

SECTION 1

RESULTS OF PRIOR SUPPORT

The research team for the second funding period of the McMurdo Dry Valleys LTER project (MCM-II) consisted of W.B. Lyons (lead P.I.- geochemist), P.T. Doran (limnologist-paleolimnologist), A.G. Fountain (glaciologist-meteorologist), D.M. McKnight (stream ecologist-hydrologist), D.L. Moorhead (ecological modeler), J.C. Priscu (limnologist-microbial ecologist), D. H. Wall (soil ecologist), and R. A. Virginia (soil biogeochemist). During MCM-II, we produced 81 papers in refereed journals, 20 book chapters, and 25 theses and dissertations. We have another 18 journal articles in press. These publications are tabulated in Section I. We supported 43 graduate students, 11 post doctoral fellows, and involved 27 undergraduates. More than 78 collaborators have been involved in MCM-II research. Details can be seen at <http://huey.Colorado.edu>.

During MCM-II, a synthesis of McMurdo Dry Valley LTER research was published as an issue of BioScience (volume 49, no. 12. 1999). This issue represents the third integrated overview and synthetic exercise for the MCM project, and follows two previous volumes published toward the end of MCM-I: (1) Ecosystem Processes in Antarctic Ice-Free Landscapes (Lyons et al., 1997) and (2) Ecosystem Dynamics in a Polar Desert: The McMurdo Dry Valleys, Antarctica (Priscu, 1998, American Geophysical Union's Antarctic Research Series). The BioScience issue summarizes our research to that date, and sets the stage for the development of later work done under the guise of MCM-II. Below we summarize the primary results of our research on each of the main landscape units and our progress in modeling and synthesis.

Meteorology Collection of meteorological data has continued. The new meteorological station installed in Beacon Valley brings the total number to 13. We discovered a large climatic gradient in Taylor Valley, which is significant for stream flow generation (Fountain et al., 1999a) and to the soil ecosystems. We have redoubled our efforts to measure snowfall, and are now recording precipitation using alternative strategies to traditional automatic methods, in addition to making manual snow measurements at 3 locations. Doran et al. (2002a) showed that for the period 1986-2000, temperature decreased by 0.7 C per decade. The cooling was most pronounced in the summer and fall, and was associated with an increase in wind and solar radiation. Nylen et al. (in press) used the meteorological data to show that significant seasonal temperature changes can result from differences in katabatic frequency alone. Moreover, winter temperatures are controlled by the interplay between inversions (cold temperatures) and katabatic winds (warm temperatures). These results have helped explain some of the divergent meteorological conditions and different lake ice characteristics observed in the valleys.

In the 2000-01 season, we received permission to erect a snow fence experiment as outlined in our proposal. It will be a major integrative and cross-site exercise, as NWT, ARC, and HBR have conducted similar experiments. Initial results (Gooseff et al., 2003) indicate that subnival soils are much colder and have more moisture and higher invertebrate populations than exposed soils.

Glaciers Glaciers are the primary source of water in the valleys. Our studies to quantify controls on melt water production must partition the small magnitude of glacier mass loss into sublimation and melt, which is inherently challenging. Lewis et al. (1999a) measured the energy balance of the glacier surface and evaluated the meteorological conditions required for melting.

This study was extended (Lewis et al., 1999b) to include the vertical cliffs that form along the lower margin of the larger glaciers, which are important sources of melt water during cool summers. Because summer air temperatures are typically below freezing, melt water production is sensitive to variations in net solar radiation. Conovitz et al. (1998) showed that solar position, relative to glacier orientation, controls the timing of peak stream flow. Even thin snow cover reflects sufficient solar radiation to reduce stream flow and its spatial pattern is important to stream hydrology (Fountain et al., 1999a; 1999b). Large depressions on the glacier melt more than flat surfaces due to multiple reflections of the solar beam and wind shadow effects (Lewis, 2001). Some of these depressions could be 1200 years old (Johnston, MS thesis 2003). Modeling of melt water production is underway. For seasonal runoff over long time periods (decades to millennia) we developed a temperature-based model (Jaros, 2003; Ebnet, in press), and for daily flows, we (Gooseff, McKnight, and Fountain) are constructing a spatially distributed model and Fountain is developing a detailed point model. To help understand the valley-wide variations in melt water production, we utilized synthetic aperture radar (SAR) to detect snowlines on the glaciers (Bardel et al., 2001), and to infer the onset of melting on glaciers, lakes (Delany, MS Thesis 2004). We maintain the network of glacier mass balance measurements to quantify glacier mass changes and define its relation to climate. The glaciers can be considered in equilibrium (Fountain, et al., in review). The larger glaciers are advancing and thinning, apparently in conflict with the mass measurements, but modeling shows that the current advance can be a delayed response to warming event about 1000 years ago (Fountain et al., in press), consistent with a lake drawdown and subsequent rise about that same time (Lyons et al., 2000).

Cryoconites, subsurface water-filled voids, are initiated from trapped aeolian sediment through a greenhouse-like effect and play an important role in the hydrology of the glaciers (Fountain et al., in press). Under some circumstances, the chemistries of cryoconite waters contrast starkly with “normal” ice melt and result from microbial activity (Tranter et al., 2004; Fortner et al., in review). This is a factor in the differential chemistries between Lakes Hoare and Fryxell (Lyons et al., 2003; Fortner et al., in review). A better understanding of the biogeochemistry of these cryoconites and recycling of aeolian material back to the valley floor has become an important MCM activity and another important area of multidisciplinary integration. A NATO grant to Dr. M. Tranter has supported his collaboration in this effort and his forthcoming work on supraglacial stream chemistry.

Streams The stream gauging and algal transect networks in Taylor and Wright Valleys have continued to operate during MCM-II. We have applied satellite techniques to predict stream flows (Dana et al., 2002). The stream discharge and lake level data indicate that annual stream flows to Lake Bonney from 1973 to 1996 were much greater than from 1903 to 1973, with an average rate of increase of about 4% per year (Bomblies et al., 2001). Since the early 1990’s to present, stream flow decreased in response to cooler temperatures (Doran et al., 2002), except for the 2001-02 summer when major floods occurred in both valleys. Because of scour of the streambed, these floods acted as resetting events for the algal mats in the streams with sparse algal mats.

The exchange of water between stream channels and their hyporheic zones is important to controlling water chemistry and stream ecosystem dynamics. We observed that stream water is retained in the hyporheic zone for periods exceeding the annual summer flow season (Gooseff et al., 2003). Our $\delta^{18}\text{O}$ and $\delta^2\text{H}$ work describes evaporative losses and valley-wide changes in

the channel/hyporheic zone system (Gooseff et al., in review). Within the streams, chemical weathering rates in Taylor Valley streams are as high as rates in temperate regions due to rapid hyporheic zone exchange (Nezat et al., 2001; Maurice et al., 2001; Gooseff et al., 2002; Lyons et al., 2003). The depth of the hyporheic zone expands significantly during the summer, e. g. from 5 cm to 50 cm, as the active layer thaws, which increases the storage of water and contribution of solutes from weathering (Conovitz et al., in review).

A taxonomic directory of cyanobacteria and diatoms in the streams has been developed. Diatoms in streams are more diverse than cyanobacteria, with a high number (about 50%) of endemic species. The distribution of endemic diatom species varies spatially and among years at the monitored algal transects. Our experiments suggest that the hyporheic zone is an important site of denitrification and further supports the importance of stream algal mats in NO_3^- uptake and conversion to NO_2^- (McKnight et al., in press; Gooseff et al., in press). The regeneration of algal mats after removal (disturbance experiments) requires two full summer seasons (Chatfield et al. in review).

Lakes Lake level and ice thickness measurements continued. After a long period of lake level rise (1903 to ca. 1990), levels receded for a decade in response to cooler summers and decreased meltwater flow (Doran et al., 2002), and then rebounded as a result of the floods of the 2001-02 austral summer. We established a network of lake ablation stakes and sensors to monitor changes in ice thickness because lake ice directly affects biologic communities within the lake ice and waters column (Fritsen and Priscu, 1999). Lake ice thickness has increased since 1986 by an average of 11 cm yr^{-1} in response to the lower temperatures (Doran et al., 2002a,b).

Measurements of chemistry and microbial activity continued. The lake ice supports cyanobacterial and bacterial populations and modifies ecological processes, including carbon dynamics within the lakes (Priscu et al., 1998; Priscu et al., 1999). The relative frequency of phytoplankton species in all three lakes changed from 1993 to 2000, probably in response to thicker lake ice and reduced stream inflows. We also initiated phytoplankton bioassays to assess nutrient deficiencies (Dore and Priscu, 2001). Sediment traps were deployed in Lake Bonney in 2000 to evaluate the magnitude and timing of sediment flux from the ice covers and to assess C, N, and P loss from the euphotic zones of the lakes. A new research effort is addressing the role of viruses on bacterial dynamics within the lakes and has shown that the burst size of infected bacteria within Lake Bonney averages 30 prophage (Lisle and Priscu, in press). Electron microscopy revealed a number of infected bacteria in poor health, indicating that viruses may regulate bacterial numbers in the lakes (Priscu et al., 1999).

Long-term benthic experiments (Doran and Hawes, in prep) initiated during MCM-I continued in Lake Hoare and were completed during the 2002-03 season. Results show that colonization of allocthonous sediment occurs from below, and that the thickness of the introduced sediment dictates the rate of colonization. Photosynthetic rates of the mats have been quantified for the first time (Hawes and Schwarz, 2001) and the carbon fixation was comparable to that in the water column of the lake. We have also established new near-shore benthic colonization experiments, defined benthic colonization rates, and confirmed annual growth layering in the microbial mats. Helium isotopic and other rare gas compositions were measured in the lakes in Taylor Valley during the 1999-00 and 2002-03 seasons. The hypolimnion of the west lobe of Lake Bonney has the highest ^4He value ever measured in non-geothermal water (Poreda et al., in review). Halogens and isotopes (^{37}Cl) were also measured to help constrain the sources of solutes and the evolutionary histories of the Taylor Valley lakes (Lyons et al.,

1999; Lyons et al., in review). Other chemical studies conducted on the lakes include: the continued characterization of dissolved organic matter (McKnight et al., 2001), the biochemistry of Si (Pugh et al., 2003), and the potential of CO₂ limitation to algal growth under the ice covers (Neumann et al., 2001).

A NERC grant to Dr. Laybourn-Parry supported work on protozoan distribution and microbial loop communities within the lakes (Roberts and Laybourn-Parry, 1999; Roberts et al., in press a, b). Measurements of the balance between photosynthesis and heterotrophy in the cryptophytes of Lakes Fryxell and Hoare showed that the phytoplankton must feed on bacteria to meet their carbon requirements. Carbon fixation by photosynthesis was similar to phagotrophic ingestion of bacteria during the 2000 austral summer (Marshall and Laybourn-Parry, 2002). Marked differences also existed in the balance between photosynthesis and heterotrophy related to the position of the cryptophytes in the water column (Laybourn-Parry, in press).

Soils Ongoing monitoring of biological, chemical, and physical properties of soils in the Hoare, Bonney, and Fryxell basins continued. This included abundance and diversity of soil biota, PAR, soil and air temperature, soil moisture, and salinity (Treonis et al., 1999; Courtright et al., 2001), and the long-term experiments examining the role of climatic variation on soil biodiversity. After five years of treatments, an overall decline in the nematode populations occurred, but with no consistent effects of warming, water addition, or carbon amendments (Treonis et al., 2002). Overall climatic cooling resulted in reduced diversity and populations of soil invertebrates (Doran et al., 2002b). The six year study of elevational transects indicated specialized habitat requirements for invertebrate species. We are investigating biological and nutrient connectivity between different components of the dry valley landscape. A network of aeolian sediment traps were installed throughout Taylor Valley. These are monitored annually, and living nematodes have been recovered, confirming the aeolian dispersal of these invertebrates. Our research has shown that nematodes survive desiccation as anhydrobiotes, perhaps contributing to their wide dispersal across the valleys (Treonis et al., 2000). Similar invertebrate species have been identified in soils, streams, lakes, and most recently glaciers (Christner et al., 2003; Porazinska et al., in press). We hypothesize that these habitats are linked through aeolian recirculation of biotic communities.

Soil organic carbon sampled at low elevations in the valley is strongly influenced by legacy carbon derived from lacustrine and marine sources left over from past climatic events (Burkins et al., 2000). In contrast, soil organic carbon at higher elevation shows less contribution from events and has an isotopic signature for C and N consistent with microbial activities of cryptoendolithic communities and soil algae over long time scales (Burkins et al., 2000). This pattern implies that today's soil food web is supported by C fixed long ago. We continue to investigate the influence of geomorphic and biological legacies on soil organic matter quantity and composition, the physical and biological controls over *in situ* soil CO₂ flux, and have recently started studies of soil inorganic N concentrations and nitrate flux across landscape gradients. Field work over the past few seasons has shown that soil CO₂ flux is strongly influenced by a temperature-driven physical process, and that some soils absorb CO₂. The process has been modeled and the contribution of soil biota to total CO₂ flux has been determined for locations spanning Taylor Valley (Parsons et al., in press). We are attempting to relate site differences in both the physical and biotic flux of CO₂ to the distribution of soil invertebrate communities. We are also studying C and N isotopic signatures of different size fractions of soil organic matter to constrain possible sources (legacy vs. contemporary). Our

work continues to examine how soils pattern the spatial distribution of biological activities, with an emphasis on understanding how soils and their life are linked to the other physical/biological processes of Taylor Valley. We continue to compare findings from MCM to warm desert settings (Wall and Virginia, 1999) and recent supplemental funding will help continue this work.

Ecological Modeling Our modeling efforts include development of conceptual and mathematical models, both within the MCM-LTER program and in conjunction with other US and international colleagues. The key milestone in conceptual development was the legacy hypothesis underlying long-term, broad-scale control of dry valley ecosystems (Moorhead et al., 1999; Lyons et al., 2000). Moreover, our views expanded the emerging concept of ecological legacies in the larger scientific community beyond a paradigm based mainly on anthropogenic and/or disturbance effects. Our mathematical models include budgetary and dynamic formulations of biological, geochemical and physical phenomena. Fountain is modeling energy relationships defining glacier mass balances driving hydrological regimes controlling long and short-term dynamics of the dry valley system (Lewis et al., 1998, 1999). McKnight has simulated hydrological patterns in the dry valleys over the past century based on recent measurements of stream flow and lake level fluctuations (Bomblies et al., 2001).

Within a biological context, determining carbon budgets and nutrient dynamics are part of our efforts to quantify whole-valley biogeochemical processes. Pools and fluxes of C and/or N have been quantified for soil and phytoplankton communities (Priscu et al., 1999; Fritsen et al., 2000; Burkins et al., 2000), and corroborate the legacy hypothesis of dry valley dynamics in that neither soil nor plankton communities approximate steady-state. Phytoplankton production has been modeled using a light-nutrient model (Fritsen and Priscu, 1999). Physiologically-based models of NPP in benthic microbial communities in lakes and streams (Hawes et al., 2001; Schmeling, 2001) have been used to evaluate both N transformation in streams (Moorhead et al., 1998) and production in upland ponds (Moorhead et al., 2003). A population model of a soil nematode (*Scottinema lindsayae*) has demonstrated the impacts of ambient temperatures on distributions and survival (Moorhead et al., 2002).

During the summer/fall of 2001, after the site review, two MCM-LTER “modeling” workshops were held. These were meetings of small groups (~10 individuals), including PIs, post docs, and graduate students. The first meeting focused on the use of stoichiometry of nutrient cycling and transfers and transformations as a framework for integration across the landscape components of MCM. The second workshop focused on the development of models to relate meteorological data to glacier melt to stream flow to lake level change. Both of these concepts were suggested originally by the site review team in January 2002. The first workshop has resulted in what we think is a very strong synthetic product that will be submitted immediately after this Antarctic field season (Barrett et al., in review). The other workshop has resulted in the supplemental funds, which are currently supporting the development of an initial model on snowmelt/stream flow. One of the major results of the stoichiometric work is to demonstrate that N vs. P limitation in the MCM lakes is directly related to the P concentration in the streambeds of the various lake sub-basins. The P content of the streambeds is in turn related to the landscape ages (i.e. time since last glaciation) of the sub-basins (Barrett et al., in review).

In conclusion, we feel that we have been successful and productive during MCM-II. The site review team states in their letter in 2002, “we believe there is no other LTER-...-that integrates the biogeochemical sciences as effectively as does the MCM.” A major goal of MCM-III is to continue to build on this strength.

SECTION 2 INTRODUCTION

The McMurdo Dry Valleys (MCM), the largest ice-free region on the Antarctic continent (~4800 km²), is a mosaic of perennially ice-covered lakes, ephemeral streams, soils and glaciers (Fig. 2.1). The MCM is one of the driest and coldest ecosystems on earth (Fig. 2.2; Table 2.1) and harbors a distinctive biota capable of surviving in the diverse habitats of the MCM (Prisco, 1999). The most complex life forms in the MCM are small invertebrates. Other eukaryotic phyla included protozoans, fungi and microalgae found in glacier surfaces, in soils and in streams and lakes.

Research in MCM-I (1993-1999) demonstrated that physical constraints control the structure and function of this polar desert (Fountain et al., 1999). We discovered that subtle changes in temperature, precipitation, and albedo have a major influence on the hydrologic cycle, biogeochemistry and productivity within the valleys. For example, a decadal scale cooling significantly reduced stream flow, lowered lake levels, and increased lake ice thickness thus reducing lake primary productivity, and decreasing soil biomass (Doran et al., 2002b). The unusually warm austral summer of 2001-2002 greatly increased glacier melt, which rapidly restored lake levels to those that existed at the beginning of MCM-I. The increased meltwater enhanced productivity and related biogeochemical processes across the landscape units (Foreman et al., in review). These events underscore the sensitivity of the MCM ecosystem to small variations in climate and the importance of the transition between solid and liquid water phases. Consequently, small changes in temperature and solar energy are amplified by large, non-linear changes in hydrologic budgets that cascade through the ecosystem (Welch et al., 2003).

The central hypothesis for MCM-II (1999-2005) was that “legacies” of past climatic events are a major factor regulating contemporary ecosystem processes (Moorhead et al., 1999; Lyons et al., 2000; Burkins et al., 2000). The term “legacy” refers to the carry-over or ecosystem “memory” of past events (Vogt et al., 1997). For example, during MCM-II we showed that the presence of Lake Washburn, which inundated Taylor Valley (TV) between 24,000-6,000 yr BP (Denton et al., 1989), followed by a subsequent cold, dry period ending about 1000 yrs BP (Lyons et al., 1998a), created old pools of organic carbon and nutrients in the soils and lakes that explain many of the ecosystem processes we now observe (Fig. 2.3). Legacy effects at other LTER sites are typically viewed as human-induced disturbance such as forest cutting (HBR, HFR, CWT, AND), conversion to agriculture (KBS), or shorter-term climate events including desertification (JRN, SEV, SGS) and catastrophic disasters, like hurricanes (LUQ).

Another result of MCM-II demonstrated that habitat suitability, overprinted by wind and water transport, largely dictates biodiversity and community structure. Many of the phototrophs in the soils and streams may represent the legacy of benthic mat communities deposited by paleolakes, whereas other species reflect more contemporary origins (Brambilla et al., 2001; Nadeau and Castenholz, 2001). Similar phylotypes exist within stream mats, lake ice, and glacier cryoconite holes (Gordon et al., 2000; Christner et al., 2003) implying that wind dispersion may be key in regulating biodiversity among landscape units in the MCM. Conversely, we also observe extensive patchiness throughout the MCM. For example, 40% of the soils in TV (Freckman and Virginia, 1998; Virginia and Wall, 1999) and the cryoconite holes on the glacier surfaces lack nematode communities (Porazinska et al., in press). Clearly dispersion, particularly by wind, is important. But, the ability of organisms to establish a population also can be strongly dependent on physical and chemical habitat factors (i.e. water, salinity and carbon). These results

raise important questions concerning the relation between biodiversity and ecosystem function. A major goal for MCM-III will be to understand both how the environment controls the diversity of organisms and how diversity itself controls the functioning of the MCM ecosystem. This is one of the hottest topics in modern ecological research (Pfisterer and Schmid, 2002; Chase and Liebhold, 2002), and the MCM lend themselves to answering these questions in a unique way.

WORKING HYPOTHESES

Long-term ecosystem research in the MCM is of particular importance for a number of reasons. Firstly, the system is poised near a significant hydrologic threshold; a small climate warming releases vast quantities of water from the frozen glacier reservoirs leading to major ecosystem responses. Such amplified responses allow us to more easily examine how the ecosystem responds to physical controls. Secondly, the biological diversity of organisms in the MCM is extremely low, which means that we can characterize biodiversity and potentially the linkages to function more readily than is possible in more diverse ecosystems. Consequently, the potential of understanding the regulation of biodiversity and biological processes is great. These regulating processes are fundamental, and understanding gained at the MCM will advance our insight into all ecosystems.

Figure 2.4 presents our conceptual model for MCM-III showing the imprint of the past dry valley ecosystem on biodiversity and the potential role of biodiversity on ecosystem structure and function. This model builds on the conceptual model presented in the MCM-II proposal, as it links the legacy effects to processes operating on the contemporary landscape. In MCM-II, we concluded that the current structure of the MCM is a result of the interplay between landscape evolution, climatic gradients, and the legacy of past environments, which together control the distribution of energy, water, nutrients, and life. MCM-III will further develop this theme with a focus on the role of resource legacy on contemporary linkages between resources, biodiversity and ecosystem level processes. Advances in our knowledge gained through MCM-II now allow us to address biodiversity issues in a more definitive manner, especially the interplay between physical dispersion and habitat suitability. Finally, based on suggestions of the site review team (2002), we have included a stoichiometry component in our research plan providing a common currency to integrate all ecosystem components through documentation of landscape scale elemental transformations.

Central Hypothesis for MCM-III: Biodiversity and ecosystem structure and function in the MCM are dictated by the interactions of climatic legacies with contemporary biotic and physical processes.

This hypothesis will be addressed within three distinct but integrated scientific portfolios: (1) hydrology; (2) biodiversity; (3) ecosystem structure and function.

Portfolio 1. Hydrology

The availability of liquid water is the overriding factor constraining biological activity in the MCM. Past variations in water balance produced the legacies we now observe. The relationships between biodiversity and ecosystem function in the MCM requires understanding hydrological responses to climate change, and we will continue to study climate controls on the hydrology. Our new focus in MCM-III will be on transport of organic and inorganic material by

water and wind, and its influence on biological diversity and stoichiometric (C:N:P) relationships.

Hypothesis 1a. The variability of glacier melt depends on the interaction of climate and landscape position, and sediment on the glacier surfaces.

Hypothesis 1b. Meltwater in interconnected subsurface passages on the glaciers creates cryoconite habitats, and biological processes in these habitats influence aquatic geochemistry throughout the MCM.

Hypothesis 1c. At the stream/soil interface, thawing of the active layer in summer drives the expansion of the hyporheic zone, increasing storage of water, solute flux from weathering reactions and microbial cycling of nutrients in the streams.

Hypothesis 1d. Spatial variation in the hydrologic characteristics of the hyporheic zone creates a mosaic of biogeochemically heterogeneous subzones.

Portfolio 2. Biodiversity

Biodiversity in many temperate and tropical systems is largely governed by biological processes, including growth rate, competition, predation, and human disturbance (Luck et al., 2004). The MCM environment constrains biological processes in all landscape units. Given these constraints, and the absence of large organisms capable of active immigration, we contend that fluvial and aeolian transport may be the primary dispersive agents for organisms in the MCM. Fluvial transport carries organisms from the cryoconite holes on the glacier (cryoconites), through streams to the lakes, and may explain the recent establishment of cyanobacterial populations in Lake Fryxell (Spaulding et al., 1994). The constant and often strong winds in the MCM (Doran et al., 2002a; Nylén et al., in press) are another powerful dispersive agent for organisms (Fig. 2.5). We propose that the biodiversity of the MCM is sustained by physical processes and modified by growth and survival rates in habitats of varying quality. Within landscape units, biodiversity is affected by spatial heterogeneity in the physiochemical characteristics of the habitat. This presence or absence of habitat suitability is primarily driven in the MCM by past legacy effects. Therefore, the distribution of organisms within the landscape units of the MCM reflects both ecological legacies and contemporary physical processes.

Hypothesis 2a. Stream and lake microbial mats provide seed populations to the contemporary MCM landscape.

Hypothesis 2b. Diversity of stream microbial mats is controlled by flood frequency, streambed stability, and small-scale patchiness related to hyporheic exchange.

Hypothesis 2c. The diversity of soil invertebrate communities is determined by soil legacies and hydrology.

Hypothesis 2d. Phytoplankton diversity is controlled by a combination of “old” nutrient input via diffusion from below the chemocline and “new” nutrient input from streams.

Portfolio 3. Ecosystem Structure and Function

Our ecosystem-based approach to the MCM will expand what is known about biodiversity in an extremely cold and arid environment, and will allow us to define functional relationships that allow life to survive in extreme environments.

Hypothesis 3a. Biodiversity in all landscape units is linked to ecosystem functioning (diversity begets function). Higher diversity is associated with greater C, N and P cycling.

Hypothesis 3b. Biogeochemical activity, nutrient deficiency, and biodiversity relationships within the MCM landscape are reflected in the elemental stoichiometry.

Hypothesis 3c. The low biodiversity and slow growth rates of its organisms make MCM ecosystems highly susceptible to local and global human disturbance.

Hypothesis 3d. Geomorphological features interacting with resource legacies of landscape units dictate the distribution of species and ecosystem function.

BACKGROUND

The Taylor Valley (TV) (Fig. 2.1) will remain the primary study site for the MCM-LTER. The general physical, chemical and biological properties in the TV ecosystem have been described in detail elsewhere (Priscu, 1998; *BIOSCIENCE* 1999, Vol. 49) and will not be repeated here.

1. The Legacy Concept within the MCM

The functional and structural linkages among the glacial, stream, lake, and soil ecosystems in the MCM are unusual in that they operate over millennial-scale time periods (Fountain and Lyons, 2003). This is due to the extremely slow landscape modification in the MCM over the past few million years (Marchant and Denton, 1996) and to the slow rates of nutrient transformations caused by limitations that the polar climate exerts on biological activity. Consequently, pools of organic matter, nutrients, salts and biota have accumulated and affect existing communities in myriad ways (Ward and Priscu, 1997; Virginia and Wall, 1999; Ward et al., 2003). Strong resource legacies are evident in the streams, lakes and soils (McKnight et al., 1999; Priscu et al., 1999; Burkins et al., 2000). For example, current resource legacies have occurred through climatically driven lake level changes, which have risen and fallen in TV many times over the past 300 Kyr (Hendy, 2000). Longer-term fluctuations in sea level and ice sheet extent led to marine incursions and valley glaciations, and these legacies are also clearly evident both biologically and geochemically (Burkins et al., 2000; Mikucki et al., in review). The characteristics of these legacies demonstrate strong functional links between ancient and modern ecosystems of the MCM and reveal aspects of the long-term responses of the MCM system to changing abiotic conditions. Therefore, the structure and function of the extant ecosystem cannot be understood without knowledge of resource legacies imprinted on the landscape during its evolution.

2. Glaciers

Glaciers in the MCM provide a large reservoir of stored water that can be released through small changes in climate. Work during MCM-II showed that the geochemistry of the glacier melt can reflect biogeochemical processes occurring within cryoconites, unique environments that contain liquid water inoculated with materials released from the particulates and melted glacial ice (Tranter et al., 2004). Molecular fingerprints of cryoconites on the Canada Glacier revealed a high level of biodiversity, including bacteria, metazoans (nematode, tardigrade, and rotifer), a truffle, a ciliate, and eukaryotic algae (Christner et al., 2003). DNA preparations had sequences similar to lake ice and microbial mat environments (Fig. 2.5). We presume that this high cryoconite diversity results from *in situ* biological processes and annual seeding from the local terrestrial environment.

Perhaps the most dramatic influence of ancient glacial resources on the contemporary dry valley ecosystem can be seen in Blood Falls, a discharge of ancient marine water emanating from the snout of the Taylor Glacier (Fig. 2.6). Blood Falls may be the oldest liquid water feature in TV, originating at a time when the valley network was a marine fjord (~ 2-4 million yrs ago). Salts from Blood Falls flow into Lake Bonney, producing a clear geochemical signature (Table 2.2a,b). Blood Falls has a microbial assemblage that continuously inoculates Lake Bonney with ancient genomes as well as marine salts.

3. Streams

For 4-10 weeks during the austral summer, the streams become an active feature of the landscape. Annual variations in flow and duration are due to microclimate variations between and within the basins (McKnight et al., 1999). The cyanobacterial mats in the streams are perennial, slowly growing during the summer flow period and over-wintering in a lyophilized state. The structural simplicity (e.g., lack of complex membrane systems) allows them to withstand the freeze-thaw cycles that occur during the summer. The metabolic diversity of these prokaryotes (e.g., ability to fix N₂) also gives them an advantage over eukaryotic cells in obtaining essential growth nutrients. These cyanobacterial mats begin to photosynthesize and fix N₂ within 10-20 minutes of being rewetted after freeze-desiccation (Vincent and Howard-Williams, 1986). Compared to stream ecosystems at other LTER sites, the MCM streams represent several extremes—they lack terrestrial inputs of organic matter, have high standing algal biomass, have low primary productivity, and are subjected to low grazing losses (McKnight and Tate, 1997). A total of 30 taxa of cyanobacteria and chlorophytes are present and the species composition of the different mat types is similar among sites, even sites that differ widely in productivity (Alger et al., 1997). The calculation of “evenness”, a ratio of actual diversity to maximum possible diversity, reveals that mats dominated by *Nostoc* have a low evenness (0.13), whereas the mats composed of the cyanobacterial species *Oscillatoria* and *Phormidium* were much more diverse (0.48-0.55). In addition to cyanobacteria and chlorophytes, 38 species of diatoms have been identified in MCM streams (Alger, 1999). Approximately 60% of these diatom species may be endemic to Antarctica. Studies of lake-ice microbial assemblages (Priscu et al., 1998; Gordon et al., 2000) and cryoconites (Christner et al., 2003) have shown that the stream mats may provide the biological seed to these environments (Priscu and Christner 2004; Fig. 2.5). Hence, growth and dispersion of stream organisms appear to influence the biodiversity and function of the TV ecosystem.

4. Soils

Dry valley desert soils are generally poorly developed, coarsely textured, high in soluble salts with permafrost at 10-30 cm depth (Pastor and Bockheim, 1980) and support low rates of biological activity. Soil temperature in summer is above freezing (Table 2.1), permitting biological activity but the desiccation gradient can be so steep that permafrost cannot furnish adequate liquid water for biota (Wynn-Williams, 1990). Research in MCM-II has focused on soil invertebrates (mainly nematodes). The habitat requirements of the three nematode species in TV (*Scottnema lindsayae*, *Plectus antarcticus*, *Eudorylaimus antarcticus*) have been characterized and the structure of the soil food web that includes rotifers, tardigrades, protozoa and microbial biomass is becoming more evident (Freckman and Virginia, 1997, 1998; Courtright et al., 2001; Bamforth et al., 1996). Soil biodiversity is low and regulated by moisture, carbon and salinity gradients resulting from ecosystem legacy. These variables have been used to determine whether

a soil habitat is suitable or unsuitable for soil communities (Freckman and Virginia, 1998; Virginia and Wall, 1999).

Studies of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in organic matter from TV imply that today's soil food web is supported, in part, by carbon fixed long ago (Burkins et al., 2000). Soil respiration studies suggest contemporary production may also be important in supporting the soil food web (Burkins et al., 2001; Parsons et al., in press). Another legacy affecting contemporary soil communities is the spatial distribution of salts deposited during fluctuations of the lakes (Virginia and Wall, 1999) and their redistribution by aeolian transport. Soils that are now highly saline—either as a legacy or from prolonged atmospheric exposure—may not be suitable for the development of the present soil communities (Freckman and Virginia, 1997).

During MCM-II, soil organisms, including nematodes, have been shown to be dispersed by wind. If dispersal to suitable habitats controls the biodiversity of dry valley soil communities, one would expect to see high rates of genetic exchange within and between the organisms in the MCM, with a tendency toward a few dominant genotypes. If aeolian dispersal rates were low, gene flow within and between valleys would be restricted. Courtright et al. (2000) found evidence for both these scenarios for the dominant dry valley nematode, *Scottinema lindsayae*.

5. Lakes

Research in MCM-I and II showed that the TV lakes have highly contrasting geochemistry and evolutionary histories (Fig. 2.7) (Lyons et al., 1998a,b; 2000). We contend that contemporary phytoplankton and bacterioplankton production in the deep water of the lakes is controlled by the upward diffusion of relict or legacy nutrients, whereas near surface assemblages are fueled by nutrient loading by extant stream flow (Priscu, 1995; Takacs et al., 2001). P:R ratios in the water columns of certain lakes are < 1 implying that ancient carbon is supporting much of the present day biological activity, particularly in the deeper waters (Priscu et al., 1999). This is in contrast to more temperate region lakes where $\text{P:R} < 1$ results from contemporary input of terrestrial carbon (Pace et al., 2004). Despite the importance of resource legacy, relatively low stream nutrient loads from 1992 and 2002 presumably have influenced phytoplankton biodiversity by reducing the cryptophyte populations (Tursich, 2003; Fig. 2.8). Consequently, both contemporary and ancient resources balance the activity and biodiversity of microbial populations within the lakes.

Given the microbial dominance in the MCM, we have begun to utilize molecular methods to address questions related to prokaryotic diversity and ecosystem function. Preliminary results showed that bacterial density, activity and diversity change significantly at the oxic/anoxic interface in the water column of Lake Fryxell (Fig. 2.9). Molecular data also show differences in vertical structure of Lake Bonney and that the majority of phylotypes identified in the ice cover differ from those in the water column (Fig. 2.10) implying that aeolian deposition does not directly regulate the biodiversity of the water. The planktonic food web is well developed and consists of photosynthetic nanoflagellates, cyanobacteria, bacterioplankton, heterotrophic nanoflagellates, ciliates and rotifers (Priscu et al., 1999; Roberts et al., in press).

Research on benthic processes in TV lakes is logistically difficult because of the requirements for SCUBA diving beneath the perennial ice covers. In Lake Hoare, benthic production rivals that of the water column (Hawes and Schwarz, 2001); however, the contribution of the benthos to whole lake productivity depends largely on the lake morphology. In lakes with a low surface area to volume ratio (e.g. Lake Bonney), the importance of benthic primary productivity is less than in lakes with a higher ratio (e.g. Lake Fryxell).

6. Syntheses and Modeling

Modeling efforts in MCM-I and MCM-II focused on developing conceptual models. The models were based on the premise that biological communities in the MCM are controlled primarily by temperature and hydrologic regimes (Fig. 2.11). These models progressed to include the role of energy availability on communities (Moorhead and Priscu 1998). MCM-II focused on our discovery that legacy controlled many current ecosystem characteristics (Moorhead et al., 1999). This model included temporal changes in hydrology and dynamics of organic matter and inorganic nutrients over time (Fig. 2.12). Ideas within this model were implicit in a recent paper (Doran et al., 2002b) that revealed the cascade of ecological consequences that followed a relatively small change in air temperature.

Based on the site review recommendations, we have begun to develop an elemental stoichiometry approach to the MCM (Barrett et al., in review a). Stoichiometry provides a link among molecular, population, community and biogeochemical approaches to describing material cycling, energy flux and the influence of life on the geochemical environment (Elser et al., 2000; Vitousek, 2004). The MCM represent an opportunity to evaluate ecosystem stoichiometry in an environment where biological diversity and activity is relatively inconspicuous and where the time scale of landscape evolution varies from thousands to millions of years. Our preliminary work suggests that the contemporary stoichiometry of landscape components presents a legacy of previous climatic impacts modified to varying degrees by modern biogeochemical processes and biological activity. The C:N:P ratios change as materials move and, in some cases, are altered by biological processes, to values closer to the Redfield ratio (Fig. 2.13).

MCM-III RESEARCH PLAN

1. Overview

The hypotheses for MCM-III, founded on results from MCM-I and II, provide a logical progression for evaluating the role of legacy in polar desert ecosystems. We will employ a multi-faceted approach, including monitoring, experiments and ecological models, to address our central hypothesis and hypotheses in each portfolio. The relationships between our hypotheses and the research plan are summarized below and in Table 2.3.

1.a. Hydrology (portfolio 1). Hypothesis 1a addresses the role of climatic variation on the distribution of liquid water and will be addressed by the meteorological, glacial mass balance, lake level and streamflow monitoring networks. Hypothesis 1b, on cryoconites, will be studied using field measurements of cryoconite holes that include the monitoring of their physical dimensions, and biogeochemical characteristics and physical modeling. Hypotheses 1c-d will examine hyporheic zone development and heterogeneity. Hyporheic processes will be examined through meteorological and streamflow monitoring, geochemical measurements (including isotopes) and supporting tracer experiments.

1.b. Biodiversity (portfolio 2). Hypothesis 2a focuses on the export of algal mat material from the streams and lakes. Their landscape influence will be investigated by comparison of biotic material collected in aeolian traps and cryoconite holes to mat material from the streams and littoral zones of the lakes. Hypothesis 2b is related to the diversity of stream microbial mats and will be addressed through on-going hydrological/ecological measurements and expanded to

include morphological and molecular-based characterizations of the mats. Hypothesis 2c concerns soil biodiversity and will be addressed through continued long-term experiments and stable isotopic investigations. Hypothesis 2d focuses on the vertical distribution of phytoplankton and bacterioplankton species and will be addressed through bioassay experiments and stoichiometric measurements in concert with 16S rDNA sequencing.

1.c. Ecosystem structure and function (portfolio 3). In our conceptual model (Fig. 2.4), biodiversity lies at the base of ecosystem structure and function, which is in-turn related to biogeochemistry, stoichiometry and nutrient availability. Hypotheses 3a-b address directly ecosystem biodiversity and function. Our measurements of C:N:P conducted in the continuing and expanded monitoring programs for the streams, soils and lakes will allow us to examine the diversity and nutrient relationships in the landscape units. Hypothesis 3c addresses the critical issue relating human disturbance to biodiversity, and ecosystem change to human well-being and will be addressed through the monitoring programs. By addressing these issues, we can cast our results within the context of other LTER projects, most of which include human disturbance as a major research theme. Hypothesis 3d will address the role of geomorphic features in determining habitat quality and associated diversity-functional relationships. This hypothesis will be supported through the monitoring programs and the new nutrient enrichment experiments that will be conducted in habitats in all landscape units. All hypotheses in portfolio 3 will increase our understanding of the evolution of this diversity-functional relationship through time (based on the concept of resource legacy) within the MCM.

2. Long-Term Monitoring

The core monitoring programs of MCM-I and II will be continued with sampling protocols and frequency tailored to the evolution of our program thus far. We will augment the program to include the new experiments and parameters required to successfully address the hypotheses of MCM-III. Core monitoring programs are briefly outlined below, while more detail is provided for the monitoring programs and experiments that will be added in MCM-III.

2.a. Meteorology. A network of 13 meteorological stations is operated in TV. These stations are located in major lake basins, at the mouth of the TV and on the Taylor, Howard, Canada, and Commonwealth Glaciers. To achieve a broad climatic perspective of the MCM, stations are located at Lake Vida, Lake Vanda and Lake Brownworth in Victoria and Wright Valleys. The stations routinely measure air temperature and humidity at 3m above the surface, soil or ice temperature, wind speed and direction, and incoming and outgoing solar flux (Doran et al., 2002a).

2.b. Glaciers. Glacial mass balance at our four sites (i.e. Commonwealth, Canada, Howard and Taylor Glaciers) will continue to be monitored. This information is used to assess whether glaciers are growing or shrinking in response to legacy and/or current climate change, as well as to constrain meltwater models. Glacial melt is the primary source of liquid water to all subsystems in the MCM and will continue to be monitored. The surface energy balance will be measured in finer detail to elucidate the extent and duration of liquid water within cryoconites.

2.b.1 Cryoconite Holes: Cryoconite hole studies were initiated during the 2001-02 season. These features are important sources of solutes, via aeolian deposited dust/salt dissolution, to meltwaters and can provide up to 20% of water to the hydrologic system. We will continue to monitor the hydrology, geochemistry and biology of these unusual ecosystems using techniques outlined in Tranter et al. (2004) and Porazinska et al. (in press). Aeolian traps will be installed at each location to quantify the seasonal sediment flux (i.e. MCM-III Research Plan 4.b). This flux will be related to cryoconite hole production. Cryoconite holes will be tracked in several ways. First we will determine which holes are connected to the subsurface hydrologic system using geochemical signatures (Tranter et al., 2004). This is important for defining, in a statistical sense, which holes are developing unique geochemistries versus those that act as conveyors of meltwater. Second, we will track the number and size of cryoconite holes over time at selected sites. These measurements will help to define whether the number and frequency of holes are relatively constant or change from year to year. Finally, we will model the annual cycle of cryoconite melt enlargement and refreezing using a detailed energy balance model that accounts for subsurface radiation absorption and transmission. The model will be constrained by field measurement of temperatures and depths to cryoconite holes.

2.c. Streams. In the context of understanding biogeochemical and biodiversity relationships in the MCM, the streams function as dynamic linkages among landscape units. Therefore, we will continue to monitor streamflow, stream chemistry and long-term changes in the growth, distribution and abundance of stream biota in the networks operated during MCM-I and II. Streams form a network through which water generated by glacial melt is transported to the lakes in the valley floors or lost to the atmosphere through evaporation. The proportion transported to the lakes decreases during cold summers, when storage in the hyporheic zone (Fig. 2.14) and evaporation dominate the hydrologic budget of longer streams. Stream ecosystems also act as biogeochemical processing centers, releasing solutes, such as phosphorus through weathering and DOC from algal mats, and transforming other solutes through biological uptake. Streams containing abundant algal have significantly lower concentrations than streams with only sparse algal mats (McKnight et al. in press). Through the analysis of stream-scale and batch nutrient tracer experiments, we have developed biogeochemical/hydrologic models, which include hydrologic exchange in the hyporheic zone and in algal mats, nitrate uptake by algal mats and in the hyporheic zone, and nitrate reduction within the mats (McKnight et al., in press; Gooseff et al., in press). These areas adjacent to the stream channel correspond to hotspots of activity and biodiversity in the spectrum of soil ecosystems (Treonis et al., 1999).

2.c.1 Continued Tracer Experiments: To understand how habitat quality and dispersal of biota influences biogeochemical processes and the linkages among the MCM landscape units, we will focus efforts in MCM-III on streams with less abundant mats. We will conduct nutrient tracer experiments in two of these streams, which will parallel studies of poor habitats in soils. We expect that in streams with sparse algal mats, the biogeochemical processing will primarily occur in the hyporheic zone and that the hyporheic zone microbial communities will have a patchy distribution and show lags in response to variable nutrient fluxes as communities develop with the thawing of the active layer. To examine the lags in response, we will conduct our tracer experiments over 4-6 days. We will use the ^{15}N signature of the experimentally-added nitrogen at natural abundance levels in comparison with the more depleted nitrogen found in the soils to try to track the incorporation of nitrogen into microbial communities of the hyporheic zone. Further,

we expect that nutrient enrichment will stimulate activity in soil ecosystems at the periphery of the streams. These studies will allow us to better interpret our monitoring results and understand how climatic variation drives changes in lake and soil ecosystems.

2.c.2 Stream Dispersal and Biodiversity: We will examine the hypothesis that dispersal processes maintain a “maximum achievable” biodiversity through detailed study of the cyanobacteria and diatom assemblages in the algal mats carried out as part of the overall study of microbial biodiversity in MCM-III led by Priscu. We have found that the same morphotypes of cyanobacteria occur in similar habitats in all streams. We hypothesize that these morphotypes are genetically similar, representing a legacy of biodiversity that is well mixed by water and wind, and is maintained by the overall isolation of the dry valleys and the extreme conditions. Our comprehensive description of diatoms in the MCM indicates that distinct diatom assemblages occur in streams with similar chemical and physical characteristics. Because of the high proportion of endemic diatom species, this result also suggests a legacy of well-adapted species that are dispersed to suitable habitats in the MCM. We will complete the analysis of diatoms in the samples collected through the monitoring of stream transect sites during MCM-II, and will target selected stream sites for annual sampling to track temporal changes in diatom species in MCM-III.

2.d. Soils. Ongoing long-term studies, both monitoring and experiments, are the framework to examine the relationships between soil biota (diversity, abundance, physiological activity) and ecosystem functioning. Response variables (and methods) for long-term field experiments are nematode, tardigrade and rotifer population size and diversity (Freckman and Virginia, 1993), soil respiration (Parsons et al., in press), available soil N (Barrett et al., 2002), soil organic matter (Burkins et al., 2001), and microbial biomass (Jenkinson and Powlson, 1976). Soil moisture and temperature are logged continuously at most sites.

Within the terrestrial landscape units of the MCM, the soil ecosystems are sensitive to environmental and climatic conditions at multiple temporal and spatial scales and are influenced by linkages to other landscape units through aeolian transport of organic material and organisms (Barrett et al., in review c). Research within the soil portfolio will continue several long-term field data sets that focus on changes in the abundance, distribution and diversity of soil biota across gradients of environmental conditions (ET- elevation transect, LTM- Long Term Manipulations, i.e. Section D.3.b.) and between basins in experimental plots where temperature and moisture are manipulated to examine biotic responses to climate variation (BEE plots). To examine the central hypothesis of MCM-III related to diversity, abundance and ecosystem functioning, the role of multiple element interactions (stoichiometry) will be studied by augmentation of field plots with C, N and P. In these manipulative plot experiments, we will use isotopic techniques to examine directly the influence of biota on ecosystem processes (C-uptake, N-cycling rates) and the reciprocal relationships of soil nutrients on biota.

Long-term field data have revealed inter-basin and inter-valley patterns of population structure, abundance, demographics and species distributions for soil invertebrates. These results imply that nematode species are dispersed broadly and geographical barriers such as mountains-valley systems and vast distances, do not limit present-day distributions (Courtright et al., 2001; Adams and Wall, unpubl). Thus, contemporary distributions may not reflect biogeographic fidelity, but rather may be determined by biogeochemical legacies and geophysical constraints. Key parameters affecting distributions may not be biotic but geophysical, combined with the

legacy effects of previous ecosystems. In MCM-III we will take advantage of previously collected data that establish correlated soil biodiversity and biogeochemistry parameters, and extend these to biogeographic patterns of eukaryotes and their prokaryotic prey. This will help resolve the question of whether nematodes and other metazoans fail to persist in certain areas because they are food resource limited, as opposed to limitations from purely geophysical constraints.

2.d.1 Augmentation of long-term soil plot studies: The rates of soil C and N cycling are important indices of ecosystem functioning. We will estimate these rates using stable isotope techniques in experimental plots with varying diversity and biomass. Stable isotope tracers (^{13}C , ^{15}N) will be applied to contained soil microcosms incubated in the field. We will measure rates of isotope incorporation into microbial and invertebrate biomass (Schimel, 1993) and will quantify associated rates of C and N mineralization. To understand the influence of stoichiometric relationships, we will manipulate C:N:P ratios of field soils by factorial additions (mannitol, N as NH_4NO_3 , PO_4^{3-}) within 1 m² replicated plots of the type used in previous soil manipulation experiments. This experiment will be replicated in the three lake basins at sites near existing experiments (BEE plots). The abundance, diversity and population structure of invertebrates and soil microbiota will be determined in all treatments. Parallel laboratory incubation studies will be used to extend results to soil types and locations where field experiments are not feasible. These experiments will parallel the nutrient enrichment experiments in the cryoconite holes, streams and lakes.

In addition, we will determine rates of soil respiration (Parsons et al. in press, Burkins et al. 2001) and N mineralization (Barrett et al., 2002) as measures of ecosystem functioning in soils that are known to differ in the complexity of the soil food web. These experiments will define the functional relationships between soil biodiversity and ecosystem process and will also support the completion of integrated C and N budgets for the soils (Fig. 2.15). By understanding pools of soil organic matter (SOM), soil respiration rates, and rates of soil productivity, we can elucidate the role of legacy and contemporary C pools in the functioning of soil communities (Barrett et al., in review b; Burkins et al., 2001). Our preliminary nitrogen budget indicates relatively low biotic influence over N cycling similar to results reported in other very arid systems (Ehleringer et al., 1992). We hypothesize that pools of NO_3^- may provide an opportunity to estimate relative surface ages of soils in the dry valleys based upon a given rate of deposition and the profile of soil NO_3^- concentrations. We will determine the spatial (surface and depth) patterns of NH_4^+ and NO_3^- distribution in soils of varying age, landscape position, and biological activity. At these sites, we will employ standard N incubations and resin strips to study mineralization (Barrett et al., 2002), estimate potential denitrification and ammonia volatilization to constrain ranges of N loss, and potential NO_3^- leaching using the soil Freezechem model. These soil measurements will be linked to N inputs to other landscape units (dry deposition collector network and snow pit profiles on the glaciers) to provide data for a stoichiometric synthesis of biodiversity and functional relationships across MCM.

We will continue to extend our knowledge of the of historical legacies on today's distributions of soil biodiversity and functioning by examining soils differing in age, mineralogy, and parent material, and its effect on N cycling for locations outside TV. For example, we are examining very old (8Myr) Beacon Valley soils (Marchant et al., 1993) and are comparing them to younger glacial sequences (8-12 Kyr) in TV. Regionalization of the MCM results will allow us to bracket the conditions suitable for soil invertebrates and to parameterize and test models

predicting soil biodiversity and food web structure as a function of soil legacies and climate (see modeling section). We are currently comparing TV soils to those at Cape Hallett (72°S), where the soils are wetter and contain more organic matter, and are studying soils collected by others from as far south as 83°.

2.e. Lake Water Column. The lakes lie at the end of the hydrologic continuum and represent a repository of past conditions within the MCM. We will maintain our routine suite of limnological measurements (Table 2.4) and will add measurements to address the hypotheses of MCM-III (Table 2.5). To define the phylogenetic and functional aspects of biodiversity of the lake biota, we will add measurements of molecular diversity, phytoplankton pigment diversity, sestonic stoichiometry (C:N:P) and microbial exoenzyme production. To further resolve the resource legacy in the lake water column, the racemization state (D- or L- isomer) of aspartic acid will be measured to define the biological age of the water (Grutters et al., 2002). Data collection and sample processing will be closely aligned with the recently funded 5-year dry valley lake microbial observatory (J. Priscu, PI; <http://mcm-dvlakesmo.montana.edu>) that is searching for novel prokaryotes and novel physiologies.

We will continue to work with the NSF to extend our field season into late fall/early winter to examine water column microbial processes during the transition from complete sunlight to total darkness to complement previous results for the polar sunrise (Priscu et al., 1999). In addition, we still desire to field a winter-over team when logistics and resources become available, as documented in our last Five Year Plan submitted to NSF-OPP in May 2002. The site review strongly urged a winter component to our science. We will begin addressing this issue via our proposed in-situ sensor development program (Section 5)

2.e.1. Expansion of long-term lake monitoring:

Under ice PAR. Photosynthetically active radiation (PAR) has been shown to be a primary driver for phytoplankton photosynthesis (Neale and Priscu, 1998) and will be used to model depth-integrated primary production within the lakes (Priscu et al., 1999).

Elemental stoichiometry. Particulate carbon (PC), NH_4^+ , NO_2^- , NO_3^- , particulate N (PN) and soluble reactive phosphorus (SRP) were measured routinely during MCM-I and MCM-II. We will add dissolved organic nitrogen (DON), particulate P (PP), and dissolved organic P (DOP) to this suite of measurements to allow detailed C:N:P ratios to be determined for both the particulate and dissolved fractions at selected depths within the water column.

Phytoplankton pigment diversity. In addition to our routine microscopic phytoplankton identification and enumeration, which is tedious and subjective, we will begin using a commercially available submersible spectrofluorometer. This instrument will allow us to differentiate, in real time, the diversity of the main photosynthetic groups within the lakes.

Molecular phylogeny. Molecular phylogeny will be used to characterize the microbial diversity annually within each lake at depths representing biogeochemically distinct layers within the water columns. Similarity indices and cluster analysis (CA) will be used to compare the level of similarity of sequence data over the geochemical gradients that exist within each lake and between lakes. These statistical methods will also be applied to the geochemical and exoenzyme parameters we measure and the resulting dendrogram(s) will be compared with the phylogram derived from the DNA data. These statistical methods will allow us to assess the features within each lake (and between lakes) most closely related to the phylogenetic data.

Bacterial biomass and productivity. Our past work has focused on measurements of phytoplankton biomass and productivity within the lakes. It recently became clear that the bacterioplankton are a major component of lake biomass and their phylogenetic and functional diversity may provide a link between past and present biogeochemical function and structure (e.g., Lisle and Priscu, in press; Lee et al., 2004). Consequently, bacterial biomass and bacterial productivity will be determined throughout the water column.

Exoenzyme-based in situ analyses. Most heterotrophic bacteria readily assimilate simple organic monomers, such as monosaccharides and amino acids. However, such compounds usually account for only a small fraction of the available DOC pool; macromolecules compose the bulk of the DOC. Hence, the rate-limiting step in DOC utilization is not monomer *uptake*, but monomer *generation* from macromolecules, a process mediated by extracellular enzymes (exoenzymes). Arrieta and Herndl (2002) have recently suggested that an increase in substrate availability induces changes in aquatic bacterial species composition, favoring the growth of beta-glucosidase producers. This, in turn, acts as a feedback loop, increasing the hydrolysis rate at the community level. We propose a series of exoenzyme studies which will provide us with two important clues to the microbial ecology: (1) a snapshot of heterotrophic processes *in situ*, and (2) the data necessary to determine if the response is the result of regulation of enzyme expression or is due to temporal trends in species diversity.

Mass loss to the sediments. The lakes represent the “sink” in the long cascade of material flow in the MCM. Hence, the determination of particulate fluxes to the lake sediments in concert with their stoichiometry will provide important information on biogeochemical processes within the ecosystem. We will deploy sediment traps just off the bottom of Lake Bonney to generate a time series of particulate C, N and P flux. If this deployment is successful, the traps will be deployed in Lakes Fryxell and Hoare for a similar period.

Amino acid racemization. All amino acids except glycine may occur as either L- or D-stereoisomer. L-amino acids are most abundant in nature because they are constituents of all living material. The formation of D-amino acids is primarily restricted to the aging of amino acids in organic matter (the L-form can racemize to the D-form). Preliminary data (Fig. 2.16) from Lake Bonney indicate that the deep saline waters are biologically old, supporting results from isotope dating (Lyons et al., 1998b). Detailed profiles will be made within each lake to determine the biological age of the water column and relate it to contemporary biogeochemical processes.

2.f. Lake Benthic Microbial Mats. In many parts of the lake systems, benthic mats are the principle element of organic material accumulation. They potentially reflect growth conditions at the time of deposition and are vulnerable to exposure/desiccation or burial during episodic events such as lake level change or floods. Past work has shown that benthic mats in Lake Hoare utilize ambient light very efficiently (Hawes and Schwarz, 1999, 2001). We will continue to conduct photosynthesis vs. irradiance experiments on mats from various depths and from other lakes so that we can refine our benthic photosynthesis model so the under-ice PAR sensors can drive it. We will continue to assess the pigment diversity of mats as well as organic matter provenance studies through the use of stable isotopes and molecular biomarkers. These measurements will allow us to assess and evaluate the distribution of legacy carbon by comparing current lacustrine mats to measurements of soil organic carbon.

2.f.1: New benthic plot studies:

Biomass dynamics. Variations in the light regime, as determined by ice cover, may change over timescales that are inconsistent with timescales of mat growth. We hypothesize that even at maximum sustainable biomass, the mats are in temporal disequilibrium. During periods of low light transmission caused by ice cover, we expect to see net declines in biomass, and during periods of high transmission, accumulations. Experiments that will enhance and retard the light experienced by mats at a given depth, will be conducted in MCM-III and we will monitor the response in terms of pigment, C, N and P content of the active layer, and trace active layer development using marked horizons. Light will be reduced using shade screens and light will be enhanced using an array of Blue LEDs suspended over the experimental plots, which should provide an order of magnitude increase variation in irradiance.

Respiration. Seasonal fluctuations in growth conditions, particularly winter-summer transitions, are likely to be significant to mat dynamics. We propose to overcome our inability to work on mats outside the austral summer by using remote technologies. We propose to develop and deploy respirometers (Fig. 2.17) that can be deployed on lake bottoms for periods of up to 1 year to investigate the annual carbon and nutrient balances of the mat communities.

Biodiversity. The benthic mat communities are a complex assemblage of prokaryotic, eukaryotic algae, and in the littoral zone. Because this assemblage is difficult to identify by microscope, we will use 16S rRNA gene and pigment diversity (Hawes and Schwarz, 1999).

Elemental Stoichiometry. Particulate C, N and P will be measured seasonally using the methods outlined for lake seston. The same suite of dissolved compounds measured in the lakes will be determined in the sediment pore water using sediment peepers inserted 1 m below the sediment surface (Teasdale et al., 1995). These data will allow us to determine profiles of sediment metabolic diversity, the flux and stoichiometry of solutes into and out of the sediments.

Pelagic-Benthic Coupling. In shallow regions of lakes in the Larsemann Hills, Antarctica (69°S), benthic mats dominate productivity, decrease phytoplankton biomass and enhance the flux of DOC into the water column (Laybourn-Parry, unpublished data). As part of MCM-III, Laybourn-Parry, Hawes and the MCM PIs will more closely investigate the interactions between mat and planktonic communities in the shallow margins of Lakes Fryxell and Hoare. This collaboration will continue research on both the characterization of DOC and its utilization by plankton (e.g. Bell and Laybourn-Parry, 2003). This work will be supported by the pore water flux measurements as well as the benthic mat diversity work listed above.

3. Continuing Long-Term Experiments

3.a. Streams – Relict Channel Reactivation: To investigate long-term patterns in stream algal communities we routed water to a relict channel (last flow in 1969) in January 1995. Within a few days of wetting, dormant algal mats began growing rapidly and had higher rates of net primary productivity than mats in streams with regular summer flow, possibly due to greater solute and nutrient concentrations in the relict channel, showing that algal mats can survive desiccation for long periods and respond quickly to hydration (McKnight et al., 1999). We found that the rates of N₂ fixation were also greater in the relict channel compared to other streams.

When we initiated the relict channel experiment, we did not anticipate the rapid response and did not understand the linkages between the streams and soil communities as we do now. We will utilize this long-term experiment in MCM-III to explore the relationships between habitat and dispersal controls on biodiversity and ecosystem function for stream and soil communities.

We will conduct an intensive study of the biogeochemistry and biodiversity in the relict channel and the upper reach of a controlled stream. At the seven established sites in the relict channel, representing decreasing extents of hydration during the cold summers of the late 90's, we will measure 1) microbial rate processes, both NPP and N₂ fixation, 2) algal species diversity using microscopic and molecular techniques, 3) the ratio of C:N:P in the mats, 4) stream channel and hyporheic zone water chemistry, and 5) variations in the abundance and distribution of nematodes and rotifers in soil/stream transects. We will also measure N and P uptake at the stream scale by conducting nutrient tracer experiments (McKnight et al., in press). On completion of this intensive study, we will then remove the diversion structure, and repeat a subset of the measurements in the subsequent years as the relict channel remains dry for an extended period (possibly 4-5 yr). When we replace the diversion structure and restore the flow to the relict channel, we will be prepared to study the rapid renewal of microbial growth by making detailed measurements in the first two weeks to learn more about adaptation of the mats and the soil communities to long term desiccation.

3.b. Soils:

Elevation Transect (ET, 1993). We will resample the spatially explicit grid spanning an elevation gradient along the south side of Lake Hoare 2-3x during MCM-III following methods in Porazinska et al. (2002). This study provides the longest record of invertebrate abundance and biodiversity for the dry valleys. The declining abundance of invertebrates coincident with climate cooling (Doran et al., 2002b) points to the value of continuing this long-term data set.

Long Term Manipulations (LTM, 1992). This experiment utilizes ITEX soil warming chambers (Marion et al. 1997) and additions of moisture and carbon (sucrose, glucose) to small plots near Lake Hoare to examine how soils might respond to climate variation and increases in limiting resources. Results show that soils are carbon limited (nematode abundance increased in sucrose amended plots after 8yrs), that soil warming decreases soil moisture and biota, and annual additions of moisture did not increase soil invertebrate populations. We have little information on how soil communities might recover from disturbance. We propose to discontinue the LTM treatments (a "disturbance") and allow these plots to "recover". We will sample them once or twice during MCM-III to examine the resilience/recovery of soil communities by comparing the trajectory of change for invertebrate populations that had previously diverged from the control treatments.

Biotic Effects Experiment (BEE 1998). This experiment employs water and temperature (ITEX chambers) manipulations to examine geographic variation in soil biodiversity and function at the lake basin scale. Soil responses to warming and moisture additions are followed in plots located in each of the major lake basins in TV. Unlike the LTM experiment at a single site, the BEE plot design allows soil conditions (resource legacy and climate) to be experimental variables.

3.c. Snow Fence: The long-term snow fence experiment was begun during the 2000-01 field season. We currently have three snow fence sites, one located in each lake basin of TV. In addition to the soil samples which are analyzed for soil invertebrates, organic carbon and total N as well as soil salinity, pH and moisture, meteorological stations are located at each site where air, snowpack and soil temperatures, and PAR are being recorded every 30 seconds. Snow depth is measured every 15 minutes. These experiments will be continued through the 2006-07 field season. Initial results comparing snow-patch vs. exposed soils indicate that subnivalian soils were

colder, had higher moisture content, higher invertebrate populations and higher species richness than exposed soils (Gooseff et al., 2003).

4. New experiments integrating stoichiometry and biodiversity across the MCM landscape

4.a. Landscape transects. In TV, the movement of glaciers during the Pleistocene produced a mosaic of tills of differing age. For example, the soils east of Fryxell date to ~6,000 yr BP whereas the Lake Hoare basin, they date to about 100Kyr. The ages of other soils in the MCM date to 2.5×10^6 yr. (Brown et al., 1991). Hence, the MCM environment is in many ways similar to the island systems studied by Vitousek (2004) that show the effect of landscape age to soil development. We will initiate a set of elemental stoichiometry (particulate C:N:P) and biodiversity measurements across landscapes within each lake basin and in the old moraines of the TV. These measurements will provide a profile of biodiversity and ecosystem structure (stoichiometry) that can be used to show how these parameters vary with stages of ecosystem development. These data will also provide us with important information on spatial and temporal variation in biogeochemistry and nutrient deficiency across the landscape. This approach will incorporate most of the major disciplinary questions being addressed in each of the subsystems in the MCM landscape – and at the same time it would ensure that a common currency is employed in all of the subsystems, and in all of the transfers between systems. Measurements within each basin will include cryoconites, streams, soils, and selected depths within the water column and lake benthos. We will attempt to integrate these measurements as closely as possible with the metabolic rate and biomass measurements described for each portfolio. Results from this suite of measurements will allow us to integrate all aspects of our conceptual model for MCM-III (Fig. 2.4) and will provide the raw material for understanding how organisms control ecosystem function, as well as how the environment controls the dynamics of organisms.

4.b. Aeolian traps. Because wind is thought to have a major role in the distribution and diversity of resources within the MCM, we will deploy a series of aeolian traps within the TV. The traps will consist of bundt pans placed in 3 transects, perpendicular to the south shore of Lakes Fryxell and Hoare, and perpendicular to the south shore of Lake Bonney. Additional traps will be placed, on the lake ice and on the 4 glaciers where cryoconite hole research is occurring. Each pan will be mounted approximately 30 cm off the ground on a PVC post. Pans will contain marbles so that airborne particles are more likely to be deposited, and stay deposited. The pans will be deployed throughout MCM-III with collections being made at annual intervals. Preliminary deployments of these traps have shown that they are effective in collecting a wide range of soil particles and organisms ranging from nematodes to bacteria. Material collected in the pans will be weighed and then analyzed for particulate C:N:P stoichiometry and molecular diversity. Similarity indices and cluster analysis will be used to compare the level of similarity of sequence data and elemental stoichiometry that exists within each lake basin and between lakes basins.

4.c. Nutrient bioassays. A series of nutrient bioassay experiments will be conducted from selected depths within each lake, within cryoconite holes from glaciers in both the Fryxell and Bonney basins, and within a selected stream from the Fryxell and Bonney basin 3 times during MCM-III. The lake water and cryoconite experiments will be based on time-course incorporation of $^{14}\text{CO}_2$ at saturating irradiances under a variety of nutrient amendments (see Priscu, 1995). Stream experiments will be done in conjunction with stream-scale nutrient tracer experiments in

streams with both abundant and sparse algal mats, carried out for 4-6 days, which represents the relevant time-scale for response given the dynamic patterns of streamflow. Because growth of algal mats on various artificial substrates has been unsuccessful (Chatfield et al., in review; Vincent and Howard-Williams, 1986) and unrepresentative of the regrowth of mats on natural substrates, we will use existing mats in our nutrient bioassay for the streams. We will identify mats in comparable subhabitats above and below the site of nutrient injection and collect 4-5 small cores of mat on a daily basis for chlorophyll-a, ash-free dry mass, C, N and P content, and bacterial cell counts (see Alger et al., 1997 and Table 2.4 for methodology) to monitor the microbial response to nutrient enrichment. Enrichments will be the same as those used in the lake and cryoconite hole bioassays. Dissolved nutrients will be monitored during the tracer experiment at a site near the subhabitat during the experiment to determine relationships between nutrient amendment and stoichiometry.

5. New measurements using in situ sensors

We currently maintain a network of sensors that measure physical parameters (e.g. meteorology, underwater PAR, stream flow, lake level, etc.) at a high frequency (several times an hour). Yet, as the site review pointed out, there is a logistical delay in retrieving portions of the previous season's data until the following year. In addition, our basic biogeochemical analysis is restricted to, on average, about 3 to 5 samples per year, which are only taken during summer months due to logistics. This low sampling frequency greatly limits our understanding of the coupling of hydrological (measured several times an hour) and ecosystem processes in the system. Furthermore, winter-over lake data have not been collected due to the difficulty in maintaining a human presence year-round. To overcome these limitations we will augment our existing physical network and develop a biogeochemical sensor network in the streams and lakes that will provide, at a minimum, high resolution measurements of temperature, nitrate, turbidity, chlorophyll-a and dissolved oxygen. Other sensors will be added as the network develops. Osmotic pumps can provide continuous samples for later analysis of other parameters in the lab. Ballast-controlled profilers could provide regular (e.g. weekly) top to bottom lake measurements. Funds are insufficient in the current budget to support a full network, but initial instrumentation could be deployed through regular equipment procurement in Antarctica, with supplemental funds being supplied through outside sources (e.g. the NSF Sensors and Sensor Network Program). As the site review pointed out, data telemetry is also considered important in reducing the need for site visitation and speeding up data delivery time. Telemetry of the new and existing sensor data will be sought in collaboration with NSF's logistics providers and was put forward as a MCM priority in our last Five Year Plan to NSF-OPP. Clearly this telemetry effort will also provide interesting outreach opportunities.

6. Ecological Modeling

Individual models for streams, lakes, soils, and cryoconites will focus on contemporary processes affecting community dynamics, primary production, biodiversity, and stability of food webs. Each model will address interconnections among soils, streams and lakes via valley-scale fluxes of water, salts, C and nutrients (N and P). The consequences of legacies for contemporary ecosystems will be accounted for via local stocks (initial values of model state variables) of water, salts, nutrients and biota.

6.a. Soils. Previous studies (Courtright et al., 2001; Moorhead et al., 2002) have identified high salinity, low moisture and organic C as the most important factor restricting soil fauna. We require a more integrative measure of dynamic moisture supply, expressed in terms of matric and osmotic potentials and accounting for effects of temperature regime and salt content to develop a predictive model of where soil communities have the potential to develop. Our soil physical model will be based on models developed for cold regions (Bigl and Shoop, 1994; Shoop and Bigl, 1997). The model will divide the soil into discrete horizons including an ice-cemented layer, and will treat diurnal solar input, surface rock color, heat flow, matric potential as a function of texture (Hunt et al., 2001), and osmotic potential as a function of salt content and temperature (Marion and Farren, 1999). Model predictions will be compared with data on soil drying after water amendment (Campbell, 2003) and on water dynamics along a transect across a melting snow bank (Gooseff et al., 2003).

Population models for invertebrates (nematodes, rotifers, tardigrades) will be derived from published nematode models (Anderson and Kirchner, 1982; Moorhead et al., 1987), and run in conjunction with the soil physical model outlined above. Faunal populations will be related to their resource base by including algae, bacteria, yeasts, and protozoa in the models based on published information (Atlas et al., 1978; Treonis et al., 2000, 2002). The population models will be evaluated using data on nematode population dynamics and spatial distributions of all faunal groups. We will estimate algal production from biomass estimates by modeling water and temperature dynamics in the surface soil. Estimates of invertebrate energy requirements will be based on observed population dynamics using the approach of Hunt and Wall (2002). Faunal energy requirements will be compared with estimated algal production and with potential energy supply from aeolian C inputs (Lancaster, 2002), and from potential use of legacy C based on ages (turnover times) and stocks of soil organic matter (Burkins et al., 2001). These calculations may help to rule out one or more potential energy sources.

The population models will be used to explore the effects of passive organism dispersal on community stability and diversity (hypotheses 2a-c), effects of predation and competition on species distributions, the effects of disturbances (climate change, species introductions, soil disturbance) on ecosystem functioning (3c), the relationship between site characteristics and organism stoichiometry (3b), the effects of faunal diversity and identity on productivity and community stability (3a, 3c), and the effects of winter survival on stability and diversity (2a).

6.b. Glacier-Stream Interactions. We are developing two models of meltwater production for MCM. The first is a general temperature-based model to estimate annual meltwater fluxes over 10^2 - 10^3 yrs. The second is a distributed energy balance model based on Tarboton and Luce (1996) to operate on an hourly to daily time scale. These models will address hypotheses 1a and 1b, and lead us to an integrated understanding of the MCM hydrological system and provide us with the ability to predict water fluxes through MCM as climatic variables change.

6.c. Streams. Two related stream-modeling activities will focus on estimating whole stream primary production, and assessing invertebrate secondary production employing similar approaches to the soil modeling. In contrast to soils, there is obvious and abundant algal primary production in streams. Thus it is surprising that total invertebrate abundance was not significantly greater in streams than in nearby soils (Treonis et al., 1999). It seems likely that secondary productivity of invertebrates is much higher in streams than in soils, but that this

productivity is expressed in population turnover rather than in greater biomass, because of the greater trophic diversity in streams. To evaluate this possibility, we will adapt the soil population models described above, with appropriate changes to the soil physical model. The stream mat model will be based on mat biomass data and observed responses of gas exchange to light and temperature (Hawes and Howard-Williams, 1998, Moorhead et al., 1997).

The model will generate estimates of net primary production, decomposition and herbivory. Predicted net ecosystem production may constrain estimates of aeolian transport of stream organic matter to soils (2a-b). We will use the model to explore: (1) the consequences of differences among types of algal mats in N₂-fixation and in exposure to desiccation and abrasion from sediment movement (2b); (2) the effects of manipulating invertebrate diversity on stoichiometry and production (3a-b); and (3) effects of varying winter survival on mat diversity (2b, 3c).

6.d. Lakes. Two basic model components will be plankton biomass dynamics and production of benthic algal mats. Both basic components will be non-spatial, tracing fluxes of C, N and P at a single point in a lake (3a-b). The basic plankton model will include mechanisms (identity of biota; effects of light, temperature and nutrients on rates of processes) to allow representation of different levels in the water column and different lakes. The benthic model will be based on gas exchange of whole algal mats as a function of light and nutrients (Moorhead et al., 1997; Hawes and Schwarz, 1999). These models will be evaluated by their ability to represent observed spatial differences in rates of primary production as a function of environmental drivers and local adaptations of biota (3d). The plankton model will represent a postulated food web including functional groups of phototrophic eukaryotes, cyanobacteria, chemoautotrophic bacteria, mixotrophic flagellates, heterotrophic flagellates, heterotrophic bacteria, ciliate protozoa, and rotifers (Laybourn-Parry et al., 1997; McKnight et al., 2000; Bell and Laybourn-Parry, 2003). Substrate pools will include DOC and POC. The most general and efficient way to relate organism stoichiometry to growth rates and nutrient supply is to distinguish structural, metabolic and storage components of biomass (Hunt et al., 1977, 1998), and we will apply this approach to phytoplankton and bacterioplankton. The model will be fitted to data on intra- and interseasonal phytoplankton dynamics (Spaulding et al., 1994; Priscu et al., unpubl.) as well as the less extensive data available for the other web components. Uncertainty remains regarding some transfers in the planktonic web (e.g., viruses and rotifers, Priscu et al., 1999). Thus the dynamic stability of the model and its ability to reproduce correlations between primary production and environmental parameters will be evaluated for a variety of assumptions about trophic relationships.

Point models will be aggregated into spatial models by dividing the lake into discrete depth zones based on gradients of nutrients and light. Whole lake C budgets have been constructed for several lakes (Takacs et al., 2001), but no mechanistic interpretation of differences among lakes has been attempted. By adapting the model separately to different lakes, we will test whether the hypothesized structures and processes incorporated into the model are sufficient to account for lake differences in terms of legacies of nutrients, salinity, light and basin morphometrics (2d, 3a-b).

Sensitivity analyses of whole lake models will be carried out to determine the importance of various processes (e.g., stream inputs, upward diffusion of legacy nutrients) to lake production, organism stoichiometry and dynamic stability (2d, 3b, 3d). Food web architecture will also be manipulated to evaluate the potential for feedbacks between biodiversity and

ecosystem functioning, and to predict the consequences of adding higher trophic levels (crustaceans) for system stability and productivity (3c).

INTERSITE COMPARISONS WITHIN THE LTER NETWORK

MCM continues to contribute to cross-site and network related research. As noted above, our snow fence experiment will allow us to compare our results to those of similar experiments run at NWT, ARC and HBR (Brooks et al., 1995; Walker et al., 1999; Groffman et al., 2001). Our preliminary results indicate different consequences in increased snow accumulation at the MCM than at some of these three sites (Gooseff et al., 2003).

In other on-going cross-site work, McKnight has been funded to help lead a DOC comparison among sites, Lyons and Fountain are involved in an upcoming Network supported workshop on the impact of extreme climatic effects on ecosystem dynamics, Lyons is a member of a larger group working on cross-site comparisons of ecosystem elemental budgets, and Priscu is working to integrate data from the NSF Microbial Observatories to the LTER sites. In addition, the MCM scientists are active in the KNZ, JRN and NWT sites. The MCM scientists took a leadership role in a recent Network workshop on disturbance, legacy and disequilibrium. Supplemental funding has recently allowed us to begin comparing nitrogen biogeochemistry at MCM and JRN, a cold vs. warm desert location. Clearly, the MCM scientist are involved in and have substantially contributed to a number of important cross-site activities.

Table 2.1 McMurdo Dry Valley averages and extremes in selected meteorological parameters. Data are from 1985 to 2000 and summarize data collected from stations in the Taylor, Wright and Victoria valleys.

Surface air temperature °C	
average mean annual	-27.6
absolute maximum	10
absolute minimum	-65.7
Degree days above freezing °C-day	6.2
Soil temperature °C	
average mean annual	-26.1
absolute maximum	22.7
absolute minimum	-58.2
Wind m s ⁻¹	
average mean annual	4.1
maximum	37.8

Table 2.2a Molar ratios of major ions in Blood Falls compared to seawater and near bottom waters of the west lobe of Lake Bonney.

	Na ⁺ :Cl ⁻	Mg ²⁺ :Cl ⁻	Ca ²⁺ :Cl ⁻	SO ₄ ²⁻ :Cl ⁻	HCO ₃ :Cl ⁻	K ⁺ :Cl ⁻	Cl ⁻ :Br ⁻
Blood Falls	0.88	0.200	0.085	0.980	0.040	0.016	569
Seawater	0.86	0.097	0.019	0.052	0.004	0.190	649
West Bonney 38m	0.78	0.175	0.027	0.020	0.034	0.019	451

Table 2.2b Biochemical composition, bacterial activity and bacterial numbers in water from Blood Falls. PC and PN = particulate organic C and N, respectively; CHL = chlorophyll *a*; Leucine and thymidine (TdR) incorporation were measured with tritiated substrates at 5 nM concentration. Bacterial numbers were obtained on DAPI stained direct counts.

PC (μM)	PN (μM)	PC:PN (moles)	CHL (μg l ⁻¹)	Leucine (nM h ⁻¹)	TdR (nM h ⁻¹)	Bacteria (cell ml ⁻¹)	Density (kg m ⁻³)
294.8	16.9	17.4	1.2	1.04	4.27x10 ⁻⁵	1.09x10 ⁵	1100

Table 2.3 Relationship of Research Plan to MCM-III Hypotheses.

Hypothesis	MCM-III Activities
1a	Monitoring: meteorological stations, glacier mass balance, glacial sediments, stream flow, lake level and lake ice variations, sensor development
1b	Monitoring: glacier mass balance, glacier albedo, cryoconite geochemistry and biology, stream flow, cryoconite hole size, shape, evolution
1c-d	Monitoring: Stream flows and chemistry, hyporheic volume and chemistry, tracer experiments
2a	Monitoring: algal mat stream transects, stream flow; GIS; relict stream channel experiment, paleoclimate experiment, stream productivity, respiration and diversity, aeolian trap analysis, stoichiometry and 16S rDNA transects
2b	Monitoring: stream flow, stream bed roughness, mat morphometry in relation to growth, particulate organic carbon transport, stream algal distribution and diversity, stream chemistry, relict stream and stream dispersal experiments
2c	Monitoring: soil diversity, soil chemistry and carbon content, stream moisture, BEE and LTM experiments, snow fence experiment
2d	Monitoring: Nutrient bioassay experiments, stream flow and nutrient levels for nutrient load models, amino acid racemization; extracellular enzyme activity, diffusion models
3a	Monitoring: Stoichiometry and 16S rDNA transects, exoenzyme measurements, bioassay experiments; aeolian traps, relict stream experiments, soil warming, wetting, and nutrient addition experiments; soil tracer studies; sensor development
3b	Rate measurements in streams, soils, lakes, and cryoconites; stiochiometry and 16S rDNA transects, valley-scale nutrient budgets
3c	Monitoring: biomass/productivity; Soil and stream manipulation experiments, snowfence experiment
3d	Monitoring: biomass productivity; Bioassay experiments across landscape units, stoichiometry and 16S rDNA transects

MCM Modeling activities will be closely tied to addressing all the above hypotheses with a focus on contemporary biodiversity and processes influencing community dynamics, production, food webs, and a valley-scale synthesis of stocks and fluxes of C, N, P, and salts.

Table 2.4 Parameters to be measured in the McMurdo Dry Valley Lakes. F=Fryxell, H=Hoare, B=both lobes of Bonney. Sampling refers to routine austral summer (AS, November-January) and early winter (EWN=February-March) research.

Parameter	Year I	Year II	Year III	Year IV	Year V	Year VI	AS (No/Y)	EWN (No/Y)
Ice Thickness	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	2	2
Lake Volume	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	2	2
Temp/Cond in vivo Fluor.	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	2-3	2
Vertical light profile	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	2-3	2
Solutes	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	2-3	2
Biomass Plankton (bact, phyto)	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	2-3	2
Benthic mat	H, F	H, B	H, F	H, B	H, F	H, B	1	0
NPP Plankton (bact, phyto, prot)	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	2-3	2
Benthic mat	H, F	H, B	H, F	H, B	H, F	H, B	1	0
Species Plankton (bact, phyto, prot)	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	2-3	2
Benthic mat	H, F	H, B	H, F	H, B	H, F	H, B	1	0

Table 2.5 Methods for New Measurements in MCM Lakes.

<u>Under Ice PAR</u> – Year-round spherical sensors (LICOR 193), located ~10m beneath the ice surface; data logged every 20 minutes in all TV lakes
<u>Elemental Stoichiometry</u> – DON via Shimadzu model TOC-V; particulate P and TP via Dore and Priscu (2001)
<u>Pigment Diversity</u> – BBE Instruments submersible spectrofluorometer, which measures fluorescent excitation at 680 nm
<u>Molecular Phylogeny</u> – Clone libraries will be prepared from PCR products using accepted techniques (Lane, 1991; Delong 1992; Amann et al., 1995). Clones will be grouped and compared to known databases (Lanoil et al., 2001). SSU-rDNA sequences will be identified and aligned (Maidak et al., 1999; Smith et al., 1994; Lanoil et al., 2001)
<u>Bacterial Biomass</u> – Epifluorescent microscopy of SYBR-gold stained cells (Lisle and Priscu, in press)
<u>Bacterial Productivity</u> - Tritiated thymidine incorporation (Takacs and Priscu, 2001)
<u>Exoenzyme-based in-situ Analysis</u> – Measurements of alpha-glucosidase, beta-glucosidase, leucine aminopeptidase, phosphatase, and esterase using the methods of Sinsabaugh et al. (1997) and Foreman et al. (1998)
<u>Mass Loss</u> – Deployment of Mark 78H-21 PARFLUX Sediment Traps at the bottom of the lakes and sediment collected for a 2 year period at monthly intervals. Collected material will be sieved into 3 size fractions and analyzed for total mass and C:N:P in each size fraction.
<u>Amino Acid Racemization</u> – Water column measurement of Land D forms of free and acid hydrolyzable aspartic acid will be made using the HPLC of derivatized material (Bruckner et al., 1994)

Figure 2.1 Aerial view of the Taylor Valley showing the position of glaciers, lakes and exposed soils.

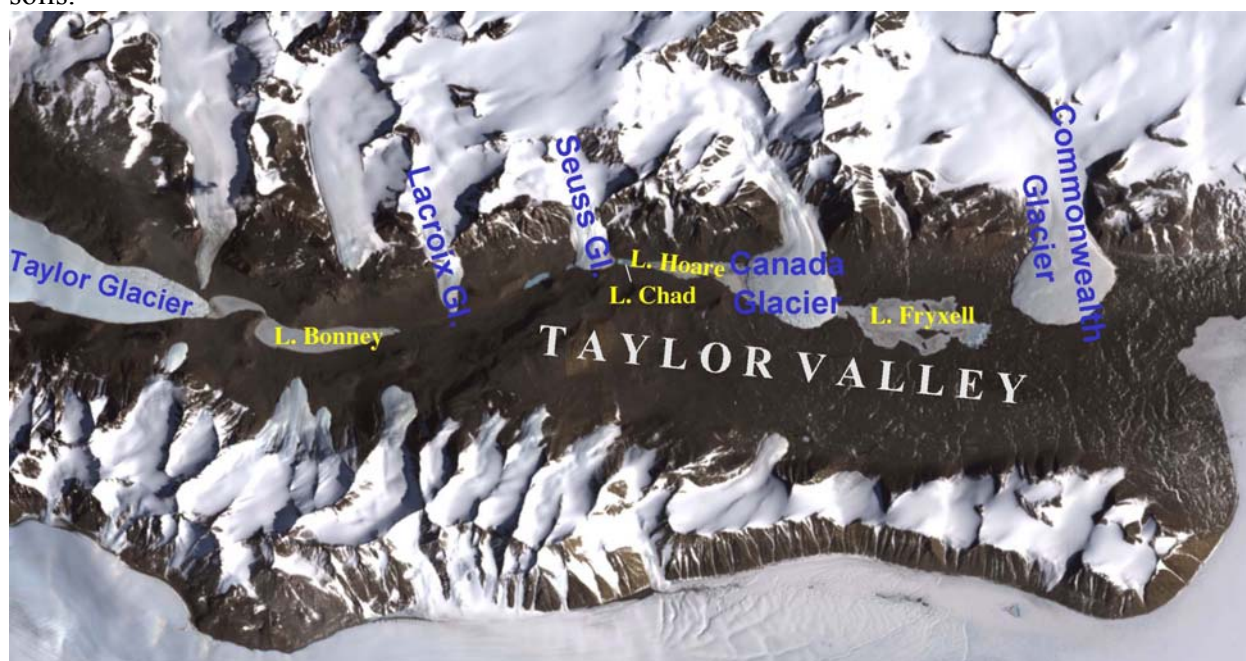


Figure 2.2 A comparison of average annual precipitation across all LTER sites. The MCM site is circled.

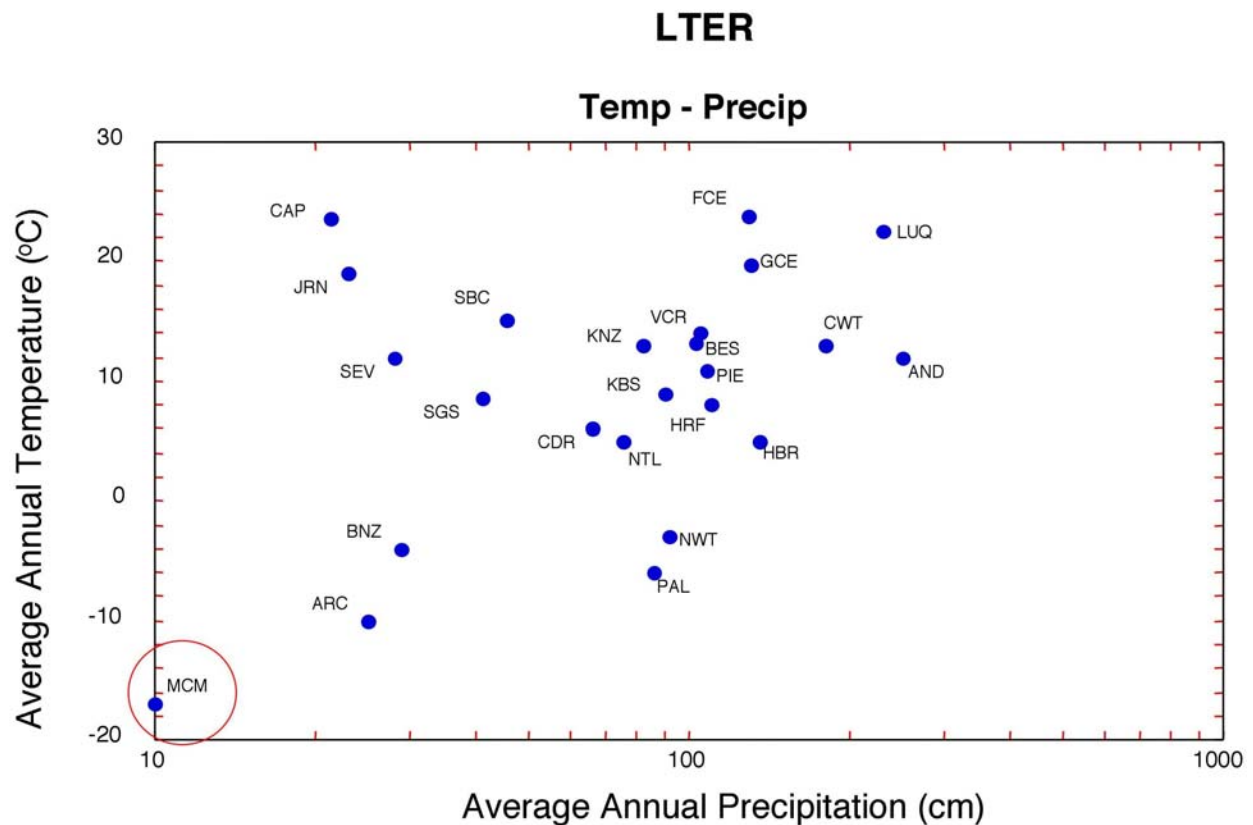


Figure 2.3 The major watershed processes and age of the various landscape units within MCM

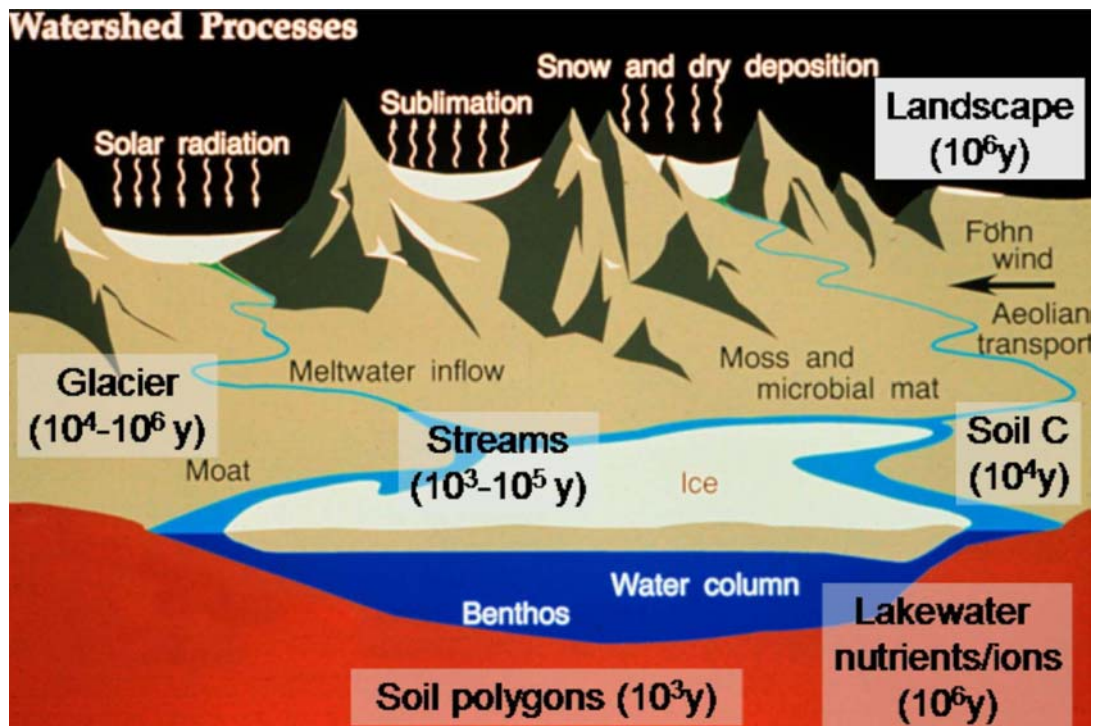


Figure 2.4 Conceptual model for MCM-III

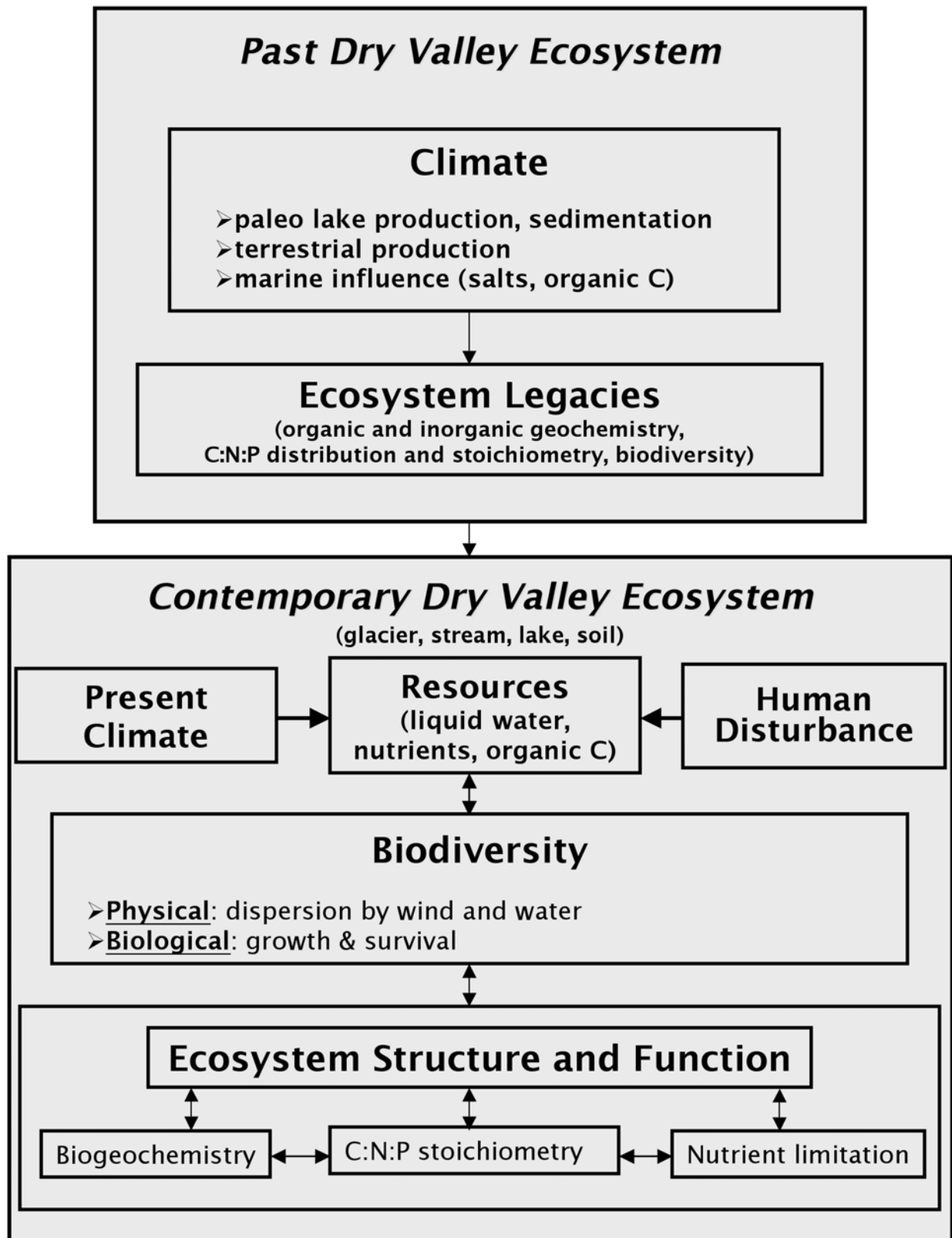


Figure 2.5 Phylogenetic analysis of cyanobacterial-related 16S rDNA sequences (106 to 781, *E. coli* ref.) using maximum likelihood. The scale bar indicates 0.1 fixed substitutions per nucleotide position. Clones from cryoconite holes and Lake Bonney ice samples appear in bold print. The high sequence identity between clones from these environments suggests that particulates blown onto the glacier from adjacent locations were responsible for seeding this cryoconite hole with viable microorganisms and that similar survival strategies may be in effect in cryoconite holes and permanent lake ice.

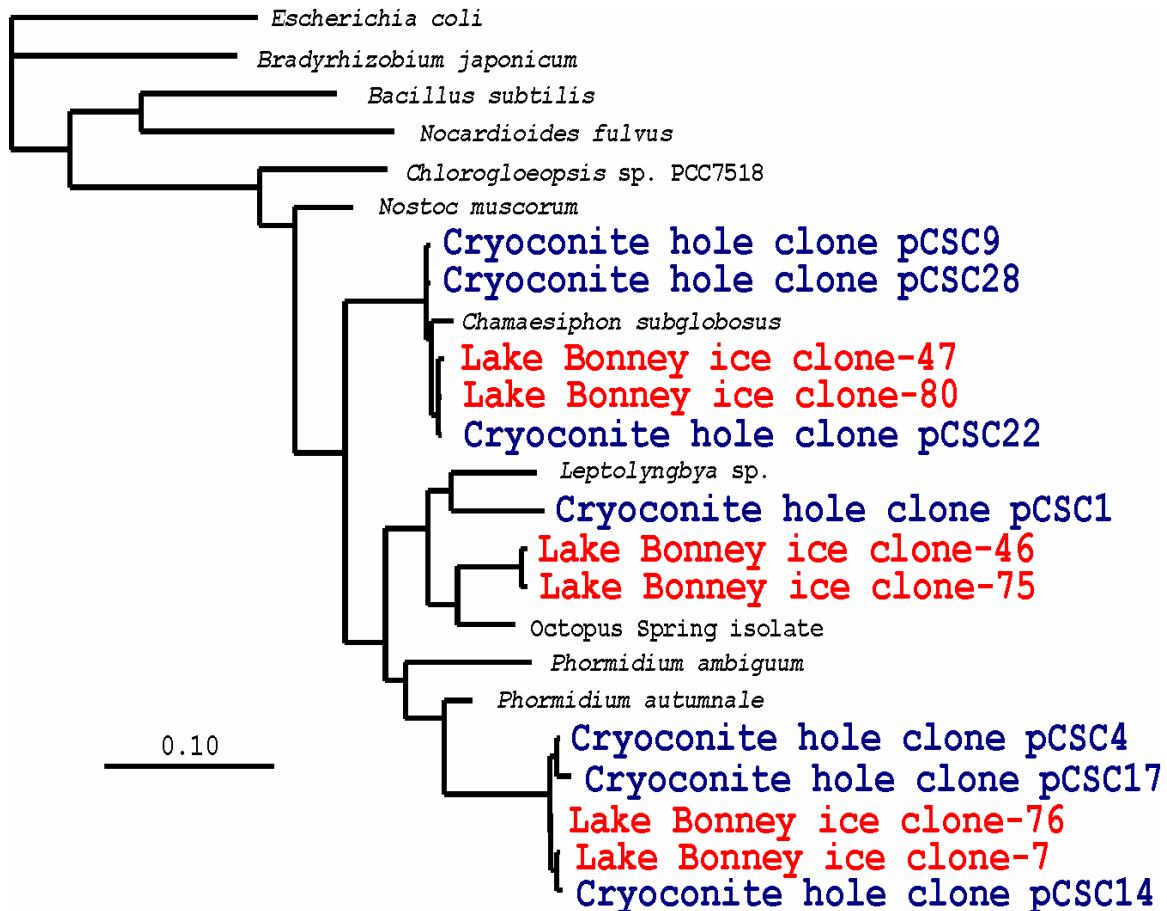


Figure 2.6 The snout of Taylor Glacier showing Blood Falls as it exits the glacier and flows over the lake ice. The person in the image is standing on the permanent ice on the west lobe of Lake Bonney.

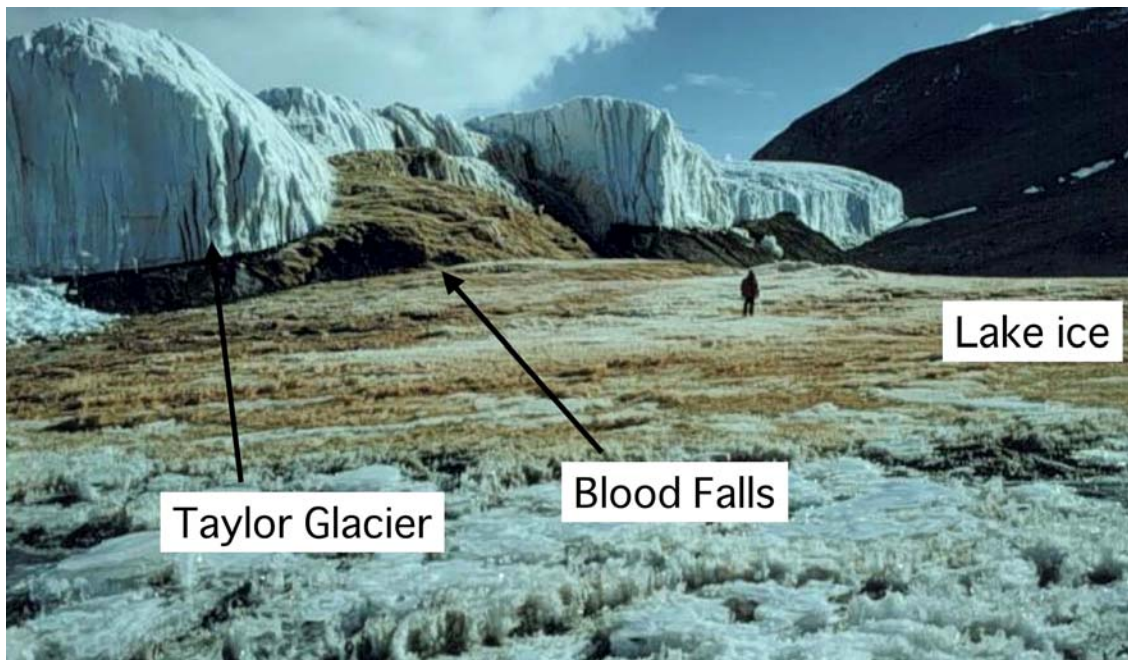


Figure 2.7 Typical salinity profiles (PSU) for the east (ELB) and west (WLB) lobes of Lake Bonney, Lake Fryxell (FRX) and Lake Hoare (HOR). Note that ELB and WLB are plotted on the secondary x-axis. PSU=Practical Salinity Scale. Depth is from the hydrostatic water level in the sampling hole (~30-50 cm below the ice interface). The ice thickness ranged from 4 to 5 m.

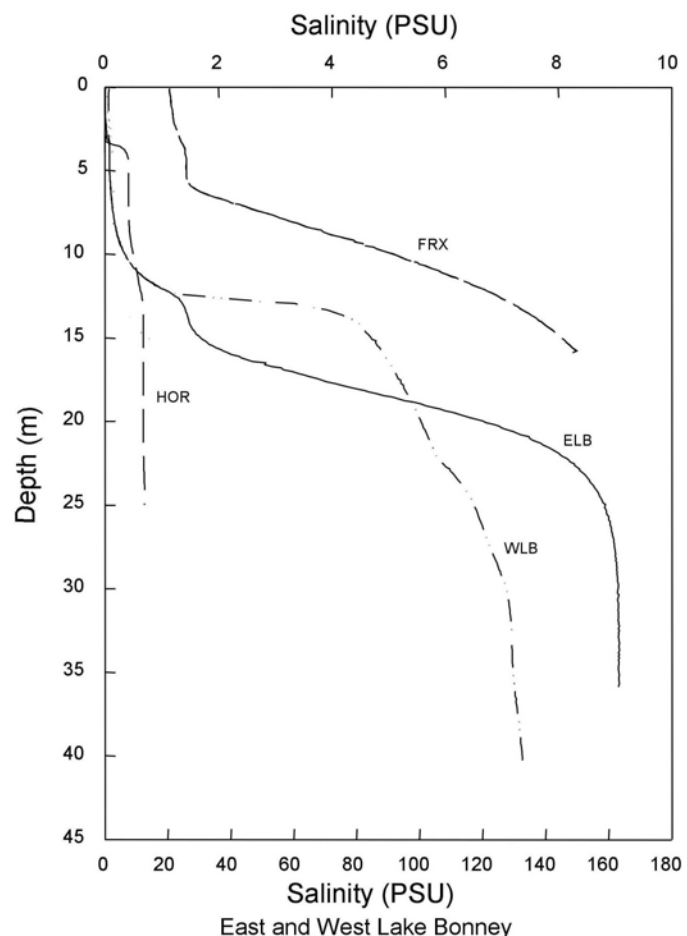


Figure 2.8 Temporal succession in the water column integrated carbon content of the major phytoplankton divisions in the west lobe of Lake Bonney. The variable line represents the yearly average; the horizontal line represents the average for the period 1992 to 2001. All data are from November and December (months common to all years of sampling). Single data points indicate actual values for each year.

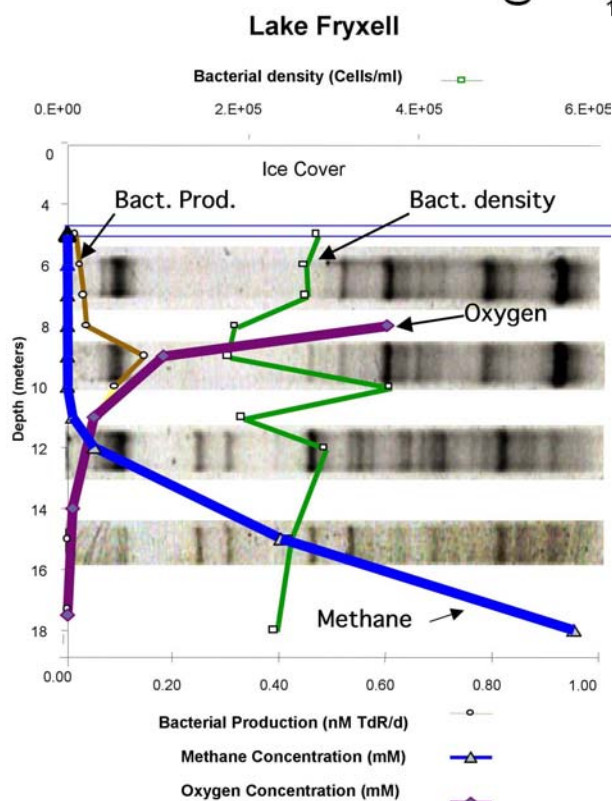
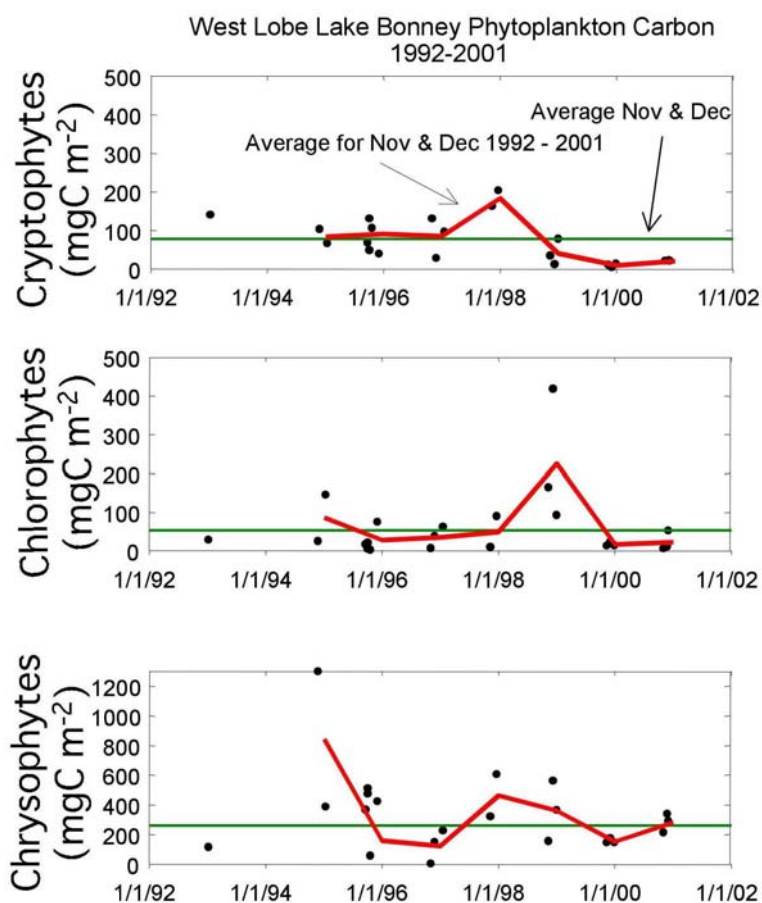


Figure 2.9 Profiles of bacterial density, bacterial productivity, oxygen and methane over the Lake Fryxell water column along with temporal temperature gradient gel (TTGE) bands showing the diversity of phylotypes at 6m, 9m, 12m and 15m, October 2002. A distinct shift in the bacterial activity and diversity occurs below 10 m where the water column becomes anoxic.

Figure 2.10 East lobe Lake Bonney 16S rDNA summary comparing lake ice sequences with water column sequences at 4.5, 13 and 25 m. These data show that the lake ice assemblage is different and more diverse than the lakewater assemblages. The water column also shows differences in diversity between the water above (4.5m), within (13m) and below the chemocline (25m).

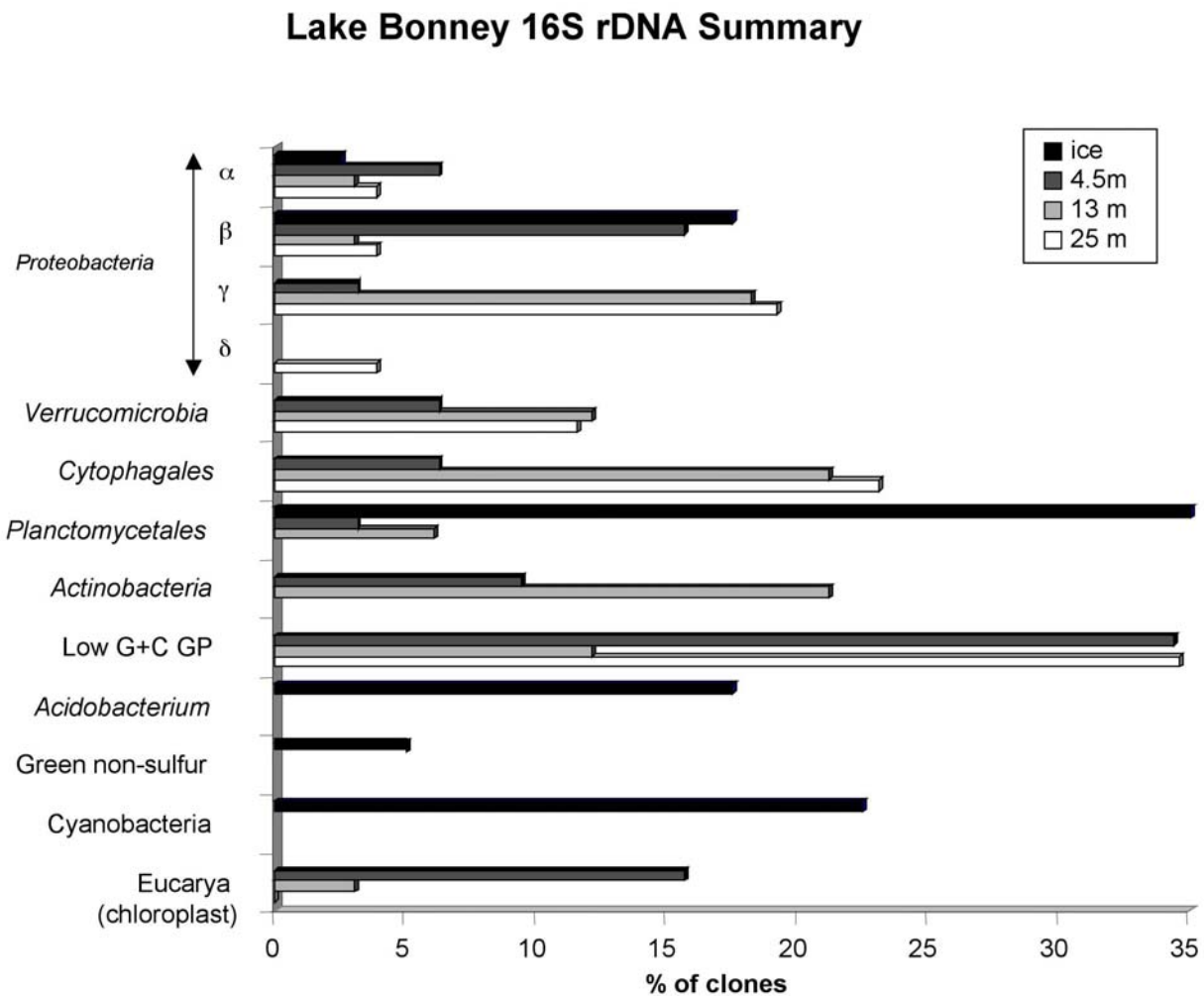


Figure 2.11 Conceptual models developed during MCM-I and MCM-II. Topographic effects on the distribution of incident radiation and the principle flow of organic carbon and water among habitats of the MCM are shown in “A”; A general model of biomass dynamics in the MCM, including inputs, outputs, and major factors controlling losses and gains of biomass is shown in “B”.

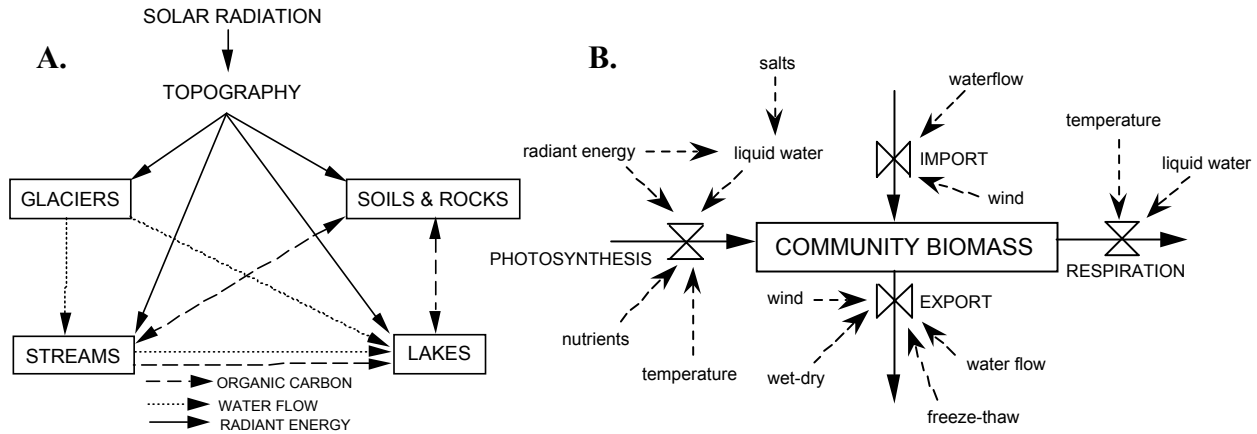


Figure 2.12 Conceptual model of temporal cycles between periods of warm/moist and cold/dry conditions, with attendant changes in hydrology and organic matter and nutrient dynamics. Outer, middle, and inner loops represent changing climatic, hydrologic, and soil water conditions, respectively. Solid lines represent temporal trajectories, and dashed lines represent forcing functions. The model shows that climate drives hydrology, which in turn drives organic matter deposition and erosion, as well as chemical accumulation and concentration.

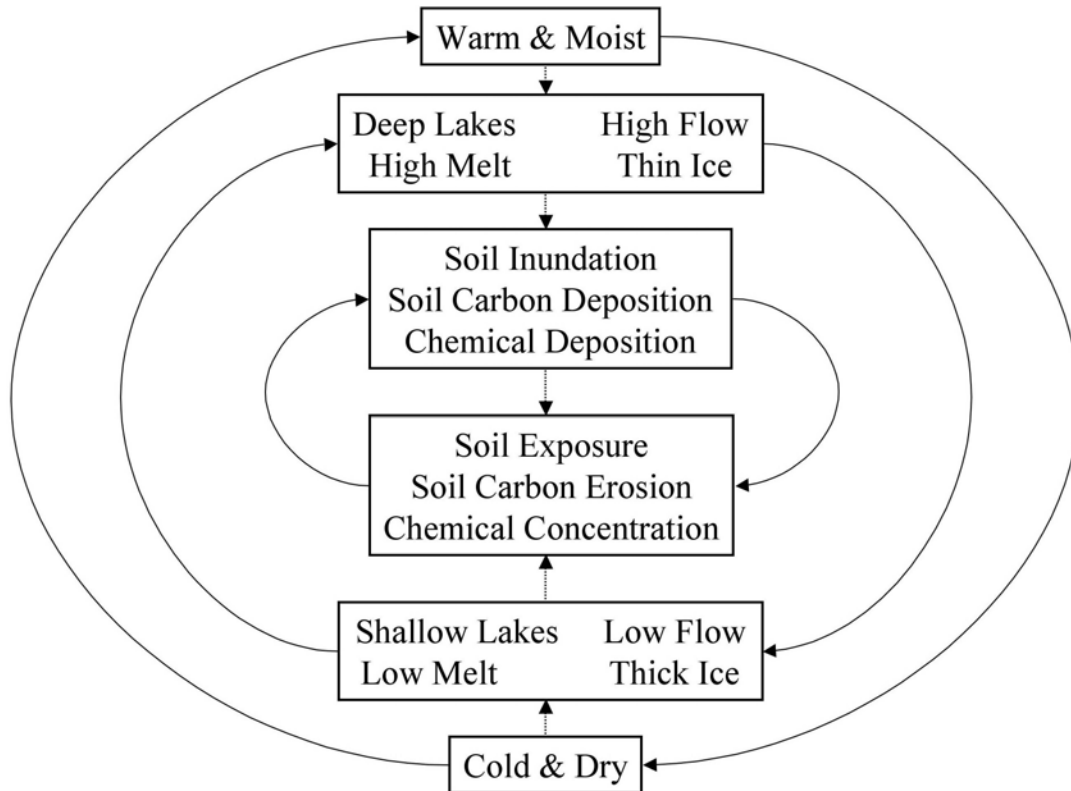


Figure 2.13 Mean molar N:P ratios for surface glacial ice, cryoconite holes, stream water, stream sediments and moat sediments in eastern Taylor Valley, Antarctica. A general narrowing of N:P ratios illustrates a biological modification of melt water along this hydrological continuum closer to the Redfield ratio of 16:1. Biological activity narrows the N:P ratios of atmospheric inputs through a hydrological continuum of melt water extending from glaciers through streams. 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.

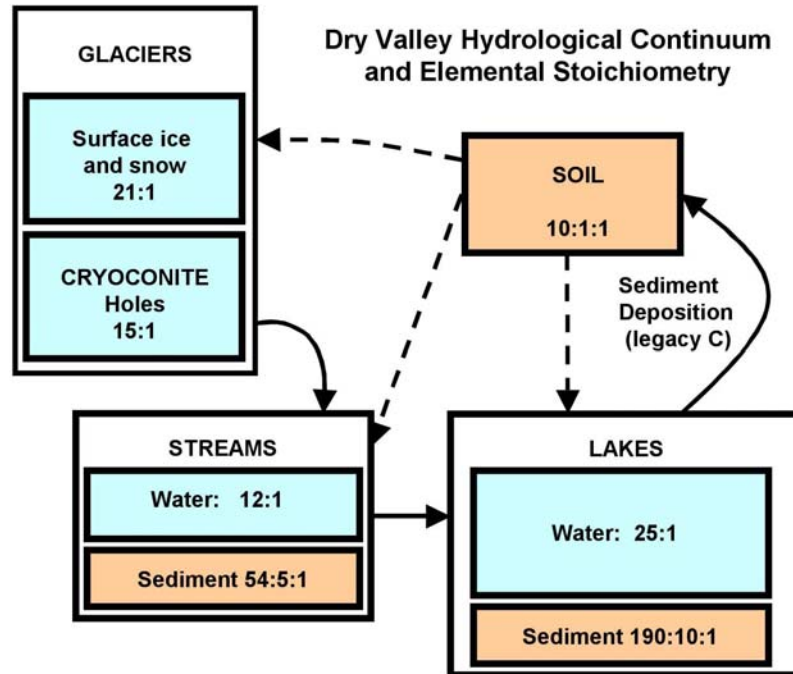


Figure 2.14 Green Creek (Fryxell Basin) showing the extent of the hyporeic zone.

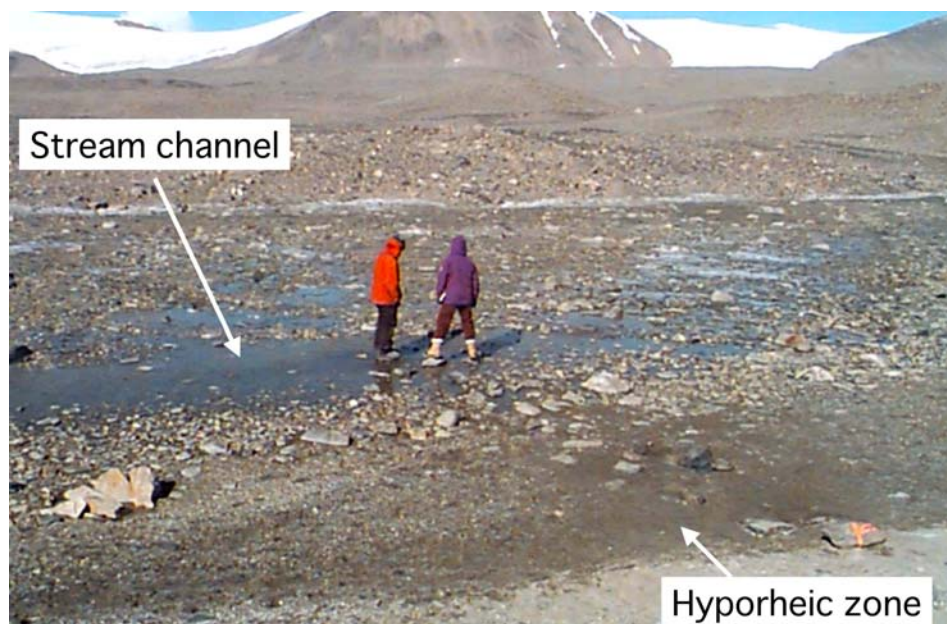


Figure 2.15 Carbon pools and fluxes in the upper 5 cm in the MCM Dry Valley soil system

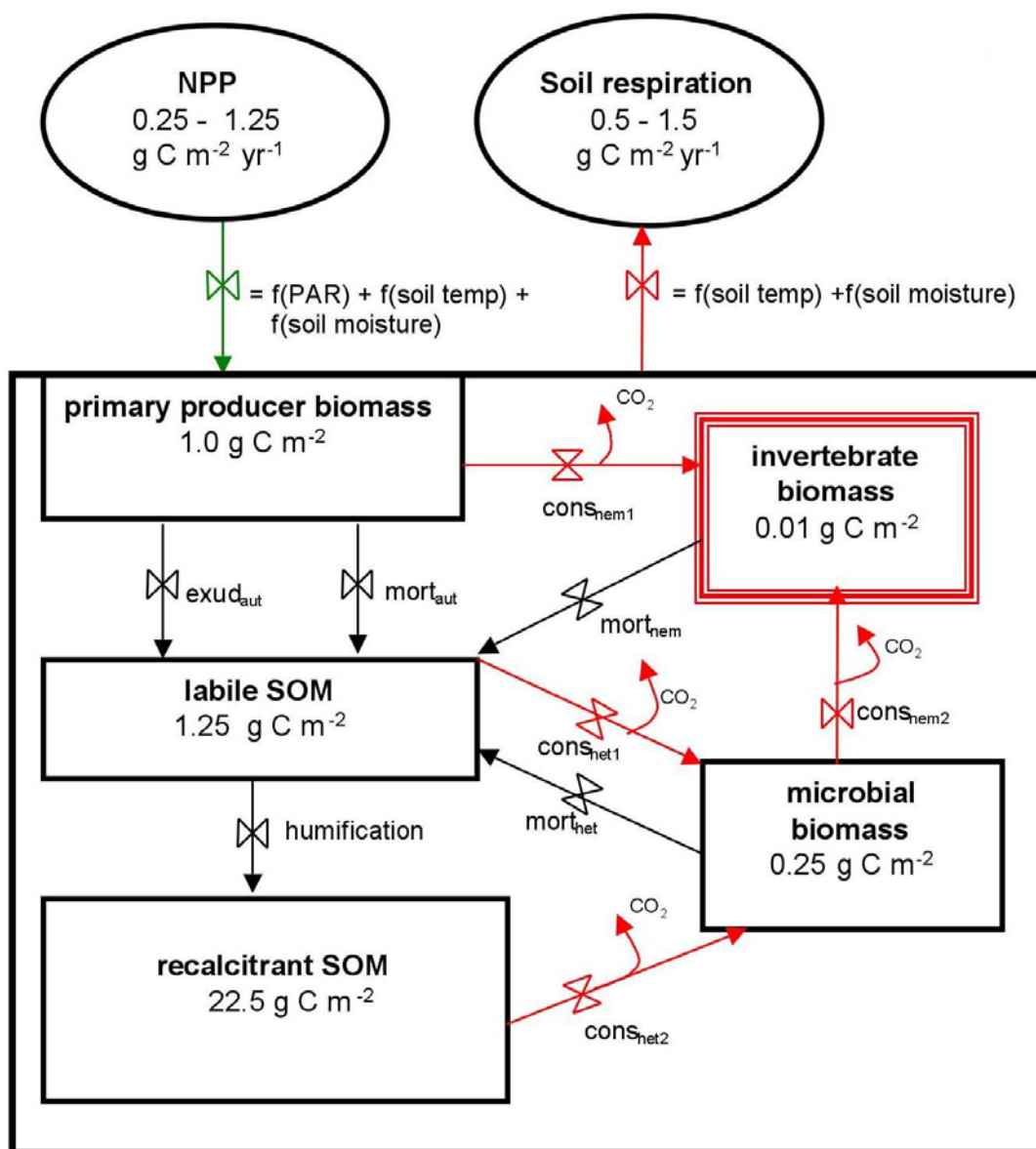


Figure 2.16 Concentration of D- and L-aspartic acid and the D/L ratio in the east lobe of Lake Bonney. This profile shows that the deeper water (below the chemocline) in the lake is biologically “older” than the water above the chemocline.

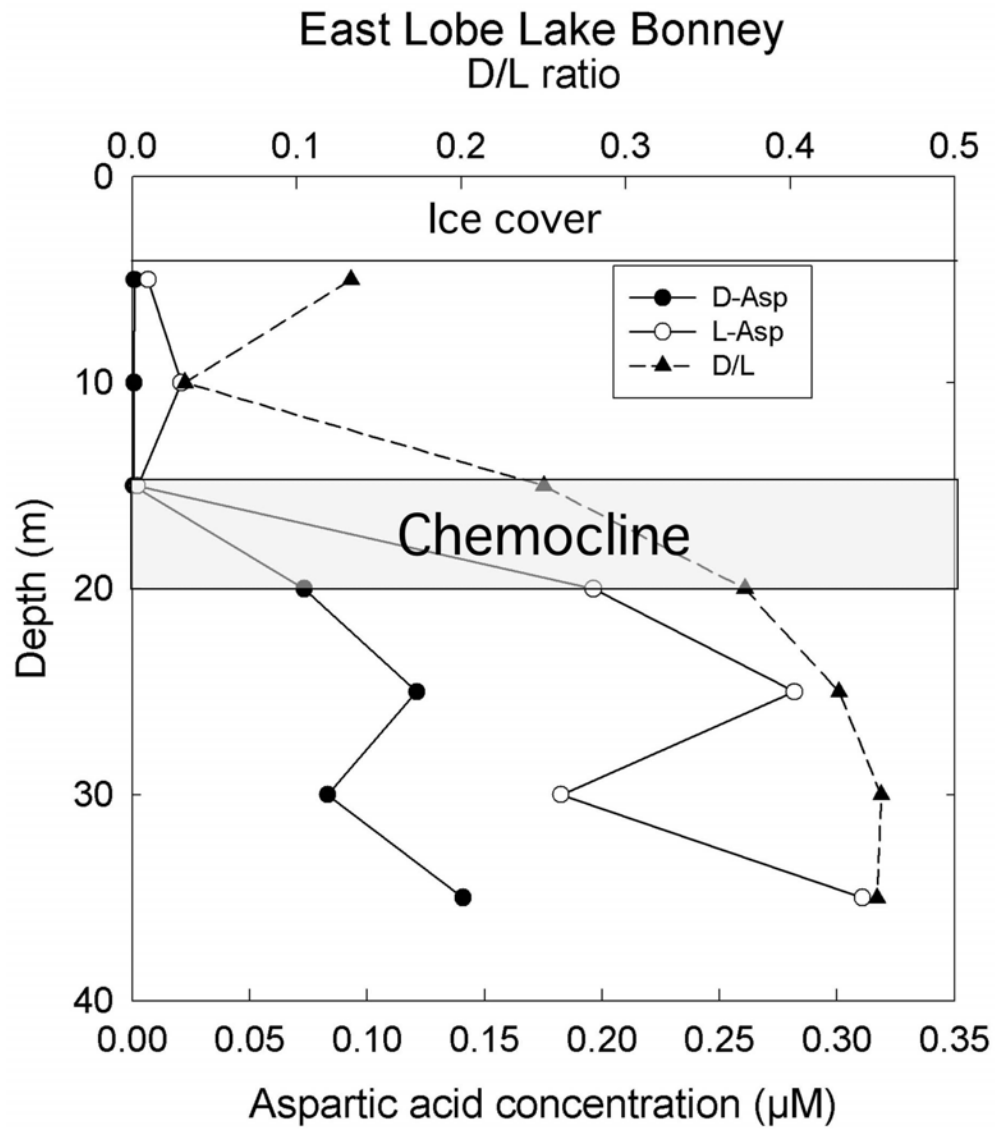


Figure 2.17 Respirometer prototype. A 0.5 x 0.5 transparent chamber (27 l volume), with a laminar flow pumping system to gently stir internal contents. Pumping system drives water over an OTD-DIVER oxygen/temperature measuring device, and has solenoid controlled ports available for collection of up to 10 samples into serum bags. System is controlled by a microprocessor, which can be interfaced to other sensors. We may employ the use of osmotic pumps if more of a continuous time series of water samples is required. Collected water samples will be analyzed to allow us to determine the release/uptake of organic and inorganic materials over time.



SECTION 3

SITE MANAGEMENT

Lyons became the lead PI in March of 1998 and McKnight became the PI responsible for information management. Lyons appointed an Executive Committee consisting of Fountain, Priscu, and Wall to help manage all phases of the project. This system continues to work well. Lyons was reviewed by the project PIs in 2001 and was unanimously supported. The 2002 site review team stated: "MCM is managed effectively in a way that fosters shared decision making and good communication within the team." For MCM-III, Lyons was asked to continue as lead PI and he will appoint new Executive Committee members - Doran, McKnight, and Virginia.

The management office of MCM is at the Byrd Polar Research Center (BPRC) at OSU. Mr. Tim Fitzgibbon is the Administrative Assistant and is responsible for the administration of the grant, and coordination of all interactions between MCM and NSF and between the PIs. Ms. Kathy Welch deals with field logistics, prepares the required field planning documents (SIP) that are due to NSF by mid April, and serves as the fieldwork coordinator during the four-month field season. This preparation includes the allocation of field personnel, field equipment, helicopter hours, and chemical analysis of samples at the Crary Laboratory in McMurdo Station. OSU and BPRC cost share ~50% of Welch's and Fitzgibbon's salaries.

The PIs meet twice a year. The first meeting is in February/March to review the activities of the past field season and to plan for the next one. The second meeting (summer) is a "science" gathering that, in most years, includes students, technicians, post docs, etc. In 2001 we began to rotate the meeting sites among the home institutions of all the PIs. In 2002, two small workshops on specific topics (nutrient stoichiometry and hydrological modeling) were convened instead of the larger meeting. In June 2003, 43 people attended the science meeting. We currently plan to alternate the science meetings between these smaller and larger gatherings. This August we will address nitrogen biogeochemistry and dynamics at a workshop in Hanover, NH and in September, another modeling workshop will be held in Ft. Collins. Communication among PIs occurs primarily through email and regular conference calls.

In MCM-III there will be two major changes to our organization. Bill Hunt will replace Daryl Moorhead as our PI for ecosystem modeling. This change was made, in part, because of concerns raised by the site review team about the needs and scope of MCM modeling efforts. Hunt brings important new abilities and outstanding experience to MCM and we are excited that he agreed to participate. In the summer of 2004, the information management (IM) operation of MCM will begin to be transferred from McKnight to Lyons. McKnight requested to be relieved of that responsibility. After some discussion among the PIs, the project agreed with Lyons's proposal to manage the IM. As lead PI he has an excellent overview of project activities and needs, and he would serve as an efficient liaison between MCM and network IM activities.

We continue to receive numerous requests from both US and foreign scientists and students to work at the MCM site. However, we are limited by NSF to 29 people due to logistical constraints. This limits our scientific activities and our flexibility to develop new experiments. This was clearly noted by the site review team in 2002. In spite of these constraints, we continue to seek important new collaborations while maintaining our long-standing commitments. To increase our breadth and depth, while minimizing the logistical and financial loads, we have a "formal collaborator" designation. This is limited to scientists who episodically participate in our fieldwork or modeling efforts. US collaborators include B. Adams, G. Dana, and F. Kenig (Table 3.1).

We believe that MCM is one of the leaders in the LTER network with regard to international cooperation and scientific visibility. We continue to maintain strong ties with New Zealand scientists involved in the Antarctica New Zealand program. This includes our collaborator, Ian Hawes, among others. Peter Doran has worked with Hawes investigating the benthic algal mats in Taylor Valley lakes. Johanna Laybourn-Parry works on the physiology of protozooplankton and their interannual variations in the lakes. We have added Martin Tranter, University of Bristol, as a collaborator. Previous collaborations with the late David Wynn-Williams, British Antarctic Survey, have also been beneficial to MCM. Doran is also working with Martin Melles, University of Leipzig, on a number of paleolimnological issues in Taylor Valley. MCM-LTER PIs also continue to be important US contributors to SCAR (Scientific Committee of Antarctic Research), as exemplified by Priscu being a US representative to the SCAR Life Sciences Standing Scientific Group (SSG), and Wall being a plenary speaker at SCAR's upcoming Open Science Conference in Germany in July. Because of our strong interest in international collaboration, Lyons has become a member of the network's first International LTER Committee that was established in 2003. We will continue our international collaborations during MCM-III. This will include an international workshop entitled, "Synthesis of Soil Biodiversity and Ecosystem Functioning in Southern Victoria Land, Antarctica" (D. Wall – PI), an NSF-OPP supported event, which will be attended by international soil scientists working in Antarctica.

Each of these collaborators brings an important tool and/or approach to MCM that is currently unavailable, and allows us to integrate and expand our research efforts (Table 3.1). The scientific challenges facing our research require the addition of these experts. Our collaborators continue to be important and productive members of our team.

In addition to our formal collaborators, the PIs acknowledge a new relationship for MCM-III, that of "investigator." Investigators are scientists who have postdoctoral experience with two or more seasons associated with MCM and who have demonstrated a commitment to polar research through the development of new research proposals that fall within the broad objectives of the MCM. These scientists may be supported by MCM and/or other projects, or may be in the process of building an independent research program as a tenure-track faculty whose focus includes polar regions. This new category allows MCM to help develop young scientists for future leadership roles in the MCM, polar research, and the LTER program. All formal collaborators and investigators with their relevant expertise are listed in Table 3.1.

The site review team recognized that MCM "is doing a lot with the number of people that they have available," but urged us to "explore ways to make more efficient use of the limited number of field slots they have." We will continue to discuss how to make increasingly efficient use of our slots and discuss these issues with OPP-NSF. We will also continue to compete for other, non-LTER grants to supplement our field operations. In MCM-II we were very successful (e.g. Priscu's Microbial Observatory) in this regard (Table 7.1).

We continue to encourage and promote diversity within MCM. Currently, two of the eight PIs, two of five investigators, and two of six formal collaborators are women. In addition, 57% of the graduate students and 54% of undergraduates involved in MCM-II were female.

Table 3.1. MCM-III Formal Collaborators and Investigators

Formal Collaborators		
Dr. Byron J. Adams	Brigham Young University	Molecular Biology, Soil Ecology
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 Nottingham, England	Protozoan Ecology, Microbial Loop Dynamics
Dr. Martyn Tranter	University of Bristol, England	Glaciochemistry, Glacial Hydrology, Glaciology
Investigators		
Dr. J. E. Barrett	Dartmouth College	Soil Biogeochemistry
Dr. Brent C. Christner	Montana State University	Microbiology
Dr. Christine Foreman	Montana State University	Microbial Ecology
Dr. Michael N. Gooseff	Utah State University	Hydrology
Dr. Dorora L. Porazinska	University of Florida	Nematology

SECTION 4 INFORMATION MANAGEMENT

The MCM data and information management system (IM) has been housed at INSTAAR, University of Colorado. We have adopted the general features of the NWT-LTER data system (Ingersoll et al., 1997), also located at INSTAAR, including a centralized data system with different levels of access, which is managed by a half-time database manager and part-time assistants as available and required. The database manager, supervised by McKnight, has worked with PIs and collaborators to fulfill our database commitment. We attempt to minimize the time between data collection, data submission, and creation of metadata to provide a timely public access. In addition we maintain an up-to-date bibliographic file, site news, and other related information, such as outreach resources during the field season.

In the summer of 2004, the IM will begin to be transferred to Lyons at Ohio State. This transfer will expedite the transition to MCM-III, which will begin in early 2005. Lyons will hire a *full time* data manager in the summer of 2004 and the IM will continue many of the protocols developed in MCM-II as outlined below. The new data manger will spend some time in Boulder as the transition occurs.

A distinguishing feature of the MCM is the high degree of coordination in planning each field season, which carries over to the IM. Templates for data entry and cross-relational file structure are prepared in anticipation of data submittal. At the end of the field season, the data manager receives the actual sampling schedule (e.g. sampling dates and depths for each lake, sample dates and location for glacier, soil and stream field measurements and samples) in the specified templates. Data are entered into electronic files in the field and at co-principal investigators' home universities. Data sets are usually submitted electronically in spreadsheet format after the quality is checked by the investigator responsible. When appropriate, both original measurements and final results resulting from the investigator's revisions, are submitted. Metadata are updated to keep pace with seasonal variances in instrument status and measurement practices, especially for the meteorological and hydrologic data. Following the approach presented by Ingersoll et al. (1997), we recognize the following types of data:

Type 1- Digitally-recorded data: e.g. continuous meteorological data

Type 2- Hard copy data: e.g. field measurements and analysis of discrete samples

Type 3- Manipulated data: e.g. continuous and discrete stream flow data which have been interpreted by using rating curves determined for each season

The data manager is not directly involved in primary data entry for Types 1 and 3 data because of the digital recording and investigator oversight. Type 2 data, because it is typically collected manually, is handled differently. The MCM has two categories of Type 2 data: fast acquisition data obtained within a few months of the field season (e.g. water chemistry data) and slow acquisition data for which the analysis is more time-consuming or costly and results are unavailable for 6-12 months or more (e.g. bacterioplankton, phytoplankton, soil biota species abundance). The data manager tracks the progress of both categories of Type 2 data with key variables in the datasets. The data manager performs the final quality assurance and quality control prior to all data sets being made available to the community, and organizes the metadata for the submitted data sets.

The manager also generates composite data sets from algorithms provided by the investigators. For example, average monthly and daily meteorological data are computed from raw meteorological data. The data manager works with the investigator to document the quality of the composite data set.

The MCM has a record of timely data submission to the data manager because of a sequential procedure to ensure timely submissions. In the future, the data manager will notify the supervising investigator on a monthly basis about the status of various data submissions. In the case of a substantial delay or lack of response to the data manager's inquiry, Lyons will contact the investigator to discuss plans that meet the needs of other investigators. Persistent unsatisfactory responses may be considered in planning future field seasons and allocation of resources. Because each field season is planned by the MCM as a team, investigators have a strong incentive to be current with their submission of data.

The MCM dedicated database computing system consists of a UNIX-based Sun/SunBlade 1000 Server that stores the data and metadata in a relational database (MS Access, Oracle 9i) and provides web access for scientists and the general public. Data are archived on the server and daily backups are routed to an external drive-bay. Both the server and a Dell 530 Workstation are used to prepare the data for inclusion in the database. In addition, a Sun/Ultra-Enterprise 150 and a Sun/SparcStation 5 client are dedicated to data analysis including full GIS functionality (Arc/INFO, ArcView). An additional server (Sun Fire V480) will be purchased in 2004. Additional software includes Microsoft Word and Excel, Visual Basic, general text editors, and HTML coding.

The data are housed in Oracle 9i, a relational database that will provide us and others with a powerful tool to download and analyze the data. Currently, the data accessible through the web are from the Oracle database mostly through query tools. The bibliographic information is also accessible through the web is from the Oracle database with query capabilities. The goal of the current IM team is to make all datasets available through query tools. The table below shows the progress in completing query tools as of Feb 1, 2004:

Meteorological data	Completed
Computed Values for Average Meteorological data	Completed
Limnological data	Completed
Stream Hydrological data	Completed
Stream Chemical and Biological data	In progress
Glacier data	In progress
Soils data	In progress

GIS Capability. The original GIS of the Taylor Valley was developed at DRI. This was superseded by VALMAP, which was developed by Dr. Mike Prentice at the University of New Hampshire with support from NSF-OPP. This new and more complete GIS includes aerial and satellite imagery, location of soil and glacier measurement sites, and the position of lake boundaries and stream paths for two different times. Importantly, the coordinate system and network of previously established benchmarks have been rectified to be compatible with use of GPS in the field to locate sites in the McMurdo Dry Valleys. This represents a critical labor-intensive step so that we can now immediately transfer the position of our data collection sites directly to the GIS and it will revolutionize our ability to develop new data layers.

In the last year, all the tabular and spatial data used to create VALMAP has been transferred to McMurdo IM. Through ARCSDE, all these data are currently stored in Oracle 9i database. By summer of 2004, we plan to have a web-based mapping tool that will allow access and use of these data.

Data Accessibility and Schedule. Data accessibility is driven by the timing of the annual field season and completion of data analyses. The continuous data sets (Type 1 and 3) are submitted to the data manager within 0-4 months after completion of the field season in mid-February. When these data are posted in the MCM database they are immediately available to other MCM researchers and the broad scientific community. This corresponds to an annual updating of the Type 1 & 3 data sets.

Type 2 data sets of core monitoring data and experimental data from either short term or long term manipulative experiments are made available to the MCM investigators once the merger of the data submitted has been completed, shortly after the field season. The core monitoring data are made accessible to the scientific community one-two years after the end of the season in which the data were collected. For example, the Type 2 core data sets from the 1993-94 through 2000-02 seasons currently are available through the web.

Information management services. Information is largely distributed through the World Wide Web. This includes scientific data files and a bibliography of MCM publications. The present bibliographic tool allows PIs to maintain their own contributions. Bibliographic entries submitted are written to an intermediate file, which the database manager can review to determine completeness and comparability before including it in the database. Planned future enhancements include text search on all the fields in the bibliography. In addition to the bibliography, MCM web site hosts details of the overall project (newsworthy events, project descriptions, etc.) and links to related web sites at PI institutions, and elsewhere.

Summary statements. The site review team stated that the “overall performance of the information management [was] excellent,” and that “the site has made significant progress toward reaching the goals for data management set in its 1998 proposal, and has successfully addressed issues concerning data management raised in earlier reviews of the site.” Clearly, the site review team felt our IM has been very successful. Lyons will work closely with McKnight to facilitate a seamless transition of MCM’s operation to Ohio State. We anticipate continued success in this area.

SECTION 5 OUTREACH

Educational Outreach

Over MCM-II, Lyons' group has been actively involved with the three MCM Schoolyard LTER (SLTER) schools and their teacher representatives (Barb Schulz, Lakeside School, Seattle, WA; Kim Ouderkirk, Tuscaloosa Academy, Tuscaloosa, AL; Carol Landis, Linworth Alternative School, Columbus, OH). In addition to presentations at the schools, we have sponsored annual meetings for the teachers to discuss goals, issues, etc. about the project. The teachers have also visited each others' classrooms to coordinate sampling protocols so that data could be compared among the three schools, as well as to Taylor Valley stream data, and to provide information to the students about their "sibling" SLTER sites. Ms. Ouderkirk presented a paper at the annual meeting of the Geological Society of America in Denver, CO (October 1999). Lyons and Welch gave a presentation at Tuscaloosa Academy about the dry valleys. Lyons spoke to Barb Schulz's class at Lakeside School and gave a talk at the Watershed Education Project meeting sponsored by the Thornton Creek Project in Seattle, WA. In addition, a web site was developed with the help of MCM staff for the Tuscaloosa Academy Schoolyard site. Also, links were established between the Schoolyard sites with the MCM site to maximize data sharing among sites. Ms. C. Nezat, one of Lyons' former staff, helped to organize a workshop, "Learning from LTER data in K-12 classrooms" at the All Scientists Meeting in 2000, and gave a presentation about the activities of the SLTERs associated with MCM.

Over the past two years, our primary activity has been with Dr. Landis and Linworth School. We have accomplished the following: (1) helped Linworth students collect river water samples using G.L.O.B.E. sampling procedures; our lab has analyzed the samples for major cations and anions and we have facilitated the interpretation of the data; (2) added a new section to the MCM website on the Columbus, OH area. The information on the website was compiled and analyzed by Linworth students and related to on-going studies of water quality and landuse change; (3) continued to update a database of teachers and organizations in the Columbus area interested in stream/river studies. In addition to these activities, Carol Landis attended the 2003 ASM and was a member of the MCM field party in 2003-04 and communicated directly with her class via email (see www.carollandis.com). She is producing an interactive CD to be used for environmental/ science education based on her field experiences. We have recently broadened our outreach to include three other teachers in the Columbus metro area (Jen Regelski, Jim Van Dyne, and Brian Wenger)

Lyons has also been involved in the COSI (Center Of Science and Industry) mentoring program in Columbus, OH. As a mentor in 2000-01, he discussed Antarctic-related climate change issues with 5 area high school students. Over the past two years, Lyons has taken part in the COSI Electronic Expert Series. He has made presentations via distance learning TV to a number of middle/high school students talking about polar science and global change. He will continue to participate in this program during MCM-III. In addition, Welch gave a presentation to 5th grade students at Sacred Heart School in Hampton, NH (2000) and to the 5th grade students at Barrington Elementary School in Columbus, OH, (2001). Nezat gave a presentation to a biology class at Opelousas Catholic High School in Opelousas, Louisiana (October 2000). Nezat and Welch gave three presentations at the Lincoln Park Elementary School in Columbus, OH for Career Day (2001).

Elissa Elliott and Valerie Sloane worked with Priscu's group with Teachers Experiencing Antarctica (TEA) during the 1998-99 and 1999-00 seasons, respectively. Dr. Virginia continues to work with his 2000 TEA fellow, Kevin Lavigne, in developing science curricula and school lab exercises for high school students. During the 1999-00 season, two TEA alumni, Barbara Schulz and Peter Amati, returned to the MCM under a new grant, TEA for TWO. Schulz and Amati conducted their own experiments and trained people in McMurdo how to provide scientific information useful to U.S. high school teachers and students. McKnight hosted Louise Hoffman in 2002-03 through the TEA program. Hoffman posted ~50 journal entries on her website and responded to hundreds of email inquiries while on the ice. She also gave over 20 presentations to K-12 students and fellow teachers in the Chicago area. McKnight's group created a website related to education/outreach and also posted information from this season on the Global School Net Foundation website (www.gsn.org), where 45 teachers from 20 states, Canada, New Zealand, and Portugal looked at the periodic postings. This past field season Doran hosted a TEA teacher, Robin Ellwood.

All the MCM-LTER PIs gave talks and participated in other K-12 and adult educational outreach. Examples of these activities are presented below. McKnight has hosted a number of INSTAAR Open Houses for middle school groups with a full day of presentations about MCM research. Fountain gave presentations at the Vancouver Academy of Arts and Academics (a high school) and a number of Rotary Clubs in the Portland area, and served as a mentor at the Oregon Museum of Science and Industry. Nylen and Johnston of Fountain's group gave presentations at Alameda Elementary School and Mountain View Middle School.

Virginia's group gave presentations at Marlboro Elementary School in Marlboro, VT. Melody Burkins (then a graduate student at Dartmouth) advised two first-year undergraduates in a research project concerning organic matter properties in Taylor Valley soils. The undergraduates were part of Dartmouth's award-winning Women In Science Project (WISP) and presented their research in a public science symposium at the end of the spring 1999 term. Wall's group has participated in outreach activities in local schools. Steve Blecker has presented "Life and Research in Antarctica" to the Poudre High School, Fort Collins, CO. Wall gave a talk entitled "Women in Antarctica" to Philanthropic Educational Organization for Women in Estes Park, Colorado. Andy Parsons and Blecker presented "Antarctica: Valley of the Dead?" - an interactive display about research in the McMurdo Dry Valleys, at the Denver Museum of Nature and Science in 2001. Doran gave a public lecture at the Adler Planetarium in Chicago. Priscu is involved in the American Indian Research Opportunities program at MSU, and has presented lectures to the Murdock Charitable Trust. Priscu's group also developed a high school lesson plan, "Popsicle," to teach about living/working in Antarctica. During MCM-II, most of the PIs gave presentations on MCM-LTER at the Sunday night lecture series at McMurdo Station. These lectures are meant for the non-research community to educate them on research activities in Antarctica.

Because of our unique location, our site is visited by both media and political figures every field season. As the site review team pointed out, "The MCM-LTER team has done an excellent job reaching out to the public, media, and Congress; it plays an important, visible role in representing NSF-supported research in Antarctica to these constituencies." We also provide outstanding representation to the importance of LTER-type research to these constituencies. A listing of some visitors to our site, and the media attention during MCM-II are shown in Tables 5.1 and 5.2.

Table 5.1. Examples of VIPs that have visited the MCM research site since the 1999-2000 field season

R. Colwell	Director, NSF
T.N. Cooley	Chief Financial Officer, NSF
C.L. Cragin	Asst. Secretary, Dept. of Defense
E.M. Kelly	Chair, NSB
J. Lubchenco	Former President AAAS, member NSB
J. Dudeney	Deputy Director, British Antarctic Survey
M. Leinen	NSF
Honorable F. Lautenberg	Senator, New Jersey
Honorable M. Sanford	Then member, House of Representatives, now Governor, South Carolina
F. Cushing, D. Baron	Staff Assistants, Subcommittee on VA, HUD, and Independent Agencies
K. Erb	Director, NSF-OPP
Honorable C.J. Swindells	US Ambassador to NZ
D. Burham	Chairman, CEO Raytheon Co.
M.A. Rubinstein	Director, NSF Budget Division
S. Blakeslee	NY Times
J.M. Nash	Time Magazine

Table 5.2. Selected Media Attention During MCM-II

- Doran granted interviews regarding the 2002 Nature paper, resulting in articles to New Scientist, Knight Ridder Press, CBS Evening News with Dan Rather, and a USA Today web page. He also gave interviews to NPR, CNN, CBS, BBC, CNBC, USA Today, NY Times, Washington Post, AP, Reuters, and the CS Monitor as well as a number of overseas news agencies. Doran's PNAS paper on Lake Vida (2003) was covered by essentially every major news source in the U.S and many abroad.
- McKnight was interviewed on TV news about climate change and tourism in Antarctica (1999).
- Icy Clues to Earth's Future; Antarctic Researchers Face a Mass of Mystery, Written by Curt Supplee, Washington Post, February 21, 1999 features Fountain and other LTER PIs.
- "The Lost World" BBC special on subglacial lakes, featured Priscu. He also had interviews in Wired, Smithsonian, Newsweek, and Discovery magazines regarding his work on the ice, and participated in a live NPR program called Science Friday with Ira Flatow. Priscu was also featured on a 15-minute segment on NPR's "All Things Considered" in May, 2001, and is advisor for NPR's DNA files.
- Several press reports were generated about Kevin Lavigne, a 2000-01 TEA from Hanover High School, Hanover, New Hampshire (sponsored by Ross A. Virginia): Hoff D.J. (2001) The Great White Lab *Education Week* **20**(22), 36-43; Hoff D.J. (2001) Polar Attraction *Teacher Magazine* **April**, 24-31.; Dartmouth Professor And Hanover High School Teacher Team Up To Research Antarctic Life Patterns. News from Dartmouth, Dec. 20, 2000. <http://www.dartmouth.edu/~news/releases/dec00/antarctica.html>
- Lyons was requested to contribute a lead article to the American Geological Institute's magazine, Geotimes, on how a geochemist became lead PI of an LTER site (Research in the Coldest Desert, *Geotimes* **48**(1), 2003). He was also quoted in the feature article in the 3 February 2003 issue of Time.
- Lexington Herald-Leader, March 3, 1999: Target: The Oldest Life on Earth; March 4, 1999: Testing Ground Found for Exploration of Mars; March 4, 1999: Testing Ground Found for Exploration of Mars
- New Scientist, April 17, 1999: Like Nothing on Earth