Environmental Management of A Cold Desert Ecosystem:

THE McMURDO DRY VALLEYS

ENVIRONMENTAL MANAGEMENT OF A COLD DESERT ECOSYSTEM: THE McMURDO DRY VALLEYS

Report of a National Science Foundation Workshop
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Cover photograph: *Sampling through the 4.5 m–thick ice cover of Lake Fryxell.*

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Equipment and waste from a field operation in the McMurdo Dry Valleys is attached as underslung load for removal from the valleys.

Executive Summary

The McMurdo Dry Valleys (latitude 77–78.5°S; longitude 160–164.5°E) is a cold desert environment containing the most expansive tracts of ice–free land on the Antarctic continent. This largely pristine landscape is a mosaic of glaciers, mountain ranges, ice–covered lakes, meltwater streams, arid soils and rock. Apart from the aesthetic and wilderness values of this region, it has enormous scientific value and many of the ongoing studies are relevant to questions of global importance. Increasing science and tourism activities in the Dry Valleys and evidence of human impacts at some research sites have generated international concern about the long–term protection of these unique values.

In March 1995, a workshop sponsored by the National Science Foundation was held in Santa Fe, New Mexico, to address the environmental concerns about this region and to formulate the first steps towards an integrated strategy for managing the Dry Valleys. The 33 participants came from nine countries and represented a broad range of disciplines including botany, ecology, geochemistry, geology, glaciology, microbiology, environmental law and tourism.

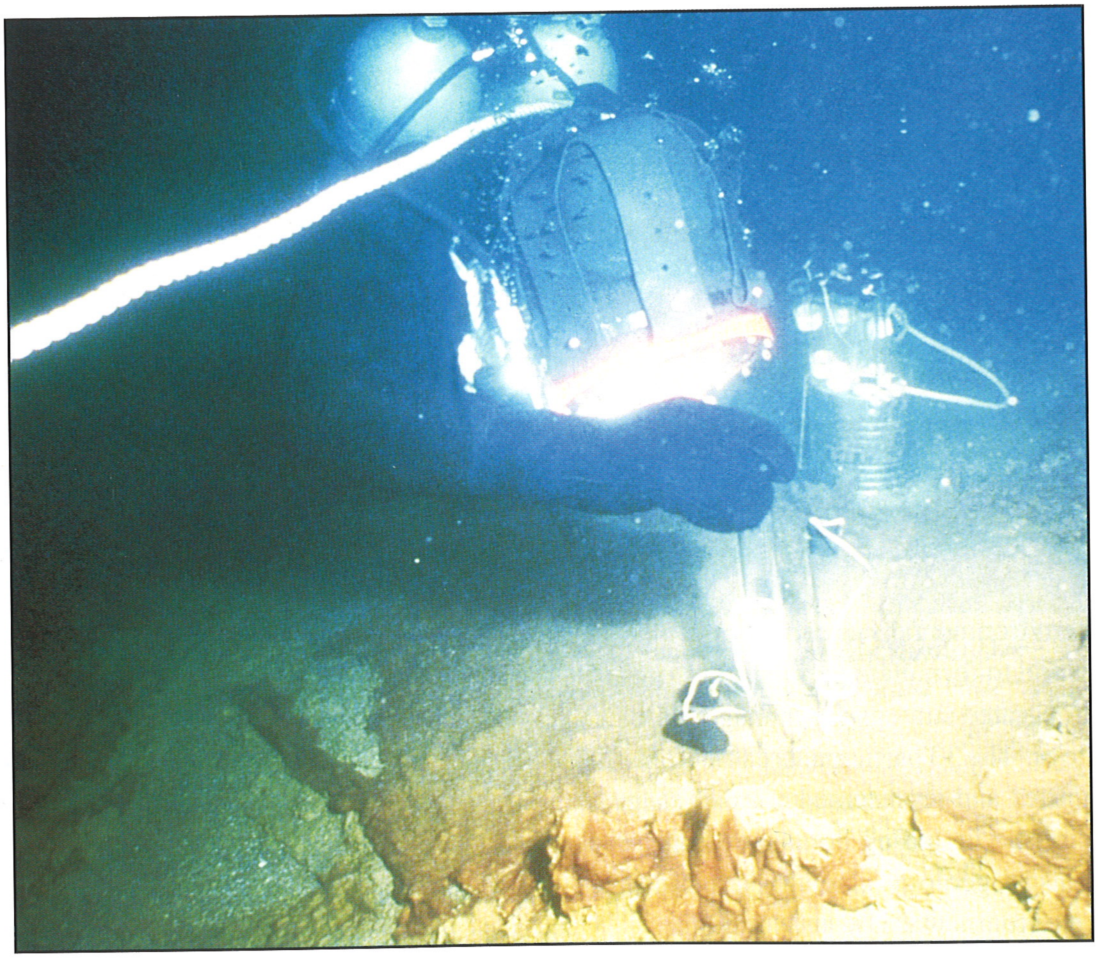
The workshop participants concluded that special priority should be given to the protection of scientific values and integrity of the region. This recognizes the global significance of the Dry Valleys as an information resource and it acknowledges the principal reason for human activities in the valleys from the past into the foreseeable future. Furthermore, protection of the scientific values of this region would also serve to protect many other values which characterize this environment. There was consensus that management should be at an ecosystem level in which protocols at any specific site are founded on knowledge of the entire Dry Valleys system.

A framework was developed for a management plan for the overall Dry Valleys region that would establish management zones based on a matrix of sensitivity to impact and the nature of disturbances. This zoning and the associated monitoring regime should be closely tied to requirements under the Environmental Protocol to the Antarctic Treaty. The proposed management strategy would rely heavily on GIS / GPS technologies. There is an urgent need to update base maps of the region and to initiate a management GIS that incorporates major landscape elements, special features (e.g., biological communities) and evidence of environmental change.

Guidelines were developed for environmental monitoring within the context of the management plan. Although many indices were identified to quantify local impacts, a major challenge will be to distinguish the long term effects of human activities within the valleys from other effects such as interannual variability, long term climate change and the long range transport of contaminants.

Two sets of practical guidelines were formulated to help individuals meet their

environmental responsibilities in the Dry Valleys: an environmental checklist for the planning phase of new and ongoing science projects, and an Environmental Code of Conduct for all personnel working in the field. Implementation of these workshop proposals should be accompanied by ongoing international and interdisciplinary consultation.



SCUBA diving operation in perennially ice-covered Lake Hoare.

PREFACE

For more than thirty years, environmental impacts and conservation have figured prominently in discussions about human activities in the Antarctic. As early as 1959, the Scientific Committee on Antarctic Research (SCAR) identified the importance of conservation of Antarctic flora and fauna. At the sixth Antarctic Treaty consultative meeting, in Tokyo, Japan, in October 1970, a formal statement (Recommendation VI–4) expressed the imperative need for environmental research and management, "recognizing that:

- *in the Antarctic Treaty area the ecosystem is particularly vulnerable to human interference;*
- *the Antarctic derives much of its scientific importance from its uncontaminated and undisturbed condition;*
- *there is an increasingly urgent need to protect the environment from human interference;*
- *the Consultative Parties should assume responsibility for the protection of the environment and the wise use of the Treaty area."*

These words have yet to be fully translated into action. Over the subsequent 25 years Antarctica has witnessed a continuing growth of scientific and technical activities, an expansion of support infrastructure and a major rise in tourism. Over this same period, however, there has been an increasing awareness of environmental issues and an evolving commitment by individual scientists as well as national programs towards protecting the Antarctic environment. The adoption of the Environmental Protocol to the Antarctic Treaty in 1991 (the 'Madrid Protocol') catalysed a renewed focus of attention on environmental management. Most of the Treaty nations now employ full time environmental officers to more closely inspect and advise scientific parties on their field activities in Antarctica. SCAR has established a working party of specialists to advise on environmental monitoring and impact assessment (GOSEAC; all acronyms are defined in Appendix 1). Initiatives have now been stimulated within many national Antarctic programs to develop specific management plans and environmental guidelines that recognize the unique attributes of a given area.

The Santa Fe workshop was undertaken against this backdrop of increased environmental interest, but also in response to specific concerns about the long term preservation of a unique, largely ice–free region of Antarctica, the McMurdo Dry Valleys. This fascinating landscape of ancient rocks and soils, lakes, streams and glaciers, has been the subject of study by scientific field parties of many nations from the turn of this century onwards. In 1993, one part of this system, the Taylor Valley, was established as a Long Term Ecological Research site within a global network of 18 LTER sites ranging from Arctic tundra to tropical rain forest (see Wharton 1993). From 1992 onwards, there has been an increasing tourist presence in the Dry Valleys. Concern about the long term cumulative impacts of scientific studies in this region, coupled with an increasing interest in the Dry Valleys by scientists and non–scientists alike, culminated in this meeting of international specialists in March 1995. The 33 participants came from nine countries (Australia, Canada, Chile, Great Britain, Germany, Italy, Japan, New Zealand and the United States) and were drawn from a broad range of backgrounds (botany, cartography, geology, geochemistry, GIS technology, glaciology, hydrology, limnology, microbiology, molecular biology, environmental law and monitoring, and tourism) to achieve an interdisciplinary, whole system perspective on environmental management of the Dry Valleys. A list of participants and their specialities is given in Appendix 2.

The workshop participants first considered two general issues for environmental management of the region: (1) key values to be protected and (2) potential impacts of continuing research. Individual groups then focused on three specific objectives to develop:

- Recommendations for management plans for regions within the Dry Valleys or for the McMurdo Dry Valleys as a whole.

- Recommendations for an environmental monitoring program, including suitable indicators, that can address project–specific impacts and cumulative impacts.

- A code of environmental conduct for scientists working in the Dry Valleys.

This report summarizes the conclusions within each of these theme areas. It is intended for present and future visitors to the Dry Valleys to aid a better understanding of their environmental responsibilities; for program managers, policy makers and environmental specialists concerned with the Dry Valleys or other ice–free regions in Antarctica; and individuals with a more general interest in environmental protection and conservation of the polar regions. In presenting this report we hope that it will stimulate discussion, research and the continuing evolution of environmental protocols for this region.

The Santa Fe workshop was organized by Carl Bowser (University of Wisconsin), Clive Howard–Williams (National Institute for Water and Atmospheric Research, New Zealand), Diane McKnight (United States Geological Survey), Julie Muhilly (Desert Research Institute), John Priscu (Montana State University), Warwick Vincent (Centre d'études nordiques, Laval University, Canada) and Robert Wharton (Desert Research Institute). It was made possible by funding from the Office of Polar Programs, National Science Foundation of the United States.

We are grateful to the many individuals who made constructive comments on earlier drafts of this report, including (in addition to the workshop participants): Iain Campbell (Land and Soil Consultancy Services, New Zealand); George Denton (Institute for Quaternary Studies, University of Maine); Maj de Poorter (Greenpeace, New Zealand); Diana Freckman (Colorado State University); W. Berry Lyons (University of Alabama); Chris McKay (National Aeronautic

bama); Chris McKay (National Aeronautic and Space Administration); Daryl Moorhead (Texas Tech University); Olav Loken (Canadian Antarctic Research Program, Ottawa); and Gillian Wratt (New Zealand Antarctic Program). I especially thank our session chairs and rapporteurs (see Appendix 2), and Drs. Polly Penhale and Roger Hanson for their support and encouragement in this first step towards an integrated management strategy for the McMurdo Dry Valleys.

Warwick Vincent, Chair

The Dry Valley Drilling Program (DVDP) drilling rig in the upper Wright Valley.

1. Introduction

"DEAR TAYLOR, I purpose to disembark a sledge–party of which you will have charge, on the sea ice of McMurdo Sound as near the Ferrar Glacier as possible. Your companions will be Messrs. Debenham, Wright, and Petty Officer Evans. You will have two sledges with food and equipment for eight weeks. The object of your journey will be the geological exploration of the region between the Dry Valley and the Koettlitz Glacier... Wishing you the best of luck, Yours sincerely, R. SCOTT." [Taylor, (1913), p. 184].

The McMurdo Dry Valleys are the largest ice–free region of the Antarctic continent. The valleys encompass an area of 15,000 km^2 with about 30% largely free of snow and ice. The region is located along the western coast of the Ross Sea at latitude 77°S, longitude 162°E, approximately 100 km west of Ross Island. It extends 200 km from the Trough Lake catchment at the southern end of the Koettlitz Glacier to the Convoy Range in the north (see "Ross Island and Vicinity, Antarctica", USGS topographic map, 1:250,000-scale). The climate is cold, windy and extremely arid; annual precipitation in the Wright Valley is less than 100 mm water equivalent (Bromley 1985), and the mean annual temperature is −19.8°C (Schwerdtfeger 1984). The desert landscape of this region contains glaciers, mountain ranges, ice–covered lakes, meltwater streams, arid patterned soils and permafrost. There is increasing evidence that this is a valley system of "enormous antiquity" (Denton et al. 1993). It contains ancient soil deposits which are more than two million years old (Campbell and Claridge 1989), and the current geomorphology of the Dry Valleys may owe its origin to fluvial erosion processes during the Miocene (or older) with little modification of existing bedrock forms over the subsequent 11.3 to 13.6 million years (Marchant et al. 1993). There is controversy, however, over the extent of change in this region due to Pliocene–Pleistocene glaciations.

Today in the Dry Valleys water flows for only 4–10 weeks each summer, from source glaciers via intermittent streams to the sea or to terminal lakes and ponds. The inland water environments encompass a remarkable span of physical and geochemical properties – perennial ice–covers up to 6 m thickness, dilute meltwaters, solar–heated lakes and ponds as well as concentrated brines that remain unfrozen even throughout winter. The present day lakes are thought to be remnants of much larger glacial waterbodies that occupied the valleys up to several million years ago and as recently as 11,000 years ago (Doran et al. 1994).

Higher plants and animals are absent from the McMurdo Dry Valleys, but the varied habitats throughout this region contain many types of microscopic life–forms that can tolerate environmental extremes (Vincent 1988; Friedmann 1993). Moss beds occur in the vicinity of streams and seeps, and lichens are especially common in the upper slope of the valleys where cloud formation occurs and where older, more weathered rocks are available for colonization. Unusual communities of microbes live in the Dry Valley soils, below the surface of rocks and within meltwater pools on the surface of glaciers. Highly simplified food webs occur in the soils with micro–invertebrates, particularly nematodes, as the top consumers (Freckman and Virginia 1996). Cyanobacteria (blue–green algae) form thick cohesive mats on the streambeds and over the bottom of the lakes, and provide a habitat for microscopic animals such as nematodes, rotifers and protozoa. Dry Valley lakes contrast markedly with those in the temperate zone in that they contain neither fish nor, unlike lakes further north in Antarctica, crustacean zooplankton. However, their density–stratified waters cause the microbial communities to grow in distinct layers. These vertically structured systems are proving to be a rich source of new information about biogeochemical processes in the aquatic environment (e.g., McKnight et al. 1991; Lizotte and Priscu 1994).

Despite the remote location and severe climate of the Dry Valleys this region is increasingly influenced by human activities. Some ten thousand visitors have entered the

Smoke grenade being used by a field party on the Taylor Glacier to guide in a helicopter. Empty canisters and their residues are still to be found in parts of the valleys.

valleys over the last 40 years of science operations and signs of these activities are clearly evident at some sites. Tourism has recently begun in the Taylor Valley and has heightened the need for environmental planning and management. Conservation measures for the Dry Valleys were advocated more than twenty years ago (Parker 1972), but the long term cumulative effect of science in the valleys has only recently become an issue of major concern. Such concern prompted Chinn (1990) to assert that the Dry Valleys area "has become the most intensively investigated part of the continent. In the 30 years since the beginning of routine scientific visits, the area has evolved from one of pristine desolation to one of possible scientific despoliation." Not all would agree with Chinn on the extent of these effects; most visitor activity has been confined to a small number of sites, and much of the Dry Valleys region is pristine wilderness that has been rarely visited or even walked upon. Most all would agree, however, that environmental impacts have affected specific parts of the valleys. The imperative now is to work to reduce such impacts and to prevent the system–wide deterioration of this unique, internationally recognized environment.

The Santa Fe workshop was undertaken as a first step towards an integrated management strategy for the McMurdo Dry Valleys. We begin this report by introducing a number of key background issues for effective management: past and present activities in the valleys; environmental progress to date; the set of values which should be given priority for environmental conservation and protection; and the "whole ecosystem" perspective which guided our discussions. We then summarize the conclusions from an exchange of views on management plan development; guidelines for monitoring; and an Environmental Code of Conduct for present and future scientific activities in this region.

2. Central Issues

"Debenham and I started together down the glacier, and experienced considerable difficulty in leaving the ice. Captain Scott had descended easily enough in 1903, so we kept along the southern edge, seeking a convenient place... Partly by slipping and partly by being lowered by the wick–straps of my gloves, I managed to reach the lateral moat, and Debenham followed safely" [Taylor, (1916), p. 134].

2.1 Human Activities – Research

There has been a long standing human presence in the McMurdo Dry Valleys, beginning with their discovery at the turn of this century, and then accelerating with field research activities from the International Geophysical Year (1957–58) onwards. A small number of sites have been impacted by long term field camps, geological excavations, stream channel installations, motorized vehicle operations (particularly during the 1960s) and the release of contaminants and other wastes. A chronology of research activities and impacts is given in Appendix 3. Most of these effects have been temporary and highly localized (a notable exception may be the physical disruption of soils in some areas; Campbell and Claridge 1989) and much of the Dry Valleys system remains close to its undisturbed state that Scott discovered in 1903.

The Dry Valleys continue to be a major focus for scientific research in Antarctica. In the 1973–74 season 636 hours of helicopter time were flown in this region; by the 1993–94 season this had risen 30% to 822 hours. This increase has been accompanied by significant changes in the type of research (Table 1). In the 1970s the geologists accounted for more than half of all publications and their field research generally involved small, nomadic camps with sampling at many locations. A notable exception to this small–scale approach was the Dry Valleys Drilling Program in the 1970s which resulted in many advances in our understanding of the geological history of this region (McGinnis 1981). While geology and glaciology continue to be major research areas in the valleys, there has been a significant rise in biological, geochemical and limnological research with an attendant need for field laboratories and instrument support, but at a lesser number of sites.

Table 1. The changing focus of science; values are the percentages by subject of all scientific articles on the Dry Valleys published during each year specified.

SUBJECT	1970	1980	1990
Geology/Glaciology	54	37	22
Biological Sciences	6	22	32
Hydrology/Limnology	18	20	22
Geochemistry	6	10	15

Source: C. Howard–Williams, NIWA.

The research programs have been accompanied by many activities other than data collection: visits by the media, political representatives, senior civil servants, contracting support agencies, program advisors, training visits by aircrew and emergency rescue personnel, and visits of opportunity by support staff from Scott Base (NZAP), McMurdo Station (USAP) and research vessels. These have amounted to a large percentage of the total valley–based activity. Parker and Holliman (1978) noted that during the 1972–75 period of their research program at Lake Bonney, of the 300 helicopter hours allocated that included a stop–over at the lake, only one half were directly related to the research program. Vanda Station, operated by New Zealand in the Wright Valley from 1969–1994, was a popular stop–over for flights because of the elite "Lake Vanda Swim Club." The total number of recorded visitors to Lake Vanda over the life of the station was 3768, and most came to swim rather than to conduct science. In 1991/92 Vanda Station ceased to operate as a fully manned summer base and the number of visitors dropped by 68%.

2.2 Human Activities – Tourism

Ecotourism is a growth industry throughout the Antarctic region. During the 1991–1992 summer season 6200 tourists visited Antarctica compared with fewer

Tourists in the Taylor Valley, February 1995.

than 2000 a decade earlier (Carvallo 1994). Commercial tourism to the Dry Valleys is recent and limited, restricted to brief visits each season since 1993 by helicopter to the Taylor Valley from the 100–passenger Russian ice–breaker, Kapitan Khlebnikov (Table 2). A total of 313 passengers were brought to the vicinity of the Canada Glacier, Taylor Valley, in 1995.

Table 2. Tourist visits to the Taylor Valley.

Date	Passengers	Time of Visit	Observers
10 Feb 1993	106	0800–1600	Dick Taylor (USAP) Malcolm McFarlane (NZAP)
8 Feb 1994	104	0600–1400	Jim Johnson (USAP) Emma Waterhouse (NZAP)
11 Jan 1995	112	0400–1200	Rick Perrin (ANARE)
3–4 Feb 1995	105	2300–0300	Tim Higham (NZAP)
22 Feb 1995	96	0700–1200	Grant Avary (NZAP)
19 Jan 1996	105	0730–1400	Deirdre Sheppard (NZAP) Lou Sanason (DOC)
17 Feb 1996	116	0500–1200	John Charles (NZAP) Phil Doole (DOC)

Source: D. Schoeling and E. Waterhouse

2.3 Evolution of Environmental Awareness

In the early phases of exploration of the continent, scientists and explorers were little aware of the potential environmental effects of their activities. Their principal concern was to preserve human life in the conduct of nationalistic exploration and the gathering of scientific data in this new, unchartered landscape. Now, nearly a century later, remains of these expeditions are viewed as historic monuments, evidence of man's will to survive in a climate and terrain totally inhospitable to human habitation, and sites worthy of restoration and preservation.

Despite the early legacy of exploration and development no evidence exists to suggest that any of these potentially harmful historic activities were in any way conducted with a lack of regard for the environment. These earlier visits were at a time when the fragility and sensitivity of parts of the environment were simply not understood. Growing awareness of the potential for environmental harm has been slow to mature, and only highlights the need for a balanced review of the types of activities that can be carried out in the Dry Valleys, their potential short and long term effects, and the need for continued reassessment of the issues by those committed to the preservation of this unique heritage, and its intrinsic scientific and cultural value.

2.4 Progress in Environmental Management

Considerable progress has been made over the last few decades in the development of environmental controls and management strategies for specific locations in Antarctica and for the Antarctic region as a whole. The most important of these within the Antarctic Treaty System has been the Protocol on Environmental Protection. This was adopted by Treaty parties in Madrid in October 1991 and declares Antarctica to be a natural reserve devoted to peace and science. The Protocol places a total ban on mineral activities for at least 50 years (Article 7) and specifies requirements for impact assessments, environmental monitoring, decision–making procedures and dispute settlement. Further details are given in Appendix 4 of this report.

Although the Protocol has yet to be ratified by all Treaty parties and is not legally in force, it has already stimulated many local and regional initiatives. Of special relevance to the Dry Valleys is an ongoing series of international forums on environmental monitoring. These began by way of a discussion report prepared by SCAR and COMNAP (Council of Managers of National Antarctic Programs). This document sets out general criteria for effective monitoring across the breadth of Antarctic environments and places emphasis on the need for hypothesis–driven strategies (SCAR / COMNAP 1992).

Attention was first directed towards the importance of environmental management in the Dry Valleys during a colloquium on conservation problems in the Antarctic in the early 1970s (Parker 1972). The first detailed environmental impact assessment was undertaken later that decade to evaluate the potential effects of a large–scale geological program in the valleys, the Dry Valleys Drilling Program (Parker and Holliman 1978). This analysis included the development and application of a valuable new tool, a semi–quantitative matrix approach towards impact assessment. Since the 1970s there have been major advances in our knowledge of this area. Important new evidence has begun to emerge on the extremely old age of the Dry Valley landscape and its surficial sediments (Campbell and Claridge 1989; Denton et al. 1993). Certain parts of the Dry Valley system that were earlier considered to be abiotic (Cameron 1972) are now known to contain many types of unusual microscopic lifeforms organized into structured communities (Vincent 1988). These and other recent discoveries in the Dry Valleys have highlighted the unique natural features of this region of the world, and their sensitivity to human impact.

A series of recent initiatives have focused specifically on better understanding and/or managing the Dry Valleys environment. The former includes the funding and establishment of the McMurdo LTER (Wharton 1993). The latter includes the removal of Vanda Station because of rising

Weirs have been placed on many of the streams of the Dry Valleys by NZAP and USAP scientists to gauge the flows as a monitor of climate change and to estimate the flux of materials into the lakes.

lake levels and the threat of flooding (NIWA 1993); the initiation of a management plan for the Canada Glacier region (ICAIR 1995); and the formulation of environmental guidelines for science operations in the vicinity of Lake Vanda (Waterhouse 1995). The national research programs operating in this region have recently implemented strict requirements for waste management; for example, all human wastes including grey water are now removed from the Valleys. However a system–wide perspective on the Dry Valleys environment and its management continues to be lacking.

2.5 Environmental Values

An essential first step in managing the Dry Valleys is to define the environmental values to be protected. Certain categories of values are not relevant to this region. For example, in contrast to Ross Island there are no heritage sites of recognized historic value. There are no known mineral deposits of commercial value; furthermore, unlike equivalent latitudes in the north polar zone, mineral resources of this region are unavailable because of international agreement. The environmental value of this region for 'downstream' ecosystems is at present unknown. There may be ecosystems outside but closely dependent upon the Dry Valleys; for example, the western coastal marine environment of McMurdo Sound should be investigated further in this regard (T. Delaca, pers. comm.); there could be terrigenous influences on the pelagic zone of McMurdo Sound (e.g., aerosol inputs from the valleys); and the influence of the Dry Valleys on regional climate needs to be more fully examined.

The region exhibits numerous aspects that provide a basis for its values as a location of major scientific interest, a site of aesthetic beauty, and as an intrinsically vulnerable ecosystem providing a home to a unique and diverse set of physical and biological features. Books, historic photographic collections, films, and even paintings and postage stamps depicting the Dry Valleys attest to their broad range of aesthetic and wilderness values. The advent of tourism in this region is evidence of the commercial response to these values. The potential for conflict between the various scientific and cultural values has heightened the need to clearly define goals and priorities for the protection of the system.

In case of mutually exclusive goals, we suggest that special priority should be given to the scientific values and the need to protect the scientific integrity of the region. This recognizes the global significance of the Dry Valleys as an information resource and it acknowledges the principal reason for human activities in the valleys from the past into the foreseeable future. Furthermore, protection of the scientific values of this region will also serve to protect many other values. For example, conservation of landscape integrity for ongoing geomorphological studies would also protect aesthetic qualities of that landscape; conservation measures applied to protect the fragile biological communities will also protect the wilderness characteristics and values as an aesthetic resource. There may sometimes be conflicts between science and other values (e.g., instrumentation networks versus aesthetics; remote wilderness values versus frequent helicopter movements and other aspects of science logistics) and priorities need to be defined that recognize the mutual interests of all parties, yet that provide for the free and open conduct of scientific and cultural inquiry without fear of detrimental environmental impacts that would destroy the conditions that the scientific studies require.

The scientific values of the Dry Valleys can be recognized at two levels, regional and global.

Regional scientific values include:

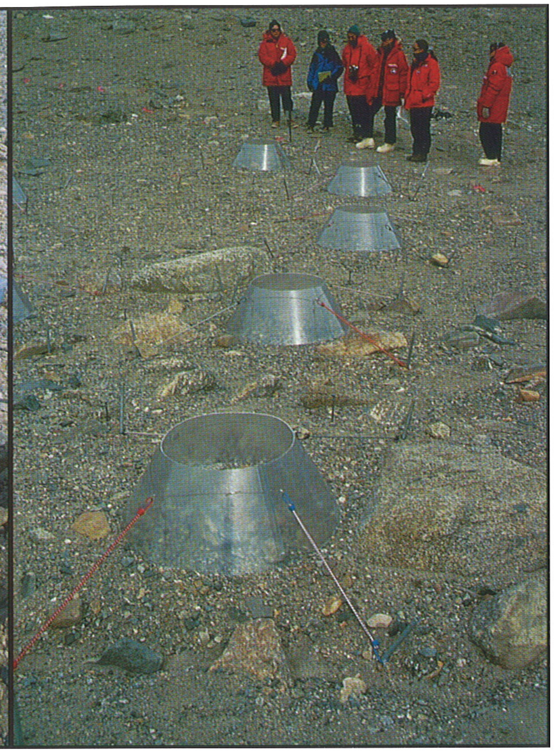
- significance as the largest ice–free region in Antarctica;
- biological features; e.g., the low diversity micro–invertebrate communities found in the soils; stratified populations of micro–algae, protozoa and bacteria living beneath permanent lake ice; microbiota in other unusual habitats such as rock and ice;
- geochemical features; e.g., lakes, ponds and ancient soils with unusual organic and inorganic compositions reflecting their unique origins and evolution; cryogenically precipitated salt deposits; and subglacial saline water discharges;

- geological features; e.g., glacial deposits; ventifacted rock formations; cavernously weathered rock formations; extensive exposures of bedrock igneous, sedimentary and metamorphic rocks;
- periglacial features; e.g., extensive areas of patterned ground; morainal deposits; proglacial lakes; ice–cored morain; and glacier meltwater streams;
- geophysical features; e.g., extreme solar heating and thermohaline convection in Lake Vanda;
- indicators of local climate change; e.g., lake levels; lake ice thickness; long–running meteorological records; biological indicators such as soil nematode communities.

Global scientific values include:

- information about ancient landscape processes;
- surface deposits that provide insights into the stability of the East Antarctic Ice Sheet;
- model systems; e.g., lake and soil communities as models for biogeochemical processes; rock communities as tests for hypotheses concerning extra–terrestrial life and the evolution of life on Earth; living stromatolites at the bottom of Dry Valley lakes;
- end members of global environmental series (e.g., temperature/aridity, salt composition, organic chemistry of natural waters, biodiversity) which can be used to identify and understand ecosystem processes at other latitudes;
- indicators of global climate change;
- highly stressed systems which provide insights into biological adaptation processes.

Two examples of these values deserve special emphasis. Surface sedimentary deposits in the Dry Valleys are now providing a key source of information relevant to the stability of the East Antarctic ice sheet (Denton et al. 1993). This question is of global significance; if the ice sheet were to melt in response to current global warming trends, mean sea level would rise by 60 m and be accompanied by massive changes in global circulation processes and regional climates. The East Antarctic Ice Sheet has been considered a stable feature that persisted intact from middle Miocene times (c. 12 million years before the present) onwards, including through periods of climatic warming to temperatures greater than at present. This view has been seriously challenged by fossil data from a sequence of rock units (known as the Sirius Group) in the TransAntarctic Mountain Range. The combination of *Nothofagus* (southern beech) wood and dated marine diatom fossils in this stratigraphic section suggest that a major meltdown of the ice sheet occurred during Pliocene warming 2.5 to 3 million years before the present (Barrett et al. 1992). These findings have been interpreted to mean that the ice sheet is highly sensitive to global warming and could again largely disappear if temperatures increased to a few degrees above present day values. Evidence from the Dry Valleys support the "stability" rather than "instability" hypothesis. Surficial Pliocene and Miocene drifts and volcanic ashes



Research on Dry Valley soils.

Permafrost drilling at Marble Point.

Soil nematode experiments near Lake Hoare using experimental enclosures of the type used in the Arctic.

are still well exposed in the Dry Valleys (glacial expansion during the Quaternary was too small to bury and disrupt them) and their persistence and chronologies imply a relict landscape that has changed little since the middle Miocene. The absence of major fluvial erosion since that time seems inconsistent with massive Pliocene deglaciation, however the glacial history of this region is still the subject of vigorous scientific debate (Horgan 1995). Geologists and glaciologists have expressed their concern about the current lack of environmental protection given to these scientifically invaluable surface features of the Dry Valley landscape.

The last two decades of research have also highlighted the remarkable microbial ecosystems of the Dry Valleys region. New micro–organisms have been discovered including freeze–tolerant species that may be endemic to Antarctica or even the Dry Valleys. The microbial populations appear to support unusual communities of micro–invertebrate consumers, including nematodes, rotifers and protozoa. New biotic environments have been discovered including habitats within porous rocks, soils and glacier meltwaters. The current biomass of some of these communities is the result of many decades to thousands of years of growth and slow accumulation; e.g., the cryptoendolithic communities are believed to have a turnover time of the order of 10,000 years (Nienow and Friedmann 1993) and the "living stromatolites" at the bottom of certain Dry Valley lakes may date back hundreds of years. These microbial structures could be irreversibly damaged by inadvertant human actions.

Potential impacts in the valleys should be evaluated relative to the local as well as global scientific values. It should be recognized, however, that scientific questions may have different levels of priority, and that there may be conflicts between values; e.g., studies in one scientific discipline may compromise the use of the site for another type of study. Such conflicts should be given close attention during the planning phase, particularly if they occur at long duration or at a system–wide level.

2.6 The Ecosystem–Level Approach Towards Dry Valleys Management

The protection and management of environmental values have traditionally been approached in one of two ways:

- Discrete and local. In this approach individual components of the environment are managed in response to impacts or concerns that are specific to certain sites, organisms, activities or species; for example, the ad hoc response to environmental emergencies. This treatment of each issue in isolation often leads to a piecemeal approach that fails to consider long term or cumulative impacts and the implications of management decisions for other components of the environment.
- Integrated, ecosystem–based. This second approach requires attention to the temporal as well as spatial properties of the environment, the dynamic links between physical, chemical and biological processes and the need to conserve ecosystem integrity. Management at any one site requires consideration of the overall properties of the system, and integration with other activities throughout the region including research and monitoring. This systems approach has already been been applied within the Antarctic region for marine living resources (CCAMLR – see National Research Council (1993), p. 80).

This workshop adopted the latter, ecosystem–based approach to develop recommendations for management plans, environmental monitoring and codes of conduct for scientific activities in the McMurdo Dry Valleys.

3. Towards an Environmental Management Plan

"We reached another lake nearly a mile long with a splendid gravelly shore, on which I decided to pitch the tent. We had brought no floor cloth, but after the wet and icy floor in the [Taylor Glacier] alcove we found the warm gravel most comfortable" [Taylor, (1916), p. 142].

3.1 General Issues

Is a management plan necessary for the McMurdo Dry Valleys? Environmental management to date in this region has operated by way of site–specific procedures (e.g., environmental protocols at the LTER camps in the Taylor Valley), reaction to acute impacts (e.g., the diesel fuel spill on Lake Vanda in the 1984–85 season) and a variety of measures to reduce future impacts (e.g., the removal of Vanda Station over the period 1993–95). These actions have mitigated many potentially serious effects on the environment. They have not, however, been entirely successful at a broader level. The current "no plan option" has left key environmental values vulnerable to damage. The short–term response to impacts has often been post hoc with insufficient time or available information to consider longer term or system–wide implications of such measures. More seriously, this disjointed approach has failed to deal with longer term degradation processes in the valleys associated with the continuing proliferation of camp and sampling sites.

A first step towards the the long term preservation of the Dry Valleys environment is the adoption of a Code of Conduct by all individuals who visit the valleys. A draft version of this Code is presented in Appendix 5. The second step which is both essential and complementary to the first is the formulation of an integrated "whole–system" environmental management plan. This should encompass the entire McMurdo Dry Valleys region, from the Convoy Range south to the Koettlitz Glacier. It should also include coastal regions such as New Harbor and Marble Point. The final implementation of this plan, however, should be streamlined such that the application, permitting and reporting requirements are not so complicated and onerous that they prevent high quality research.

Here we propose an approach towards such a management plan. The primary tools to be used are a matrix of types of activity and their effects, and an impact zoning map. These concepts derive directly from models used in urban and rural planning and are widely adopted in many countries. A matrix approach has been previously applied to the Dry Valleys in relation to the drilling program in the 1970s (Parker and Holliman 1978). In developing this plan we are aware that there are alternative approaches towards, for example, the scale and type of zoning (Harris 1994). We present the following as recommendations to stimulate discussion, and as the suggested framework for an operational management plan.

3.2 Plan Overview

In recognition of the need for a concerted, whole–system approach the plan developed here is for the entire McMurdo Dry Valleys region, with individual valleys as the primary management unit. Within the valleys, watersheds form a natural sub–unit and within watersheds are a number of habitats. These habitats form convenient, identifiable units, however there are complex interactions between them which must also be considered in the management plan. It should also be noted that Dry Valley watersheds have a unique hydrology compared to mountainous watersheds in temperate regions. In the Dry Valleys, the glaciers are the source of water to the streams and there is essentially no runoff from most of the exposed land surface to these streams. There are biogeochemical interactions occurring in the saturated region immediately adjacent (1–10 m) to the stream which influence the chemistry of the running waters.

The central approach towards a Dry Valleys management plan involves three steps:

1. Identification of the environmental values to be protected. These have been examined in detail in Section 2.5.

2. Classification of research activities according to their likely degree of impact on these values. Activities and their potential impacts are linked to specific habitats by way of an activity impact matrix.

3. Creation of zones according to the maximum acceptable impacts.

The combination of impact descriptions and zone criteria is then used to specify the acceptable activities that can occur in any particular area.

3.3 Value and Impact Criteria

The objective of a management plan should be to manage activities within an area rather than to attempt to manage the environment. In so doing, however, it must be recognized that actions to preserve one value may compromise other values. The management plan presented here accords preservation of the scientific values of the McMurdo Dry Valleys (see Section 2.5 of this report) as special priority. This is consistent with the Madrid Protocol and is in recognition of their history of use for science (see Section 2.1). Of course the McMurdo Dry Valleys are of value for reasons apart from scientific and there may be specific locations where protecting these other values should take precedence over protecting the scientific values.

A framework management plan is suggested which takes into account a number of concepts with zonation as the central theme. This approach is sketched out here in illustrative rather than definitive terms. For the purposes of this framework, the degree or severity of threat to the scientific values has been determined according to the following:

- Impact on scientific values has been defined as an effect which compromises the use of an area for further scientific activities.
- Degree of impact arising from a given activity depends on the habitat in which the activity occurs.
- Activities have been accorded a degree of impact on a four point scale (low, medium, high and unacceptable) according to the spatial extent and/or temporal duration of effect (Table 3).

This latter scale must eventually be coupled to the terms of the Madrid Protocol which recognizes three levels of environmental impact (details in Appendix 4). The exact meaning of the words which describe these levels is currently a subject of international consultation and discussions, but an interim approach would be to consider the following equivalencies:

Low = less than minor or transitory (e.g., sampling of small amounts of soil);

Moderate = minor or transitory (e.g., temporary stream weirs);

High = greater than minor or transitory (e.g., installation of major camps).

Table 3. Classification of environmental impacts in the Dry Valleys according to their spatial and temporal components.

Impact level	Temporal component		Spatial component	
	Duration	Criteria	Extent	Criteria
Low	Reversible within a season	<1 year	Localized, no 'downstream' effects small fraction of total habitat	<1m
Moderate	Reversible over several seasons	1–10 years	Significant fraction habitat affected	1–10m
High	Several decades for full site recovery or restoration	10–50 years	Entire habitat affected	10–500m
Unacceptable	Chronic long term effects	>50 years	Significant 'downstream' effects on other habitats	>500m

3.4 Activity Impact Matrix

The impact matrix describes the expected level (intensity) of impact that is likely to occur due to a particular activity executed within a specific habitat (Table 4). Habitats of the Dry Valleys form one dimension of this matrix and activities form the other. Cell entries within the matrix are the expected levels (intensities) of impact classified according to the descriptions given in Table 3. The matrix is flexible in that new habitats and new activities may be added and cell entries (impact intensities) may be revised as needed. By itself, the matrix is a theoretical construct that summarizes the potential consequences of the each named activity in each identified habitat.

Table 4. An example of an environmental impact matrix for several types of research activity in the McMurdo Dry Valleys. Key: L= low impact zone; M= moderate impact zone; H= high impact zone; X= unacceptable. The impact criteria for these categories are defined in Table 3; see text for relationship with the Madrid Protocol.

ACTIVITIES	TERRESTRIAL				AQUATIC			GLACIAL	
	Mountain tops	High plateau	Slopes	Valley floor	Moss beds	Streams	Lakes	Accumulate	Ablate
Helo landings	MH	LM	H	LM	HX	HX	LM	LM	LM
Tent camp	H	LM	M	LM	X	X	MHX	L	M
Semi–permanent camp	X	HX	X	MHX	X	X	X	X	X
Fuel cache	MH	LM	M	LM	X	X	HX	X	X
Walking	MH	MH	LMH	LM	MH	MH	L	L	L
ATVs	X	X	X	X	X	X	LM	X	X
Diving							MHX		
Manipulation: plot	M	LM	LM	LM	MHX	MHX	H	LM	LM
Isotope addition: field	HX	HX	HX	HX	HX	HX	HX	HX	HX
Collections (small)	L	L	L	L	LM	LM	L	L	L
Blasting	HX	HX	HX	MHX	X	X	X	X	X
Soil pits	HX	MHX	MHX	MHX	MHX	MHX			
Coring: hand	LMH	LMH	LM	LM	MHX	LMH	LM	LM	LM
Coring: power	MHX	MHX	MHX	MHX	HX	HX	HX	MHX	MHX

More than one symbol indicates that the classification would depend on the scale and exact location of the activity.

The assessment of impact intensities could be further refined and strengthened by reference to ecological disturbance theory. For example, Pickett and White (1985) identify a number of general attributes that influence the sensitivity of ecosystems to disturbance: their ability to resist disturbance, their resilience (ability to recover from disturbance) and their speed of recovery. Although we surmise that these resistance and recovery abilities are generally poor in the Dry Valleys, there is a lack of experimental data and there are likely to be large differences between habitats and sites. Disturbances can also be characterized, for example in terms of extent, persistence, frequency and severity. The existing body of knowledge in this branch of ecosystem science may help identify and better define specific combinations of environments and disturbances, as well as help guide the much–needed research on disturbance and recovery processes throughout the Dry Valleys system.

3.5 Zoning Criteria

A five–level scale of impact zones may be defined from a combination of the relevant spatial and temporal components. These incorporate a blend of criteria based on allowable use and the acceptable level of impact:

- <u>Zero Impact Zone</u>. Set aside for possible later use, therefore defined by use (in this case "leave alone") rather than by acceptable level of impact. There has been very little human activity in the extensive ice–free area of the Dry Valleys region south of the Taylor Valley, and large parts of this southern region could be considered for inclusion within this category (e.g., within the vicinity of Trough Lake).

- <u>Minimal Impact Zone</u>. Set aside for baseline activities (e.g., monitoring as a reference site) or certain types of minimal impact research, thus defined by use rather than by an acceptable level of impact. This would probably include the current SSSIs (internationally recognized sites with access restrictions and permit requirements) within the Dry Valleys: Barwick Valley (SSSI No. 3); Canada Glacier, Lake Fryxell (SSSI No. 12) and Linnaeus Terrace, Asgard Range (SSSI No. 19).

- <u>Low Impact Zone</u>. Defined by acceptable level of impact. Acceptable level of impact – short term (<1 year) and localized (no 'downstream' effects, contained).

- <u>Moderate Impact Zone</u>. Defined by acceptable level of impact. Acceptable level of impact – longer term (1–10 years) and localized (meters or less) OR short term (<1 year) and more than localized (> several meters to significant fraction of zone).

- <u>High Impact Zone</u>. Defined by acceptable level of impact. Acceptable level of impact – conflicts with or removes the possibility of other uses within the habitat for the foreseeable future, significant downstream effects (conflicts with other uses in other habitats in the longer term). Several sites within the Taylor Valley would fall within this category.

3.6 Integration of the Activity Matrix and Zoning

Environmental management will be implemented by linking the activity impact matrix to an impact zoning map. The activity zoning map is a document that delineates acceptable levels of impact as an overlay on a topographic base map. Zones on the map are the same four impact categories that are the cell entries in the activity impact matrix (Table 4). It is not necessary or desirable that all zones appear on a given map; for example "high" impact zones may be deemed to be unacceptable throughout the area.

Erection of greenhouses in the vicinity of the Canada Glacier SSSI (before its establishment) for experiments with flowering plants from New Zealand. The importation of non–indigenous plants and animals into Antarctica is now restricted by permit under the terms of the Madrid Protocol and there is an increased awareness of the need to protect the Dry Valleys as much as possible from introduced species, including microbiota.

The matrix and the map are linked through the expected impact level. In practice, only those activities that have, for example, a low level of impact on a given habitat, will be allowed to occur in areas of that habitat that have been zoned for low level impacts. Activities with high levels of impact on a specific habitat, must be done in areas of that habitat that have been zoned for high level impacts. Several contiguous habitats may have the same zoning designation. A single habitat may have different areas zoned for different impact levels. The zoning map is flexible in that zones may be added, deleted, upgraded, or downgraded as needed based on experience. The matrix may be revised on the basis of new information about expected impacts of an activity on a given habitat. These changes will be reflected automatically in the zoning map, much as in a relational database. Reciprocally, revisions to the zones on the map relate to and carry forward the information contained in the impact matrix.

The final management plan must also consider a number of features or types of features in the Dry Valleys that require additional protection measures; for example, specific fossil surfaces; endolithic communities; moss beds; mummified seals and birds. These features should be precisely located by GPS and considered "special management cases" in the overall plan.

3.7 GIS/GPS Requirements

Development and implementation of the management plan as discussed here will depend heavily on GIS (Geographic Information System) and GPS (Global Positioning System) methodologies. Information in both the matrix and the map are ideally suited for storage, manipulation, and use in a GIS database. This database should ultimately contain an inventory of the spatial coordinates of all habitat zones, natural resources and "special management cases." It should also record the location of known environmental impacts in the past and present. Maps can be easily generated from the GIS database at a variety of scales, depending on the intended use of the map; e.g., general information versus decisions about sampling points within a specific, small–scale area should be incorporated into the overall management GIS. We envisage that GIS techniques will play an increasingly major role in setting, tracking and refining management policies for the McMurdo Dry Valleys as well as elsewhere in the polar regions.

GPS techniques will be required to precisely locate sampling and impact zones or locations of special interest. Field research should entail routine use of such devices ranging from simple, hand–held units to more precise instruments that are tied to fixed–position transceivers. A major problem at present is the mismatch between currently available maps of the Dry Valleys (which use an outdated astronomic datum) and the coordinates given by modern GPS instruments. Updating these maps and correcting the datum is an urgent priority.

4. Development of Monitoring Protocols

"Next morning before rising Wright remarked on the severity of his exercise the day before, which had left him so bathed in perspiration that he felt clammy all night. On examining his sleeping place, however, he found that something had blocked the stream by the tent, and its icy current had been flowing under his bag most of the night." [Taylor, (1916), p. 138].

4.1 General Issues

The prevention of environmental damage is clearly preferable to post–impact clean–up and monitoring. The environmental Code of Conduct (Appendix 5 of this report) and the policies set in place by an eventual Dry Valleys Environmental Management Plan (Section 3) should help reduce the need in the future for continuous post hoc management practices. However, monitoring can serve as a useful addition to preventative measures and can help ensure that any further degradation of the Dry Valleys environment is identified at an early stage and arrested. Under the terms of the Madrid Protocol environmental monitoring is a mandatory requirement for some research activities in Antarctica (see Appendix 4).

Potential monitoring objectives for the Dry Valleys encompass a vast span of time scales, state variables and processes. Ideally we would like to detect short–, intermediate– and long–term environmental impacts (as defined in Section 3) varying in magnitude, importance, duration and probability. Such impacts should be monitored in the airshed as well as watersheds of the Dry Valleys, with consideration of the aquatic, terrestrial, lithic and glacial components of the ecosystem. The monitoring procedures should be able to track overall landscape integrity as well as the maintenance of values at specific locations. We also need to be able to distinguish the effects of long–term climate change and long–range contaminant transport from the impacts of human activities within the valleys. This is a challenging set of objectives which is unlikely to be achieved in full. In this section we identify some of the issues which are central to environmental impact monitoring in the region, and we suggest ways to focus the selection of procedures.

The overall approach advocated here is a matrix system for identifying geographic locations, habitats, scientific/logistic/tourism activities, associated impacts and ways of detecting them. This approach is directly compatible with the zoning and activity impact matrix developed for the Dry Valleys Management Plan in Section 3.4 of this report. Development of this plan should be accompanied by a monitoring program that focuses special attention on the impact categories demarcated "high" and "unacceptable" (categories 3 and 4 in Table 3).

4.2 Steps Towards Monitoring

Identification of Dry Valley habitat types is a key element of the Management Plan and is also a logical starting point for the development of an environmental monitoring strategy. The next step is to develop an environmental impact sketch for each habitat type that includes:

- current and future activities within this habitat, including tourism; this must also consider environmental accidents that have occurred in the past or that could occur in the future;
- potential contaminants (including biological) associated with each activity, their transport pathways into, within and out of the habitat; and their impacts on ecosystem structure and processes;
- potential physical impacts of each activity e.g., sediment disturbance, stream course modification, physical disruption of microbial mats, changes in albedo or light transmission properties;
- conventional monitoring options to detect such impacts;
- alternative methodologies which should be evaluated to monitor as well as minimize impacts.

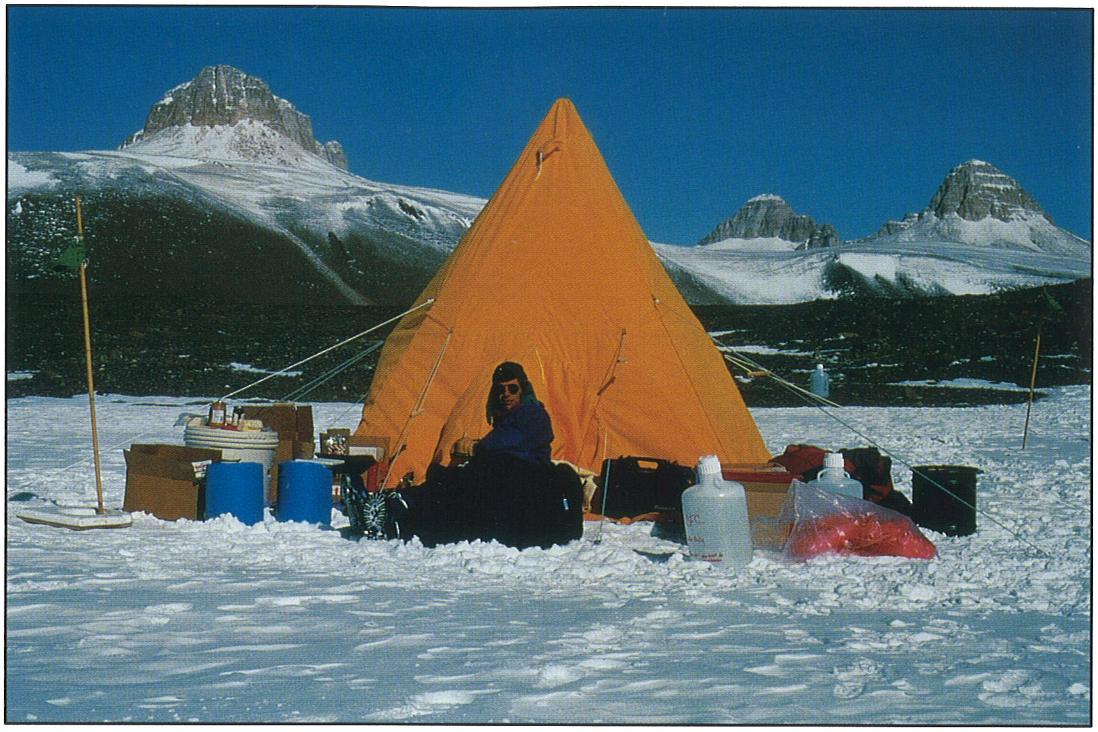
All of these components can be readily summarized within a database constructed as a matrix with four dimensions: (1) habitat region; (2) activity; (3) impact; (4) monitoring options. This approach is consistent with the "hypothesis–oriented" strategy for monitoring advocated by SCAR / CONMAP (1992); specific impacts are hypothesized to result from specific human activities and monitoring options are evaluated on the basis of their ability to detect and quantify such impacts.

4.3 Habitat Regions

Four broad habitat regions can be recognized within the McMurdo Dry Valleys. Here we present a brief environmental impact sketch for each region. Many of the impacts and monitoring options described are common to several types of habitat and are not repeated for each. Furthermore, the habitat regions are interconnected. For example, aerial transport of materials may provide an important natural link between and within each of the habitat zones as well as for the exchange with regions outside the Dry Valleys. Certain human activities may accelerate such transfers; e.g., accelerated erosion of disturbed soils and streambanks. The four habitat regions examined here will eventually require further subdivision; e.g., plateau versus ridges in the high desert (>1000m altitude) category; primary versus secondary valleys; valley floor areas near and away from large semi–permanent camps. A GIS inventory of landscape features in the Dry Valleys (section 3.7) would substantially aid this classification process.

4.3.1. Coastal Boundary

Current activities include marine and glaciological studies at New Harbor, operations support at the Marble Point fueling facility; LTER research activities at the seaward end of the Taylor Valley, and biological investigations at specific coastal sites, e.g., botanical studies in the vicinity of



Field camp in the Barwick Valley SSSI.

Granite Harbor. The installations range from small (2–4 people) tent camps (e.g., the botanical studies) to semi–permanent huts with much larger numbers of researchers and support personnel. Potential contaminants include food, human waste, drilling fluids, blasting debris, vehicle and generator emissions, fuel and lubricants, preservatives and other research chemicals. Potential accidents include the loss of vehicles through the ice, fuel bladder and line spills and the release of sling loads from helicopters. Loss pathways include via the wind which often blows across this boundary region into the valleys, immobilization by penetration into the dry, unflushed soils (surficial soils may be readily transported by the wind, however), volatilization, transport by meltwater streams, transfer via skuas which are known to enter the valleys and food chain transfers (including possible bioconcentration and biomagnification) within the sea ice, water column and benthic food webs.

Potential biotic impacts in the coastal zone include changes in benthic community structure and the extinction of unusual Antarctic species (e.g., the giant foraminifer *Notodendrodes antarctikos* first described from New Harbor by De Laca et al., 1980). Physical impacts include excavation for operations support (e.g., Marble Point) and drilling or otherwise profiling for geological investigations. Monitoring options include the cataloguing of spills, soil analysis for contaminants (relative to a reference site) and non–destructive or small–sample analysis of the marine benthic community. An approach towards measuring physical disturbance has recently been developed at Marble Point (Campbell et al. 1993) and is also applicable to other habitat regions as a monitoring tool.

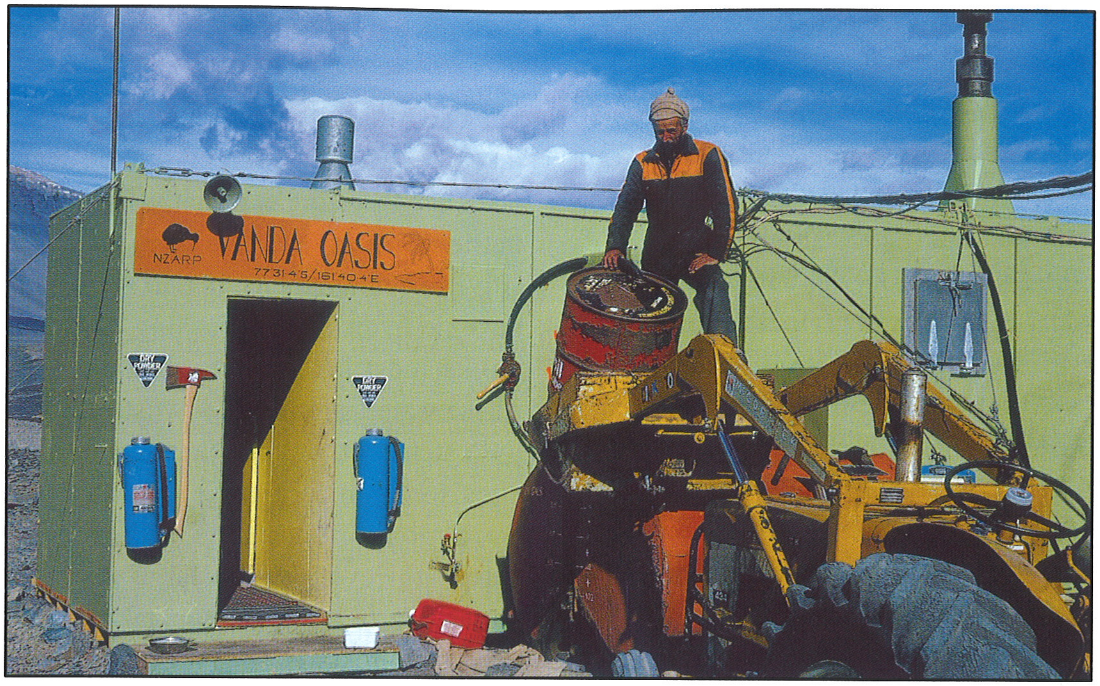
4.3.2. Valley Floor and Walls (including secondary valleys)

This region requires separate consideration of soils, streams and lakes, and the interactions between them. It is the most heavily visited part of the Dry Valleys, with science activities beginning towards the end of winter (August–September) and continuing through to early February. The total peak population size in summer (excluding tourist visits, see Section 2.2) is around 50–100 based out of temporary tent camps and semi–permanent huts. Winter–over camps have operated in the past and are likely to be considered again in the future. An increasingly dense instrumentation network is maintained in the Dry Valleys throughout the year, particularly in conjunction with the Taylor Valley LTER. Separate and more intensive monitoring strategies are required for the immediate vicinity of the large research camps of this region.

Potential impacts include the acute effects of chemical spills (including oil, lubricants, radioisotopes, preservatives, antibiotics, inhibitors and other research chemicals, nutrient–rich waters such as human wastes and deep lakewater) and physical disturbance. The latter include unintentional effects (e.g., soil compaction by trampling and helicopter landings) as well as temporary modification of the environment for scientific purposes (e.g., weir construction; sampling trenches). Potential accidents include fire, crash of aircraft, storm dispersal of research/logistic materials, and the loss of snowmobiles, ATVs, instruments or other materials through the lake ice or via flooding.

Longer term, chronic degradation processes are of major concern in this region. For example, there has been a gradual contraction of contiguous undisturbed areas because of the proliferation of small, temporary campsites. The number of larger campsites has also started to mount. There are currently five semi–permanent camps in the Taylor Valley (including one at New Harbor), two semi–permanent camps in the Wright Valley, a helicopter refueling camp at Marble Point, and several sites where semi–permanent camps have been decommissioned including the DVDP sites, Vanda Station, the NZAP camps at Lake Fryxell, Lake Miers and in the Asgard Range, and the earlier USAP camp at the eastern end of Lake Bonney.

GIS cataloging will be an essential part of monitoring this heterogeneous region. This spatial data base should eventually include campsite and sampling locations, the



The station in 1980.

The restored site in 1995.

The Vanda Station site in the Wright Valley before and after decommissioning and removal of the station.

number and duration of visits, the nature of the research, as well as environmental data from the lakes, streams and soils. A regularly updated spatial plot of the distribution of visitor–days throughout the Valleys would provide an especially valuable management tool and might ultimately be used to set visitor–day limits in some areas. Keeping track of scientific articles and reports from the region will also provide another useful guide to activities in the recent past.

Techniques to track changes in microbial community structure should be an integral part of future monitoring in the Valleys. Microscopic life forms dominate the biology of this region and environmental perturbation will cause changes in the diversity and abundance of species. A wide variety of techniques should be explored including the traditional recovery of organisms on agar media; direct counts by fluorescence microscopy; the use of lipid and other molecular markers including nucleic acid probes; immunofluorescence assays and measurement of specific metabolic activities. Such methods may also be important in tracking biological contamination. For example, the solar–heated waters of Lake Vanda could probably support a much greater diversity of organisms than occurs there at present and it is especially prone to accidental introductions via research activities. Microbiological techniques could be used to identify the magnitude and pathways of contamination.

Micro–invertebrates are numerous in some habitats (e.g., soil nematodes) and occur at the top of the food web. These communities have been used as sensitive biological indicators of perturbation and environmental impacts in the temperate zone, and such assays may be especially appropriate in the Dry Valleys where nematode populations are abundant and widely distributed.

The algal biomass of the Dry Valley lakes is strongly nutrient–limited and the lakes are therefore especially vulnerable to nutrient enrichment. The lakes are also sensitive to contaminants, in part because they have no hydrological flushing mechanism, unlike most lakes in the temperate zone. These waters are at the downstream end of the catchment and are therefore attractive sites for monitoring the overall system. Such monitoring efforts will be complicated, however, by the large interannual variability (e.g., in phytoplankton species composition; Spaulding et al. 1994) and by long–term climate change as indicated by rising lake levels in this region (Chinn 1993).

4.3.3. Ridge–Tops and Plateau ("high desert")

Current activities operate from temporary camps by helicopter out of McMurdo and focus on the microbial ecology of delicate endolithic communities, the micro–invertebrate communities, geophysical (including microclimate) and geological research, and studies on biogeochemical weathering processes. Apart from the chemical effects and potential accidents as described for region B, the microbial communities within the rocks of this region are especially sensitive to indiscriminate sampling and to physical damage by trampling. Monitoring activities should include precise recording of campsite locations, visual estimates of physical damage and chemical analysis of components that can be used as indices of general contamination. The setting of flight corridors, zoning of campsites and the increased use of remote sensing technologies would help to reduce impacts in this region.

4.3.4. Glaciers

Glaciological research to date has included mass balance and hydrological studies, microbiological research on the cryoconite pools on the glacier; and ice core analyses for studies of paleoclimate and future climate change. Temporary camps are rare on the glaciers, however there is an increasing deployment of semi–permanent markers and automated instruments. Contamination is most likely from helicopter operations, and by wind transport of materials from within or outside the valleys. The dispersal of materials (e.g., fuel spills) could also result in highly localized secondary effects such as reduced albedo and increased rates of melting. Contaminants in this habitat type will eventually enter the valleys via stream flow. Monitoring should include detailed record keeping on camp–sites, sampling activity and installations, as elsewhere in the valleys. GIS compilation of stream water chemistry and discharge will provide a useful approach towards tracking physical and chemical changes in the glacier environment, but this will primarily reflect inter–annual variability in discharge and regional climate change rather than local human impacts. Photogrammetry (including satellite imagery) will similarly provide a valuable option for assessing long term changes in glacier size, morphology and surface properties.

4.4 Practical Considerations

Who should coordinate, execute and pay for monitoring the Dry Valleys environment? Much of the burden of responsibility should be placed on current and future users of the region. For example, the Code of Conduct as presented in Appendix 5 places the onus on individuals to record the exact location of camp sites, research activities, impacts and accidents. These records must eventually be standardized for incorporation into a Dry Valleys GIS. The distribution of visitor–days, for example, may turn out to be one of the few cost–effective monitoring variables. Where and how this spatial database is developed and operated is now a matter for urgent consideration.

It is not feasible to monitor all variables at all locations. It will be important to establish what long–term records already exist for the valleys (e.g., stream flow, lake levels, lake ice thickness, meteorological data, records of helicopter hours) before identifying additional variables for monitoring. The close reciprocal benefits of monitoring and research on specific scientific questions should be considered. Visual inspection criteria, for example in the immediate vicinity of camps and at other key sites, provide the most cost–effective approach towards tracking many potential impacts, but will require a standardization of protocols (e.g., as in Campbell et al. 1993). Priorities for more detailed environmental analysis could be determined by the visual identification of impacted sites and also by the location of habitats within the overall Dry Valley ecosystem. For example, the lakes are the ultimate recipients of contaminants, nutrient enrichment and sediment disturbance in their drainage basins and would seem appropriate integrators for long term monitoring of the catchment environment (Matsumoto 1994).

A formal review process must be an integral part of future monitoring in the McMurdo Dry Valleys. This process must be open to international scrutiny and input. It should consider questions such as:

- Does the monitoring activity itself have the potential to cause environmental damage?
- Is the sensitivity, spatial extent and frequency of monitoring still appropriate to detect the hypothesized impacts?
- Is the monitoring strategy able to differentiate human impacts from inter–annual variability and longer term climate change?

Drilling through the 5–m–thick ice–cap of Lake Hoare.

- Is the monitoring strategy able to differentiate local contamination from long range transport (methods developed for PCBs in the Arctic are relevant to this question; e.g., Bright et al. 1995).
- Are there new potential impacts to consider?
- Are the key indicator variables still "key" and should new ones be added?
- Are our monitoring sites still "optimal"?
- Is there still a balance of resources towards monitoring acute site–specific effects and chronic longer term or larger scale changes.

The final series of potential monitoring options should be ranked according to their value (scientific relevance; sensitivity to impacts; value as an index for changes in many other environmental variables that are not measured) and feasibility (financial, logistic, analytical, ease of interpretation). This prioritization should also be revised and updated at regular intervals.

5. Environmental Codes of Conduct for Scientific Activities in the Dry Valleys

"After supper I took the prospecting dish (which was the last article purchased in New Zealand) and washed for gold in the gravels alongside the lake ... We knew there would be no water available on the remainder of our journey, so I depôted the pan on a boulder by Lake Chad, where some future archaeologist will discover striking evidence..." [Taylor, (1916), p. 145].

5.1 General Issues

The purpose of planned management of activities in the Dry Valleys is to understand and protect these important and unique ecosystems from unnecessary damage and disruption. The valleys have been subjected to an increasing level of visitation over the past 40 years. During this period attitudes about the environment have changed markedly and what was previously acceptable behavior is now considered significantly damaging. The scientific investigations have greatly extended our knowledge of this unique area but have also produced some changes in the Dry Valleys, some of which may be effectively irreversible and many of which give concern for how they might affect future investigations. Minimizing future disturbance while allowing scientific activities to continue should be the primary management goal. Documenting the historical usage of this region is another major challenge.

The Dry Valleys continue to be a rich source of information about ecosystem processes, microbial ecology and specific questions of global significance, for example the stability of the East Antarctic ice sheet (see section 2.5). It must therefore be assumed that scientific research will continue in the valleys. With few controls and little record keeping, previous investigators were able to camp, sample and experiment wherever and whenever they wanted. The results of this now indicate that without controls the future scientific value of the Dry Valleys is likely to decline and that unmanaged use will increasingly cause one type of science to prejudice that of other disciplines.

The most important feature of the suggested new approach is the acceptance by the individual that curtailment of options and opportunities may well be necessary in pursuit of longer term environmental stewardship. In addition, and equally important, every individual must accept responsibility for his or her actions while in the valleys. It may even be thought necessary to require individuals to formally acknowledge (e.g., a signed statement) that they have read and accepted the Code of Conduct before entering the Dry Valleys.

In considering how effective management could be organized several interlocking levels have been identified. Clearly, the highest level, and the considerations with most legal importance, are those embedded in the Protocol for Environmental Protection (Appendix 4). Application of these principles to the Dry Valleys follows at the planning phase and during the subsequent execution of the research. This final stage of field operations should provide guidelines to all personnel implicated in field activities: base support staff (e.g., those responsible for cargo preparation for Dry Valley events), flight crews, non–science visitors and research personnel.

The first tool developed here (section 5.2) is a set of guidelines of how project planning and implementation could be best approached in order to limit or mitigate potential environmental impacts on Antarctica. The second is a practical document for application in the field – an environmental Code of Conduct for researchers and other visitors to the Dry Valleys. This aims to provide a simple structured guide on what every visitor should do (or avoid doing) in the field in various habitat types. It includes ideas and suggestions expressed in Walton and Shears (1994) and Waterhouse (1995), and is presented in Appendix 5.

5.2 Planning of Dry Valleys Field Activities

The following presents a checklist of points to be considered during the planning phase. Firstly, two general features of the McMurdo Dry Valleys should be kept in mind in selecting the appropriate research strategy:

1. The region contains ancient features that could be easily destroyed by inadvertent human actions. The geomorphology of the valley system may have changed little over more than ten million years, although the extent of modification by more recent geological and glacial events in the Pliocene–Pleistocene is a subject of ongoing research and debate. Some of the exposed sediments (soils) in the valleys have been dated at more than two million years. Biological communities and structures within the Dry Valleys have taken from many decades to thousands of years to develop.

2. The region is a polar desert with only a limited natural capacity to recover from environmental impacts. The slow landscape processes in this region means that the return–time after physical perturbation (e.g., soil disturbance) is extremely long. The environment for organisms is severe – cold temperatures, extensive aridity, osmotic stress, and few available nutrients – and the biological capacity to decompose contaminants and other wastes is limited. In the lakes, low light levels, slow nutrient supply rates, low biodiversity and the absence of hydraulic flushing make these communities unusually sensitive to environmental impacts. Similarly the low biodiversity and aridity of the soils makes these communities unusually sensitive to disturbance.

These general features require special emphasis to be placed on minimizing the long term cumulative impacts of the research and logistic support. Specific ques-

A LTER field hut and instrument housing on Lake Fryxell. Surplus water from the lake sampling (which may be rich in dissolved salts and metals) is now collected and removed from the valleys to prevent contamination of the lake ice.

tions which researchers should be asked to consider during the planning phase are:

(a) Are there alternative approaches to the proposed activity that would lessen the expected environmental consequences?

(b) What is known about the present state of the area for which the work is proposed, and how will the research activities and methods affect this state?

(c) Can the nature, extent, duration, and intensity of the likely impacts of the research be estimated and could these impacts affect other users of the valleys?

(d) What would be the cumulative impacts of the research in light of existing activities and other known planned activities, and what can be done to reduce these?

(e) How could the research team monitor the impacts of their activities, and how would this help to minimize impacts and deal promptly and effectively with accidents?

(f) Can the scientific value of the research activities be clearly justified against the unavoidable impacts?

(g) Where are the gaps in available knowledge in estimating the possible impacts of the proposed research activities?

There are two further requirements, both of which rely absolutely on the availability of GIS as a management tool. Firstly, the need to inform other science groups working in the same or a contiguous location. This is both a courtesy and a feature of good environmental management since the pooling of interests with another group of co–workers can result in new scientific approaches which may be less disruptive. Documentation for project approval should incorporate a summary of projected key environmental impacts. Secondly, careful attention should be given to how the exact location and effects of the research visit will be recorded so that future visitors can make the necessary allowances in their own work. Only in this way can the present generation of scientists ensure that future generations have an equal opportunity to conduct high quality research in this unique area.

6. Conclusions and Recommendations

1. Three system–wide features of the McMurdo Dry Valleys result in their extreme sensitivity to human impacts, and their limited natural ability to recover from impacts:

- cold desert climate,
- low biodiversity and slow–growing biological communities,
- ancient landscapes and slowness of some landscape processes.

2. Apart from the obvious aesthetic and wilderness features of the McMurdo Dry Valleys, this region has enormous scientific value. Many of the ongoing studies in this region are highly relevant to questions of global importance.

3. These scientific values can only be protected in the long term by an integrated, ecosystem–level approach to environmental management. This approach should consider the entirety of the Dry Valleys, from the Convoy Range in the north to the Trough Lake catchment (Koettlitz Glacier region) in the south. It will require an improved knowledge of ecosystem processes and their response to disturbance in this region.

4. Initiating such a management strategy for this unique area must be considered a stepwise process. It will require ongoing international and interdisciplinary consultations to ensure that management proposals take into account the many and varied legitimate uses of the valleys. The application, permitting and reporting requirements should be streamlined and not be so onerous that they prevent high quality research.

5. As the first step, the Environmental Code of Conduct (Appendix 5) should be implemented as soon as possible. This will sensitize visitors to the potential for damage of the Dry Valley environment from inadvertent human action. It will formalize many practices already in effect within NZAP and USAP and will help individuals to recognize, mitigate and take environmental responsibility for the impacts of their own activities in the valleys.

6. Management of such a complex area with multiple uses can only be undertaken successfully by using modern data management tools. A system–wide GIS for the Dry Valleys should be initiated. This will provide an essential framework for "Code of Conduct" reports (e.g., sampling site locations) and will provide the first step in monitoring (e.g., visitor–day and campsite tracking). It will play a central role in the development of management plans and in the synthesis of maps that can be used in the field to avoid fragile areas. This spatial database would logically build upon the GIS development currently underway for the Taylor Valley LTER and for Specially Managed Areas within the McMurdo Sound Region (ICAIR).

7. A critical step towards a management GIS will be to identify precisely the location of landscape elements (e.g., alpine glacier ice–land–water systems; drift sheets) and special features (e.g., areas of extreme fra-

gility; biological communities; geological features; stratigraphic features with implications for regional and global questions). This will first require correction of the datum and updating of existing topographic base maps for the Dry Valleys.

8. An environmental management plan should be formulated based on zoning for permissible activities and access restrictions to reduce impacts. It should build upon the existing management plans for SSSIs within the region, and this framework should be coupled to the GIS database. Interim environmental restrictions should be placed on the use of the Dry Valleys to stem the current deterioration; e.g., establishment of new temporary and semi–permanent campsites should be reduced to a minimum.

9. An important key to effective management is a monitoring program to provide feedback on the success of the management scheme. The monitoring protocols suggested here should be further developed in concert with the management plan and GIS development. This should take into account any ATCM agreements on human impact monitoring.

10. The proposals from this workshop may be relevant to other polar desert areas in Antarctica (e.g., Larsemann Hills) and the high Arctic. They should be transmitted via the appropriate channels to SCAR and IASC for wider discussion. The implementation of these proposals will need to take into account those mechanisms already agreed within the Madrid Protocol for the protection and management of areas of scientific importance.

7. References

Barrett, P.J., Adams, C.J., McIntosh, W.C., Swisher, C.C. and Wilson, G.S. (1992). Geochronological evidence supporting Antarctic deglaciation three million years ago. Nature 359: 816–818.

Bright, D.A., Dushenko, W.T., Grundy, S.L. and Reimer, K.J. (1995). Evidence for the short range transport of polychlorinated biphenyls in the Canadian Arctic using congener signatures of PCBs in soils. Science of the Total Environment 160/161: 251–63.

Bromley, A.M. (1985). Weather observations in Wright Valley Antarctica. New Zealand Meteorological Service Information Publication 11: 37 pp.

Cameron, R.E. (1972). Pollution and conservation of the Antarctic terrestrial ecosystem. P. 267–306 in Parker, B.C. (ed.) (1972). Conservation Problems in Antarctica. Virginia Polytechnic Institute and State University, BlacksBurg, Virginia.

Campbell, I.B. and Claridge, G.G.C. (1989). Antarctica: soils, weathering processes and environment. Elsevier, Amsterdam, 368 p.

Campbell, I.B., Balks, M.R. and Claridge, G.G.C. (1993). A simple visual technique for estimating impact of fieldwork on the terrestrial environment in ice–free areas of Antarctica. Polar Record 29: 321–328.

Carvallo, M.L. (1994). Antarctic tourism must be managed, not eliminated. Forum for Applied Research and Public Policy 9: 76–79.

Chinn, T.J. (1990). The Dry Valleys. P. 137–153 in T. Hatherton (ed.) Antarctica: the Ross Sea Region, DSIR Publishing, Wellington.

Chinn, T.J. (1993). Physical hydrology of the Dry Valley lakes. In: W.J. Green and E.I. Friedmann (eds). Physical and biogeochemical processes in Antarctic lakes. Antarctic Research Series 59: 1–51.

De Laca, T.E., Lipps, J.H. and Hessler, R.R. (1980). The morphology and ecology of a new large agglutinated antarctic foraminifer (*Tertulariina: Notodendrodidae* nov.) Zoological Journal of the Linnaen Society 69: 205–44.

Denton, G.H., Sugden, D.E., Marchant, D.R., Hall, B.L. and Wilch, T.I. (1993). East Antarctic ice sheet sensitivity to Pliocene climatic change from a Dry Valleys perspective. Geografiska Annaler 75A: 155–204.

Doran, P.T., Wharton, R.A. and Lyons, W.B. (1994). Paleolimnology of the McMurdo Dry Valleys, Antarctica. Journal of Paleolimnology 10: 85–114.

Freckman, D.W. and Virginia, R.A. (1996). Nematode biodiversity and survival in Antarctic Dry Valley Soils. In press in Battaglia, B., Valencia, J. and Walton, D.W.H. (eds.) Antarctic Communities: Species, Structure and Survival. Cambridge University Press. Cambridge.

Friedmann, E.I. (ed.) (1993). Antarctic Microbiology. Wiley–Liss Inc., N.Y. 634 pp.

Harris, C.M. (1994). Standardization of zones within specially protected and managed areas under the Antarctic Environmental Protocol. Polar Record 30: 283–286.

Horgan, J. (1995). The big thaw: stability of the Antarctic ice remains uncertain. Scientific American 273 (5): 18–20.

ICAIR (1995). Draft management plan for Antarctic Special Protected Area, Canada Glacier, Taylor Valley, Victoria Land. 7 pp.

Lizotte M.P. and Priscu, J.C. (1994). Natural fluorescence and quantum yields in vertically stationary phytoplankton from perennially ice–covered lakes. Limnology and Oceanography 39: 1399–1410.

Marchant, D.R., Denton, G.H., Sugden, D.E. and Swisher, C.C. (1993). Miocene glacial stratigraphy and landscape evolution of the western Asgard Range, Antarctica. Geografiska Annaler 75A: 303–30.

McGinnis, L.D. (ed.) (1981). Dry Valley Drilling Project. Antarctic Research Series 33.

McKnight, D.M., Aiken, G.R. and Smith, R.L. (1991). Aquatic fulvic acids in microbially based ecosystems– results from two desert lakes in Antarctica. Limnology and Oceanography 36: 998–1006.

Matsumoto, G. I. (1994). Geochemical monitoring of Antarctic lakes and their ecosystems. Proceedings of the NIPR Symposium on Biology 7: 158–172.

National Research Council (1993). Science and Stewardship in the Antarctic. National Academy Press, Washington D.C. 107p.

Nienow, J.A. and Friedmann, E.I. (1993). Terrestrial lithophytic (rock) communities. P. 343–412 in Friedmann, E.I. (ed.) (1993). Antarctic Microbiology. Wiley–Liss Inc., N.Y.

NIWA (1993). Review of the Draft Initial Environmental Evaluation on: Decommissioning Vanda station Wright Valley Antarctica. New Zealand Freshwater Miscellaneous Report No. 136. 8 pp. + appendix on contaminated soils at Vanda Station.

Parker, B.C. (ed.) (1972). Conservation Problems in Antarctica. Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 356 pp.

Parker, B.C. and Holliman, M.C. (eds) (1978). Environmental Impact in Antarctica. Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 390 pp.

Pickett, S.T.A. and White, P.S. (1985). The Ecology of Natural Disturbance and Patch Dynamics. Academic Press, San Diego. 472 pp.

SCAR / COMNAP (1992). Environmental monitoring in Antarctica: A discussion document. 23 pp.

Schwerdtfeger, W. (1984). Weather and Climate of the Antarctic. Developments in Atmospheric Science Vol. 15. Elsevier Publishing, N.Y.

Spaulding, S.A., McKnight, D.M., Smith, R.L. and Dufford, R. (1994). Phytoplankton population dynamics in perennially ice–covered Lake Fryxell, Antarctica. Journal of Plankton Research 16: 527–41.

Taylor, G. (1913). The Western Journeys. P. 182–221 in L. Huxley (ed.) Scott's Last Expedition Vol. 2, Second Edition, Smith, Elder and Co., London.

Taylor, G. (1916). With Scott: The Silver Lining. Mead and Co., N.Y. 464 pp.

Vincent, W.F. (1988) Microbial Ecosystems of Antarctica. Cambridge University Press, United Kingdom. 304 pp.

Walton, D.W.H. and J. Shears. (1994). The need for environmental monitoring in Antarctica: baselines, environmental impact assessments, accidents and footprints. International Journal of Environmental Analytical Chemistry 55: 77–90.

Waterhouse, E.J. (1995). Lake Vanda Environmental Operating Procedures. New Zealand Antarctic Research Program.

Wharton, R.A. (1993). The McMurdo Dry Valleys: A Cold Desert Ecosystem. Desert Research Institute, special publication, 51 pp.

Appendix 1
Acronyms used in this report

ANARE	Australian National Antarctic Research Expeditions
ATCM	Antarctic Treaty Consultative Meeting
BIOTAS	Biological Investigations of Terrestrial Antarctic Systems
CCAMLR	Convention on the Conservation of Antarctic Marine Living Resources
CEE	Comprehensive Environmental Evaluation
CEP	Committee for Environmental Protection
COMNAP	Council of Managers of National Antarctic Programs
DFA	Diesel Fuel Arctic
DOC	Department of Conservation (New Zealand)
DVDP	Dry Valleys Drilling Program
GIS	Geographic Information System
GOSEAC	Group of Specialists on Environmental Affairs and Conservation
GPS	Global Positioning System
IAE	Italian Antarctic Expedition
IASC	International Arctic Science Committee
ICAIR	International Center for Antarctic Information and Research (New Zealand)
IEE	Initial Environmental Evaluation
LTER	Long Term Ecological Research program (NSF)
NASA	National Aeronautical and Space Administration (USA)
NIWA	National Institute for Water and Atmospheric Research Ltd. (New Zealand)
NSF	National Science Foundation (USA)
NZAP	New Zealand Antarctic Programme
PCB	Polychlorinated biphenyls
PI	Principal investigator (project leader)
SCAR	Scientific Committee on Antarctic Research
SMA	Specially Managed Area
SPA	Specially Protected Area
SSSI	Site of Special Scientific Interest
USAP	United States Antarctic Program

Appendix 2
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Appendix 3
Chronology of Activities in the Dry Valleys

List of activities and impacts in the Dry Valleys from their discovery onwards. Compiled by Clive Howard–Williams (NIWA).

YEAR	ACTIVITY
1903	Discovery of "Dry Valley" by Scott, Evans, Lashley.
1908	Reconnaissance of the lower end of the Dry Valley (Shackleton's expedition).
1911	"Dry Valley" explored by Griffith Taylor (Scott's expedition).
1947	First air photos of Dry Valleys (Operation High Jump).
1957	First traverse of Taylor Valley since 1911 (Llano party).
1958	Helicopter flights to the Dry Valleys begin.
	First visit to Wright Valley, and Victoria valley. Field camp at Lake Vida.
1959	Expeditions with camps to Victoria and Barwick Valleys. Field camp also set up at Lake Vashka.
1958–1967	Eleven consecutive Dry Valley expeditions by New Zealand research teams.
1960	Lake Vanda ice cap drilled for limnological sampling.
1962	Lake Bonney ice cap drilled for limnological sampling.
1968	Vanda Station (New Zealand) established – First large base in Dry Valleys.
1969	Onyx River gauging weir first built. First overwinter in the Dry Valleys (Vanda Station). Wheeled vehicle (tractor) in the Dry Valleys.
1971	Dry Valleys Drilling Program (DVDP) initiated.
1972	Lake Bonney facility extended (Chemistry Lab) Lake Bonney Research Project set up – continued to 1979.

1972–73	DVDP drilling began at Lake Vanda and Don Juan Pond.
1973–74	DVDP drilling at Lake Vida and lower Taylor Valley.
1974–75	DVDP drilling at lower Taylor and Wright Valleys.
1974–76	Mars Viking Lander programme (NASA)
1975	The Barwick Valley established as a SSSI.
1977–78	Lake Bonney hut removed and Chemistry Lab moved due to rising lake. Huts installed at Lake Fryxell.
1979	Plastic greenhouse built at Lake Fryxell. Vegetables grown.
1979	Huts installed at Lake Hoare.

1981	Lake Miers hut set up.
1983	Fryxell greenhouse destroyed by winter storm.
1984–85	Air drop of diesel fuel (DFA) spills fuel on Lake Vanda ice.
1985	SSSI established at Canada Glacier in the Taylor Valley
1986	Vanda weir rebuilt (included blasting into permafrost).
1987	Lake Fryxell camp (north shore) constructed.
1989	New Lake Bonney camp constructed.

1993	Long Term Ecological Research (LTER) program begins in the Taylor Valley.
1993–94	Lake Hoare camp extended.
1993–95	Vanda Station demolished following IEE. Asgard Hut removed.
1994–95	New Vanda set up using NZAP huts moved from Miers and Fryxell. Vanda weir demolished – replaced by control structure. Second Lake Fryxell camp established (south shore).

Appendix 4
Protocol on Environmental Protection to the Antarctic Treaty

The following summary tables were derived from material presented at the workshop by Dan Bodansky (University of Washington).

Table 4.1. Elements of the Antarctic Treaty System

Antarctic Treaty 1959:

Measures adopted pursuant to Article IX:

- Agreed measures for the conservation of flora and fauna, 1964
- Code of conduct for Antarctic expeditions and station activities, 1975
- Environmental impact assessment guidelines, 1987
- Waste disposal guidelines, 1989
- Marine pollution guidelines, 1989

Environmental Protocol, 1991.

Convention on the Conservation of Antarctic Seals, 1972.

Convention on the Conservation of Antarctic Marine Living Resources, 1980.

Convention on the Regulation of Antarctic Mineral Resource Activities, 1988.

Table 4.2. Protocol on Environmental Protection, 1991 (the Madrid Protocol)

Declares Antarctica to be a natural reserve devoted to peace and science.

Sets general governance arrangements:

Principles:

- limit adverse impacts;
- need information sufficient to allow prior assessments;
- monitoring of impacts;
- cooperation.

Institutions:

- Committee for Environmental Protection (CEP)

Decision–making procedures:

- advice by CEP;
- decisions by ATCM – tacit amendment procedures for annexes.

Implementation:

- inspections;
- annual reports;
- compulsory dispute settlement.

Sets substantive standards:

Article 7: ban on mineral activities;

Annexes (currently 5): integrate and consolidate existing environmental measures.

Table 4.3. Requirements for environmental assessment as given in Annex I of the Madrid Protocol.

Mandatory for all governmental and non–governmental activities.

Implementation by national authorities.

Three levels of environmental impacts:

De minimis impacts (less than minor or transitory)

- no assessment (Article 1(2)).

Minor or transitory impacts

- Initial Environmental Evaluation (IEE, Article 2) containing:
  description of the proposed activity;
  consideration of alternatives;
  procedures to assess and verify impacts.

Substantial impacts (more than minor or transitory)

- Comprehensive Environmental Evaluation (CEE, Article 3) containing:
  description of the proposed activity and possible alternatives;
  description of initial environmental reference state;
  consideration of:
  – likely direct impacts;
  – possible indirect impacts;
  – cumulative impacts.
- International review through CEP, ATCM;
  decisions must be based on CEE (Article 4).
- Monitoring of impacts of activities that proceed following CEE (Article 5).

Table 4.4. Area protection and management as specified in Annex V of the Madrid Protocol.

Types of special areas:	
	Specially Protected Areas (SPA)
	Specially Managed Areas (SMA)
Similarities between the two special area types:	
	Collective designation of the area by ATCM, on the advice of CEP
	Management plan required, to be approved by ATCM
Differences between the two special area types:	
SPA:	permits needed for access and activities; conditions for permits specified in the management plan (if there is no plan, then for compelling scientific reasons only); permits to be issued by national authorities.
SMA:	multiple use areas; no permits required;– management plan specifies code of conduct re: access, activities, etc.

Appendix 5
ENVIRONMENTAL CODE OF CONDUCT FOR FIELD WORK IN THE MCMURDO DRY VALLEYS

Why are the Dry Valleys considered so important by the scientific community? The Dry Valleys ecosystem contains geological and biological features that date back thousands to millions of years. Many of these ancient features could be easily and irreversibly damaged by inadvertent human actions. Unusual communities of microscopic life forms, low biodiversity, simple food webs with limited trophic competition, severe temperature stress, aridity and nutrient limitations are other characteristics which make the Dry Valleys unique. Research in such systems must always aim to minimize impacts on land, water and ice to protect them for future generations. This code suggests how you can help to ensure this.

General:

This ancient desert landscape and its biological communities have very little natural ability to recover from disturbance. In your visit to the valleys, strive for "zero impact."

Everything taken into the valleys must be taken out. This also means avoiding the use or dispersal of foreign materials that are difficult to collect and remove; e.g., do not use spray paint to mark rocks; where possible, perform all cutting, sawing and unpacking inside a hut or tent.

Field camps:

– arrival and setting up

- Campsites should be located as far away as practicable from lakeshores and streambeds to avoid contamination.
- Campsites should be re–used if at all possible (a management plan will eventually specify allowable sites).
- Ensure that equipment and stores are properly secured at all times to avoid dispersion by high winds. High velocity katabatic winds can arrive suddenly and with little warning.
- Tents pitched on ice should be secured by looping guys through holes in the ice, without the use of ice screws or deadmen. If the use of ice screws is unavoidable they should be retightened every two days during summer as they melt out very rapidly.
- Maximize the use of fixed helicopter pads so that the site can be cleaned up when the camp is removed.

- Use markers clearly visible from the air to mark helicopter pads. Avoid building cairns.

– water, fuel and chemicals

- Water used for any human purpose should be removed and not poured on the soil or into a lake or stream.
- Use solar or wind power as much as possible to minimize fuel usage.
- Only refuel generators and vehicles over trays with absorbent spill pads.
- Only use fuel cans with spouts when refuelling generators.
- Never change vehicle oil except over a drip tray.
- Chemicals of all kinds should be dispensed over drip trays.

Sampling and experimental sites:

- Do not collect specimens of any kind except for scientific and educational purposes; in SSSIs or SPAs the sample size will be specified in your collecting permit.
- Avoid leaving markers (e.g., flags) and other equipment for more than one season without marking them clearly with your event number and duration of deployment.
- Ensure that you record the position and usage for all sites in your field report for transfer to the management GIS.
- Backfill soil pits to prevent wind erosion and dispersal of deeper sediments; record the GPS co–ordinates so that others can exactly locate the disturbed area.
- When permitted to use radio–isotopes, precisely follow all instructions provided by the environmental officer.
- Take steps to prevent the accidental release of chemicals such as antibiotics, laboratory reagents and stable isotopes.

Travel:

- Restrict vehicle usage to snow and ice surfaces.
- Only use vehicles on lake ice when essential; park the vehicle on permanent ice rather than moat ice during the period of summer melt.
- Stay on established trails wherever possible.
- Ensure that you remove all feces and urine.
- Avoid trampling on vegetated areas and delicate rock formations.

Lakes:

- Scrupulously clean all sampling equipment to avoid cross–contamination between lakes.
- Pouring any unwanted water or sediment onto the ice surface contaminates it; it should be collected and shipped out.

- Never use explosives on a lake.
- When handling chemicals on a lake ensure you have materials with you to catch and absorb spills.
- Once you have drilled a sampling hole keep it clean and make sure all your sampling equipment is securely tethered.
- Try to ensure that you leave nothing frozen into the lake ice which may ablate out and cause later contamination.
- Avoid swimming or diving in the lakes if at all possible. These activities could contaminate the water body and physically disturb the water column, delicate microbial communities and sediments.

Streams:

- Do not camp in dry stream beds – you may leave contaminants behind that pollute the stream when flow begins.
- Avoid walking in the streambed at any time; you may disturb the stream biota which maintain a large freeze–dried inoculum over winter and which represents several decades of slow growth.
- Avoid walking too close to stream sides as this may affect bank stability and flow patterns.
- Use designated crossing points whenever possible.

Valley floor and sides:

- Do not displace or collect ventifacts or fossils except for scientific or educational purposes.
- Avoid disturbing mummified seals or penguins; apart from the importance of leaving them in place, they may contain skin pathogens.
- Avoid sliding down screes or sand dunes; these features have taken many thousands of years to form and may also contain surface deposits of major scientific importance.
- Soil sampling sites should be mapped and their exact locations measured and recorded.
- Soils should be sampled with clean equipment to avoid contamination.

High desert:

- Some of the rock formations are especially fragile to trampling – beware of causing damage, especially when the rocks are concealed by snow. Some of the biological communities in the rocks (most commonly in Beacon Sandstone) have taken several thousand years to develop.
- Collect only the minimum sample of endolithic community required for scientific analysis.
- Record the location of all sampling activities for transfer to the management GIS.

Glaciers:

- Minimize the use and extent of stake networks to the extent practicable; where possible, label these with event number and duration of deployment. Record their exact position so that they can be later found and removed.
- Minimize the use of liquid water (e.g., with hot water drills) which could contaminate the isotopic and chemical record within the glacier ice. Avoid the use of chemical–based fluids on the ice.
- Take care not to leave travel equipment behind; e.g., ice screws, pitons.

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