lakes of Taylor Valley (Bonney, Hoare, and Fryxell) and Lake Vanda in Wright Valley have been generally rising since the late 1960's, with the exception of the cooling period from 1986-2000 (**Figure 3**). Annual lake level rise is not readily attributable to annual air temperatures or differences from prior years (Chinn, 1993). Because the hydrologic inputs to (mostly stream flow) and outputs of (sublimation and evaporation) the lakes are dependent upon meteorological conditions that affect the surface energy balance of the lake surfaces, the lake levels represent an integrated hydrometeorological signal of summer melt and year-round lake water or ice loss. Thus, the pattern of lake level rise can be interpreted as an imbalance of these two processes. Whether the lakes are out of balance due to conditions prior to MCM, a result of suppressed loss or increased meltwater production is unclear. Overlain on these physical process templates, the lakes also represent biological integrators as they respond to inputs of dissolved nutrient and other solute loads, which are functions of both discharge and biological processing along flow paths from glaciers to the lakes.

Since the 1990's, the McMurdo LTER project has monitored these lake level changes, as well as discharge and dissolved chemistry for most of the contributing streams, and spatially distributed, high temporal resolution meteorological data. These datasets provide an excellent starting point from which to develop an integrated hydro-biogeochemical model for the lakes. Here we propose the development of such a model. A preliminary step in the development of this numerical model will be a lake water (including ice) mass-balance module, which would simulate lake water mass balance on a sub-daily temporal scale simulating the amount of lake ice sublimation, and lake water evaporation (from the lake-edge moats that develop in the austral summer), accounting for stream flow inputs during the summer and phase changes of the lake water. Calibration of this model would be constrained by the historic lake level measurements, and the geomorphology of the lake basin (available from bathymetry and the digital elevation model available from NASA for the area).

Stream Biogeochemical Inputs into the Lakes

Another part of this model will be a predictive simulation of stream-specific biogeochemical inputs to the lakes. It has been well-established that in the MCM dry valleys, longer streams provide less water and lower concentrations of nutrients to lakes during low-flow years. The former occurs because the streambed provides a large reservoir of space that must be filled with stream water before stream flow can progress viably. The latter occurs because longer streams provide habitat to more benthic microbial mats and there is more potential for hyporheic exchange in longer streams, both of which lead to nutrient uptake. The objective this module is to develop stream solute concentration(C)-discharge(Q) relationships from historic stream records to estimate the mass loadings of a variety of nutrient (C, N, and P species) and major ions (Ca, Cl, Na, K, etc.) over a variety of discharges and temporal record. These C-Q relationships will be developed with existing stream flow and chemistry records, and will account for possible hysteresis in these relationships, specific to each solute and each stream.

Soil Moisture Fluctuations, Nutrient Cycling and Habitat Suitability

The hydrology of the soils, away from the streams, is controlled by snowfall patterns and by permafrost either in interstitial form or in massive ice (Bockheim, 1997). Both ice-rich permafrost and large snowfall (~10 cm water equivalent) occurs near the coasts (Fountain et al., 1999) under a relatively thin active layer creating relatively moist soils. Soils dry with distance inland with reduced snowfall (~0.1 cm water equivalent), warmer air, thicker active layers, and much less interstitial ice in the permafrost. Much of the snow is sublimated and makes little contribution to soil moisture. The amount entering the soil versus that lost to the atmosphere is unclear. Within this overall pattern, snowdrifts form in the lee of boulders or in small topographic depressions locally elevating soil moisture (Gooseff et al., 2003). In addition, buried massive ice, presumably replenished by subsurface streams from melting snow at higher elevation, also elevates soil moisture locally during warm summers or form streams that supply narrow pathways with moisture (Harris et al., 2007). Thus the pattern of soil moisture is composed of transient patches of high moisture content superimposed over a trend of drier soils inland. Episodic water availability in warm deserts has significant consequences on nutrient cycling, and the magnitude of this effect partly depends on resource availability and soil organism distribution (Austin et al., 2004). Our modeling efforts will be extended to analyzing how changes in temperature and/or precipitation may impact soil moisture patterns in an attempt to link soil nutrient cycling and biodiversity to water availability.

Conclusion

With this functional hydro-biogeochemical model, we intend to explore several questions related to landscape biological and biogeochemical dynamics as they are affected by changes in water/moisture. In addition, this coupled model can be used to assess climate change impacts to the broader dry valley ecosystem by simulating species responses to many different conditions (warmer, colder, drier, etc.). Because the major thrusts of MCM-III are geared toward stoichiometry and biodiversity, the ultimate goal of the model would be to simulate how nutrient distribution and species composition would change as the climate varies. This is very timely, as a much warmer Antarctica has been predicted for the next 50-100 years by the recent IPCC report.

These activities are the first in a larger effort to simulate water and biogeochemical fluxes, stores, and transformations throughout the MCM dry valley ecosystem. The power and utility of this overall modeling approach lies in the ability to accurately simulate physical processes, which is critical to understanding ecosystem response.

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Appendix C. Publications

Refereed Journals and Book Chapters

Adams, B. J., R. D. Bardgett, E. Ayres, D. H. Wall, J. Aislabie, S. Bamforth, R. Bargagli, C. Cary, P Cavacini, L. Connell, P. Convey, J. W. Fell, F. Frati, I. Hogg, K. Newsham, A. O'Donnell, N. Russell, R. Seppelt, and M. I. Stevens. 2006. Diversity and distribution of Victoria Land biota. *Soil Biology and Biochemistry*. 38: 3003-3018.

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Yang C. (2006) Effects of acid mine drainage on nesting tree swallows. *Master's Thesis*. Advisor: McKnight, University of Colorado. (note: thesis completed while serving as MCM-LTER information manager)