Environmental Protection and Stewardship of Subglacial Aquatic Environments

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Environmental stewardship is a guiding principle of the Antarctic Treaty System. Efforts began in the 1990s to generate specific guidelines for stewardship of many terrestrial environments, including surface lakes and rivers. The relatively recent documentation of widespread subglacial aquatic environments, and planning for acquiring samples from them, has generated a need for stewardship guidelines for these environments. In response to a request from the U.S. National Science Foundation, the National Research Council of the National Academies of Sciences (NAS) created the Committee on the Principles of Environmental and Scientific Stewardship for the Exploration and Study of Subglacial Environments. The committee made 13 recommendations and a decision tree as a framework and flow chart for environmental management decisions. The committee report was also largely the basis of a Code of Conduct (CoC) for the exploration of subglacial environments formulated by a Scientific Committee on Antarctic Research Action Group. Both the NAS report and CoC have been used as guidance, to varying degrees, by subglacial research currently in progress.

1. INTRODUCTION

Antarctic subglacial aquatic environments (SAEs) have been documented for some time using remote sensing, geophysical techniques, but only very recently have there been plans devised and implemented to sample and study these environments directly. The long lead up to the sampling of these lakes is largely related to the logistical difficulty of penetrating their thick ice caps, but also due to the cautious approach warranted by the pristine nature of the environments and their almost completely unknown capacity to sustain viable ecosystems.

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Environmental stewardship is one of the central principles of the Antarctic Treaty System. Although the initial treaty did not deal with environmental issues directly, the "Protocol on" Environmental Protection to the Antarctic Treaty (also known as the Madrid Protocol) adopted in 1991, extends wide environmental protection over the continent. The protocol codified all the many recommendations on environmental management and proposed specific approaches for various tools like environmental impact assessments. The protocol also provides for the establishment of a Committee for Environmental Protection (CEP) to advise the Antarctic Treaty Consultative Meeting (ATCM), requires the development of contingency plans to respond to environmental emergencies and provides for the elaboration of rules relating to liability for environmental damage (details at the Antarctic Treaty System website: http://www.ats.aq/e/ep.htm).

In this chapter we first review the leading initiatives to protect surface aquatic environments in continental and maritime Antarctica. We then describe the findings of a committee formed by the National Research Council (NRC) of the National Academies of Sciences (NAS), United States to address standards of responsible exploration of SAEs in Antarctica. The detailed recommendations of that committee, summarized below, subsequently formed the basis for a "Code for Conduct for the Exploration and Research of Subglacial Aquatic Environments," which was developed by a Scientific Committee on Antarctic Research (SCAR) Action Group for submission to the Antarctic Treaty System. We conclude the chapter by briefly describing current subglacial exploration projects and their approaches toward environmental stewardship.

2. PROTECTION OF ANTARCTIC SURFACE WATERS

The Protocol on Environmental Protection to the Antarctic Treaty lays down general principles and specifies the legal obligations and procedures for environmental stewardship throughout the Antarctic region. From the 1990s onward, efforts have been made to adapt and apply these requirements specifically to Antarctic lakes and their catchments. This work has resulted in site-specific management plans and Codes of Conduct (CoCs) to minimize the impacts of human activities and to preserve environmental properties of surface lakes and rivers at several locations in maritime and continental Antarctica.

Some of the earliest work on environmental protection of Antarctic lakes and their catchments took place in the McMurdo Dry Valleys. This is the largest ice-free region of Antarctica (about 4800 km^2) and contains deep, perennially ice-capped lakes fed by glacial meltwater streams that flow for several weeks each summer [*Priscu*, 1998]. Initial discussions about conservation issues in Antarctica noted that such lakes are useful sites for monitoring environmental change, including natural variations in the past and present, but that they are also highly vulnerable to disturbance by human activities, including scientific research [*Parker*, 1972]. The latter concern was explicitly addressed in two workshops in the 1990s convened by the National Science Foundation (NSF) of the United States of America that brought together international experts from many disciplines, including microbiology, marine biology, geomorphology, terrestrial ecology, geochemistry, glaciology, hydrology, environmental law, and tourism, to identify the key environmental values to be protected and potential strategies to ensure success. The recommendations from these workshops depended on full support from the science community as well as the national programs [*Harris*, 1998]. They were fully endorsed by the two main operators in the region, NSF Office of Polar Programs, and the New Zealand Antarctic Program, which led to their rapid acceptance and implementation by the Antarctic Treaty System.

The proceedings of the first NSF workshop on environmental protection of the McMurdo Dry Valleys concluded that there was an urgent need for an ecologically integrated management plan that recognized all of the activities in the region, and that set guidelines and zoning regulations to minimize long-term degradation as well as to avoid immediate impacts [*Vincent*, 1996]. This workshop also resulted in the first draft of an Environmental CoC for all visitors to the region. The second workshop focused specifically on environmental protection of the lakes and streams and further contributed to the development of the management plan and CoC [*Wharton and Doran*, 1999]. These efforts came to fruition with designation of the McMurdo Dry Valleys in 2004 as an Antarctic Specially Managed Area (ASMA no. 2 under the terms of the Madrid Protocol). The purpose of an ASMA is to assist in coordination and planning of activities within an area, minimize conflict and improve cooperation between various Antarctic programs, and minimize environmental impacts. The Dry Valley ASMA was accompanied by a hortatory internationally agreed management plan (available online at: http://www.ats.aq/documents/recatt/Att208_e.pdf), and an associated Environmental CoC. The management plan specifically states that

> All operators in the Area shall ensure that all personnel in their programs visiting the Area have been briefed on the requirements of the Management Plan and in particular on the Environmental Code of Conduct that applies within the Area.

The McMurdo Dry Valleys Code of Conduct (CoC) aims to educate visitors to the region about the special environmental values that require their care and protection; the more recent development of a code for exploration and stewardship of subglacial waters took a similar approach (see below). The McMurdo CoC begins as follows:

> Why are the McMurdo Dry Valleys considered to be so important? The McMurdo 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 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 that make the McMurdo Dry Valleys unique. This ancient desert landscape and its biological communities have very little natural ability to recover from disturbance. Research in such systems must aim to minimize impacts on land, water and ice to protect them for future generations.

The code then provides a series of general procedures (e.g., "Everything taken into the Area should be removed and returned to the appropriate national program station for proper handling") followed by specific requirements (e.g., "Explosives should not be used on a lake; Avoid walking in the streambed at any time to avoid disturbing the stream biota"). Some of these recommendations may seem intuitively obvious, yet explosives were routinely used for many years on the ice at Lake Vanda, for example, and few visitors to the valleys had realized the unique biological communities that coated the stream beds. A McMurdo Dry Valley management team, with membership from the United States, New Zealand, and Italy, was largely responsible for implementing the formation and awareness of the ASMA, including production of a pocket-sized field guide to the McMurdo Dry Valleys that contains maps from the management plan and the CoC.

One of the conservation elements of the McMurdo Dry Valleys management plan of particular relevance to future stewardship of Antarctic subglacial lakes (see below) is the designation of specific areas as reference sites in which scientific activities are by permit only and limited to minimal access. An area of 325 km^2 at Barwick and Balham valleys was originally designated as a Site of Special Scientific Interest based on a proposal by the United States of America that this was "one of the least disturbed and contaminated of the Dry Valleys of Victoria Land" and therefore a valuable reference location for measuring changes in comparable ecosystems elsewhere in McMurdo Dry Valleys where scientific investigations are more regularly undertaken. The current management plan for the Barwick-Balham site (Antarctic Specially Protected Area No. 123; details are at http://www.ats.aq/documents/recatt/Att390_e.pdf) notes the presence of lakes and streams and that "Protection on a catchment basis serves to provide greater representation of the ecosystem features, and also facilitates management of the Area as a geographically distinct and integrated ecological system."

The importance of preserving surface lake and stream ecosystems and their catchments has also been recognized elsewhere in Antarctica and has led to specific requirements within other ASMAs or at more localized sites designated Antarctic Specially Protected Areas (ASPAs, including all sites previously called Sites of Special Scientific Interest and those designated as Specially Protected Areas). ASPA no. 143 is for Marine Plain Mule Peninsula, in the Vestfold Hills, itself a region of numerous lakes with unusual geochemical and biological properties. The ASPA (details are at http://www.ats.aq/documents/recatt/Att193_e.pdf) states that

> The meromictic and saline Burton Lake, together with several smaller lakes and ponds in the ASPA, provide important examples in the spectrum of hypersaline to fresh water lake types in the Vestfold Hills and present the opportunity for important geochemical and limnological research. The interrelationships between environment and biological communities in lakes such as Burton, provide considerable insights into the evolution of the lake environments and consequently, Antarctic environmental development. It is currently the only meromictic lagoon that has been protected within East Antarctica.

The ASPA prohibits entry into the Area except in accordance with a Permit issued by an appropriate national authority and with several conditions including those that relate specifically to the lakes, for example: "motorised boats are not to be used on Burton Lake," and researchers must undertake steps "ensuring equipment is washed before entry to the ASPA to prevent contamination from other lakes."

The Larsemann Hills is an oasis of ice-free land that lies 80 km from the Vestfold Hills and includes about 150 lakes and ponds, most of which contain luxuriant benthic mats of cyanobacteria. This region has experienced a number of environmental effects associated with the construction and occupation of three national bases, including pronounced hydrological impacts on lakes caused by road construction [*Burgess and Kaup*, 1997]. It has now been designated ASMA no. 6, (details at http://www.ats.aq/documents/recatt/Att358_e.pdf). The management plan explicitly notes "The lakes and streams provide a series of habitats that contain a rich and varied fauna very typical of the Antarctic region," as well as unusual microbial communities:

> The most obvious biotic feature observed in almost all the lakes are extensive blue-green cyanobacterial mats, which have accumulated since ice retreat, in places being up to 130 000 years old. These cyanobacterial mats are found to exceptional thicknesses of up to 1.5 m, not normally observed in other Antarctic freshwater systems, and are also widely distributed in streams and wet seepage areas.

The management plan includes a CoC, with several precautions that specifically address the aquatic environments, including the following:

> Minimise the use of liquid water and chemicals that could contaminate the isotopic and chemical record within lake or glacier ice; Scrupulously clean all sampling equipment to avoid cross-contamination between lakes; To prevent lake contamination, or toxic effects on the biota at the surface, avoid reintroducing large volumes of water obtained from lower in the water column.

In maritime Antarctica, Deception Island has been designated ASMA no. 4, and includes lakes and streams (details at http://www.ats.aq/documents/recatt/att290_e.pdf). Protection of these waters has been given little attention in the management plan, although it is noted: "Freshwater streams or lakes, or vegetated areas, shall not be used to dispose of human wastes." One of the richest lake districts in the maritime region, and perhaps in all of Antarctica, is Byers Peninsula, Livingston Island, in the South Shetland Islands [*Toro et al.*, 2007]. This is now designated ASPA no. 126 under the Antarctic Treaty System. This seasonally ice-free area contains 60 lakes, many ponds and streams, extensive cyanobacterial mats, and an unusually diverse fauna of aquatic invertebrates including three crustacean species, a benthic cladoceran, two species of chironomids (midges) and an oligochaete (freshwater worm). The ASPA management plan (available at http://www.nsf.gov/od/opp/antarct/aca/nsf01151/aca2_spa126.pdf) provides considerable information about the freshwaters and their biota but no specific protection measures that make reference to these ecosystems. The plan does, however, put forward a number of general protection measures: access is by permit (like all ASPAs), with the conditions that "All movement should be undertaken carefully so as to minimize disturbance to animals, soils, geomorphological features and vegetated surfaces, walking on rocky terrain or ridges if practical to avoid damage to sensitive plants, patterned ground and the often waterlogged soils." It addresses biological contamination by stating that "Of concern are microbial or plant introductions sourced from other Antarctic sites, including stations, or from regions outside Antarctica. All sampling equipment or markers brought into the Area shall be cleaned or sterilised."

In summary, considerable effort has been made toward protection of surface waters at many sites in Antarctica. A broad, albeit nonstandardized, range of requirements has been put into effect at each of these sites, and these provided useful starting points and guidance for the development of subglacial lake protocols, within the terms and spirit of the Madrid Protocol.

3. NAS COMMITTEE AND REPORT BUILDING PROCESS

With increasing interest in subglacial systems expressed by Earth scientists and biologists, combined with the need for caution, the U.S. NSF requested guidance from the National Academies to address standards of responsible exploration. In response, the National Research Council of the National Academies created the Committee on the Principles of Environmental and Scientific Stewardship for the Exploration and Study of Subglacial Environments (herein referred to as "the committee"). The committee was asked to (1) define levels of "cleanliness" for equipment or devices entering SAEs, (2) develop a sound scientific basis for contamination standards recognizing that different stages of exploration may be subject to differing levels of environmental concern, and (3) recommend the next steps needed to define an overall exploration strategy.

The committee was also charged to consider contamination potential of current technology and to bring to light potential needs for technological development or studies needed to reduce contamination. Other goals were to assess the scientific benefit of immediate study versus waiting and to identify potential targets among the many Antarctic SAEs.

The NAS was established in 1863 to "investigate, examine, experiment, and report upon any subject of science or art" whenever called upon to do so by any department of the government. Most of the National Academy's science policy and technical work is carried out by its operating arm, the NRC, created in 1916. The NAS and NRC work outside the framework of government to ensure independent advice on matters of science, technology, and medicine (http://www.nasonline.org).

As with other NRC studies, before personnel selection began for the committee, the study was defined by NAS personnel and the sponsor, in this case NSF. Committee members were then carefully selected to provide a group with an appropriate range of expertise and a balance of perspectives. Each committee member is also screened for conflicts of interest. Owing to the nature of the study, this committee had a strong multidisciplinary and international composition with members from Canada, Germany, United Kingdom and the United States of America.

The study was carried out through four face-to-face meetings of the committee, which included visits by invited experts to provide information needed by the committee. The committee then drafted a report, which was reviewed by 10 additional outside, international experts. After all committee members and appropriate NAS officials signed off on the report, it was transmitted to the sponsor (NSF) and released to the public.

There has been some controversy in the literature about whether microorganisms currently reside in SAEs. Many types of microbes can be found in the overlying ice, and some may still be viable as they enter the SAE. Therefore, despite the extreme environment microbes would need to reside in, there is a possibility of microbial metabolism and growth, albeit at very low rates. As a guiding principal, the committee concluded that until there is definitive data concerning the absence of microbial life, a conservative approach should be adopted. The committee considered ". . . the identity and diversity of life, the nature of the electron donors and acceptors that support life (if life exists), and all the other related ecological and biogeochemical properties as fundamental, but unanswered questions." Proof of the absence of life cannot come from a single sampling, but will need multiple samples from multiple locations, analyzed at multiple laboratories around the world.

New data were being generated with regard to SAEs throughout the tenure of the NAS committee and the development of these recommendations. At the start of the committee's work, it was thought that these environments were isolated lakes. But with new data [e.g., *Gray et al.*, 2005, *Wingham et al.*, 2006, *Fricker et al.*, 2007], it quickly become clear that rather than lakes, these environments are comprised of vast watersheds containing interconnected lakes, swamp-like features and thin films of water under the ice. The committee decided early in its discussions that even though the statement of task referred to lakes specifically, it had to consider all SAEs. Furthermore, it was recognized that the interconnectivity of the SAEs has significant implications for risk of spreading contamination, particularly microbial contamination. These new perceptions of SAEs were captured in the report, but the freshness of these ideas at the time is evident, as much of the discussion remains focused on lakes. Furthermore, one implication of the interconnectivity that was discussed, but was not directly included in the report was the concept of proximity to the ocean, or essential "stream order." The committee recognized that contaminating headwaters was a much more serious concern than contaminated subglacial environments that are within a few miles of discharging to the ocean.

The committee report [*National Research Council*, 2007] offered both a set of recommendations (below) (reproduced with permission by the National Academy of Sciences, courtesy of the National Academies Press, Washington, D. C.) and a decision tree (Figure 1) as a framework and sequence for moving forward with environmental management decisions.

Recommendations for the Scientific and Environmental Stewardship for the Exploration of Subglacial Aquatic Environments

Recommendation 1

Direct exploration of subglacial aquatic environments is required if we are to understand these unique systems. Exploration of subglacial aquatic environments should proceed and take a conservative approach to stewardship and management while encouraging field research.

Recommendation 2

Exploration protocols should assume that all subglacial aquatic environments contain or may support living organisms and are potentially linked components of a subglacial drainage basin.

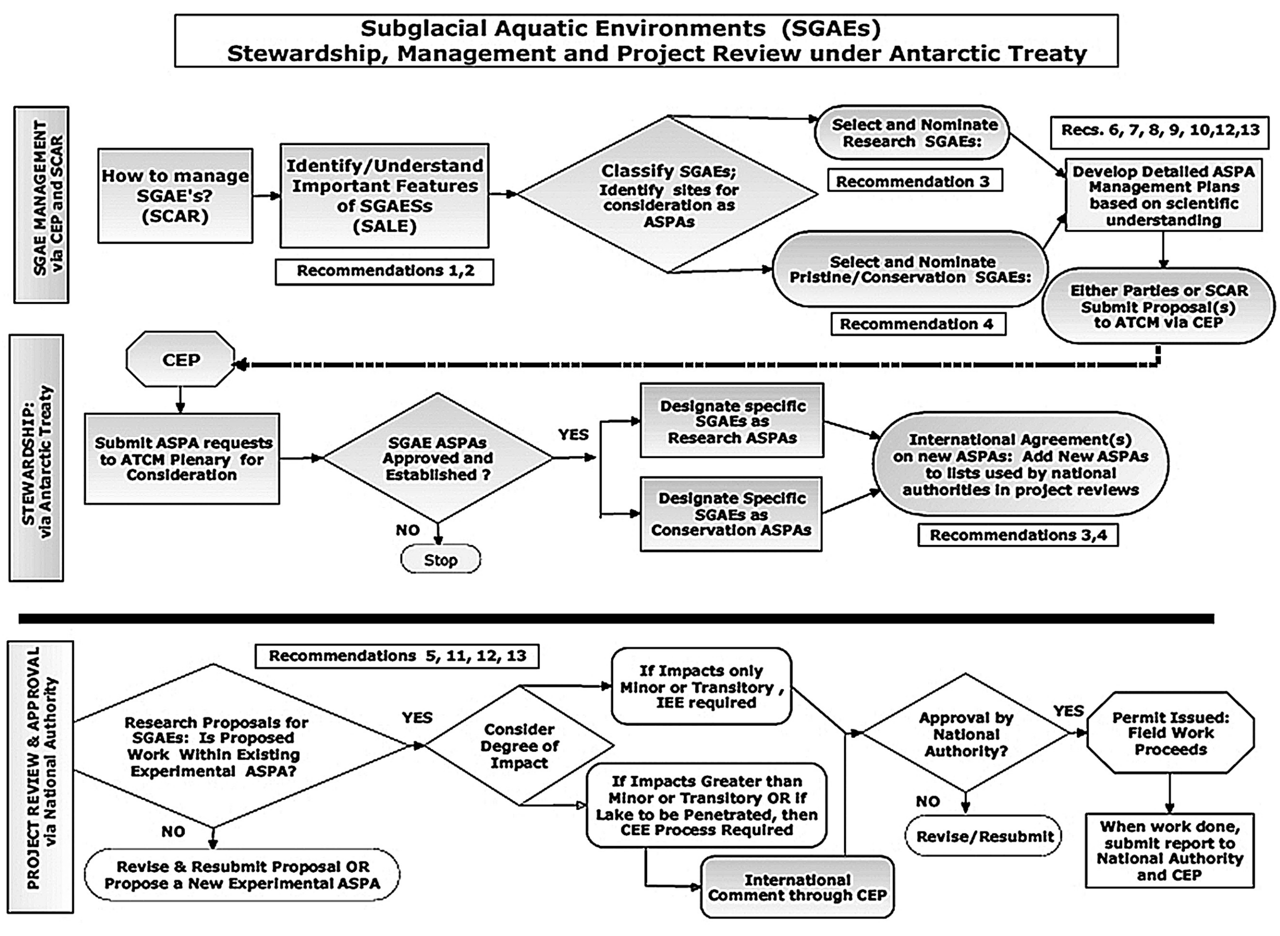

Figure 1. Sequence and framework for addressing stewardship, management, and project review for subglacial aquatic environments [from *National Research Council*, 2007]. Image courtesy of M. S. Race.

Recommendation 3

As soon as adequate survey data have been gathered to provide a sound basis for description, all subglacial aquatic environments intended for research should be designated Antarctic Specially Protected Areas to ensure that all scientific activities are managed within an agreed international plan and are fully documented.

Recommendation 4

As soon as adequate survey data have been gathered to provide a sound basis for description, actions should be taken to designate certain exemplar pristine subglacial environments as Antarctic Specially Protected Areas for long-term conservation purposes.

Recommendation 5

Multinational projects should be encouraged in the study of subglacial aquatic environments, and all projects aiming to penetrate into a lake should be required to undertake a Comprehensive Environmental Evaluation.

Recommendation 6

The National Science Foundation should work in conjunction with the United States representatives to the Scientific Committee on Antarctic Research and to the Committee on Environmental Protection to involve all Antarctic Treaty nations in developing a consensus-based management plan for the exploration of subglacial aquatic environments. This plan should seek to develop scientific understanding and ensure that the environmental management of subglacial aquatic environments is held to the highest standards.

Recommendation 7

Drilling in conjunction with sampling procedures will inevitably introduce microorganisms into subglacial aquatic environments. The numbers of microbial cells contained in or on the volume of any material or instruments added to or placed in these environments should not exceed the minimum concentration of microbes in the basal glacial ice being passed through. Based on research to date, a concentration of 10^2 cells/ml should not be exceeded, until more data are available.

Recommendation 8

Drilling in conjunction with sampling procedures will inevitably introduce chemical contaminants into lakes and associated subglacial aquatic environments. Toxic and biodegradable materials should be avoided, as should the introduction of non-miscible substances. At a minimum, the concentrations of chemical contaminants should be documented and the total amount added to these aquatic environments should not be expected to change the measurable chemical properties of the environment. The amount added would be expected to have a minor and/or transitory impact on the environment.

Recommendation 9

Notwithstanding their compliance with Recommendations 7 and 8, investigators should continue to make every effort practicable to maintain the integrity of lake chemical and physical structure during exploration and sampling of water and sediments.

Recommendation 10

Allowances should be made for certain objects and materials to be placed into experimental subglacial aquatic environments for scientific purposes—for example for monitoring or tracing dynamics. These additions should follow the microbiological constraints in Recommendation 7 and include discussion of environmental risk versus scientific benefit analysis as required by the Comprehensive Environmental Evaluation.

Recommendation 11

As the initial step to define an overall exploration strategy, the United States, together with other interested parties, should begin immediately to obtain remote sensing data to characterize a wide range of subglacial aquatic environments. As a second step, preliminary data and samples should be obtained from subglacial aquatic environments as soon as practicable to guide future environmental stewardship, scientific investigations and technological developments.

Recommendation 12

Remote sensing of the potential aquatic environments beneath the Antarctic ice sheet is underway but is far from complete. The following actions should proceed in order to make a decision about which subglacial aquatic environments should be studied in the future:

- Continent-scale radio-echo sounding data should be assembled and subglacial aquatic environments identified;
- All regions where the basal melt-rate is likely high should be identified;
- Detailed radio-echo sounding of known lakes should be done;
- A hydrologic map of the subglacial drainage system for each catchment should be constructed;
- Potential target environments should be identified based on the subglacial drainage system.

Once potential research sites are identified, the likelihood of attaining scientific goals should be evaluated based on the representativeness for other lakes and settings, for accessibility, and for the constraints of logistics and cost. The committee recognizes that plans are underway to sample Lake Vostok, and in the longer term Lake Ellsworth and Lake Concordia. The data collected from these endeavors should be used to assess whether the levels of cleanliness suggested in Recommendation 7 are appropriate.

Recommendation 13

Research and development should be conducted on methods to reduce microbial contamination throughout the drilling, sampling, and monitoring processes, on methods to determine the background levels of microbes in glacial ice and lake water, and on development of miniaturized sampling and monitoring instruments to fit through the drilling hole. The following methods and technologies need to be improved or developed:

- A standard method to ensure cleanliness for drilling, sampling and monitoring equipment that can be verified in the field;
- New ways of drilling through the ice sheet that include drilling fluids that would not be a substrate for microbial growth;
- Inert tracers in the drill fluids or fluids used to enter the lake to track the level and distribution of contaminants within the lake;
- Methods to determine baseline levels of microbes in the glacial ice and subglacial waters;
- Instrumentation scaled to fit through a bore hole, to measure chemistry and biology of these environments and transmit data back to the ice surface;
- Methods to provide clean access to the lake water for extended periods. The committee recognizes that plans are underway to sample Lake

Vostok, and in the longer term, Lake Ellsworth and Lake Concordia. The data collected from these endeavors should be used to better assess the requirements of future methodologies and technologies.

4. SCAR ACTION GROUP

Following the publication of the report, the SCAR made a recommendation which was approved by the Delegates at XX SCAR that in recognition of "the value of these environments and the need to exercise wise environmental stewardship" a SCAR Action Group should be formed to devise a code of conduct that would provide "guiding principles for SAE exploration and research." The group was assembled by the SCAR Subglacial Antarctic Lake Exploration (SALE) committee and included members from that committee as well as external members. The resultant Action Group had broad disciplinary and international representation, with members from Japan, Russia, New Zealand, Italy, United Kingdom, Canada, and the United States. Three of the action group members also sat on the NRC committee.

The SCAR Action group drafted an SAE CoC, which drew heavily on the NAS report. At the time of writing this book chapter, the CoC had not yet been approved by the full SCAR membership, so we present here the version tabled for voting at the XXXI SCAR Delegates Meeting, Buenos Aires, Argentina, 9–11 August 2010.

CODE OF CONDUCT FOR THE EXPLORATION AND RESEARCH OF SUBGLACIAL AQUATIC ENVIRONMENTS

1. Background

This Code of Conduct (CoC) is to help guide the science community in the exploration and research of Antarctic subglacial aquatic environments (SAE). It has been prepared by an Action Group of the Scientific Committee on Antarctic Research (SCAR) in consultation with SAE specialists from a wide range of disciplines including the Committee of Managers of National Antarctic Programmes (COMNAP). SCAR has a long history of leadership in SAE research and development including the Subglacial Antarctic Lake Group of Specialists (SALEGoS 2000–2004) and the Scientific Research Program Subglacial Antarctic Lake Environments (SALE 2004 onwards). The present document results from a recommendation approved by the Delegates at XXX SCAR that in recognition of 'the value of these environments and the need to exercise wise environmental stewardship' a SCAR Action Group should be formed to devise a code of conduct that would provide 'guiding principles for SAE exploration and research'. The preparation of this CoC by the Action Group has drawn upon all relevant literature, with special attention to SALE reports and the US National Academies report on environmental stewardship of SAE. It will be modified and refined as new scientific results and environmental impact reports become available from planned SAE exploration campaigns.

2. Introduction

Antarctic ice is now widely recognised as a key constituent of the Earth System, driving ocean currents and global climate as well as strongly affecting world sea level. Early models for ice flow from the interior of the continent to the ocean assumed considerable friction between the bottom of the ice sheet and the underlying rock. The discovery of Lake Vostok and the subsequent detection of more than 380 other lake-like features beneath the ice changed our view of the subglacial environment. Drilling through ice to bedrock revealed the presence of water at the rock/ice interface whilst remotely sensed height changes in the ice surface over lakes suggested a discharge mechanism beneath the ice. From these and related observations, we must assume that the ice/rock interface may normally have free water present, that this water film may collect in lakes within watersheds, and that scientific activities that inadvertently contaminate one area may result in widespread contamination of this subglacial environment by down-slope flow. Much scientific attention is also focused on the possibility that this liquid water contains microbial communities that survive or grow in the extreme subglacial environment. To safeguard these unique lakes, and the subglacial aquatic environment as a whole, an internationally agreed upon Code of Conduct is essential. In developing this Code, SCAR is building on international discussions at SALE and on the US National Academies recommendations on environmental protection.

3. Guiding principles

3.1 Responsible stewardship during the exploration of subglacial aquatic environments should proceed in a manner that is consistent with the Protocol on Environmental Protection to the Antarctic Treaty, that minimizes their possible damage and contamination, and that protects their value for future generations, not only in terms of their scientific value but also in terms of conserving and protecting these pristine environments.

3.2 In accordance with the Protocol on Environmental Protection to the Antarctic Treaty, all proposed activities must undergo environmental impact assessment prior to an activity commencing. Projects aiming to penetrate into subglacial aquatic environments are certain to require an Initial Environmental Evaluation (IEE), and a subsequent Comprehensive Environmental Evaluation (CEE) may be the appropriate level of assessment given the potential impacts expected from such an activity. The CEE will ensure that all relevant information is available internationally, that proposals are exposed to a wide range of expert comment and that the scientific community uses best-available practices.

3.3 In accordance with the principle of scientific cooperation found in the Antarctic Treaty, multinational participation in SAE exploration is encouraged.

3.4 Exploration should take a conservative, stepwise approach in which the data and lessons learned at each step are archived and used to guide future environmental stewardship, scientific investigations and technology development. This information should be freely disseminated in the public domain, and firstly via national operators to the Committee on Environmental Protection.

3.5 It is recommended that each potential exploration site is evaluated within the context of geophysical datasets that identify lakes and other regions where there is basal melting. This would assist in typifying the unique character of each site and selecting drilling locations. Additional considerations related to location include accessibility, logistic constraints, cost and potential environmental impacts of the surface camp.

3.6 Accurate records should be collected, maintained and made freely available for all subglacial sampling efforts.

3.7 Annex V of the Protocol allows areas to be designated as Antarctic Specially Protected Areas (ASPA), either to manage areas for research purposes or to conserve them as pristine exemplars for future generations. Subglacial lakes used as research sites should therefore be demarcated ASPAs to protect their long term scientific value, to regulate activities at these sites, and to formalize the requirements for full documentation and information exchange. In this way, each lake researched will have a known history of usage that later researchers can take into account. Once more direct information is available about the characteristics of subglacial lakes, attention should also be given to selecting and designating exemplar subglacial aquatic environments as ASPAs for long term conservation, in accordance with Article 3 of Annex V of the Protocol.

4. Drilling and SAE-entry

4.1 Unless there is site-specific evidence to the contrary, drilling to the base of Antarctic ice sheets should assume that the basal ice is underlain by liquid water, and that this water forms part of a subglacial drainage network requiring a high level of environmental protection. In general, downstream sites, particularly those closest to the sea, can be viewed to have lower environmental risk than upstream sites.

4.2 Exploration protocols should also assume that the subglacial aquatic environments contain living organisms, and precautions should be adopted to prevent any permanent alteration of the biology (including introduction of alien species) or habitat properties of these environments.

4.3 Drilling fluids and equipment that will enter the subglacial aquatic environment should be cleaned to the extent practicable, and records should be maintained of sterility tests (e.g., bacterial counts by fluorescence microscopy at the drilling site). As a provisional guideline for general cleanliness, these objects should not contain more microbes than are present in an equivalent volume of the ice that is being drilled through to reach the subglacial environment. This standard should be re-evaluated when new data on subglacial aquatic microbial populations become available.

4.4 The concentrations of chemical contaminants introduced by drill fluids and sampling equipment should be documented, and clean drilling technologies (e.g., hot-water) should be used to the full extent practicable.

4.5 The total amount of any contaminant added to these aquatic environments should not be expected to change the measurable chemical properties of the environment.

4.6 Water pressures and partial pressures of gases in lakes should be estimated prior to drilling in order to avoid downflow contamination or destabilisation of gas hydrates respectively. Preparatory steps should also be taken for potential blow-out situations.

5. Sampling and instrument deployment

5.1 Sampling plans and protocols should be optimized to ensure that one type of investigation does not accidentally impact other investigations adversely, that sampling regimes plan for the maximum interdisciplinary use of samples, and that all information is shared to promote greater understanding.

5.2 Protocols should be designed to minimize disrupting the chemical and physical structure and properties of subglacial aquatic environments during the exploration and sampling of water and sediments.

5.3 Sampling systems and other instruments lowered into subglacial aquatic environments should be meticulously cleaned to ensure minimal chemical and microbiological contamination, following recommendations under point 4.3.

5.4 Certain objects and materials may need to be placed into subglacial aquatic environments for monitoring purposes. This may be to measure the long term impacts of human activities on the subglacial environment and would be defined in the project's environmental impact assessment, or it may be for scientific purposes; e.g., long term monitoring of geophysical or biogeochemical processes. These additions should follow the microbiological constraints in 4.3, and for scientific uses should include an analysis of environmental risks (e.g., likelihood and implications of lack of retrieval) versus scientific benefits in the environmental assessment documents.

Members of the SCAR Action Group:

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5. ONGOING DEVELOPMENTS

At the time of writing this chapter, there are three projects underway with the goal of exploring SAEs: (1) the Russians have plans to penetrate into Lake Vostok; (2) a U.K.-led international consortium is planning to enter into subglacial Lake Ellesworth; and (3) the United States has initiated efforts to penetrate and sample beneath the Whillans Ice Stream in West Antarctica. The Russian effort in Lake Vostok went through the CEE process prior to the NAS report and CoC. The UK group at Lake Ellesworth is preparing a CEE and has been making extensive use of both the NRC report and the CoC in that process. They are currently evaluating the levels of cleanliness they will be targeting (R. Clarke, personal communication, 2009). The U.S. group (Whillans Ice Stream Subglacial Access Research Drilling) has also found the NRC report and CoC to be a valuable resource. The United States is preparing an IEE to cover the project in its various phases, rather than deciding ahead of time that the impact will be more than minor or transitory. If they determine that there will be significant impacts, they will work on developing mitigating measures (i.e., engineering controls, management strategies, changing the scope of the operations, etc.) to offset the risks. If the risk(s) cannot be mitigated, then the United States will proceed with a CEE (P. Penhale, personal communication, 2009).

6. CONCLUSIONS

The Protocol on Environmental Protection to the Antarctic Treaty sets general principles and requirements that provide an overarching framework for the stewardship and protection of Antarctic SAEs. Antarctica contains many unusual surface water features, and at several continental and maritime sites, these more readily accessed aquatic environments have been accorded more specific protection through instruments associated with the Protocol. These include detailed management plans, designation of specially protected areas, and the implementation of environmental codes of conduct. There has been little attempt, however, to standardize these protocols across sites, and the sharing of best environmental codes and practices deserves further attention, for example, by the Committee of Managers of National Antarctic Programs.

Building on the NSF-led stewardship of surface aquatic environments and the work of the SCAR SALE group, the NAS Committee report provided steps toward the integrated management of SAEs throughout Antarctica, including specific recommendations and a flow chart for environmental decision making. This, in turn, laid the foundation for a CoC formulated by a SCAR Action Group and now submitted via SCAR to the Antarctic Treaty System. In all of these ongoing efforts, the quality and extent of stewardship depends on input from many disciplines and continued exchange and collaboration among nations.

Exploration of SAEs is still in its infancy, and many fundamental questions remain to be answered about these unique environments. Direct sampling has yet to occur and will need to take place before we get answers to these questions and resolve the ongoing debate about the existence and nature of life in these extreme environments. The potential for there to be a unique flora and fauna in pristine SAEs dictates that extreme caution must be taken in logistics and science planning in order to follow proper guidelines for environmental stewardship. The NRC report and subsequent CoC reviewed here are first and necessary steps in laying the groundwork for proper, long-term environmental management of SAEs.

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