# Section 1. Results of Prior Support

The research team for the initial 6-year phase of the McMurdo Dry Valleys LTER project (MCM-I) consisted of R. A. Wharton, Jr. (lead PI/limnologist), A. G. Fountain (glaciologist), D. W. Freckman (now D. H. Wall) (soil ecologist), W. B. Lyons (geochemist), D. McKnight (stream ecologist/hydrologist), D. L. Moorhead (ecological modeler), J. C. Priscu (limnologist) and C. M. Tate (stream ecologist). During MCM-I, we produced 68 papers in refereed journals, 32 book chapters, and 8 unrefereed journal articles, 7 dissertations and theses, over 95 abstracts from national and international meetings, and 37 papers in the NSF-Office of Polar Programs publication, Antarctic Journal of the United States. We supported 28 graduate students and 7 post doctoral fellows. A total of over 60 collaborators have been involved in MCM-I research. For more details, see the McMurdo LTER publications web page.

Results of the initial 6-year phase of the McMurdo Dry Valleys LTER project recently have been compiled and published in two synthesis volumes (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 Unions Antarctic Research Series). These two books represent our first attempts at integration and present an overview and synthesis of ecosystem processes within this extreme environment, including interactions between physical, chemical, and biological components. In both books, the dry valley regions of Antarctica are presented within an ecosystem context representing a significant departure from earlier subject-specific compilations of Antarctic dry valley studies (Pickard 1986; Green and Friedmann 1993; Bormann and Fritzsche 1995). A CD-ROM also accompanies the Priscu volume and provides detailed geospatial data to support the text.

Prior to MCM-I, research in the MCM was sporadic, discipline-specific and lacked an integrated ecological basis. Among the most important contributions of MCM-I was the integration of these earlier site-specific studies on streams, lakes, glaciers, and soils, into an ecosystem perspective of Taylor Valley (the principle site of MCM-I investigations; Fig. 1.1). This framework has proven critical to evaluating both interactions among various elements of the MCM ecosystem and their responses to current and projected environmental change. Our work in addressing the LTER core areas of research and developing a modeling framework to simulate the functioning of the MCM ecosystem, provided a means of predicting ecosystem behavior. Below we summarize the main results of our research on each of the major landscape units (lakes, streams, soils, glaciers) including our progress in modeling and synthesis.

Fig. 1.1 TAYLOR VALLEY, southern Victoria Land, Antarctica, primary field location of MCM-I and MCM-II.
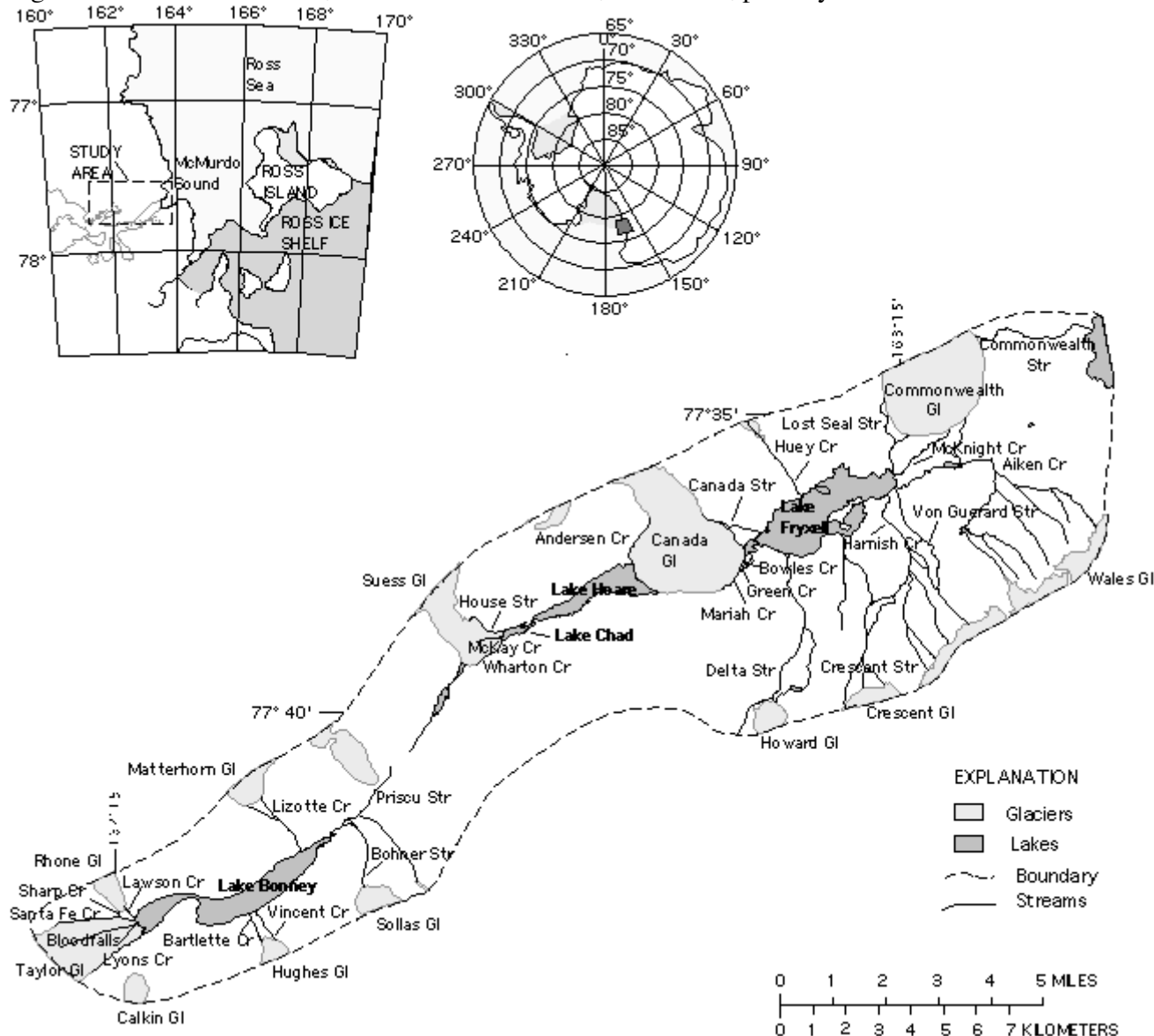
Meteorology: Climate drives and shapes all ecological systems, so all LTER sites include some degree of meteorological monitoring. However, MCM requires a particularly large meteorological program because no larger network of meteorological stations exists in the region, meteorological conditions show a high degree of spatio-temporal heterogeneity, and biological activities are particularly sensitive to microclimatic conditions. Our LTER Automatic Weather Network (LAWN) consists of eleven stations (Fig. 1.2) collecting all the standard meteorological variables as well as specific measures particularly important to the MCM (Doran et al. 1995). Significant differences in the climate regime in MCM occur over very short distances. For instance, the three main Taylor Valley lake basins lie within 20 km and 47 m elevation, but Lake Bonney experiences a continental climate driven by katabatic winds and Lake Fryxell experiences a maritime climate (Table 1.1). The climate of Lake Hoare is transitional between the two, possibly because the Nussbaum Riegel (700 m high hill in the center of Taylor Valley) blocks moisture-bearing clouds from the ocean from reaching the Lake Bonney basin (Fountain et al. 1998; Lyons et al. in review b). This landscape feature controls the pattern of precipitation, humidity, and winds in Taylor Valley, which partly defines ecological conditions.

Table 1.1. Average meteorological conditions within three lake basins of Taylor Valley during summer (1994-96).

Basin	Temperature (°C)	Relative Humidity (%)	Wind Speed (m/s)	Solar Radiation (mmol/m²/s)

Fryxell	-7.7	59.3	3.4	76.0
Hoare	-7.4	59.7	2.8	57.0
Bonney	-6.7	53.3	4.6	45.6

The meteorological data have been used in most aspects of MCM-I research, such as predicting glacial melt (Dana et al. 1998) and streamflow (Conovitz et al. 1998; Lewis et al. in press, a; Fountain et al. 1998), and as drivers for soil ecosystem dynamics (Treonis et al. 1997) and ecological modeling (Moorhead and Priscu 1998). Indeed, micro-meteorological conditions have important implications for the distribution and productivity of the biological communities in terrestrial and aquatic environments. For example, low humidity and snow results in more arid and saline soils and limited soil biota in the Lake Bonney basin compared to the Lake Fryxell basin. Less snow cover within the Bonney basin also reduces albedo, which increases the melt water flux from glaciers and reduces interannual variability in streamflow (Fountain et al. 1998). Spatio-temporal patterns of solar radiation within Taylor Valley are strongly influenced by topography (Dana et al. 1998), and are modified by lake ice thickness and snow cover. The pattern in solar radiation influences primary production in the Taylor Valley lakes (Lizotte and Priscu 1998).

Glaciers: Our long-term program of glacier measurements is unique among LTER sites, and a critical component of the MCM project because melting glaciers provide the bulk of water to the streams and lakes in the MCM (Chinn 1993). For any given elevation, the annual mass balance decreases with distance away from the ocean in a manner consistent with the meteorological gradient (Fountain et al. in review). Changes in glacier mass define the magnitude of ice lost to evaporation and melt water to the streams and lakes. Results show that the glaciers have been increasing in mass since 1993, the start of MCM-I, which coincides with a period of cooler than normal summers and more than average snowfall. The larger glaciers seem to be advancing, but this advance is primarily a legacy of past climate, roughly 1000 years BP (Fountain et al. 1998).

To predict melt water flow from the glaciers, field measurements of the energy balance are collected from the glacier surface; 40-90% of the mass from the ablation zone (lower elevations) is lost to evaporation/sublimation but the remainder is lost as melt water (Lewis et al. in press, a). Previous studies concluded that air temperature was the dominant factor in controlling melt (Wharton et al. 1993). However, our work shows that snow cover is equally important and controls the variability in streamflow from different glaciers (Lyons in review b). Snow cover reflects solar energy that otherwise would be absorbed by ice. When snow cover exists during the early and late portions of summer, ice cliffs that form on the lower margins of the larger glaciers become important water sources that are critical to maintaining streamflow (Conovitz et al. 1998; Lewis et al. in press b).

Streams: The MCM streams flow during the summer and some contain abundant algal mats, persisting in a freeze dried state in winter. Compared to other stream ecosystems in the LTER network, MCM streams represent several extremes because of their lack of allochthonous organic inputs, high standing algal biomass, low primary productivity and low grazing losses (Webster and Meyers 1997; McKnight and Tate 1997). We have documented the range of productivity by mapping the distribution of algal mats at sites in 11 streams in Taylor Valley (McKnight et al. 1998; Alger et al. 1997). High algal abundance occurs in moderate gradient streams with a stable stone pavement in the streambed. In streams with sparse mats, parafluvial seeps draining the hyporheic zone are important habitats (McKnight et al. 1998).

We established a gauging network to monitor flow of major streams in Taylor Valley, and have shown that flow patterns are controlled by glacier melt and stream geomorphology, including water storage in the hyporheic zone (saturated area beneath and adjacent to the stream) (Von Guerard et al. 1995; Conovitz et al. 1998). Tracer experiments indicate rapid hyporheic exchange in MCM streams (Runkel et al., in press). Major cation and silicate data indicate chemical weathering generates solutes in the hyporheic zone and that weathering rates are high (Lyons et al. 1997b, 1998).

Previous work focused on the biogeochemical evolution of the lakes, but our data demonstrate that instream processes also influence lake chemistry (Moorhead et al. 1998). Monitoring of stream chemistry showed that nutrient concentrations are higher in streams without mats than in streams with mats (Table 1.2). We conducted a

nutrient injection in a stream with abundant algal mats with injectate concentrations corresponding to drainage of nutrient-rich hyporheic water in late summer (55 M and 18 M for NO3(-) and PO4(3-), respectively) (McKnight et al. in review a). By 497 m below the injection, nutrients remained below detection (<1-2 M) during the arrival of the Cl tracer, illustrating rapid nutrient uptake. At two intermediate sites, production of NO2(-) and NH4()+ indicated occurrence of dissimilatory nitrate reduction in the hyporheic zone. We used a solute transport model with nutrient uptake represented as a first order process to determine reach scale parameters for N and P uptake. The best match to the experimental data was a model in which P uptake occurred in the main channel and N uptake occurred in the main channel and in the hyporheic zone, representing the loss due to dissimilatory nitrate reduction (7-16% of total N uptake).

Table 1.2. Visual Algal abundances for Taylor Valley Streams and related NO3 and PO4 values.

["*Low*" *denotes <50% surface cover;* "*high*" *denotes >50% surface cover; ND denotes "no data available"*]

Stream and Basin	Total Stream Length (km)	Visual Algal Abundance	(Sites nearest NO3 (uM)	the outlet) PO4 (uM)
Fryxell Basin				
Huey Creek	2.1	low	4.62	0.40
Canada Stream	1.5	high	0.74	0.25
Bowles Creek	0.9	high	0.71	0.21
Green Creek	1.2	high	0.79	0.15
Delta Stream	11.2	high	0.81	0.09
Von Guerard Stream	4.9	high	0.89	0.42
Hoare Basin				
Andersen Creek	1.4	low	4.17	0.23
House Creek	2.0	low	3.91	0.65
Wharton Creek	1.0	low	ND	ND
Bonney Basin				
Priscu Stream	3.8	low	5.98	0.36
Lawson Creek	0.3	low	12.17	0.21
Bohner Stream	1.9	low	9.28	0.61

Monitoring of stream chemistry has shown that the streams have high HCO3(-):DOC molar ratios (~4.5) compared to ratios of 1.0-1.6 for Arctic rivers (Gordeev et al. 1966; Cauwet and Sidrov 1996) and average ratios of 3.5 for rain forest streams (McDowell and Asbury 1994; LUQ). The higher HCO3(-):DOC ratios in MCM streams reflect the lack of terrestrial organic carbon input, the interannual preservation of freeze-dried algal mats and high weathering rates producing HCO3(-) (McKnight et al. 1991; Lyons et al. 1998). Measurements of stream suspended load (SSL) have shown that total SSL from the Fryxell and Hoare basins are much lower than those from the Bonney basin (Table 1.3). Stream DOC concentrations are more variable than particulate organic matter (POM) concentrations, and streams in Fryxell basin have higher DOC:POC ratios than those in Bonney basin. The Fryxell ratios are similar to those of tundra (2.6) and tropical (1.1) fluvial systems, while those of

Bonney are closer to warm desert rivers/streams (0.4) (Ludwig and Probst 1996). Such differences in the partitioning of organic carbon reflect fundamental differences in carbon transport between basins.

Table 1.3. Sediment load, POC and DOC loading (mg/L) from Taylor Valley streams.

Stream	Suspended Load	POC	DOC	DOC/POC
Fryxell Basin				
Green	1.4	0.6	1.25	2.1
Aiken	8.4	1.2	2.08	1.7
McKnight	4.2	1.0	1.50	
Bowles	4.6	1.2	1.35	1.12
Mariah	17.8	0.7	0.53	
Hoare Basin				
Anderson	13.0	0.6	0.47	0.78
Bonney Basin				
Lawson	52	1.3	0.47	0.47
Lyons	293	1.45	1.81	0.33
Santa Fe	362 +/- 30	2.7	0.68	0.48
Priscu	69	0.7		

To understand the long-term persistence of stream algal mats, we studied a relict stream channel for which sustained flow was last recorded in the summer of 1969 (McKnight et al. in review b). We routed meltwater to the channel and found that relict algal mats began growing within a few days at rates exceeding those of mats in streams with regular summer flow, because of greater solute and nutrient concentrations. This long term experiment of MCM-I has shown that cryogenic preservation of algal mats in inactive channels allows for rapid response to climatic and geomorphological shifts.

Lakes: Although many lakes in the LTER sites develop winter ice-cover, lakes in the MCM are unique among LTER sites because they are covered by 3-6 m of perennial ice. This ice reduces light penetration and circulation, alters sediment pathways, severely reduces mixing, and restricts gas exchange with the atmosphere. Planktonic food webs also are unique in that they are limited to algae, bacteria, protozoans and rotifers (Laybourn-Parry et al. 1997; James et al. 1998). Our studies have provided fundamental information on the physical, chemical, and biological attributes of the three main lakes (Bonney, Hoare, and Fryxell) in Taylor Valley.

Changes in lake volumes represent regional climate change in the recent past, as lake levels generally have been rising from the 1960s to 1992, and Lake Bonney has been rising since 1905 (Chinn 1993). Measurements from 1993-98 indicate that lake levels are no longer rising significantly. These observations are consistent with measurements of streamflow and glacier mass balance and result from cooler temperatures and heavier snows during summers. The lack of physical mixing leads to stable physical and chemical stratification. The geochemistries of the surface waters and monimolimnia of the lakes are distinct (Table 1.4), implying differences in glacier source, stream length, stream channel geology, and different developmental histories, respectively (Lyons and Welch 1997; Lyons et al. 1998; Lyons et al. in review a).

Table 1.4. Chemical characteristics of Taylor Valley lakes, September 1995.

Lake	Depth (m)	Li (M)	Na (mM)	K (mM)	Mg (mM)	Ca (mM)	Cl (mM)	Br (mM)	SO4 (mM)	DIC (mmol)
Hoare	5	0.7	2.47	0.27	0.22	0.75	2.2	0.0022	0.42	1.72
Hoare	30	2.3	7.81	0.77	1.4	2.14	6.3	0.0062	0.92	8.18
Fryxell	5	1.6	7.9	0.54	0.99	1.35	7.59	0.009	0.45	4.68
Fryxell	18	16	117	4.79	13	3.76	99	0.141	1.58	48
W Bonney	5	3.1	10	0.36	1.47	1.79	12	0.022	1.54	0.91
W Bonney	38	656	1789	43	402	62	2299	5.06	47	78
E Bonney	5	3.6	12	0.381	1.78	2.05	14	0.028	1.73	1.41
E Bonney	39	1169	2701	67	1247	32	5100	19	36	3.66

Our data indicate that respiration exceeds primary production in the water column of MCM lakes (Lyons et al. in review b), despite extremely low inputs of allochthonous organic carbon (McKnight et al. 1993; Aiken et al. 1996). Thus, MCM lakes are net heterotrophic systems, much like other unproductive aquatic systems (del Georgio et al. 1997). The source of excess carbon is a large pool of organic carbon that appears to be a legacy of a previous stage in lake development (Aiken et al. 1996), as indicated by 14C dating of the POC pool (Doran 1996). The surface pool of POC in Lake Bonney is 10,000-13,500 yrs old (Doran 1996), but only 20% of it is refractory humic materials (McKnight et al. 1991). Therefore, the carbon dynamics of the MCM lakes are different than those of other lakes in the LTER network (NTL, HBR, NWT and ARC), and may be comparable to some lakes in Siberia where such legacy carbon also is being utilized as an energy source by modern communities (Zimov et al. 1997).

Phytoplankton communities in MCM lakes exist in an environment characterized by low light intensity. Light intensity and spectral composition vary with depth and phytoplankton occur in relatively distinct, stratified layers (Spaulding et al. 1994; Lizotte and Priscu 1998). A considerable degree of shade adaptation exists among phytoplankton (Neale and Priscu 1998). Vertical nutrient profiles suggest that deep maxima of primary production are driven by diffusion of nutrients from even deeper water, where nutrient pools have accumulated as a legacy of past stages in lake development (Priscu 1995). Although these systems lack many of the grazers found in aquatic communities, grazing by microzooplankton and protozooplankton may affect phytoplankton communities, and recent investigations are beginning to identify and quantify the taxa comprising planktonic food webs (Laybourn-Parry et al. 1997; James et al. 1998). An interesting discovery of MCM-I is that mixotrophic phytoplankton species have been identified and phagotrophy observed. Mixotrophy represents a survival strategy in that phytoplankton may utilize heterotrophic metabolism during prolonged periods of low light conditions (Moorhead and Priscu 1998). A study of the over-winter dynamics of phytoplankton in Lake Fryxell (Fig. 1.3) showed that mixotrophic species increased in abundance (McKnight et al. 1998). Large concentrations of virus-like particles have been found in Lakes Hoare and Fryxell (Kepner et al. 1997), suggesting a possible role of viruses as regulators of microbial community dynamics (Fig. 1.4).

MCM lakes also support abundant growths of benthic microbial mats. These mats are dominated by cyanobacteria and, though acclimated to the continuously low light environment, are always light limited. Light limitation has been used to explain the decrease in mat biomass with depth in Lake Hoare (Wharton et al. unpublished; Moorhead et al. 1997b). Lacustrine organic matter, representing a legacy of past productivity, is found in soils, perched deltas on the valley walls, and former lacustrine sand mounds on the valley floors. In modern times, organic matter does accumulate in the surface sediments of Lakes Fryxell and Hoare, mostly from benthic microbial mat production (Lawrence and Hendy 1985; Anderson et al. 1993; Doran et al. in review).

__Soils:__ The MCM serve as a model system for elucidating the ecological roles of soil biota. Globally, there are no other soil systems where nematodes represent the top of the food chain and where food webs have such simple structure. The food webs in the soils are limited largely to algae, yeasts, bacteria, protozoans and nematodes (Freckman and Virginia 1997a, 1998). The majority of soils sampled across the valleys (65%) support up to three soil invertebrate taxa (tardigrades, rotifers, nematodes), although other sites show a complete lack of these invertebrates. Protozoa also contribute to the diversity of soil communities and may compete with the endemic microbial-feeding nematode, *Scottnema lindsayae* (Bamforth et al. 1996). Despite their trophic dominance, the species diversity of nematodes is very low (n = 3), representing only 2 functional levels (predator and microbivore) compared to 5 functional groups more common in other systems (e.g. JRN, SEV, CSGS, BNZ).

We investigated the distribution and functional significance of these low biomass and low diversity soil communities throughout the MCM. This information is being compared to our knowledge of soil biotic function in other arid systems, including those of the LTER network (JRN, SEV, CSGS). For example, detailed examinations of the survival and community ecology of soil nematodes in the MCM show that, in contrast to hot deserts where plant-related factors limit soil biotic communities, soil chemical factors may be most important in defining location and structure of communities (Freckman and Virginia 1997). There is no single soil property that defines a suitable or unsuitable habitat, but where soil biodiversity is reduced, soil physical and chemical heterogeneity is high (Freckman and Virginia 1997). We have found that ribosomal and mitochondrial DNA of *Scottnema lindsayae* varies across small (<1 m2) and large (60 km2) spatial scales, suggesting that the species may be evolving (to date, 11 distinct maternal lineages have been detected in the MCM, Courtright et al. in press). This evolution may be a response to the high spatial heterogeneity of the soil environment (Ho et al. 1995).

The simple food chains found in MCM soils appear to be strongly influenced by human disturbance. A long-term manipulation experiment shows that soil warming and increased moisture and carbon availability have major effects on the nematode community, decreasing the abundance of the omnivore-predator species, increasing the abundance of a microbivorous species (Freckman and Virginia 1997), and altering soil respiration (CO_2 efflux). We presently are examining how community composition influences decomposition (Treonis et al. 1997; Burkins et al. 1997).

We have developed an initial soil carbon budget for the MCM based upon systematic regional sampling of soil profiles (Brown et al. 1996; Burkins et al. 1997). The natural abundances of 13C and 15N in soil organic matter indicate that relative contributions of marine, soil derived, and lacustrine (recent and legacy) sources to soil pools is a function of location in the MCM landscape (elevation; distance from lakes, streams, or paleolakes; distance from marine sources). Relationships between soil community structure, biological activity and quantity and source of soil organic matter suggest that the soil carbon cycle in the MCM represents an extreme end-member of global soil ecosystems, with an extraordinarily slow rate of C-cycling, perhaps comparable to Arctic peat.

__Ecological Modeling:__ Our initial view of the MCM ecosystems was that biological communities were controlled primarily by temperature and hydrologic regimes, as they determine the availability of liquid water. However, energy availability likewise controls the location, structure and activity of MCM communities (Moorhead and Priscu 1998). Paradoxically, microsites with exposure to radiant energy also may be subject to rapid desiccation and potentially rapid freeze-thaw cycles that limit biological activity. A generalized ecosystem model has been developed to simulate energy and nutrient dynamics in MCM communities (Fig. 1.5). Organic matter may accumulate through on-site photosynthesis or allochthonous inputs, and be lost through on-site respiration, release of dissolved organic carbon or mechanical erosion by wind and water. However, ecosystems within the MCM differ with respect to the importance of various environmental controls. Because the activity of biota are restricted to those times and places with a favorable juxtapositio n of energy and moisture regimes, measurements of microclimate and energy availability needed to drive simulation models of primary and secondary productivity must be available at high resolution in both space and time. For these reasons, modeling activities of MCM I have focused on aquatic environments, for which patterns of moisture availability are known with some certainty.

To date, we have developed models to simulate primary production of benthic microbial mats found in stream and lake beds (Moorhead et al. 1997a, 1997b, 1998), as well as plankton communities in MCM lakes (Davis

1988). Photosynthesis of these communities saturate at low-light intensities, and Moorhead et al. (1997b) explored the ramifications of using different models of photosynthesis (rectangular hyperbolic, hyperbolic tangent and linear response models). We found that because stream mats usually are light-saturated, only maximum rates of photosynthesis affected simulation results. However, lake mats receive such low levels of radiant energy (Howard-Williams et al. 1998) that differences in low-light responses of the various models had substantial impacts on model behavior. These results demonstrated the critical need for monitoring light regimes within the water columns of MCM lakes at higher spatial and temporal resolution.

Results of our modeling studies suggest a positive, net annual primary production of microbial mats in streams and shallow depths in lakes, in part, because decomposition is slow and other hetrotrophic activity is virtually absent. For these reasons, organic carbon accumulates, consistent with the notion that ancient aquatic ecosystems in the MCM produced much of the organic carbon reservoir present in modern soils (Burkins et al 1997). This modeling approach also has been used to simulate immobilization of nitrogen by microbial mats in streams (Moorhead et al. 1998), and has shown that N immobilization approximates that required to balance net C fixation. This model now is being used to evaluate N and P limitations to the location and productivities of plankton communities in MCM lakes (Davis 1998).

Legacies and Linkages: Doran et al. (1994) and Lyons et al. (1997a) have summarized the importance of past climate conditions on MCM and the ecological legacies that these climatic changes have created, and Priscu (1995) has demonstrated the importance of these legacies on the current lacustrine ecosystem. A model of how past and present variations in climate have controlled the chemical and biological evolution of the MCM lakes has been developed (Lyons et al. in review, b). The degree to which the individual lakes interact with their surrounding environment (i.e. landscape position) is a key to the understanding of their past and present development. Present microclimatic variation and its manifestation over the past 6000 years have led to the differences observed in modern lakes. Heterogeneity characterizes organic carbon and nutrient distributions within modern landscapes as a result of past climate regimes. The PIs are also committed to five articles in *Bioscience* (due June 1998) on MCM-LTER with legacy as the central theme.

PUBLICATIONS FROM LTER MCM-I

Books

- Lyons W. B., Howard-Williams C., and Hawes I. (eds.) (1997) Ecosystem Processes in Antarctic Ice-Free Landscapes, pp. 281. Balkema.

- Priscu J. C. (ed.) (1998) Ecosystem Dynamics in a Polar Desert: The McMurdo Dry Valleys, Antarctica, pp. 369. American Geophysical Union.

Refereed Journal Articles

- Aiken G., McKnight D., Harnish R., and Wershaw R. (1996) Geochemistry of aquatic humic substances in the Lake Fryxell Basin, Antarctica. *Biogeochemistry* 34, 157-188.

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MCM-LTER Datasets Electronically Available - Field Data

LT

Category	Title	Short **T**erm / **L**ong **T**erm Study
I. Bathymetry		
	Bathymetric Polynomials	ST
	Bathymetry Raw Data Files	ST
	Bathymetric Values From Contour Map Digitizing	ST
	Depths, Areas, Volumes	ST

Bathymetric Hypsographic Function Values	ST

II. Geochemistry

Major Ion Concentrations for Glacier Ice, Snow and Melt Water Samples	LT
Major Ion Chemistry for Miscellaneous Locations Throughout Taylor Valley	ST
Limnological Water Column & Pore Water Cations/Anions	ST
Limnological pHs	LT
Lake Nutrients	LT
Miscellaneous Stream Chemistry Samples Throughout Taylor Valley	ST
Stream Nutrients (nitrate, nitrite, ammonium, reactive phosphorus)	LT
Stream Chemistry / Dissolved Organic Carbon 1990-1993	LT
Stream Chemistry / Major Ion Concentrations	LT
Stream Conductivity, pH 1990-1992	LT
Major Ion Data for Lake Ice Samples	ST
Limnological Chemistry / Major Ion Concentrations	LT

III. Glaciology

Glacier Snow Densities	LT
Glacier Mass Changes	LT
Average Stake Heights, Snow Depths Found at Glacier Stakes	LT
Glacier Stake Heights, Snow Depths	LT
Canada Glacier Ice Temperatures	LT
Canada Glacier Eddy Correlation Data	ST
Glacier Mass Balance Summary	LT

IV. Hydrology

Discrete Stream Gage Measurements pre-1980 (pre-LTER)	LT
Mean Daily Stream Gage Measurements 1969-1997	LT
Discrete Stream Gage Measurements 1980-1989 (pre-LTER)	LT
Discrete Stream Gage Measurements 1990-1997	LT
Taylor Valley Water Budgets	LT
Field Meter Stream Measurements 1990-1997	LT

V. Limnology

Ice Thickness, Piezometric Depths for Taylor Valley Lakes	ST
Winter Phytoplankton 1990-1991 (pre-LTER)	ST
Chlorophyll-A Concentrations in Lake Hoare Benthic Mats 1996-97	ST
Lake Chlorophyll, Primary Productivity, Respiration	LT
Phytoplankton Densities	LT
Dissolved Oxygen, Photosynthetically Active Radiation	LT

Bacterial Productivity and Density	LT
Lake Temperature and Conductivity	LT

VI. Meteorology

Commonwealth Glacier Meteorological Station Measurements (1993-1997)	LT
Average Meteorological Measurements for Canada Glacier (1994-1997)	LT
Lake Brownsworth Meteorological Station Measurements (1994-1997)	LT
Lake Bonney Meteorological Station Measurements (1993-1997)	LT
Lake Vanda Meteorological Station Measurements (1994-1997)	LT
Canada Glacier Meteorological Station Measurements (1995-1996)	LT
Lake Hoare Meteorological Station Measurements (1993-1997)	LT
Lake Fryxell Meteorological Station Measurements (1993-1997)	LT
Lake Vida Meteorological Station Measurements (1995-1997)	LT
Explorer's Cove Meteorological Station Measurements (1995-1996)	LT
Taylor Glacier Meteorological Station Measurements (1994-1997)	LT
Howard Glacier Meteorological Station Measurements (1993-1997)	LT

VII. Soil Ecology

Soil Organism Responses to Long-Term Soil Manipulation	LT
Chlorophyll-A Responses to Long-Term Algae Amendment	LT
Soil Moisture Responses to Long-Term Algae Amendment	LT
Soil Organism Responses to Long-Term Algae Amendment	LT
Chlorophyll-A Responses to Long-Term Soil Manipulation	LT
Soil Moisture Responses to Long-Term Soil Manipulation	LT

VIII. Stream Ecology

Stream Algae Ash-Free Dry Mass (1994, 1995)	LT
Algal Species, Morphotype Descriptions	ST
Stream Algae Photosynthesis/Light Measurements (1995)	LT
Stream Algal and Moss Biomass (1994-1997)	LT
Stream Algae Primary Productivity (1995, 1996, 1997)	LT
Stream Invertebrate Taxa Qualitative Abundances (1994)	
Stream Algal Abundances (1994)	LT

IX. Study

Locations

Locations, Dates, Codes for Lake Chemistry, Biology Samples	ST
Stream Lengths for Taylor Valley Streams	ST
Stream Gage Locations	ST
Stream Transect Locations	ST
Coordinate List of Stream Transect Points	ST
Coordinate List of Stream Gage Features	ST
1993-94 Geodetic Survey Results / Stream Transect Reference Marks	ST
GPS Data, Optical Observations Producing Coordinate Files	ST
Glacier Stake Locations	ST
1996-97 MCM-LTER GPS Coordinate Locations	ST
Relative Positions of Stream Transect Line Points	ST

X. Data Extraction Tools

Meteorological Data Extraction Tool	LT
Hydrological Data Extraction Tool	LT

When the database was located at DRI, the Antarctic hydrology and meteorologic data bases were publicly available. The Antarctic hydrology website was linked to other Antarctic websites (e.g. the ICAIR site) and USGS hydrologic websites, in addition to the LTER site. Unfortunately, we do not have documentation for the use of these databases by non-MCM-LTER scientists. Most other databases have only become publicly available since the transfer of the database to INSTAAR in the summer of 1997.

Section 2. Research Proposal

A. INTRODUCTION

The McMurdo Dry Valleys (MCM) represent the largest of the ice-free oases on the Antarctic continent (ca. 4800 km²). They are among the coldest and driest terrestrial environments on earth, with an average annual temperature of ca. -20°C and total annual precipitation of 6 cm, received as snow during winter. The dry valley landscape is a mosaic of perennially ice-covered lakes, ephemeral streams, soils and glaciers. Despite the extreme conditions, biological communities exist in these lakes, streams and soils.

Much of what is known about such extreme polar deserts has been discovered by work conducted in Antarctica because few comparable systems exist elsewhere. Much of our knowledge about the structure and function of these polar desert ecosystems has been discovered only recently, resulting, in large part, from the first phase of the McMurdo Long-Term Ecological Research program (MCM-I 1993-99; see Section 1. Results of Prior Support). In MCM-I, our research explored the physical constraints controlling the structure and function of this polar desert. We discovered that subtle changes in temperature, precipitation, and albedo have profound effects on the hydrologic cycle, biogeochemistry, productivity and biodiversity within the valleys. Moreover, local effects are modified by landscape position and topography.

The MCM ecosystem is sensitive to very small variations in climate because the change between solid and liquid phase of water is delicately poised in this environment. Thus, small changes in temperature and radiant energy regimes are amplified by large, non-linear changes in hydrologic budgets that can ramify throughout the system. The presence of liquid water remains the primary limiting condition for life in Antarctica (Kennedy 1993), so the relationship of energy balance to liquid water availability, ecological function and biological diversity will continue to be a major emphasis of the proposed McMurdo Dry Valley LTER renewal (MCM-II).

A second focus of MCM-I was generated by observations that biological activities in the dry valleys were affected by the transport of water, nutrients and organic carbon between landscape units (glaciers, streams, lakes and soils). Such linkages have been shown to considerably influence ecosystem structure and function (Turner and Gardner 1991), but are most evident in extreme environments, such as deserts (Schlesinger et al. 1990) and tundra (Shaver et al. 1990; Reynolds and Tenhunen 1996). Perhaps the best example of a critical linkage among landscape units is represented by the glacier-stream-lake continuum, in which water and solutes move from glaciers to lakes by streamflow (McKnight et al. 1998; Lyons et al. 1998). This movement of water defines the streams in which biological activity is restricted to periods of liquid water availability. Water in streams stimulates weathering of minerals in streambeds and transformation of nutrients by stream communities (Lyons et al. 1998; Moorhead et al. 1998). Thus , water reaching the lakes has a very different chemical signature than glacier melt water.

Within the context of an extreme sensitivity to variations in climate and significant linkages among landscape units, it has become clear that "legacies" of past events influence the structure and function of the modern ecosystem. Geomorphic evidence indicates that the MCM environment has been remarkably stable over the past few million years, with extremely slow rates of landscape modification in comparison to temperate regions (Brown et al. 1991; Wilch et al. 1993). In addition, nutrient cycling has been slow because biological activity is limited by the harsh polar environment. As a consequence, legacies of the past, such as pools of soil organic matter deposited by paleo-lakes, and nutrients in the hypoliminia of modern lakes, directly impact present ecosystem function.

The term "legacy" refers to the carry-over or "memory" of the ecosystem of past events (Vogt et al. 1997; Little et al. 1997). A climatic legacy strongly imprints current ecosystem functions at MCM, including inundation of the entire Taylor Valley by Lake Washburn during the late Pleistocene (24,000-6,000 yr BP; Denton et al. 1989), and a subsequent cold, dry period ending about 1000 yrs BP (Lyons et al. in review a, (Table 2.1). Legacy effects at other LTER sites usually are viewed as much shorter-term consequences of historic land-use patterns, such as forest clearing (HBR, HFR, CWT, AND), grazing and resultant desertification (JRN, SEV, SGS), and conversion to agriculture (KBS), or resulting from severe weather (e.g. hurricanes, LUQ) and fires (KNZ, AND).

Table 2.1. Relationship of Research Plan to MCM-II Hypotheses*

Hypothesis	MCM-II Activities
1a	Monitoring: meteorological stations, glacier mass balance, stream flow
1b	Monitoring: glacier mass balance, stream flow; GIS
1c	Monitoring: lake levels; GIS
2a	Monitoring: algal mat stream transects, stream flow; GIS; relict stream channel experiment, paleoclimate experiment
2b	Monitoring: biological parameters in lakes, light; sediment dump experiment
2c	Monitoring: biological, chemical, physical properties of soils; GIS; paleoclimate experiment, paleocarbon experiment, long-term soil manipulation experiment
3a	Monitoring: stream chemistry, stream flow, stream algal distribution
3b	Monitoring: stream chemistry, stream flow, lake chemistry, lake primary production and respiration

The modeling studies and snowfence experiment will be used to test all of the above hypotheses.

*The focus areas associated with research plan activities are bracketed [] in the text.

B. WORKING HYPOTHESES

The interrelated systems of climate, biota and physical landscape change naturally over time. The polar regions have long been considered areas where changes in climate are "amplified" (Chen and Drake 1986). In MCM-I, we hypothesized that "the structure and the function of the Taylor Valley ecosystems are primarily controlled by physical constraints." These constraints dealt primarily with the modern environment of the MCM. The small changes in climatic conditions (T and precipitation) over the past 24,000 yr led to dramatic changes in ecologically significant features of the landscape (Doran et al. 1994). These inherited landscape features, in turn, continue to affect the biological activity and diversity and the important biogeochemical processes occurring in the MCM ecosystem today. This "amplification" of small changes in climatic variables and the resultant landscape changes are the ecological legacy of MCM. Figure 2.1 presents our new conceptual model of MCM.

Central Hypothesis: Past climates in polar desert environments strongly overprint present ecosystem structure and function.
Results of MCM-I research suggest that "memory" exists in all landscape units in the dry valleys. A hydrological memory exists in lake and glacier volumes, a chemical memory resides in lakes, a geomorphic memory controls stream processes and an organic carbon memory is evident in soils; the approximate ages of these memories are shown in (Fig. 2.2). In addition, biological memory is manifest in the distribution of present-day organisms across the landscape (spatial pattern of biodiversity). Our working hypotheses are derived from three dominant legacies that are now apparent in the valley ecosystem (lake, stream, and glacier characteristics; pools of organic and inorganic compounds in lakes and soils; distribution and diversity of biota). The impacts of these legacies on modern ecosystem processes are determined partly by the linkages between the soils, streams, lakes, and glaciers, cast within an overall context of the modern climate.

FOCUS 1. HYDROLOGY>
Climate controls the hydrology of this polar desert, providing water through the melt of ice and snow. Liquid water is necessary to support biological and geochemical processes, and defines important linkages among landscape units. Past climate regimes have determined many attributes of the current landscape by influencing lake levels. Periglacial and fluvial processes during past regimes have determined the geomorphic features of current streams. Understanding the structure and function of the dry valley ecosystem requires understanding

hydrological responses to climate, both now and in the past. For these reasons, we propose to continue our studies of climate controls on the hydrology. We also propose to expand our studies to include an evaluation of past climatic effects on lake level fluctuations, which resulted in several important legacies.

Hypothesis 1a (Glacier Melt). The variability in timing, duration and amount of water derived from glacial melt is determined by the interaction of climate (temperature, radiant energy, snow cover) and landscape position of glaciers (slope, aspect, elevation).

Hypothesis 1b (Streamflow). The variability in timing, duration and amount of stream discharge is controlled by glacier melt and by long-term periglacial and geomorphic processes.

Hypothesis 1c (Legacy). Subtle changes in temperature and precipitation have determined the hydrologic balance of lake levels over the last 24,000 yrs through direct control over mass balance of glaciers providing melt water.

FOCUS 2. BIOLOGICAL ACTIVITY AND DIVERSITY

The distribution and activity of biota in the dry valleys are determined largely by the availability of water. Results of MCM-I indicated that other factors also constrain biological activities (e.g. temperature, nutrients, energy, etc.), but that linkages among landscape units can ameliorate some of these limitations. Legacies of nutrients and organic carbon that have accumulated through past biological and geochemical processes within ancient hydrological regimes may also drive modern communities. Thus, current patterns of biological activity and diversity partly reflect past distributions of water, nutrients, organic carbon and biota.

Biological activity in streams primarily is limited to microbial mats that are found on stable substrates (Algers et al. 1997; McKnight et al. 1998), which are active when liquid water is present and nutrient availability is adequate. Primary production in lakes is limited by available light and nutrients, but sources of nutrients differ with respect to location in the water column. Surface waters receive nutrients from streams flowing into lakes, whereas phytoplankton in deeper water rely on the upward diffusion of ancient nutrient pools from deep water and sediments. Also, the upward diffusion of ancient DOC from deep water and sediments apparently results in the current, negative values of net primary production observed in phytoplankton communities. The activities of soil communities are limited by a number of factors, including temperature and the availabilities of water and organic carbon. Sources of organic carbon include *in situ* production, modern transport from remote sources, and ancient carbon residing in soil profiles.

Hypothesis 2a (Stream Biota). The distribution, abundance, community structure and activity of stream biota are dictated by the timing, duration and amount of water derived from glacial melt, in conjunction with the stability of streambed habitat created by periglacial processes.

Hypothesis 2b (Lake Biota). The distribution, abundance, community structure and activity of lake biota are controlled by the water balance and the availabilities of radiant energy, ancient and modern nutrient and dissolved organic carbon.

Hypothesis 2c (Soil Biota). The distribution, abundance, community structure and activity of soil biota are controlled by allochthonous inputs of organic carbon from modern and ancient sources, within the context of favorable soil moisture, temperature and salinity regimes.

FOCUS 3. BIOGEOCHEMICAL PROCESSES

Biogeochemical processes responsible for the immobilization and mineralization of nutrients, and geochemical weathering, require a medium of liquid water. Hence, the timing, duration and location of biogeochemical processes in the past and the present are controlled by water availability. Also, hydrologic linkages among landscape units provide both a medium for these processes and a conduit for transport of chemical moieties. It is for these reasons that legacies of carbon, nutrients and other chemicals are present throughout the modern dry valley landscape.

Hypothesis 3a (Stream Chemistry). The chemistry of stream water is dictated by the timing, duration, amount and chemistry of water derived from glacial melt, in conjunction with stream location, geomorphology,

mineralogy of streambed materials, and biota.

Hypothesis 3b (Lake Chemistry). The chemistry of lake water is dictated by the (1) timing, duration, amount and chemistry of stream water, (2) biogeochemical processes occurring within the lake, and (3) retention of past inputs and products of biogeochemical processes by the lack of hydrologic flow through stable stratification and restricted interaction with the atmosphere.

C. BACKGROUND

Most of Antarctica is covered by ice that may exceed 3,000 m in depth, but the McMurdo Dry Valleys (76°30' to 78°30'S, 160° to 164°E) form the largest ice-free expanse on the continent (ca. 4800 km²). The MCM are among the most extreme deserts in the world, far colder and drier than any other LTER site (Fig. 2.3). They contain perennially ice-covered lakes, ephemeral streams, glaciers descending from the encompassing mountains, extensive areas of soils and expanses of exposed bedrock.

Taylor Valley is the main research area for the MCM-LTER and is composed of four main basins (Fig. 2.4). The Lake Fryxell and the Lake Bonney basins are enclosed basins and are the two largest watersheds in the valley. They are divided by the Nussbaum Riegel, a hill of ca. 700 m elevation. The Lake Hoare basin also is an enclosed basin and is formed by the Canada Glacier, which blocks flow to Lake Fryxell. The Commonwealth watershed is adjacent to the coast and all streams in this basin flow to the ocean (McMurdo Sound).

The biological diversity of MCM is relatively simple, represented almost entirely by microbiota (no higher plants or animals) that comprise relatively short food chains. Cyanobacteria, bacteria and yeasts are abundant throughout the MCM. Many species of eukaryotic algae occur in the lakes and streams, microzooplankton are present in the lakes, and nematodes are found in the soils. Despite this taxonomic simplicity, the basic ecological processes of primary and secondary production, decomposition, nutrient cycling, and energy flux within the MCM demonstrate complex interactions among biological entities, as well as between biota and abiotic factors of the environment. The extreme environment, coupled with a paucity of higher trophic groups, implies strong "bottom up" controls on ecosystem structure with minimal influence of "top-down" controls exerted by predation common to other environments (e.g. Carpenter 1988). Thus, MCM offers a natural laboratory for study of ecosystems and basic ecological processes wit hout the complications introduced by a plethora of higher organisms.

C.1. Streams
MCM streams flow for 6-12 weeks per year, between late November and early February. In addition to current active channels, relict channels associated with past advances of glaciers or with fluvial sediment deposition can be observed throughout MCM. Annual variations in flow and duration are related to landscape position (Lyons et al. in review b), with streamflow in Bonney basin (Fig. 2.5) being more stable than in Fryxell basin, due to the microclimatic variations between the basins (Fountain et al. 1998). Increases in solute concentration from the glacier source to the lake outlet can be several orders of magnitude, and stream chemistry varies in relation to stream length (Fig. 2.5a), landscape location and the abundance of algal mats (Lyons et al. 1998). The longer streams in Fryxell Basin have higher concentrations of silicate weathering products, such as $H4SiO4$ and $K+$, and streams entering Lake Bonney have higher marine aerosol salts components, such as $Cl-$ (Fig. 2.6). Moreover, streams with abundant al gal mats are depleted in nutrients (McKnight et al. in review a; Moorhead et al. 1998).

In many streams, dense mats of filamentous cyanobacteria grow during summer streamflow and are freeze-dried during the rest of the year. Abundance ranges from extensive, blanket-like coverings on rocks and streambed to sparse patches restricted to the margins of active channels or on the undersides of rocks (Vincent 1988; McKnight et al. 1998). The cyanobacterial mats are composed of an upper layer, enriched in accessory pigments, and an under layer with greater chlorophyll-a content (Vincent 1988). Mats that have remained desiccated through the winter can begin photosynthesizing within 20 minutes of being wetted (Vincent and Howard-Williams 1986) and mats that have been desiccated for years to decades can achieve high biomass and rapid growth within 2 weeks (McKnight et al. in review b). Mosses occur on the streambanks, where they are wetted for short periods or in flat areas that become damp (Alger et al. 1997).

Algal mats are most abundant at sites which have moderate gradients and streambeds composed of large cobbles arranged in a flat stone pavement (McKnight et al 1998; Alger et al. 1997). These stone pavements have been created by periglacial, freeze-thaw processes probably acting over centuries. Abundance is lower at high gradients and on deltaic deposits. Black, orange, and green algal mats occur at most sites (Fig. 2.7). Black mats are found near the channel margins and are composed of *Nostoc sp.*, and green mats are found on the underside of rocks and are composed chiefly of *Prasiola calophylla* or *P. crispa*. Orange and red mats occur in flowing water, either in the main channel or in parafluvial seeps draining at the stream margins, are composed of species of *Oscillatoria* and *Phormidium* and are rather diverse in composition.

In streams with abundant mats, the assimilation capacity for nitrate and phosphate is very high resulting in low nutrient concentrations (McKnight et al. in review a). However, streams with sparse mats have higher nutrient concentrations. Gross rates of photosynthesis in microbial mats of the streams approach an upper limit of 4-8 g/Cm/h which increase with temperature (Hawes and Howard-Williams 1998). In the thicker mats, gross photosynthesis essentially is equivalent to respiration, and the development of high biomass in some locations is hypothesized to require a lack of physical disturbance (Hawes and Howard-Williams 1998).

C.2. Lakes

Despite their proximity, the lakes in Taylor Valley differ in many respects. The differences in geochemistries of the bottomwaters imply distinct histories and/or different sources of solutes (Lyons et al. in review a), i.e. bottomwater of Lake Hoare is fresh, Lake Fryxell is brackish, and Lake Bonney is hypersaline (Fig. 2.8). Lyons et al. (1998) noted that surface waters from Lake Hoare and Lake Bonney would evolve to Na(+), Mg(2+), SO4(2-), Cl(-) - rich waters upon sublimation and/or evaporation, while Lake Fryxell would evolve to Na(+), HCO3(-), and CO3(2-) - rich waters.

The MCM lakes have abundant planktonic and benthic microbial populations (Vincent, 1988; Lizotte and Priscu 1998). Benthic microbial mats primarily are composed of bacteria, cyanobacteria, pennate diatoms and eubacteria (Wharton et al. 1983). Differences in biomass and net primary production occur between the lakes, presumably as a result of differences in nutrient availability, light intensity caused by lake ice thickness, and grazing losses (Priscu, 1995). Maximum rates of primary production coincide with peaks in phytoplankton biomass, often occurring where favorable light regimes overlap zones where nutrients are diffusing from deeper water (Fig. 2.9). Gross primary production rates vary markedly between the lakes, with deep photosynthetic maxima of ca. 10 gC/L/d at 8 m in Lake Fryxell and at 13 m in the west lobe of Lake Bonney, respectively. Profiles from Lake Hoare and the east lobe of Lake Bonney generally decrease with depth, from maximum values < 2 gC/L/d near the surface. Respiration, estimat ed by ETS activity, is highest in Lake Fryxell, reaching a maximum rate just below the oxic/anoxic boundary. Lake Fryxell also contains the highest DOC values of all the lakes (McKnight et al. 1991, 1993).

Prior to MCM-I, little was known about the planktonic food web in dry valley lakes. Primitive rotifers constitute the only metazoa present in the plankton, but flagellates and ciliates are abundant and their abundance differs dramatically among lakes (Laybourn-Parry et al. 1997; James et al. 1998). Large interannual variability exists, probably resulting from variations in streamflow and food availability driven by meteorological conditions. The planktonic food web consists of phytoplankton, bacterioplankton, heterotrophic nannoflagellates (HNAN), ciliates and rotifers (Fig. 2.10). Mixotrophy is an important mode of metabolism and provides a mechanism for over-winter survival (and overall biodiversity) of certain phytoplankton species (Roberts unpublished; McKnight et al 1998). Grazing by ciliates, rotifers and nannoflagellates and settling of filamentous cyanobacteria reduces planktonic biomass during the six months of winter darkness (Lizotte et al 1996; McKnight et al 1998).

Because these stream-lake systems are unusual in their biogeochemistry, species distribution and evolutionary history, they serve as interesting comparisons to more temperate systems. Because of the minimal amount of terrestrially produced organic matter entering these systems (Aiken et al. 1996), unlike streams at other LTER sites (e.g. HBR, CWT, KNZ, NWT, AND), they serve as important end-members in the understanding of carbon dynamics in aquatic systems.

C.3. Soils

Many ecosystem processes are mediated by soil organisms (Freckman et al. 1997; Brussaard et al. 1997). For

example, they control rates of organic matter decomposition and, consequently, regulate the mass of stored carbon. Despite their importance, the ecological and edaphic factors controlling the distribution and populations of soil fauna are poorly known (Hendrix et al. 1986; Freckman and Caswell 1985; Freckman 1994). Research on soil communities with low diversity, such as in Antarctica, provides an opportunity to elucidate relationships between species diversity, physical and chemical factors, and ecosystem functioning that otherwise are masked by the overwhelming complexity of soil biodiversity found in most terrestrial ecosystems.

Antarctic soils are the oldest, coldest, and driest on Earth (Pastor and Bockheim 1980; Bockheim 1997) and share similarities with the arid soils of the JRN and SEV LTER sites. The soils found in the MCM are poorly developed, coarse-textured, and often have high salinities. They also have the lowest organic carbon and biological activity of any soils on this planet (Campbell and Claridge 1987; Campbell et al. 1998). The physical and chemical environment of Antarctic soils varies along gradients of temperature, moisture, organic matter content created in part by legacies of past climates (Campbell and Claridge 1987).

No other soil systems are known to exist in which nematodes represent the top of the food chain and where food webs are as simple in structure. The nematode community in MCM soils consists of an endemic species *Scottnema lindsayae* (Timm 1971), a microbial feeder (bacteria and yeast), *Plectus antarcticus*, a bacterial feeder, and *Eudorylaimus antarcticus*, an omnivore-predator (Freckman and Virginia 1991). Because nematodes are aquatic animals, moisture is a more important factor for survival in Antarctica than low temperature (Kennedy 1993). Moisture from melting snow and streams is available to soils only intermittently , so organisms must be capable of prolonged survival with limited moisture and temperatures below freezing (Cameron and Conrow 1969). Nevertheless, nematodes are ideally suited for survival in this extreme environment. They can enter a survival state, anhydrobiosis, for extended periods. This effectively decouples them from the nutrient cycle, which may contribute to the extremely slow rate of nutrient and carbon exchange in the MCM.

C.4. Ecological Modeling

We are aware of no models developed to simulate ecological processes within the Antarctic dry valleys prior to MCM-I. Indeed, few ecological models exist for any polar desert. Moreover, many of the data necessary to develop such models were seldom collected before MCM-I, such as concurrent measurements of biomass (providing state variables), biological activities (relevant equations and parameters) and environmental controls (the driving functions). Thus, ecological models developed during MCM-I represent some of the first efforts to capture the dynamics of polar desert ecosystems in formal mathematical models. As mentioned above, our initial view of the dry valley ecosystems was that biological communities were controlled primarily by temperature and hydrologic regimes, as they determine the availability of liquid water. However, energy availability likewise controls the location, structure and activity of dry valley communities (Moorhead and Priscu 1998). Thus, the presence and activity of biota are restric ted to those times and places with a favorable juxtaposition of energy and moisture regimes.

Results of modeling studies of benthic mats in MCM streams and lakes suggest a positive net annual primary production (Moorhead et al. 1997a, 1997b). Ongoing studies of phytoplankton production are more equivocal (Davis 1998). Patterns of secondary production are even less certain.

Autotrophy in soil systems has not been examined in detail, although soil respiration and populations of soil fauna respond to experimental manipulations of microclimate and additions of substrate. Simulations of population dynamics of soil nematodes demonstrate enormous uncertainty in model behavior due to uncertainties in microclimatic regimes within soils. Moreover, the lack of correlations between physicochemical attributes of soils and the distributions and abundances of soil organisms has made it difficult to verify the primary environmental controls on these communities (Powers et al. 1995; Freckman and Virginia 1997, 1998).

Patterns of secondary production are difficult to determine for MCM communities because of low abundances of organisms comprising food webs. Respiration rates usually are lower than potential photosynthetic rates for benthic mats in streams (Hawes and Howard-Williams 1998) and this may be the case for microbial mats in lakes (Moorhead et al. 1997b). Studies also demonstrate extremely low rates of respiration in plankton communities of the lakes (Lizotte and Priscu 1992), although net annual respiration may exceed photosynthesis.

Trophic webs in planktonic and soil communities consist of few taxa, many with low abundances (Powers et al. 1995; Freckman and Virginia 1997, 1998; Laybourn-Parry et al. 1997; James et al. 1998).

C.5. Legacies

Recent syntheses of studies confirm that many MCM landscape do not exist in steady state. These disequilibria appear to be persistent, natural phenomena, manifested in ways that relate to patterns of biological activities. Present work linking climate to glacier mass balance, streamflow, lake ice thickness and lake volume (Fountain et al. 1998) will provide many of the drivers for ecological models, and serve as the basis for interpreting long-term ecological responses to changes in climate over past millennia. In addition, the spatial heterogeneity in current landscape patterns (i.e. distribution of former lake sediments and stream channels) resulting from past climates, influence the modern biotic communities (Miller et al. 1997). For example, one hypothesis of MCM-I was that a principle source of soils organic carbon was from ancient lakes in Taylor Valley, which existed ca. 10,000 yrs BP. Stable isotopic signatures of soil organic matter (Fig. 2.11) confirmed this hypothesis (Burkins et al. 1997). Thus, m odern food webs in the soil are supported by carbon that was fixed long ago, similar to Arctic ecosystems in which peat may fuel a significant component of aquatic food webs. This relationship between past autotrophy and present heterotrophy is controlled by long-term hydrological regime (lake level) driven by fluctuations in streamflow and climate. Thus, the MCM behave in a similar function to the other LTER sites in that major ecological links occur where terrestrial and aquatic systems meet (Swanson et al. 1982). In the dry valley environment, however, an important element of this linkage is temporally separated.

D. MCM-II RESEARCH PLAN

Our hypotheses provide a basis for the direction and organization of the research of MCM-I. A multi-faceted approach is required to address our hypotheses, including monitoring, experiments, and ecological models. The following research plan outlines these components of our proposed research and the hypotheses.

D.1. Overview of Research Plan to Address Hypotheses

Our hypotheses direct and organize MCM-LTER and their relation to the research plan are discussed below and summarized in Table (2.1A).

D.1.a. Hydrology (focus 1). The production, transport, distribution and accumulation of liquid water is the key driving variable of the MCM ecosystem. Hypotheses 1a-1c address the role of meteorology variation (both spatial and temporal) in the distribution of liquid water throughout the various landscape components of the ecosystem. The relationship of climate to glacier mass balance to streamflow to lake-level rise and fall is the key to understanding the current ecosystem as well as legacies left from the past. The monitoring of climate (i.e. meteorological data), glacier mass change, streamflow and lake level are integral to our understanding of ecosystem dynamics. We are therefore investing a considerable amount of resources in understanding the dynamics of water in the system.

D.1.b. Biological Activity and Diversity (focus 2). The distribution of biological activity is related to current and past distribution of liquid water in MCM. Hypotheses 2a and 2b address the importance of present day hydrologic regimes in controlling biomass, primary production and decomposition in the streams and lakes of MCM. Hypothesis 2c focuses on the role of past hydrologic regimes and present-day soil chemistry influencing biological activity and diversity in the soils of MCM. The occurrence and utilization of soil organic carbon today is a legacy (and, hence, a direct linkage) to past hydrologic regimes in the MCM.

D.1.c. Biogeochemical Processes (focus 3). Biogeochemical processes and the cycles of nutrients and carbon they produce are the linkages between physical components and the biological ones in the MCM. In our conceptual model, biogeochemical processes are also linked to the past through legacy effects (Fig. 2.1). The transformation of nutrients and carbon is brought about by biological activity. Transport of these chemicals is related to the movement of water, present and past. Therefore, our studies of biogeochemical processes in the MCM represent an integrative activity. The work outlined below addresses these biogeochemical processes and hypothesis 3a and 3b. Streamflow measurements and stream chemistry will be used to determine the flux of important biogeochemicals from the glaciers to the lakes. Biological measurements in the streams will delineate the influences of biotic factors on these fluxes.

D.2. Long-Term Monitoring

The core MCM-I monitoring program will be continued with sampling protocols and frequency adjusted based upon the results obtained so far. We will augment the program to include newly required parameters; these augmentations are highlighted below. Methods are presented in the following section.

D.2.a. Meteorology (Hydrology). All LTER sites acquire continuous meteorological data. For MCM-I, a network of 8 meteorological stations are operated in Taylor Valley (Doran et al. 1995). Valley-floor stations are near the edge of Lakes Bonney, Hoare, and Fryxell, and at the mouth of the valley. Four other stations are located 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 (Fig. 1.2).

Snowfall measurements. For MCM-II, we need accurate measurements of the frequency and magnitude of precipitation because of its dramatic effects on glacier melt, streamflow, light levels in lakes (by transmission through surface ice and snow) and soil biota. We will make manual measurements of snow fall at each occupied camp throughout the field season and install precipitation gauges on each meteorological station. We will also install a new station at 1000 m elevation on Howard Glacier to obtain a better indication of the vertical gradient in climate within the dry valleys. This work will be the responsibility of Dr. Fountain.

D.2.b. Glaciers (Hydrology). Because glacial melt is the source of water to streams and lakes, we will continue to monitor glacier mass balance. Measurements of surface energy balance will continue because glacial melt is sensitive to small changes in radiant energy, temperature and snowfall. The relation between surface energy balance and glacier mass balance is a driving force for hydrological memory. This work will be the responsibility of Dr. Fountain.

Glacier mass balance. We will measure the surface energy balance to partition mass loss between melt and sublimation-evaporation. Ablation stakes and bamboo poles provide only total mass change. Because sublimation-evaporation accounts for 40-90% of the mass loss and inherent measurement errors occur with typically small magnitudes of change in mass balance (~10 cm/yr), an alternative method is needed to estimate melt. To provide daily estimates of melt needed for comparisons to streamflow data, we will develop models of continuous glacial melt based on energy balance measurements.

Slope and aspect influences on mass loss. Large differences in mass loss from the vertical ice cliffs (~ -35 cm/yr) and the sub-horizontal glacier surface (~ -10 cm/yr) suggest that slope and aspect control mass loss on glacial surfaces. A small-scale network of stakes (placed on Canada Glacier in 1996-97) will be followed to measure variations in ablation caused by differences in slope and aspect. These results will help extrapolate the coarser-scale measurements of glacier mass loss to different areas of a glacier and to different glaciers.

D.2.c. Streams. Streams are the hydrologic links between the melting glaciers and the lakes. Small climate variations affect glacial melt and produce spatial and temporal variations in streamflow and chemistry. In-stream processes, including solute exchange with the hyporheic zone, sediment and chemical modification of the water by the geologic substrate, mosses and algal mats, determine the chemistry of water entering lakes. Moreover, the ecology of the streams is a dynamic component of the MCM ecosystem. Thus, we will continue to monitor streamflow, stream chemistry, long-term changes in the distribution, and abundance and growth of stream biota. This work will be the responsibility of Drs. McKnight, Priscu and Lyons.

Stream gauge network (Hydrology). During MCM-I, a network of 15 recording stream gauges was operated in Taylor Valley. The gauges provide a continuous record of discharge. Continuous measurements of temperature and conductivity are included at half the gauges to allow estimates of annual solute load to the lakes. The stream chemistry has proven to be extremely variable (Lyons et al. 1998), so we will continue this monitoring program for MCM-II. Although we attempted during MCM-I to relate solute concentrations to discharge (Lyons and McKnight unpublished), the years of MCM-I were extremely low-flow years compared to the late 1980s and early 1990s (reference USGS web site). Given inherently high variation in flow rates and stream chemistry, and the relatively slow response of lake chemistry to changes in stream inflow, more data are needed to establish a quantitative relationship between the chemistry and discharge in these stream/lake systems. We have begun to

measure both suspended sediment load (SSL) and particular organic matter in the streams. This will continue during MCM-II to quantify sediment and allochthonous carbon inputs to the lakes.

Stream transect network (bioactivity and biodiversity). For MCM-I, stream algal mats were studied for transects at 16 stream sites in Taylor Valley in January 1994 and 1998 (Alger et al. 1997; McKnight et al. 1998). These sites include 10 locations in the Fryxell basin and 3 locations in each of the Hoare and Bonney basins. The mats were characterized for pigment content, algal species counts, particulate organic C, N and P content, and location areal of coverage of streambed and position relative to thalweg and stream margins. Comparison of results from resampling these sites in 1997-98 with results in 1993-94 shows that four years of low flow have promoted growth and development of algal mats, especially in stream reaches which were uninhabitable during previous years of high flow. The lateral extent of algal mat coverage contracted at some sites due to lower flows and mosses moved inward and colonized patches of *Nostoc* mat. For MCM-II, we will continue monitoring of mats at these transect si tes and will maintain a schedule of every 3-4 years. In the event of a high-flow year, we will resample the following year to document persistence or loss of algal mats. The monitoring program of MCM-I included measurements of primary productivity at transect sites. However, the variation among replicate samples from the same mat type in a transect site was generally equal to the variation for that mat type from different transect sites. These measurements will only be continued for a few sites. Gradual changes in extent of coverage and species distribution is a more useful metric for long term productivity in these streams.

D.2.d. Lake Water Column. In order to have two basins influenced by continental climate and two by the maritime climate, we monitor both the east and west lobes of Lake Bonney, as well as Lakes Fryxell and Hoare. Each lake has distinct physical, chemical and biological characteristics which can change over time in response to streamflow inputs of water, major ions and nutrients (Priscu 1995; Lyons et al. 1998). We have added measurements of microzooplankton to address Hypothesis 2b (at the suggestion of the MCM-I advisory committee). Selected parameters and sampling intervals are listed in Table 2.2 and are collected during routine limno runs at each site. In context of Hypothesis 2b, the lake biota are active throughout the year (unlike stream and soil biota) and upward diffusion of nutrients and DOC continues year round. In the event of opportunities for year around field activity from McMurdo Station, we would propose to conduct a lake monitoring program during a spring/winter/fall period on MCM-II This work is the responsibility of Drs. Priscu, Lyons, Doran and McKnight.

Table 2.2. 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 winter (WN) research. Winter sampling frequency is for Lake Hoare.

Parameter	Year I	Year II	Year III	Year IV	Year V	Year VI	AS (No/Y)	WN (No/Y)
Ice Thickness	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	2	3
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	3-4	6
Vertical light profile	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	3-4	6
Solutes	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	F,H,B	3-4	6
Biomass Plankton (bact, phyto, prot) Benthic mat	F,H,B H, F	F,H,B H, B	F,H,B H, F	F,H,B H, B	F,H,B H, F	F,H,B H, B	3-4 1	6 0
NPP/RS Plankton (bact, phyto,	F,H,B H, F	F,H,B H, B	F,H,B H, F	F,H,B H, B	F,H,B H, F	F,H,B H, B	3-4 1	6 0

prot) Benthic mat								
Species Plankton (bact, phyto, prot) Benthic mat	F,H,B H, F	F,H,B H, B	F,H,B H, F	F,H,B H, B	F,H,B H, F	F,H,B H, B	3-4 1	6 0

Physical and chemical characteristics (Hydrology and Biogeochemical processes). Lake levels are measured both intermittently and continuously. Lake ice measurements include thickness, the piezometric water level, surface ablation and temperature (cf. Chinn 1993). Thickness controls light transmission to underlying waters. Ablation of lake ice is the principle path of mass loss from the lakes because they have no outlets. These measurements will be related to glacier melt and stream discharge data to better quantify the water flux and balance through landscape units (hypotheses 1a,b,c).

Photosynthetically active radiation (PAR) is a primary driver for phytoplankton photosynthesis, so we will continuously monitor underwater radiation at depth. Underwater profiles will be made on monthly intervals (coincident with primary productivity measurements). During limno runs, temperature, conductivity and in situ fluorescence (a measure of chlorophyll *a*) will be measured with a Seabird model 25 CTD probe. We will collect water samples from the entire profiles for major ion chemistry at least two times each yearearly in the season and in late January. Because the top 10 m of these lakes are so responsive to hydrologic variation, major ion chemistry samples will be collected from the surface 10 m during all limno runs. Ecologically important solutes, such as DIC, nutrients and DOC, will also be collected at all depths during all limno runs.

Plankton abundance and productivity/(Bioactivity and Biodiversity). Because phytoplankton exist in narrow bands in the lakes (Spaulding et al. 1994; Priscu 1995), both discrete and high resolution *in situ* profiles are necessary for determination of phytoplankton biomass. Phytoplankton species distribution will be monitored to understand variations between years and between lakes. Measurement of bacterial abundance and heterotrophic activity will also be continued. The abundance of protozoa will be added to MCM-II to obtain a complete picture of the changes in the lake ecosystems in response to climate. Detailed studies of grazing by ciliates and nannoflagellates conducted in MCM-I will allow for interpretation of these data to assess the response of the changing conditions.

D.2.e. Lake Microbial Mats (Bioactivity and Biogeochemistry). Microbial mats in Lake Hoare are accumulators of carbon and nutrients. Our studies during MCM-I indicate that mat primary production rates are equal to the rates in the top 15 m of the water column and that mats influence the overall lake biogeochemistry. We will examine changes in C, N and P content of specific mat layers. Because the physiologically active layer contains photosynthetic pigments which may vary with depth in the mat, chlorophyll *a*, phycoerythrin and accessory pigments analyses will be used to determine layers with potential photosynthetic activity and provide information on the species present (e.g. Lizotte and Priscu 1998). This activity will be the responsibility of Dr. Hawes, Priscu, and Doran.

Lake mat transects. Our monitoring program for the benthic mats will focus on transects at permanent sites in each lake, extending laterally from just under the ice to beyond the maximum depth of colonization. We will study Lake Hoare primarily, but will sample other lakes in Taylor Valley on an every 4 year schedule comparable to the stream site monitoring. Measurements will match those of stream mats: pigment content of upper layers, algal species counts, and long-term record of mat vertical growth by measuring height with reference to fixed points, and particulate organic C, N and P content of specific mat layers. We will focus on static variables and will be able to compute temporal changes, providing net rates of growth or loss. We will measure instantaneous changes in primary productivity and respiration on the cohesive upper layer of cores at selected sites. The role of protist grazing in benthic mats is unknown and may be an important pathway in carbon and nutrient cycling. In MCM-II, we will enumerate protists from representative mats. To place the lake mat community into our overall legacy concept, we will collect samples from each of the lakes for natural isotopic abundance of carbon and nitrogen.

D.2.f. Soils. MCM-II will study soil ecosystems in a comprehensive manner. Continuous measurements of soil microclimate at study sites in the Hoare, Bonney and Fryxell basins will include PAR, soil temperature at several depths and air temperature at 5 cm (inside chambers), and at 1 m above the surface; soil moisture and salinity will be measured at several depths. This activity will be the responsibility of Drs. Wall and Virginia.

Elevational Transects (Bioactivity and Biogeochemistry. Soils in Taylor Valley represent a range of dry to moist habitats, differing soil types and salinities and varying geomorphic features at varying elevations. There are no soil maps. Because material transport, on an annual basis, influences soil chemical and physical properties as well as biotic communities, in MCM-I, we established a transect at three elevations near Lake Hoare to monitor soil properties and biological communities on a long-term temporal scale. The three 10m^2 plots on this transect were selected based on geomorphological features and they have distinct differences in climate, soil moisture, soil properties and soil nematode diversity. We will continue to monitor this transect every three years, looking for long term patterns of soil community change as a function of climate. Results from MCM-I indicate that biodiversity and attributes of the soil environment are more spatially variable in the MCM than in most other ecosystems (Freckman and Virginia 1998). To extend our understanding of spatial variation in soils and biota essential for regionalization, we will examine spatial variation in soil properties and biota along replicated 70 m transects located at sites in the Bonney, Hoare and Fryxell basins. Samples (n = 36) will be collected in a nested scheme along each line to minimize the number of samples required to minimize spatial autocorrelation from cm to m scales (Robertson and Gross 1994; Cavigelli et al. 1995). Semivariagrams for nematodes and soil properties (organic C, NO3(-), pH, conductivity, moisture) will be used to determine if biota and soil environmental factors vary over similar spatial scales in the dry valleys. Our results will be compared with similar studies conducted on another arid LTER site (JRN), where the impact of desertification on soil heterogeneity is a central focus (Schlesinger et al. 1990).

Material Transport (Bioactivity and Biogeochemistry). Aeolian transport of organic material and viable biota, such as anhydrobiotic invertebrates (nematodes, rotifers and tardigrades), protozoa and microbial propagules, may be an important link between streams, lakes and soils, as well as being a means of establishing soil and stream invertebrate communities. We propose to continue monitoring wind transport of organisms and material using 2 methods tested during the past two years by Wall and Virginia. Tube pans weighted with marbles will be placed at various locations throughout the valley and on soil near streams, and on lake ice, and left over winter. In the spring, the pans will be collected, contents placed in a sterile bag and subsamples of materials examined for organisms using sterile methods. Material collected will be analyzed for chlorophyll a to assess production. Remaining subsamples will be frozen for other investigators to use for identification. The second approach uses air part icle collectors (made of Frisbees attached to a collecting bottle) successfully employed by the British Antarctic Survey and ourselves, which will allow cross-Antarctic comparisons of wind inocula to soils and aquatic systems throughout Taylor Valley (BAS; BIOTAS Handbook, 1997).

Biotic Effects on Soil Decomposition, Carbon and Nutrient Bioavailability (Bioactivity and Biogeochemistry. Increases in soil temperature and moisture may change the bioavailability of essential elements by altering solubility and diffusion rates in soils, or by changing the amounts of organic compounds (responses to increased productivity or increased grazing of soil invertebrates on bacteria). We will establish a long-term experiment in the Bonney, Hoare and Fryxell basins, that consists of a control and 3 treatments 1) increased moisture, 2) soil warming (ITEX chambers), and 3) soil warming + increased moisture. The potential rate of decomposition processes will be determined by measuring the tensile strength of 100% cotton strips placed vertically in the soil and sampled periodically over six years. In some plots we will bury fine mesh litter bags containing dried lake algae to determine if this traditional method can be used in Antarctic soils. Biotic influences will be assessed by measuring organic carbon fractions in soil from experimental plots. Available ions in the soils will be assessed using ion exchange membrane sheets and treatment differences in the amount of absorbed ions (NO3(-), PO4(3-)) on the resins will be compared to the biodiversity and biomass of organisms on the plot and soil.

D.3. Continuing Long-Term Experiments (Bioactivity and Biodiversity)
In MCM-I, we initiated 3 long-term experiments designed to elucidate processes controlling the persistence and biodiversity of biota in the streams, lake benthos, and soils. These questions continue to be a focus in MCM-II and the results from the experiments have been valuable in formulating our hypotheses on Bioactivity and

Biodiversity. These experiments will be continued with some adjustments in either sampling frequency or expansion of measured parameters.

D.3.a. Long-Term Relict Channel Reactivation Experiment. To investigate developmental patterns of stream algal communities, during January 1995 we routed meltwater to a relict stream channel. Based upon aerial photography, the last period of sustained flow in this channel was in 1969. Soon after wetting, relict algal mats began growing. These mats grew more rapidly than mats in streams with regular summer flow, possibly due to greater solute and nutrient concentrations in the relict channel (Fig. 2.12). Clearly, algal mats can survive desiccation for long periods and respond rapidly to hydration. We will continue this experiment during MCM-II, to follow changes in algal mats and solute concentrations as the relict streambed and hyporheic zone is leached. Further, we will follow the development of invertebrate communities with the downstream advance of flow each year, and along transects across the stream channel to the adjacent soils as the moisture gradient evolves. The reactivated channel has, so far, only experienced low-flow conditions. We anticipate that the relict channel biota will change more dramatically during a high flow year than biota in streams with regular flow.

D.3.b. Long-Term Sediment Dump Experiment. One perturbation to the lake benthos environment is sudden deposition of sediment from the overlying ice-cover as it melts. This is a spatially heterogeneous process and the magnitude of the disturbance may be related to climate influences on the ice-cover. During MCM-I, a sediment addition experiment was begun to assess rates of benthic microbial mat growth as well as the mechanisms by which sediment recolonization occurs. This experiment provides insight into how the lake benthos may respond to small changes in climate.

We placed sediments of known organic matter concentration on the bottom as pre-formed, frozen, sediment patties with a total of 9 treatments plus controls. Six of these treatments were set up in triplicate and three of the treatments have had five experimental units put in place. This allows for uniform experimental units with no loss of sediment-associated organic matter. The initial design of the experiment calls for retrieving four patties every two years. These results will allow quantification of both the rate and principal modes of recolonization of sediments deposited from the overlying ice-cover.

D.3.c. Long-Term Soil Manipulation Experiment. We have hypothesized that climate (water and temperature) control the activity of soil organisms, but that energy supply determines population density and biodiversity of soil communities. One energy source may be wind blown algal material from lakes and streams, representing a linkage between soils and aquatic systems. During MCM-I we found that aeolian organic carbon has characteristics indicating an algal source and that there are significant variations in deposition among basins. In MCM-I, a long-term experiment was started at Lake Hoare. This incorporates a randomized block design of eight replicates of eight treatments, representing combinations of increased water, soil warming and carbon added as either sucrose or mannitol solutions. Soil is warmed approximately 2°C by placing 0.83 m diameter polycarbonate International Tundra Experiment chambers (ITEX, Marion et al. 1997) over the soil. A related experiment compares additions of lake algae as a supplemental C source and its interaction with soil warming. Soils are analyzed for soil temperature, soil moisture, soil respiration, protozoa diversity and abundance, nematode diversity, life stage and abundance, other invertebrate diversity and abundance, total bacteria, and soil physical and chemical properties. Changes in nematode populations are useful indicators of disturbance to soil and sediment communities (Freckman 1982; Freckman 1988; Bongers 1990). Because this long term experiment will help us to understand linkages between landscape units, we will continue application of soil treatments through MCM-II with decreased sampling frequency (once every 2-3 years) to extend the experiment through MCM-II (limited soil is available for sampling).

D.4. New Experiments--Testing Our Conceptual Model
For MCM-II, we propose to conduct two new experiments which will further test in an integrated manner our hypotheses relating to 1) the legacy concept of the McMurdo Dry Valleys and 2) the dependence of ecosystem function on small changes in annual climate. The "paleoclimate" experiment examines the potential response of a valley comparable to the Taylor Valley in the past and involves transplant and manipulative experiments in soils and stream channels. The snow fence experiment is a long-term manipulation experiment in which changes from increased snow accumulation will be followed in all environments in all basins of Taylor Valley. Both of these experiments will test our conceptual model that climate interacts with landscape legacies and linkages to

determine functioning of the present day ecosystem. All PIs will participate in both of these experiments. The paleoclimate experiment will be lead by Drs. Doran and Wall and the snow fence experiment will be lead by Drs. Fountain and Moorhead.

D.4.a. Paleoclimate Study. The notion of temporal disturbance and recovery has been a major theme in landscape ecology (Turner et al. 1993). We can examine this notion by comparing the modern ecosystems in Taylor Valley to a paleoclimatic analog when temperatures and precipitation were lower, the nematode community was less diverse, and streamflow was more irregular. In so doing, we will be able to establish the rate of recovery for soil and stream ecosystems. This comparison is termed the "paleoclimate experiment" because it allows us to "look" backwards in time to observe the MCM ecosystem prior to the last warming event that began about 103 years before present. Within 45 km of the MCM site, the Arena and Beacon Valleys (Fig. 2.13) are thought to have undergone little disturbance for at least the past 8.1 and 4.3 M years, respectively (Marchant et al. 1993). These valleys are colder than Taylor Valley with a mean annual temperature -30° to -35°C and precipitation about 10 mm (Bockheim 1982; Marchant et al. 1993). These current environments may be analogs to Taylor Valley at ~1500 yrs BP during the lowest recorded lake levels in both Taylor and Wright Valleys (Matsubaya et al. 1979; Lyons et al. in press).

Surveys of Soil and Stream Communities. In Years 3 and 4 of MCM-II, we will establish soil and stream transects in Arena and Beacon Valleys to compare species composition and abundance between these environments and our ongoing work in Taylor Valley. We will exchange 0.5 m² x 10 cm deep boxes of carefully excavated soil from Taylor Valley and Arena or Beacon Valley. Cotton strips will be placed in each plot to determine decomposition rates. Soil samples will be removed periodically to assess the physical, chemical, and biologic characteristics. Meteorological stations, glacier ablation stakes, and stream gauges will be established to compare the meteorological and hydrological environments with Taylor Valley during the study period. Stream biota in current active stream channels will be documented at stream transect sites comparable to those in Taylor Valley.

Reciprocal Soil and Mat Transplant Experiments. Biodiversity of soils is hypothesized to vary with soil moisture, temperature, organic matter and other soil factors. To examine climatic controls on biodiversity, we propose to exchange soils and their communities from the Fryxell basin, where soils have a younger geologic age, higher organic carbon content, and a more diverse nematode community, with soil from Arena Valley, which is colder, has older soils and a less diverse nematode community. Because biological activity peaks between 2-10 cm depth (Powers et al. in press), we will remove sufficient soil to fill ten, 0.5 m² x 10 cm deep boxes at each site, and transplant it to the comparison site where soil was removed. Care will be taken to minimize disturbance to the soils, and to layer the soil so as to simulate the original soil 'structure'. Cotton strips will be placed in each plot in sufficient numbers to allow decomposition to be measured over a 6-year period (BIOTAS). Soil samples will be removed for initial analyses of soil chemistry and annual analyses of total bacteria and nematodes. Relict channels may be present in Arena and Beacon Valleys as in Taylor Valley. If so, we will look for stone pavement habitats and collect samples of sediments on dried mat material. We will then attempt to culture algae from these samples and examine species distribution.

D.4.b. Snow Fence Experiment. One of our major findings in MCM-I is that changes in snow cover exhibit profound effects across all components of the ecosystem. We propose an experiment that increases snow accumulation on all key components of the dry valley ecosystems and measures subsequent ecosystem response. We will increase snow accumulation by either transporting snow from the high elevations to the valley floor or by erecting barricades (i.e. snow fences) that collect wind drifted snow (Fig. 2.14). We prefer the latter as they better simulate natural accumulations of snow on the valley floor. A snow fence experiment at NWT led to an increase in snow accumulation which had a large effect on the carbon balance and associated biogeochemical cycles in the soils (Brooks et al. 1995). Similarly, we will evaluate the role of increased moisture on the physical and chemical conditions of the underlying substrate which, in turn, effects ecosystem dynamics.

We anticipate that increased snowpack will increase soils biomass and increase atmospheric chemical and particle fluxes to all landscape types. It will, however, decrease biologic activity in the lakes because of reduced light, and will decrease water and nutrient fluxes from the glaciers and streams to the lakes. Once the snow has ablated, biologic activity and water flux will soon return to or exceed previous levels. We will carefully obtain snow cores to examine vertical gradients in snow density, chemistry, sediment, and organisms. Over soils or

stream algal mats, if a sufficient plug of soil is collected, sub-snow moisture and biologic activity can be determined. Thermistors will be embedded in snow-covered and adjacent snow-free soil to monitor temperature changes.

We will install 2 fences over each landscape component (soils, lake ice, streams and glaciers) in the Lake Bonney and Lake Fryxell watersheds. Installing fences in different watersheds will take advantage of the different climatic regimes in the valley and help test climatic sensitivity. Snow accumulation on the leeward side of the fence will decrease with distance from the fence, providing a gradient of moisture. Thus with one experiment we can address *all* MCM-II hypotheses and linkages. Our ability to conduct this work will depend on review for environmental impacts under NSF guidelines and the Antarctic Conservation Act.

Snowpack and Soil Samples. Snowpack measurements will be taken at intervals determined by the weather. At minimum, measurements will be taken in the spring and fall to determine the seasonal variation in snow accumulation, and after every snow storm. Measurements will be taken during periods of rapid melting to assess rate of snowpack depletion. Melt water flux from the snowpack will be estimated from thermistor measurements and the nearest meteorological stations and calculations of snow sublimation. Nutrients and chloride will be measured in the snow cores during early season, the most important period, and immediately after major snowstorms. Soils or stream substrate will be sampled at each location along the fence in late season when a gradient of snow melt has provided moisture for the activity of the biota. Soil samples will be analyzed for the nematodes, chlorophyll *a*, total bacterial biomass, organic carbon and nitrogen and total soluble salt.

Material Transport. Accumulation of aeolian sediment and biota will be determined using collection pans weighted with marbles and placed in front of the fence and along the accumulation gradient. They will be sampled in spring and in fall to capture the seasonal variation in material transport. Based on the mass collected, we will prioritize analysis of sediment and biotic factors. If possible, samples will be analyzed for total suspended sediment load and size distribution, and for nematodes, algal species, chlorophyll-a and total bacterial biomass.

D.5. Integrative Studies

D.5.a. GIS--Mapping and Remote Sensing (Hydrology). A significant limitation to current research within the McMurdo Dry Valley LTER program is the lack of accurate maps of the region. This situation makes it extremely difficult to express data within a spatially explicit context and restricts development of landscape models. A priority task at the International Centre for Antarctic Information and Research (ICAIR; Christchurch, New Zealand) is the production of an accurate base map and Geographical Information System (GIS) of the McMurdo Dry Valley region. Work at ICAIR has focused on two GIS elements 1) ensuring that a new datum network is established for the dry valleys and 2) digitization of the relevant USGS 1:50K sheets from the mylar originals for every layer of data for the series. A comprehensive, complete and integrity-checked set of layers has been combined with ICAIR's original topo data for this series. These data layers now are being converted to the new datum so that the entire area will be registered before year's end. Once a corrected 1:50K base map is prepared, other existing thematic layers (hydrology, glaciology, etc.) will be added. Field verification of active stream channels is underway in MCM-I. These maps are critical for casting MCM research in a spatial context.

D.5.b. Carbon Budget for Taylor Valley (Biogeochemical Processes). Results of MCM-I studies indicate that the carbon cycle of the dry valleys integrates soil, lake and marine systems, linked across space by the physical transport of organic materials, and linked through time by fluctuating lake levels. Developing a comprehensive budget of carbon dynamics in MCM minimally requires working knowledge of in situ carbon dynamics of modern soil and lake communities, as well their spatio-temporal linkages. During MCM-II, Drs. Doran, Virginia, Wall and Lyons will continue to develop a map of d13C distributions throughout Taylor Valley. Modern mat communities in lakes and streams at various water depths and locations will be compared to soil carbon values. The goal of the work is to understand the sources of carbon throughout the modern landscape and to project future patterns from current biological activities and transport mechanisms. Aspects of this integrative project have been previously described, but additional studies are proposed to aid in this integration, as follow.

D.5.c. Soil Carbon Pools (Biogeochemical Processes). Soil carbon cycle in the McMurdo region has importance as an extreme "end-member" of global soil ecosystems. A soil carbon budget for Taylor Valleys is required to

integrate our studies of the carbon legacy with current rates of NPP and nutrient cycling. Soil carbon pools will be determined based upon systematic regional sampling of soil profiles (Brown et al. 1996; Burkins et al. 1997) located at varying distances and elevations from lakes, streams, and the ocean. The possible origins of this carbon (soil derived, lacustrine, marine) will be determined by measuring the natural abundance of 13C and 15N in the soil organic matter. Measurements of lake mat d13C abundance will constrain the isotopic variation of lacustrine carbon sources (see below). The quality of soil organic carbon will be assessed by separating light fraction carbon (labile, rapidly cycling C) and heavy fraction carbon (Connin et al. 1997a, b). Our goal is to develop a coar se-scaled soil carbon map for Taylor Valley to relate soil carbon quantity, quality, and source to soil NPP, respiration, and biodiversity.

Soil NPP and its spatial variation will be examined by determining soil chlorophyll concentrations (an index of soil algal biomass; Metting 1994), by gas exchange and by 14C (Warembourg and Kummerow 1991). For soil NPP, closed chambers will be placed over the soil, incubated in light or darkness, and the CO2 concentration in headspace determined. Soil respiration also will be measured using an open gas exchange system and soil cuvette (LICOR 6200). Our intent is to develop a relationship between chlorophyll, which is relatively easy and inexpensive to measure, and a smaller number of more intensive measurements of carbon fixation. The data are important for the carbon cycle model.

D.5.d. Paleocarbon in Lakes (Biogeochemical Processes). In order to better understand the legacy of the lake organic matter in the soil ecosystem and the processes leading to the production and preservation of lacustrine carbon today, a series of investigations will be undertaken. Dr. Doran has performed experiments on the control of d13C in organic matter buried in deltaic and lake bottom regions in coordination with the work of Drs. Lyons and Priscu on d13C and DIC dynamics in the lakes. The results show 1) that there is significant variation in d13C of mat organic carbon and 2) that these differences may be associated with water column CO2 depletion (Neumann et al. in review). In the CO2 saturated bottomwater of Lake Hoare, mats fractionate carbon isotopes by values of 30%, as predicted from theory. In contrast, shallow Lake Hoare mats display enriched d13C values, consistent with the CO2 undersaturation of these waters (Fig. 2.15). Therefore, the d13C of mat material reflects the depth zone of formation of that material. It is clear that the ancient lacustrine carbon is not uniformly distributed throughout the landscape. This patchiness is due to the location of features of the ancient high stand lake. During MCM-II, we plan to coordinate the carbon/nitrogen isotope work in soils and lakes. This will provide better understanding of the source and location of the "legacy" organic carbon now in the soils.

D.5.e. Lake Nutrient Balances (Biogeochemical Processes). The hydrology and geochemistry program initiated in MCM-I provided the preliminary data for us to begin the construction of nutrient balances for dissolved inorganic nitrogen and phosphorus species within each lake. We will use (and refine) existing (MCM-I) and proposed (MCM-II) streamflow and nutrient chemistry to develop detailed budgets for each of our study lakes. Ratios and concentrations of these "new" nutrients will be related to the relict pools within each lake to determine the turnover rates of each pool. Upward diffusion of relict nutrients will be computed as described by Priscu (1995). These data, in concert with existing nutrient bioassay data (Priscu 1995) and routinely collected primary productivity data, will provide us with information on the roles that new and relict nutrient pools have on phytoplankton growth and vertical structure. The relative roles of these two nutrient pools will depend upon interannual variation in glacial melt, resultant streamflow, nutrient transformations within the streams and weathering processes associated with the stream channels.

D.6. Ecological Modeling (Biogeochemical Processes)
Bioactivity and development of ecological models for interactions within ecosystem components are important means to test and develop our hypotheses. The modeling effort is conducted by Dr. Moorhead in collaboration with other PIs.

D.6.a. Primary Production. In MCM-II, our conceptual model (Fig. 1.5) will be applied to the cyanobacterial communities embedded within permanent lake ice (Spigel and Priscu 1998). It also will be used to simulate primary production in soils at the narrow interface where light penetration from above and water vapor movement from underlying permafrost overlap to provide a suitable microhabitat for algae. Higher resolution of light and nutrient regimes in lakes will permit estimating patterns of primary production at higher spatial and temporal resolution for phytoplankton and benthic mats, a priority of MCM-I (Moorhead et al. 1997b, 1998).

D.6.b. Secondary Production. Food webs in soils are limited largely to algae, yeasts, bacteria, protozoans and nematodes (Freckman and Virginia 1997, 1998), and aquatic food webs are limited to algae, bacteria, protozoans and rotifers (Laybourn-Parry et al. 1997; James et al. 1998). Investigations of MCM-I are providing species identities, estimates of abundance and biomass of trophic groups, as well as measures of community respiration, which will be used to develop food web models of energy and nutrient flow in MCM-II (see below).

Studies also are planned to improve resolution of temperature and light responses of respiration and photosynthesis. Models of production and turnover for particular groups of heterotrophs in dry valley ecosystems will be possible when more detailed data of abundance and distributions of taxa through time and space are available (see below).

D.6.c. Population Dynamics. Few of the species present in MCM ecosystems have been examined sufficiently to support a population model incorporating developmental stages of the organism. The primary exception is the soil nematode, *Scottnema lindsaye* (Overhoff et al. 1993). A model that previously was used to simulate population dynamics of the nematode, *Acrobeloides nana*, in a warm desert environment (Moorhead et al. 1987), was modified to estimate development of *Scottnema* in dry valley soils (Fig. 2.16). Soil temperatures recorded during MCM I were used to drive the model. Results suggested that *in situ* development of this species may require several Antarctic summers due to short summer seasons and slow nematode development at the prevailing low temperatures. A priority of MCM-II is to gain more detailed soil climate data, including moisture levels. This information will permit a more accurate assessment of development, activity and respiratory patterns of *Scottnema*, and may permit application of the model to other species.

D.6.d. Food Webs. A model was developed to simulate energy and nutrient flux through the food webs of MCM soils (Fig. 2.17), utilizing the approach of Hunt et al. (1987, 1989). In essence, biomass estimates of the various groups are assumed to represent steady-state values (a particularly valuable approach when temporal resolution of data is low). General metabolic characteristics of these types of organisms (cf. Hunt et al. 1987) are used to estimate ingestion, egestion, assimilation and mineralization of carbon and nitrogen, driven by climate regime. Flows of material between trophic groups are assumed to balance demand, resulting in a cascade of cumulative top-down demands for energy and nutrient supply throughout the food web. Current efforts focus on the initial formulation of this model and application to sites where soil climate and trophic structure are known. Continued and expanded monitoring of soil climate, especially soil moisture regimes, and structure of soil food webs will suppor t further model development and application to other sites during MCM-II. Moreover, such a modeling approach may be suitable to address energy and material flow through food webs existing in microbial mats and planktonic communities in aquatic environments, as supporting data become available.

D.6.e. Productivity, Complexity and Stability. A suite of recent modeling studies by Moore et al. 1993, have explored potential relationships between productivity and structural complexity of simple food chains. In essence, they propose that fluctuations in energy supply may limit the complexity of food webs, especially in simple systems. The central premise of this hypothesis is that probabilities of extinction are related to energy supply, with vulnerability to extinction increasing with trophic distance from the source of energy that drives the system. The soil communities of the dry valleys are a model system in which to test this notion because they consist of short food chains and few species (Freckman and Virginia 1998). Moreover, the number of species varies between locations in a manner that at least partly is independent of physicochemical characteristics of the site, random extinction could account for this pattern. A proposed modeling activity of MCM-II is to explore the possible im pacts of extinction processes on structuring food webs in MCM soils. Moore's approach is based on the Lotka-Volterra equations of predator-prey interactions, which may be developed from baseline estimates of energy flows through components of the food web model (see above).

Unlike soil organisms, plankton live in a more predictable and less variable environment in MCM lakes, but MCM-I studies have shown that the relative abundance of particular species fluctuates over time in a manner that is not clearly related to changes in physicochemical characteristics. Thus, controls over population dynamics are not apparent. Indeed, May (1974) was one of the first to demonstrate that complex patterns of population dynamics could result from relatively simple interactions among species. Another modeling goal of MCM-II is to explore the population dynamics of planktonic species using Lotka-Volterra competition equations to simulate interactions among the numerically dominant taxa. The bases for defining the relative strengths of competition

coefficients among different species (as required for this method) are not clear. However, we propose to calculate potential competition on the basis of (1) light absorption, expressed as a function of average cell diameter for each species, assuming con stant optical densities of cellular constituents, and 2) nutrient uptake, as a function of average cell diameter for each species, assuming uptake to be proportional to surface area. This approach, albeit crude, will define competition according to the relative abilities of cells to compete for energy and nutrients, and provide a basis of comparison to more traditional "chemostat" type models of population dynamics for planktonic organisms driven by abiotic factors.

D.7. Intersite Comparisons within LTER Network

Our cross-site efforts over the past year included the following: participation in the LTER comparison of stream productivity, a contribution to the Freshwater Biology special issue from the LTER-NTL sponsored workshop, Cross-site Comparisons, Syntheses and Interactions, and our participation in the LTER Intersite Hydrology project at H. J. Andrews experimental Forest. Dr. Doran attended the Archaeoclimatology Workshop in Santa Barbara hosted by PAL-LTER. In addition, Lyons has been working with Dr. G. Kling (ARC) in an attempt to compare chemical weathering rates between the two sites. It has traditionally been thought that polar conditions should inhibit chemical weathering; however, recent work in Siberia has suggested that this is not the case. Chemical weathering controls the CO_2 composition of the atmosphere over geologic time scales (Berner 1995). Lyons has proposed to the Network office the beginning of an intersite comparison that would include all sites with surface water or ground water flux measur ements. The goal is to utilize hydrologic and chemical data to calculate weathering rates and then evaluate the roles that climate, presence and absence of vegetation and land use patterns have on chemical weathering. This concept was initially approved by the Network office in late 1997.

E. FIELD AND EXPERIMENTAL METHODS

E.1. Monitoring

E.1.a. Meteorology. Stations query sensors at 30 s intervals and store data every 20 minutes. Stations measure air temperature and humidity at 3 m above the surface, soil (or ice temperature) at multiple depths, wind speed/direction, and incoming and outgoing solar flux. Lake stations measure PAR, and glacier stations measure longwave radiation. Barometric pressure is measured at Lake Hoare and Canada Glacier. Snowfall is measured using Belfort gauges, by a salt dilution method.

E.1.b. Aqueous Geochemistry. Glacier ice/snow, meltwater, streams, and lakes are analyzed for parameters in (Table 2.3). Major ion chemistry is analyzed using ion chromatography (Welch et al. 1996). Samples are filtered through Whatman GF/F filters and stored at 20°C. Ammonium, nitrite, nitrate and soluble reactive phosphate are determined with a LACHAT autoanalyzer. Reactive silicate is determined colorimetrically (Toxey et al. 1997). DOC samples are analyzed with an O-I carbon Analyzer. Oxygen is measured using Winkler titrations. Dissolved inorganic carbon (DIC) is by infrared spectrometry on acid sparged samples.

Table 2.3. Routine methodology to be used for aquatic samples.

Parameter	Method(s)
Lake Volume	Chinn (1992)
Ice Thickness	Wharton et al. (1992)
Temperature	SEABIRD SBE 25 CTD UNIT
Conductivity	SEABIRD SBE 25 CTD UNIT
In Vivo Fluorescence	SEABIRD SBE 25 CTD UNIT
Under Water Irradiance	LICOR Spherical Quantum Sensor
pH	Calomel Electrode

Particulate Organic Carbon	Carlo Erba 1500
Particulate Organic Nitrogen	Carlo Erba 1500
Dissolved Oxygen	Winkler
Na, K, Mg, Ca	Ion Chromatography
Cl, SO4	Ion Chromatography
NH4, NO2, NO3, SRP	Lachat Autoanalyzer
Stable Isotopes (d13C, d15N)	Mass Spectrometer
Chlorophyll *a*	Fluorescence of Acetone Extracts
Net Primary Production	14C-Bicarbonate Uptake
Respiration	Electron Transport System Activity
Species Composition	Inverted Fluorescent Microscopy
Dissolved Organic Carbon	Combustion
Reactive Silicate	Colorimetrically

E.1.c. Glaciers. Mass balance is measured on 4 glaciers: Commonwealth, Canada, Howard and Taylor (Fig. 1.1) using a network of bamboo poles drilled into the ablation zone (ice-covered region in the lower elevations). Snow accumulation and loss of ice is measured at each pole. Measurements are made in spring and fall to capture seasonal changes.

E.1.d. Streams. Discharge is measured manually at different stages and a rating curve developed for each gauge (VonGuerard et al. 1995). Gauges with a Parshall flume and a rectangular weir in the cutoff wall are used for the most accurate data at low flow. Other gauges use natural channel controls and provide data with 10% accuracy for flows above 10 L/s. Each lake basin has 2 gauges with flumes. Discharge for ungauged streams is measured 3-4 times per season.

Algal mats are characterized according to color. Five samples of each color type are collected using a #13 cork borer. Sample location is mapped on small contour maps. Samples are preserved in 10% formalin for species analysis and filtered onto GF/C filters for chlorophyll determination (Strickland and Parsons 1972). Species composition and relative abundance are determined using a Nikon Diaphot phase contrast microscope. Subsamples are placed in a 2 ml settling chamber with a 26 mm diameter (Utermohl, 1958) and examined at 400x magnification. Seven random fields (a total area of 0.44 mm²) are tallied. Descriptions of morphotypes are presented in McKnight et al (1998). Percent cover is determined by measuring the length and width of all specimens. Cell "depth" is measured to estimate biovolume.

E.1.e. Lakes. Lake sampling is monthly from October to January. Water samples are collected at 2 m intervals using a Teflon coated Niskin bottle. Methods are summarized in Table 2.3 and details are provided below.

Manual measurements of lake level are made in spring and fall using a survey level from a Bench Mark calibrated to those of the New Zealand Antarctic Program. Continuous measurements (20-min. intervals) are recorded using a pressure transducer suspended between a buoy and anchor. Ice temperatures are measured using a thermistor string frozen into the ice-cover.

Spherical sensors (LICOR 193) are deployed at 10 m beneath the ice surface. Sensor output is logged continuously at 20 min (summer) or hourly (winter) intervals. This instrument has been specifically designed for under-ice use and produces high resolution (~5 cm) profiles (Spigel and Priscu 1998). Density is obtained from CTD measurements using modified equations of state for seawater (Spigel and Priscu 1996).

Phytoplankton productivity is measured as 14CO2 uptake in light and dark bottles suspended *in situ* for 24 h (Priscu 1995). Discrete and high resolution *in situ* profiles are used to determine phytoplankton biomass. Discrete samples are filtered through Whatman GF/F filters and chlorophyll *a* (phaeophytin corrected) is measured by fluorometry (Lizotte and Priscu 1998) and used to convert *in situ* fluorescence profiles to absolute chlorophyll values. Samples for algal enumeration are preserved in Lugol's solution, settled and counted with an inverted microscope.

Bacterial productivity is measured as tritiated thymidine incorporation with a protocol which is linear for 20 h (Takacs and Priscu, in review). Conversion of thymidine incorporation rates to *in situ* rates and to carbon-based, production-use factors determined in laboratory bacterial growth experiments (Takacs and Priscu in review). Bacterial (>0.2 um) numbers are determined by epifluorescent spectrometry of acridine orange stained cells (0.01% final concentration) preserved with 5 % formalin. Biomass is determined with geometric measurements of fluorescent cells.

Protozoa are studied in samples preserved with buffered glutaraldehyde. Nannoflagellates are counted by staining 30-50 ml with DAPI filtering onto 2 mm polycarbonate membranes, and counting 20 Whipple grids under both UV and blue filters with epifluorescence microscopy (to distinguish phototrophic and heterotrophic cells). Ciliate samples (500 ml or 1-liter) are preserved in 1% Lugol's solution, concentrated to 1 ml and counted in a Sedgewick-Rafter chamber. Cell sizes are determined with a line graticule and biovolume calculated using the nearest geometric shape. Biovolume to biomass conversions are obtained using a carbon conversion factor for nannoflagellates from Borsheim and Bratbeck, 1987 and for ciliates from Putt and Stoeker, 1989. Growth rates are determined using the method of McManus (1993). One unscreened sample is a control; the second sample is screened through a 10 mm mesh for nannoflagellates, or a 100 mm mesh for ciliates, to remove predators. Because there are no mesozooplankton predators on ly one unscreened incubation is required. Water samples are poured into 4 L containers and incubated at *in situ* conditions. At 8 time intervals, 3 subsamples are preserved and protist abundance determined.

E.1.f. Benthic Mats. Cores are collected with SCUBA with a polycarbonate core tube (5 cm dia.). The cohesive surface layer is removed and analyzed for species composition (epifluorescence microscopy), chlorophyll *a* (spectrophotometric analysis of DMSO/acetone extracts), phycobilin pigments (spectrophotometric analysis of water extractable material remaining from the DMSO/acetone extracts) and accessory pigments using High Performance Liquid Chromatography (Lizotte and Priscu 1998). Vertical growth is measured at three permanent transects established using horizontal aluminum bars driven into the sediment. The horizontal bar has a series of holes to accommodate calibrated needles dropped from the bar to measure distance to the mat surface. Cores for elemental analysis will be frozen and sectioned. Sections will be dried and analyzed for particulate organic C and N using a Carlo Erba elemental analyzer. Particulate phosphorus is measured after wet oxidation (Solorzano and Sharp 1980). Elemental results will be normalized to sample area and sediment weight.

PAR measurements are made using a LICOR 6200. Mat samples (upper 3 cm) will be examined for ciliates by a method of Finlay et al. (1979). The mat surface is washed with filtered lake water and examined. The ciliates are counted until 150 ciliates have been recorded. Mat samples are examined microscopically to verify ciliate removal.

E.1.g. Soils. Soil and air temperature are monitored using thermocouples. Soil moisture and salinity are measured at 2, 5 and 10 cm depths with the Hydra Soil Moisture Probe (Campbell 1990). Decomposition measurements use the loss of tensile strength in cotton strips as a measure of mass loss, as used by the BAS at Antarctic sites. Because small treatment plots cannot be sampled repeatedly, available ions will be measured using thin rigid (2.5 x 2.5 x 0.1 cm) ion exchange membrane sheets placed in the soil (Abrams and Jarrell 1992).

All soils and biota samples are placed in sterile Whirl-Pak bags and returned to McMurdo Station laboratories. Soil chemical and physical properties are determined using standard procedures (Freckman and Virginia 1997, Virginia and Jarrell 1983): pH of a saturation paste; Organic N and organic C by dry combustion following removal of carbonates with acid (Carlo-Erba Model 1500 C/N Analyzer, Nelson and Sommers 1982), KCl-extractable NO3(-) and NH4(+) and NaHCO3(-) extractable P on a Lachat autoanalyzer (Olsen and Sommers

1982); water extractable (1:5 soil:water) cations (Ca(2+), Mg(2+), Na(+), SO4(2-) and K(+) by ICP optical emission spectrometry; conductivity (EC) using a conductivity meter; and texture by hydrometry.

Microbial biomass is determined by epifluorescence microscope counting on DAPI stained samples, with image analyses for enumeration. Biovolume measurements are used for total and bacterial biomass (van Veen and Paul 1979; Bloem, et al. 1995). Cellular shape and sizes is recorded as a measure of diversity.

Soils in 4 cm diameter polycarbonate tubes will be examined for ciliates (Finlay et al. 1979). Water will be added to soil samples until ciliate species can be discriminated from soil particles (usually involves a dilution of 10x). Stream mat samples will be washed with a known volume of lake water and one drop (5ul) examined using a magnification of 100-200x. Ciliates in each drop will be counted until 150 ciliates have been recorded. Protozoa will be analyzed using the Most Probable Number identification outlined in Bamforth (1991, 1995). Nematodes, rotifers and tardigrades are counted and taxa preserved for further species identification (Freckman and Virginia 1993). Nematodes are identified to species, trophic group and life stage, and tardigrades and rotifers (and any other biota) will be enumerated (Table 2.4).

E.2. Methods for continuing and new long term experiments

E.2.a. Relict Channel Reactivation Experiment. A 1-ft high sand bag wall was constructed in January 1995 at the base of the upper reach of Von Guerard Stream, directing about 50% of the flow to channels to the west. During the subsequent four years, sampling sites have been established as flow advances downstream. In January 1997, the flow in the relict channel reached the confluence with Harnish Creek for a few days. A gauging station is in place above this confluence, but only temperature and conductivity have been recorded due to the very low flow. The summer of 1997/98 was very cold and flow did not reach the gauge. Sampling and mapping of stream mats and chemical analysis are conducted in the monitoring program.

E.2.b. Sediment dump experiment. Simulated sediment dumps were deployed by SCUBA dives on the lake bottom in January 1997. Resampling is planned every two years. Sediment was collected from Lake Hoare ice (by melting). Sediment had an average moisture content of 13.4% and an OM content of 0.48% (SD = 0.02%, n = 10).

E.2.c. Paleoclimate experiment. The methods for the soil and stream transplant and manipulation experiments are the same as in the monitoring program.

E.2.d. Snow fence experiment. Fences about 1.5 m high x 5 m long made of spaced vertical wooden slates wired together will be installed perpendicular to prevailing winds on the glaciers and lakes, over stream channels and on soils. Although other fence styles may be more efficient at collecting snow, the reduced cost, ease of transport and installation outweigh the disadvantages. To minimize disturbance, measurements will be made from a portable aluminum ladder that bridges the snow by leaning on the fence. Snow depth will be measured using a thin rod. Snowpack density and water equivalent will be measured using a snow-tube sampler (e.g. Mt. Rose sampler). The ladder will be repositioned over the snow at several locations to replicate measurements. Snow samples will be melted at 2°C and filtered for analysis following procedures in the monitoring program. Sediment will be analyzed for nematodes, chlorophyll *a*, total bacterial biomass, organic carbon and nitrogen and total soluble salt. Over soi ls or stream algal mats, if a sufficient plug is collected, sub-snow moisture and biologic properties will be determined.

In the MCM, the bands marking the high lake stands of 20,000-10,000 years ago are unmistakably apparent on the valley walls. From our research in MCM-I, we have become aware that this and other legacies from past climate regimes strongly overprint the modern MCM ecosystem, in conjunction with the modern interannual climate variability. Significant linkages between landscape units are active both in the modern day and through legacies from past climate regimes. Here, we present hypotheses relating to the "legacy effects" in our conceptual model of MCM. We propose to examine these hypotheses by continuing the MCM monitoring program with some modifications, by continuing and expanding our long-term manipulative field experiments, and by integrative and modeling studies. The new long-term experiments are the paleoclimate experiment and the snow fence experiment, both of which will integrate studies of glaciers, streams, lakes and soils.

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Section 4. Site Management

As pointed out, in 1997, by the Site Review Team, the "PIs have very good to excellent interpersonal working relationships," and "there is a remarkable collegiality among the group members." The Site Review Team also highlighted a number of site management issues that needed to be examined before resubmittal. Because of these concerns and other factors, the structure of MCM leadership and management has changed in several important ways during the past year.

In March, 1997, R. A. Wharton, Jr. announced that he would not be involved in MCM-II. Within a few weeks of this announcement Dr. Lyons was elected lead PI for the resubmittal. At this time, it was decided to move the Data Management component of MCM-I from DRI to INSTAAR at the University of Colorado under the direction of Dr. McKnight. In September, 1997, Dr. Wharton resigned as lead PI for the remainder of MCM-I. In response, year six of MCM-I has been transferred from the Desert Research Institute, University of Nevada, Reno to the University of Alabama as of March 1998, but Dr. Lyons has currently served as *de facto* lead PI of MCM-I since September 1997. Dr. Lyons appointed an Executive Committee of Drs. Fountain, Priscu, and Wall to help manage the MCM. Before this time, a "committee-of-the-whole" functioned as the Executive Committee, an arrangement found problematic for the future by the Site Review Team. Currently all issues involving science management, personnel, allocation of field slots and other resources are taken up by the Executive Committee. This new protocol provides both flexibility and rapid response to internal changes in science/resource priorities and to external Network requests and addresses the concerns posed by the Site Review Team. In addition to these management changes, Dr. Ross Virginia (Dartmouth College) has become a PI for year 6 of MCM-I and for MCM-II to add expertise in soil biogeochemistry. Independently, the Site Review Team pointed to the same deficiency. The responsibility for components of the core monitoring and experimental program is distributed among the PIs. This approach has worked well for MCM-I (based on complete submission of data sets), and will be continued for MCM-II.

The PIs formally meet twice a year. One meeting is in the late winter/early spring to address logistic and scientific needs for the upcoming field season. NSF's Office of Polar Programs requires a detailed summary of our logistic needs, often exceeding 100 pages, by 1 April for the upcoming field season starting in October. During this meeting, the PIs re-evaluate the financial and logistic resources to meet changing scientific priorities and opportunities. This meeting is rotated among the home institutions of the PIs. The second formal meeting is a science workshop to which all individuals, either associated with, or interested in MCM, are invited. The Site Review pointed out that we did not have a open forum to exchange scientific information between PIs, students, and the staff of the project. In response, we held our first workshop in Boulder in June, 1997. Because of its great success, the workshop will continue to serve as an important opportunity for integration and synthesis within the various compon ents of MCM. We feel strongly that we have made significant and positive changes in our scientific management and we have addressed the concerns outlined by the Site Review Team.

For MCM-II we recruited two new PIs to the project: Dr. Virginia (previously discussed) and Dr. Peter Doran. Dr. Doran (University of Nevada-Reno) will study paleohydrological/ paleolimnological aspects of the MCM and be responsible for a suite of measurements (identified as core data in MCM-II) on the physical characteristics of the lakes. Dr. Cathy Tate decided not to participate in MCM-II and Dr. McKnight will continue the stream ecology component. The benthic algal mat work initiated by Dr. Wharton in MCM-I will be continued by Dr. Ian Hawes, an official collaborator from the National Institute for Water and Atmosphere, Christchurch, New Zealand. He has been active with MCM since 1995 and has worked in Antarctica since 1978. In addition to Dr. Hawes, we will continue our formal collaborations with Dr. Johanna Laybourn-Parry, University of Nottingham, England (protozoa), Dr. Gayle Dana, Desert Research Institute (radiation energy balance, remote sensing), and Dr. David Marchant, Boston University (geomorphology). We will continue our long-term cooperation with USGS-WRD personnel, especially with Dr. Ned Andrews, in our hydrology/fluvial geomorphological studies.

We receive numerous requests every year from scientists desiring to work with us on MCM. Because we are limited by the number of individuals that NSF-OPP can support in the field, we discuss and prioritize, as a group, our collaborations for the upcoming field season at our Spring PI meeting. Within this framework, MCM-I has

collaborated with over 60 other scientists during the past five years in both field work and in collaborations involving provision of samples and intersite comparisons. This does not include Dr. Wall's collaboration with SCAR's BIOTEX (Biological Investigations of Terrestrial Ecosystem) experiment which consists of a number of British and Italian scientists. MCM-LTER collaborators included a large number of international scientists from New Zealand, Russia, Canada, Britain, Germany and Italy. We are developing a Memorandum of Understanding (MOU) with the Terrestrial and Freshwater Life Sciences Division of the British Antarctic Survey (BAS). This MOU would encourage the exchange of scient ists, especially those working on the soil ecosystem, between our two groups. This adds more expertise in the area of terrestrial ecosystem research to MCM. The MCM-LTER has recently been recognized as an important component of the international global change research programs as outlined by the Scientific Committee for Antarctic Research (SCAR). Recently, Dr. T. Kulbe of the Wegener Institute of Polar and Marine Research, Potsdam, Germany, has proposed a collaboration with us to the DFG in Germany to obtain sediment cores from Lake Bonney in support of our legacy/paleoclimate related work. We feel that MCM has been at the forefront of international LTER collaboration. We will continue to encourage non-LTER scientists (both U.S. and international) to collaborate with us within the constraint of limited field slots.

Section 5. Data Management

The MCM-LTER data and information management system is housed at INSTAAR, Univ. 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 full-time data manager. The manager is supervised by Dr. McKnight and works with PIs and collaborators to meet database needs and to merge data sets relating to common sampling sites and times. Our system is designed to minimize the time between data collection, data submission, acquisition of metadata, and to provide timely public access to data files and other site related information (e.g. maps, bibliographic resources, site news).

A distinguishing feature of the MCM-LTER is the high degree of coordination among investigators in planning each field season which carries over to the data management program. The data manager can anticipate which data sets will be submitted following the analysis of the field data at the home institution. Data sets are routinely submitted to the data manager in an electronic format after quality assurance by the investigator. Our core data sets are 1) continuous year-round (such as meteorological data), 2) continuous during the austral summer (streamflow), and 3) for discrete time points at specific locations (e.g. lake water chemistry). These core data need to be promptly accessible by all investigators to interpret their results. Following the approach presented by Ingersoll et al. (1997), we recognize the following types of data:

- Type 1- Electronic data: e.g. continuous meteorological data
- Type 2- (Electronic) Hard copy data: e.g. field measurements and analysis of discrete samples
- Type 3- Electronic manipulated data: e.g. continuous and discrete streamflow data which have been interpreted by using rating curves determined for each season.

The data manager is not directly involved in primary data entry. The data manager merges the Type 2 data sets to verify that a record is complete and to identify inconsistencies that can be resolved by querying the field team. The Type 1 and Type 3 data sets are from established meteorological and stream gauging networks and, thus, require only slight modifications between years.

The configuration of the hardware and software used to archive and manage data is shown in Figure 5.1. Data are entered on computers at co-principal investigators' home institutes. Files are then submitted in PC-format using ftp. Metadata (documentation to go with data files) are submitted electronically and/or by specifying a publication containing the necessary information. INSTAAR's UNIX system (a Sun/Ultra-Enterprise 150 Server) is used to retrieve files submitted electronically, manually enter data and text from hard copies, store raw data, revise formats for representation in a relational mode, and generate files to use on the web page. Available software includes Microsoft Word, Excel, and Access, as well as general text editors and HTML coding.

In addition to providing comma-delimited ASCII files for all sets of data, special data management tools were developed for meteorological and hydrological data. The meteorological tool was created by a former data manager (Ken McGwire). This tool is a web-based front end to a CGI program written in the C programming language. The met tool allows the user to subset data covering specified time periods and to aggregate these data according to standard time intervals. Users may extract values simultaneously for multiple parameters and multiple meteorological stations. Data are taken from ASCII flat files for each station. This tool currently resides on a UNIX machine at DRI, and is hotlinked to our main web site; it will be transferred to Colorado in year 1 of MCM-II. The hydrological tool was created at the USGS office in Wisconsin. It is Oracle-based, and, similar to the meteorological tool, allows the user to extract data while specifying multiple criteria for what is desired. This tool currently resides at the USGS, and is hotlinked to the web site at INSTAAR. Development of a tool similar to both of those described here, but covering multiple types of data (meteorological, limnological, soil, etc.), will occur at the INSTAAR in the near future using Oracle-based software.

The data manager communicates with all science teams before the field season about the sampling plan, permitting preparation of templates for data entry and cross-relational file structure 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),and prepares a master data template for use by the investigators in submitting their data.

The MCM-LTER 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. This information about progress is used to devise long-term plans for allocating resources for subsequent analysis. The data manager performs the final quality assurance and quality control prior to a data set being made available to the community and organizes the metadata for the submitted data sets. The data manager also posts updates regarding availability of delayed Type 2 data on the web site.

Upon request and time permitting, the data manager generates composite data sets from algorithms provided by the investigators. For example, one composite data set is the annual solute flux to a dry valley lake from a given stream or for all streams flowing into that lake. This employs continuous Type 3 data from the hydrologic network and discrete chemical data obtained for samples collected at specific times. The data manager works with the investigator to document the quality of the composite data set for a particular year. This approach is illustrated in Figure 1.

A GIS of the Taylor Valley was developed at DRI. This provides a means to organize the spatial data and can also be used to develop maps of system characteristics. The GIS and map-maker function can now be accessed by the web site.

The MCM-LTER has a record of timely submission of data to the data manager. We have a sequential procedure to ensure that timely data submission is maintained. The data manager keeps the supervising investigator (Dr. McKnight) informed of status on a weekly basis. In the case of a substantial delay or lack of response to the data manager's inquiry, Dr. McKnight contacts the investigator to discuss plans which meet the needs of other investigators. Dr. Lyons, as the lead PI, conducts further discussion as needed. Persistent, unsatisfactory conditions may be considered in planning for future field seasons and allocation of resources. Because each field season is planned by the MCM-LTER as a team, with decisions made about distribution of "slots" on the ice, equipment purchases, etc., investigators have a strong incentive to be current with their submission of data.

Data Accessibility and Schedule: Data accessibility is very much 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 2-4 months after completion of the field season in mid-February. When these data are posted in the MCM-LTER database they are immediately available to other MCM-LTER 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-LTER 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 two years after the end of the field season. For example, the Type 2 core data sets from the 1993-94, 1994-95, and 1995-96 seasons currently are available through the web. We also plan to continue to publish data reports which organize and synthesize discrete data sets for sites which are being monitored in the long term (e.g. Alger et al. 1997).

Information management services Information distribution is largely handled through the world wide web. The MCM data manager is responsible for a bibliographic database of MCM-LTER publications. The present bibliographic tool allows for PIs to be responsible for maintaining the bibliography through a simple interface. The bibliographic tool provides a web-based front end to a BibTex format bibliographic reference file. The tool consists of a set of HTML templates for data entry and update, backed by a set of CGI programs written in the C programming language. This tool also has a CGI program that performs a text search on all fields in the bibliographic file. Viewing, saving, printing, and/or searching parts or all of the bibliography is available to the public, while editing the bibliography is password protected. The data manager is responsible for regular review of the site and will request that PIs update the site when necessary. Also through the main MCM web site the

public is able to view details of the overall project (information on PIs, project descriptions, etc.), and connect to related web sites at DRI, Colorado State University, INSTAAR, and the USGS.

Section 6. Outreach

We believe that our outreach efforts have been excellent. Our group has been involved in educational outreach of all types. These include hosting three secondary science teachers (1993-94, Mr. Jim Schulz from Bozeman, MT; 1996-97, Ms. Barb Schutz from Seattle, Washington; 1997-98, Mr. Paul Jones from Montezuma, IA). This activity was supported through NSF's Teachers Experience in Antarctica Program. One high school student in NSF's High School Student Experience in Antarctica was also hosted. Numerous talks and presentations were given, and letters/e-mail from various elementary, middle and high schools were answered by the PIs. Two minority high school students, supported by the American Chemical Society's SEED program supplemented by MCM-LTER funds, worked in Dr. Lyons' laboratory the past three summers analyzing Antarctic samples.

In addition to these activities, a number of the PIs participated in LIVE FROM ANTARCTICA!, a PBS production that was produced in Antarctica during our field season of 1994. Presentations were given to a number of civic organizations (e.g. Senior Citizen's organization by Wall, Boy Scouts by Moorhead, Rotary Club by Lyons, McKnight participated in a USGS Open House for the public, and Fountain lectured at a lay geology club). REU students have been supervised by MCM PIs during the last four years of the grant. A number of MCM's female scientists were featured in a recent book for teenagers by Rebecca L. Johnson entitled, Braving the Frozen Frontier (Lerner Publications, 1997).

Because of our unique location, our site is visited by both media and important political figures every austral summer. For example, as we prepare this proposal, Ms. Cory Dean, science editor of the New York Times is writing an article, based on her recent visit, on the ecology of MCM (scheduled publication, 3 February, 1998). This past season alone (1997-98) our site hosted a reporter from Science, four members of the National Science Board, a reporter and photographer from the Rocky Mountain News (Denver newspaper), four members of House Science Committee, including Representative Boehlert (R-NY), a reporter from Newsweek, D. J. Baker, the NOAA Administrator and six Senators from the Appropriations Committee including Senator Stevens (R-AK). This activity is typical, and a complete account ranges between 30-40 dignitaries and reporters per field season visiting our site. In our presentations to these visitors, we emphasize the importance of LTER research and the position of the MCM-LTER within the framework of the other LTER sites.