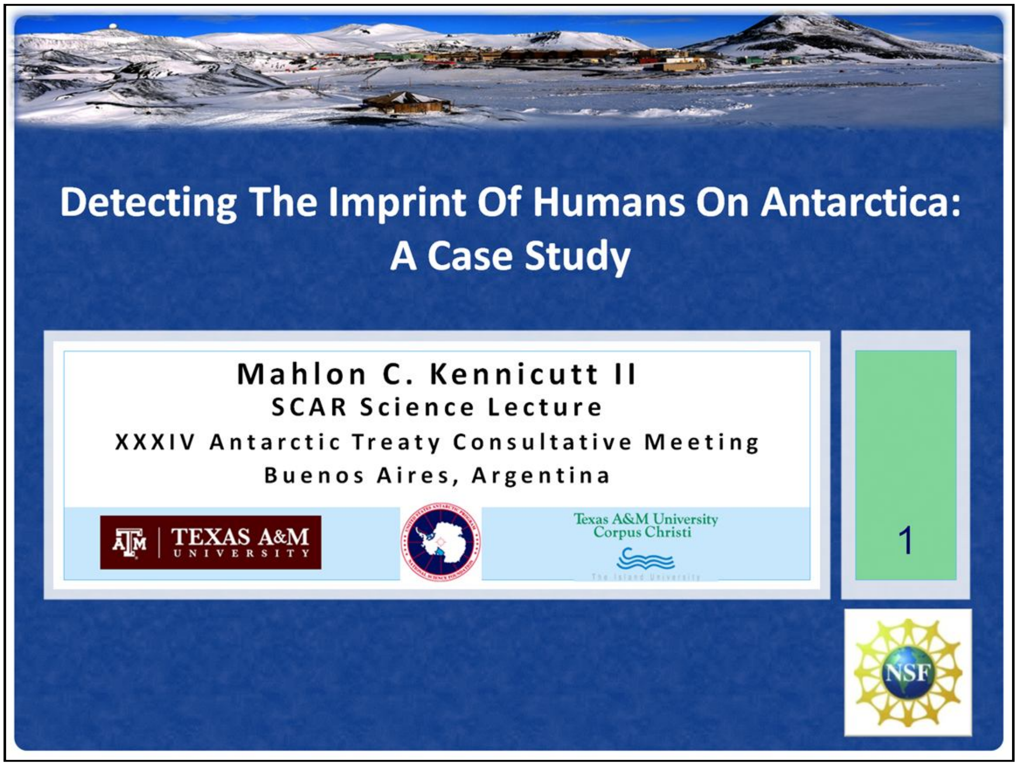


I appreciate the opportunity to talk to you today about an important issue that is currently before the Committee on Environmental Protection and a matter of interest for all Antarctic Treaty Parties. The topic is monitoring and how it can be used to support environmental stewardship efforts in Antarctica. As you will see when I review the history of various agreements, conventions, and protocols regarding environmental protection, monitoring is a critical element of environmental stewardship.

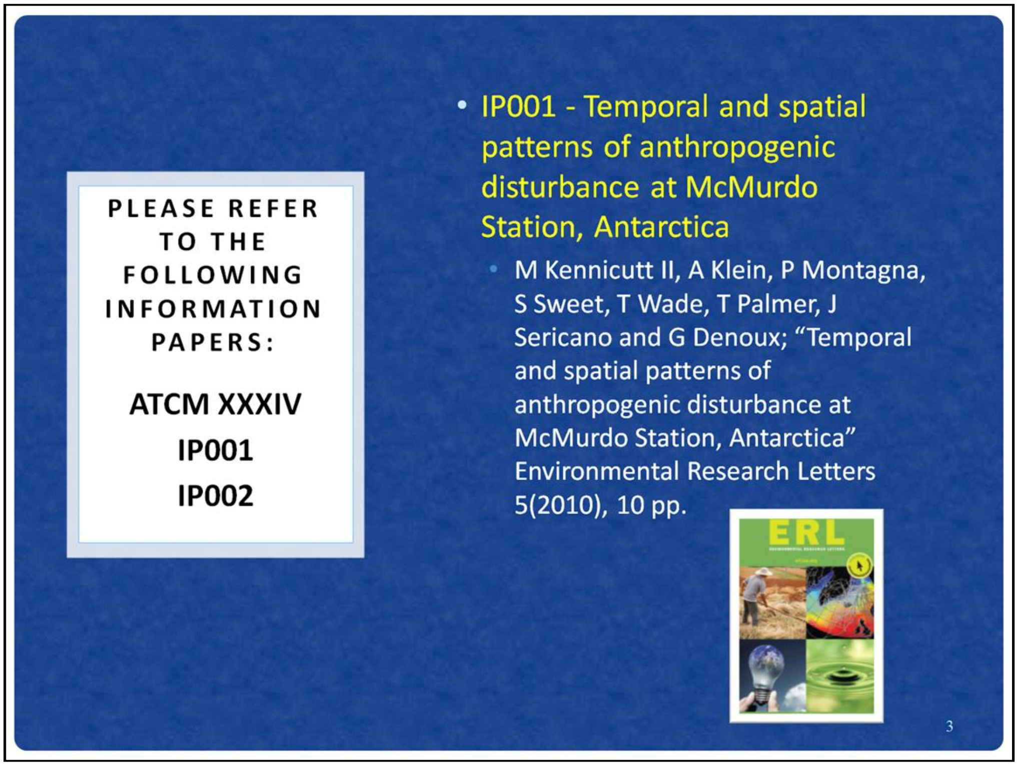
In the simplest sense, monitoring, or observing, is essential to provide information not only about impact once it has occurred but also as a tool to assess if management actions are having the wished for affects. Without such methodical observations, effective protection, mitigation and remediation are not possible. Monitoring programs are intended to establish the status of and trends in the impact of humans on the environment.

A fundamental concept underlying environmental monitoring is that the presence of humans produce deleterious changes in the surrounding environment that can be measured. Natural environments are intrinsically variable and if monitoring is to be effective, natural variability must be separated from change caused by the presence of humans. The Antarctic environment is particularly variable so it is critically important that long term observations be collected based on a statistically robust design in order to unambiguously recognize change due to human disturbance.

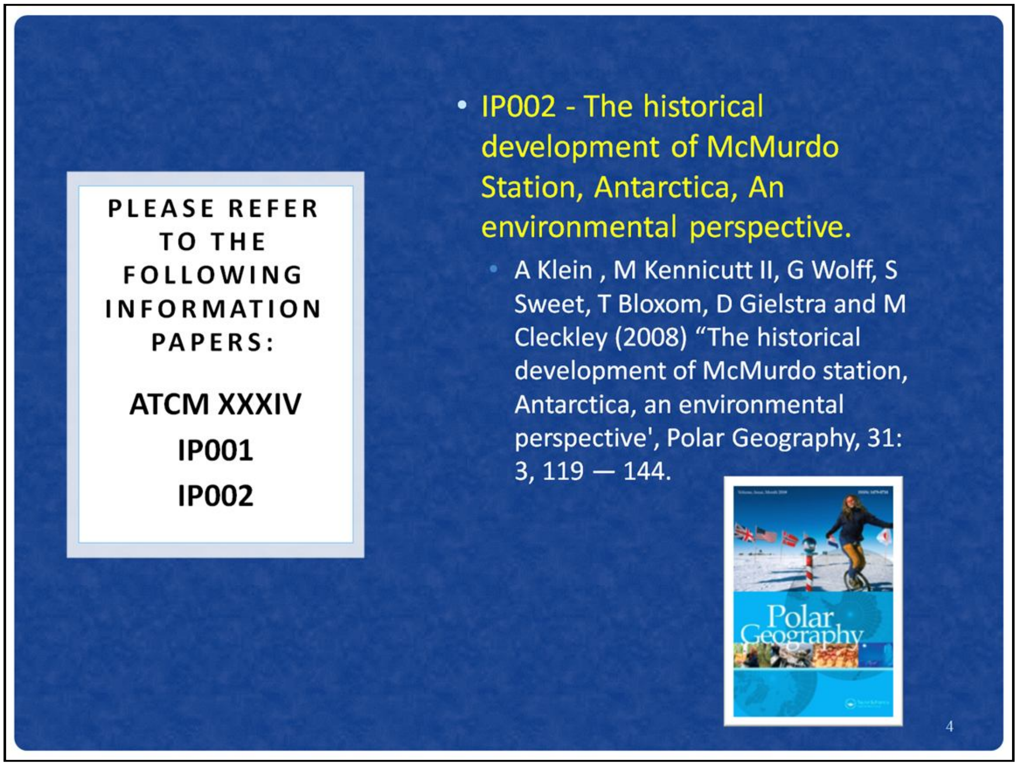
There is a long history of environmental monitoring design efforts in temperate climates that is relevant o designing monitoring activities in Antarctica. While these approaches need to be customized to the special circumstance of monitoring in harsh, polar climates - the basic underlying principles can be directly used to design effective environmental monitoring programs in Antarctica.

Today I will present the results from nearly 10 years of environmental monitoring conducted at the largest scientific station in Antarctica, McMurdo Station, and summarize the lessons learned and their implications for monitoring of human activities throughout Antarctica.

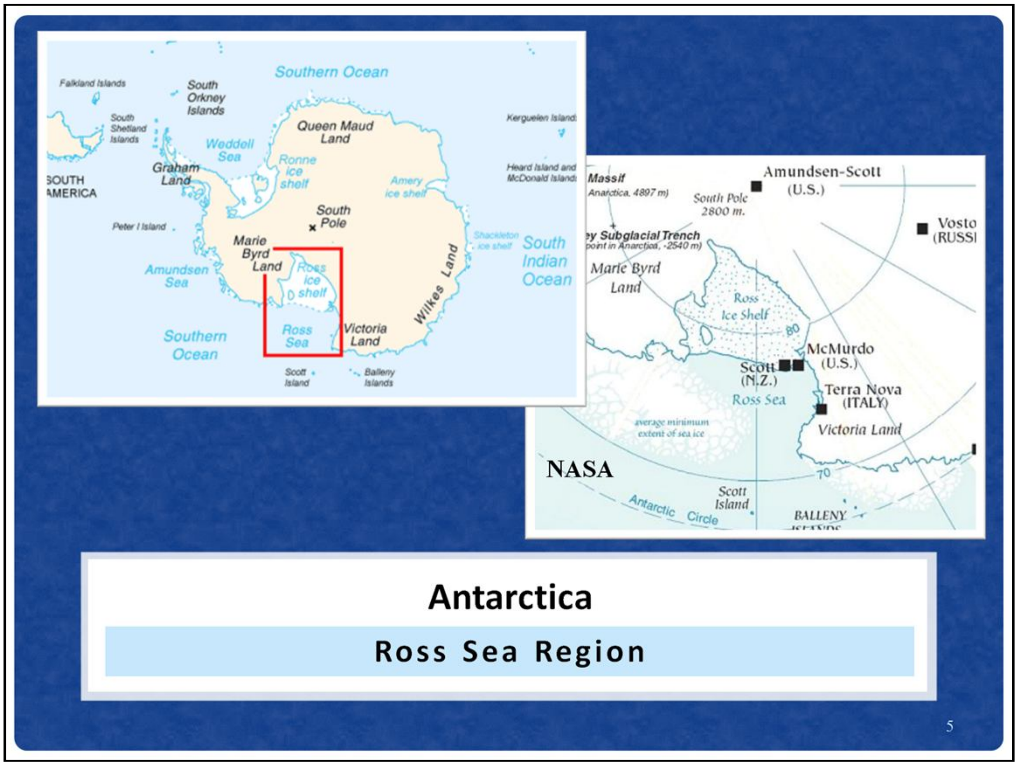
The work to be presented was financially supported by the Environmental, Safety, and Health Section of the Office of Polar programs at the National Science Foundation. I thank them for their support over the years. Contracting ser ies were provided through the US Army Corp of Engineers Cold Regions Research and Engineering Laboratory.



I call your attention to Information Papers 1 and 2 that include, as an addendum, peer-reviewed published papers containing details about the results presented here. I also want to recognize the my co-authors who were participants in this program. The first paper was recently published on-line in Environmental Research Letters.

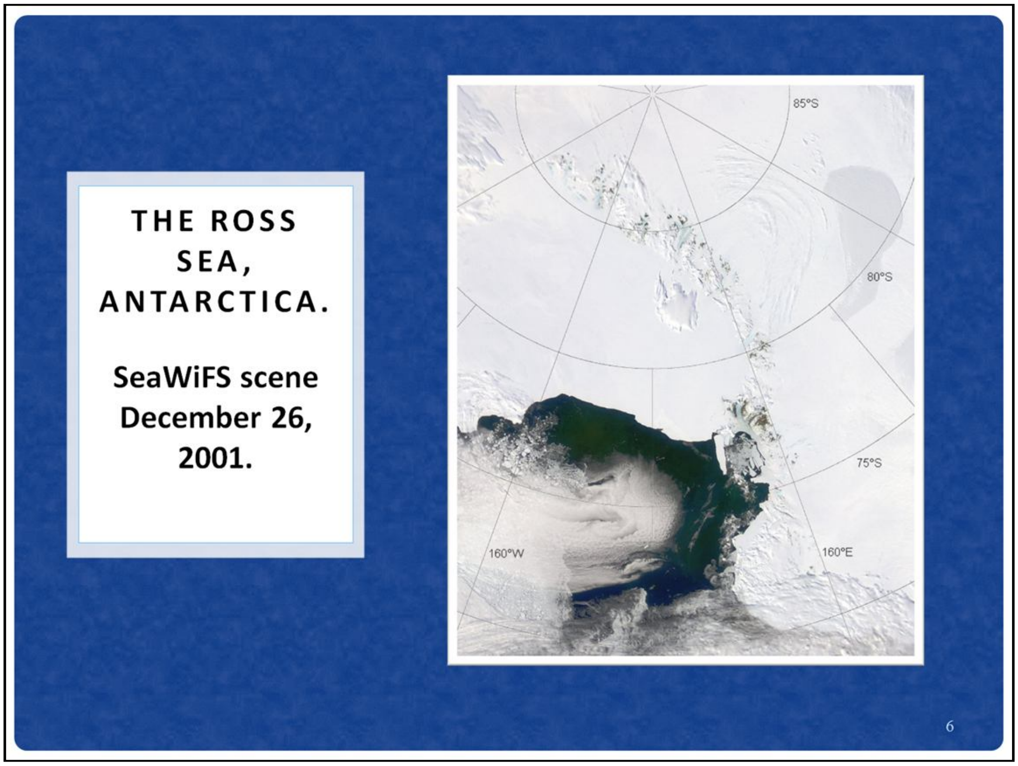


The second paper was published in 2008 in Polar Geography.

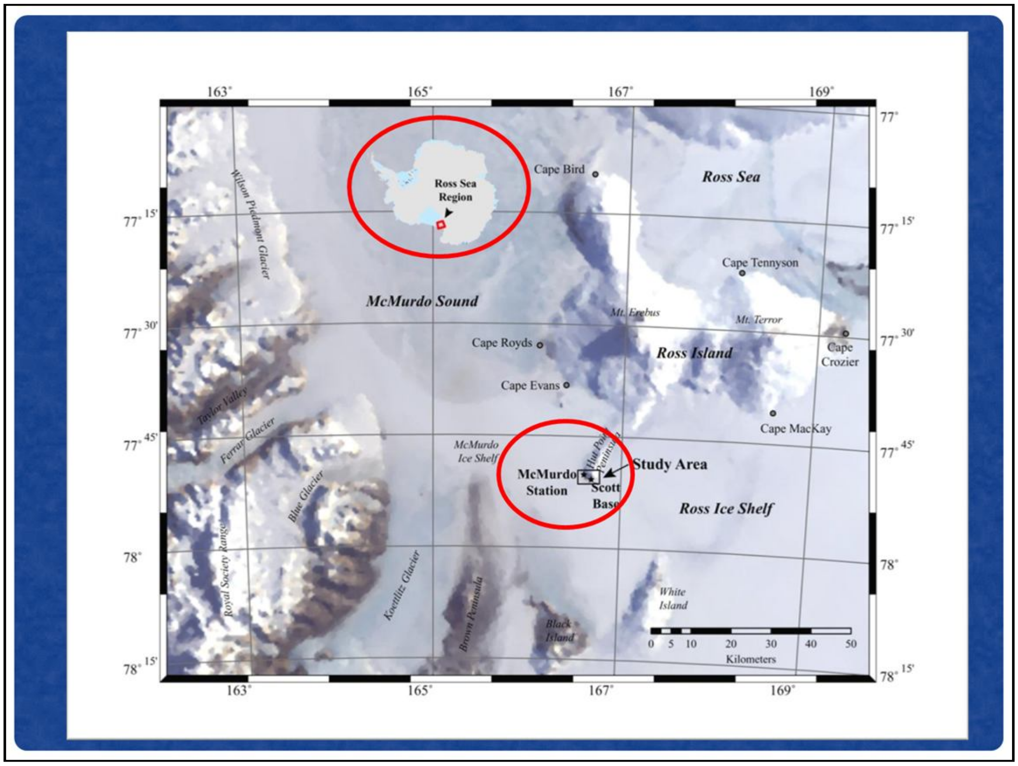


To set the scene, McMurdo Station is in the Ross Sea region. The Ross Sea is a deep bay of the Southern Ocean between Victoria Land and Marie Byrd Land. It was discovered by James Ross in 1841. The southern part is covered by the Ross Ice Shelf.

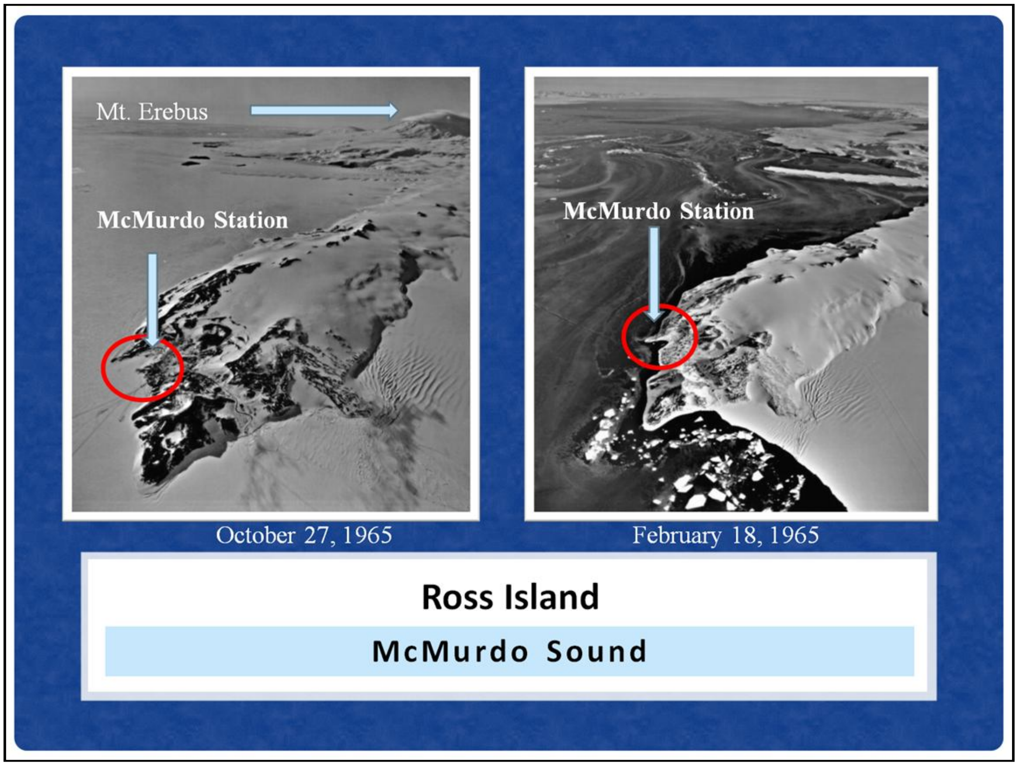
Many of the heroic Age Expeditions were launched from this area including the that of Roald Amundsen who started his South Pole expedition 100 years ago in 1911 from the Bay of Whales.



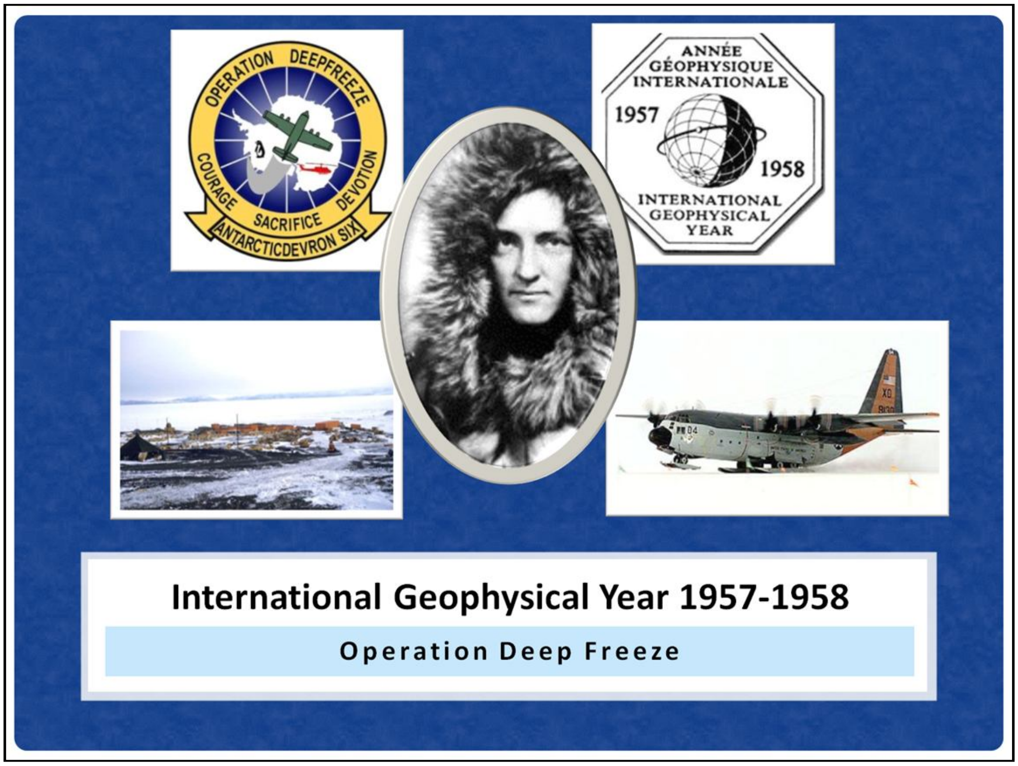
This image shows a rare clear view of the South Pole and the Ross Sea, Antarctica. The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) acquired the scene on December 26, 2001.



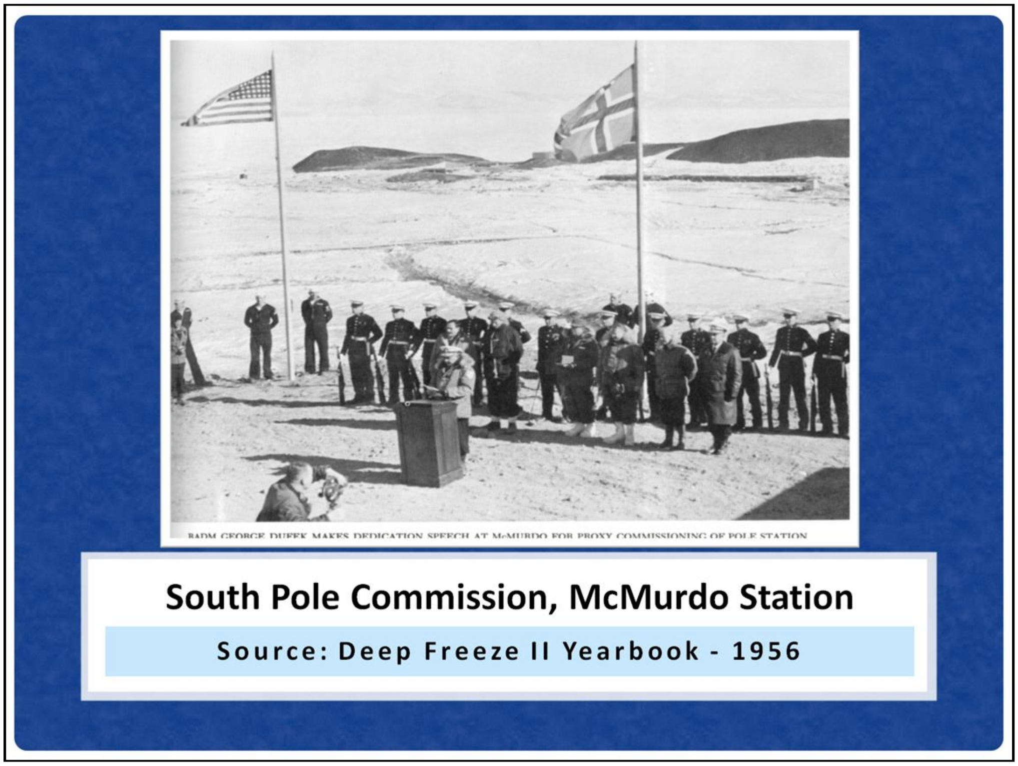
McMurdo Sound, named after Lt. Archibald McMurdo of HMS Terror, opens to the Ross Sea to the north. The McMurdo Ice Shelf is the Sound's southern boundary and less than 10 percent of McMurdo Sound's shoreline is ice-free. Ross Island is the eastern boundary of McMurdo Sound served in the past as a jumping-off point for polar explorers.



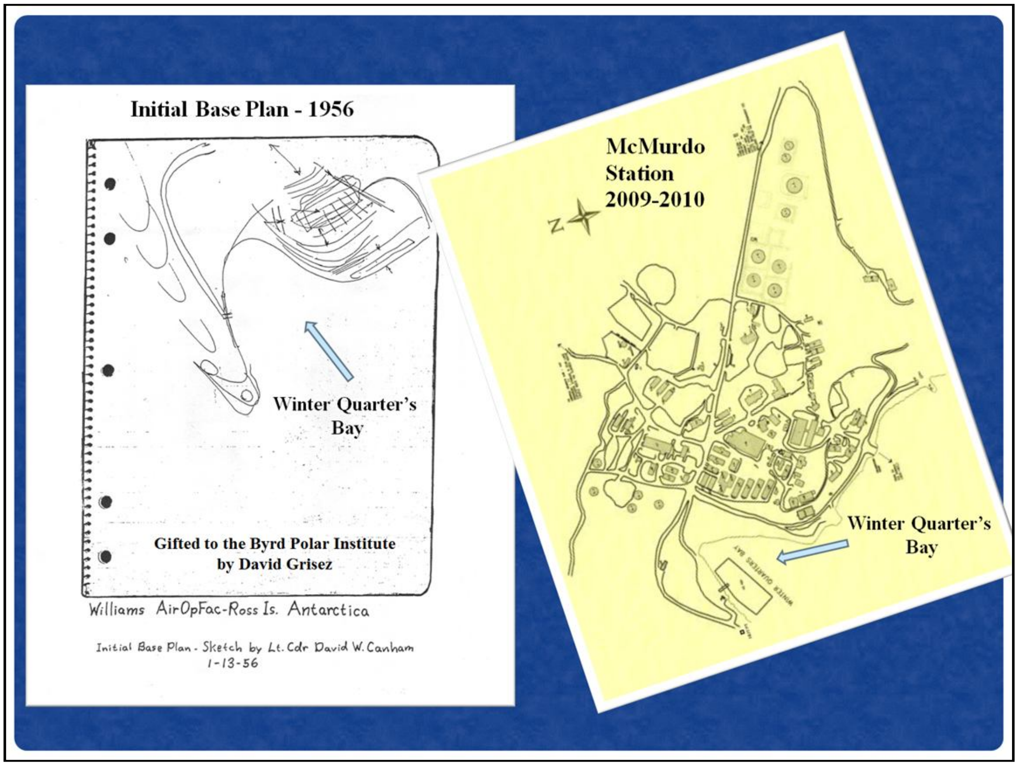
Ross Island is dominated by the active volcano Mt Erebes at 12,448 feet (3,794 m) . In the west of the Ross sea, McMurdo Sound which can be free of ice during the summer. The images are oblique Trimetrogon Photographs taken in 1965. Coastal ice conditions can be highly from year to year. Antarctica's largest science base, the United States' McMurdo Station, as well as New Zealand's Scott Base are located on the island's south shore.



While human presence on Ross Island dates to the early 20th century, the modern era of human occupation of McMurdo Station area begins with preparation for the International Geophysical Year in the mid- 1950's. Operation Deep Freeze is the codename for a series of United States missions to Antarctica beginning with "Operation Deep Freeze I" in 1955–56. Given the continuing and constant US presence in Antarctica, "Operation Deep Freeze" has come to be used as a general term for US operations in the area and includes regular missions to resupply US Antarctic bases. The impetus behind Operation Deep Freeze I was the International Geophysical Year 1957–58. IGY. Operation Deep Freeze I prepared a permanent research station and paved the way for more exhaustive research in later Deep Freeze operations. The expedition transpired over the Antarctic summer of November 1955 to April 1956.

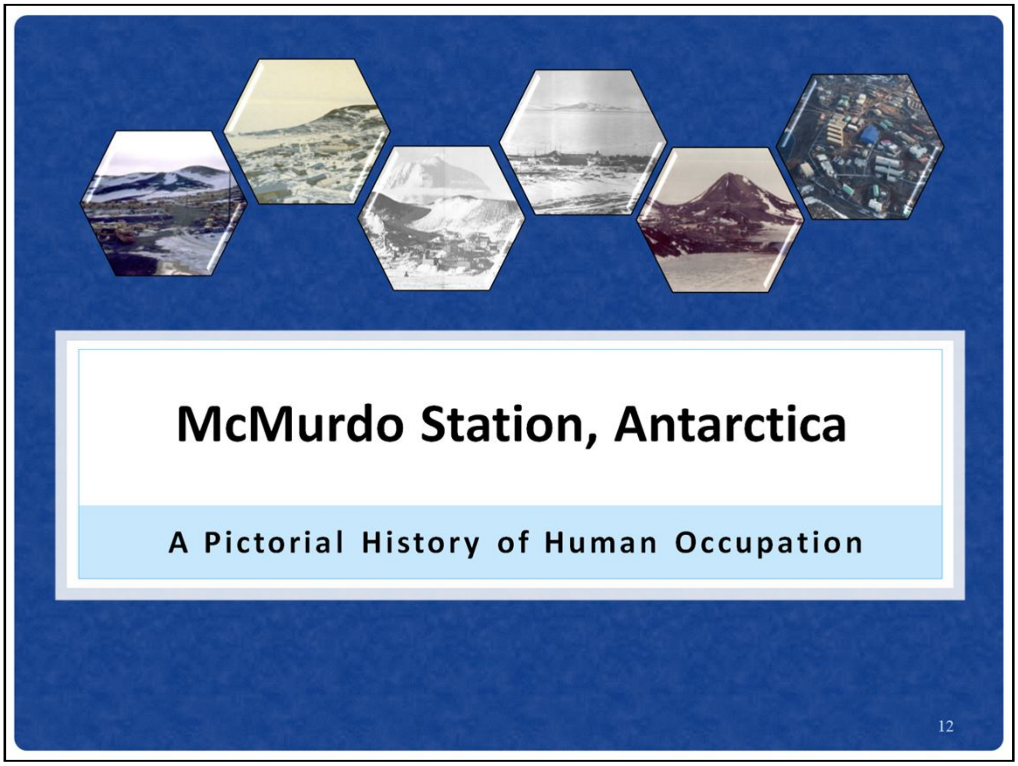


Operation Deep Freeze I prepared a permanent research station and paved the way for more exhaustive research in later Deep Freeze operations. The expedition transpired over the Antarctic summer of November 1955 to April 1956. Pictured here is Rear Admiral George Dufek making the dedication speech for establishment of South Pole Station in McMurdo Station in 1956. The United states maintains 3 year-round stations in Antarctica with McMurdo Station being the hub for US activities in Antarctica.



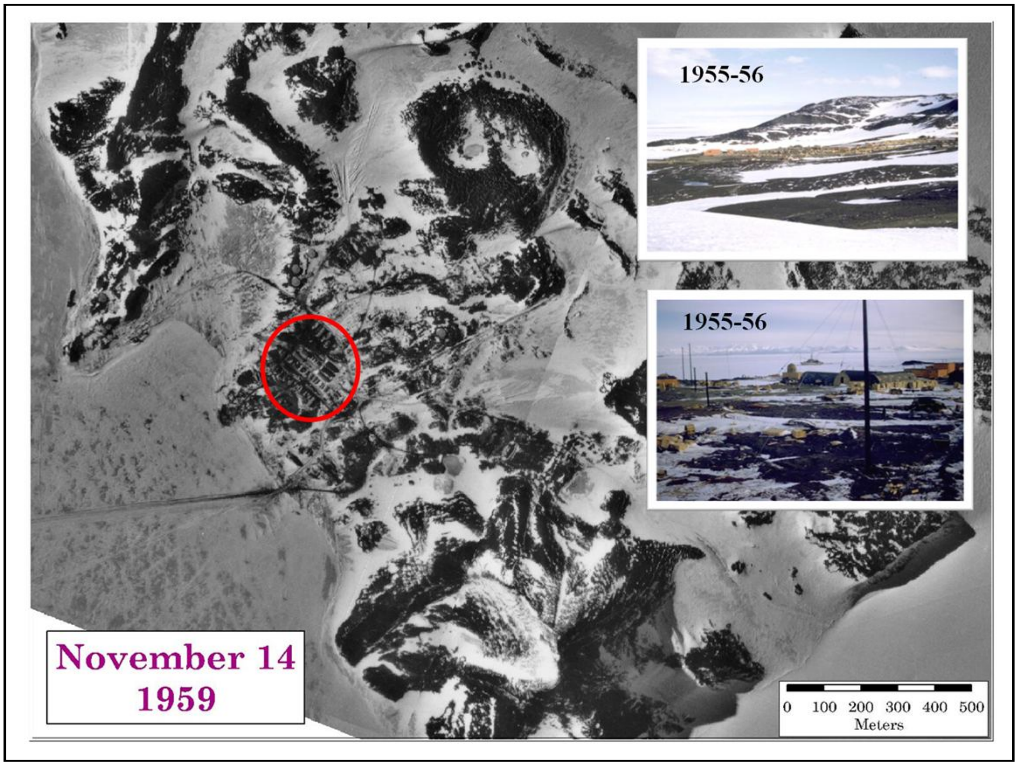
This slide presents the original hand drawn plan for McMurdo Station on the shores of Winter Quarters Bay in 1956. Next to it is the detailed graphic of the McMurdo Station configuration in 2009-2010. The following presentation provides a review of development in the area over the more than 50 years since the IGY and the resultant changes in the environment due to the presence of humans.

The USA began permanent occupation of the site in December 1955, establishing Naval Air Facility McMurdo as a logistics base from which to construct and support a research facility at the geographic South Pole during the 1957/1958 International Geophysical Year (IGY) (Sullivan 1957). Following the IGY, this base, renamed McMurdo Station in 1961, has continued to be the central science and operations facility of the US Antarctic Program (USAP).



Historical photography can used to establish a visual picture of the evolution of McMurdo Station. It also provides a long term view of the Station that pre-dates the environmental monitoring program. The photographic record can also be digitized and converted to a quantitative record of various attributes of the station such as length of roads and area of buildings. The following series of photographs will walk you through more than 50 years of McMurdo Station history.

The format of each slide is first an aerial photograph with a red circle used to place yourself geographically within the Station area. These are followed by pictures from ground level to give you a feeling for what the Station looked like from eye level perspective. On occasion a feature is identified and circled on both photographs to place you geographically. The date of the aerial photograph is identified in the lower left hand corner and the ground level photographs are labeled accordingly.



THE EARLY YEARS

McMurdo Station is Antarctica's largest community. It is built on the bare volcanic rock of Hut Point Peninsula on Ross Island, the farthest south solid ground that is accessible by ship

Air photos prior to the year 2000 are part of the collection of over 500,000 aerial photographs held by the USGS the Polar Geospatial Center. A member of our team visited the ARCcenter at the USGS in Reston and went through their complete aerial photography collection of the station and selected the best I

images of the station to use for the study.

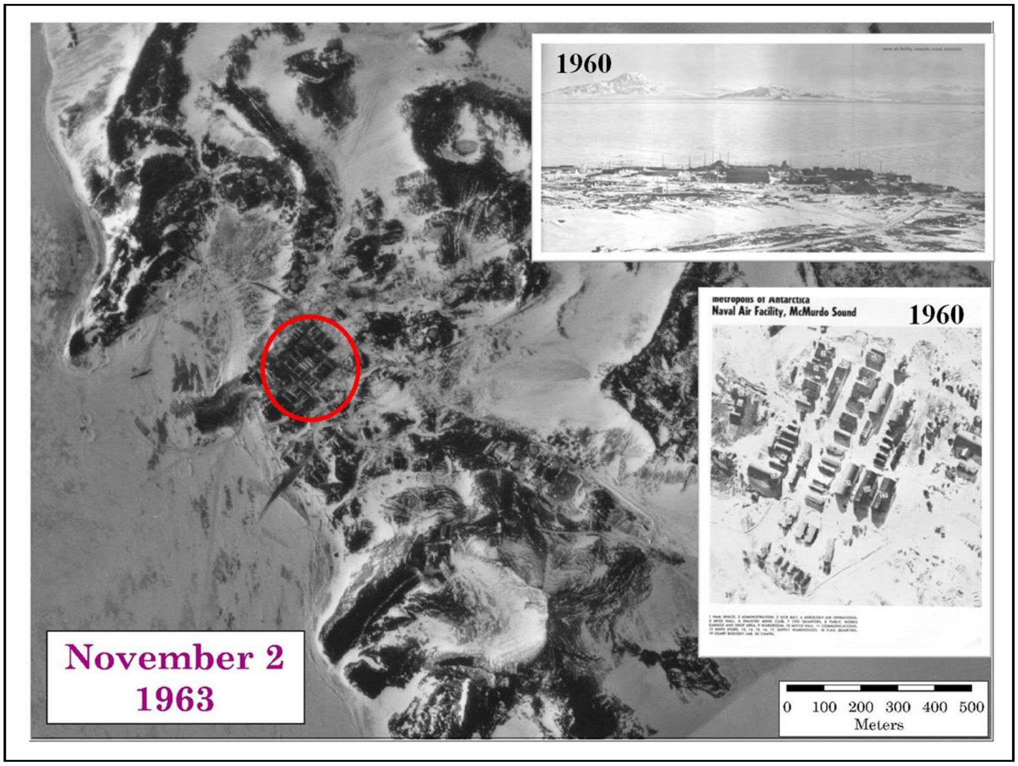
The images were geolocated to create aerial photo image mosaics of the station at a number of times in its history. Many of the photographs were taken with a 3 camera system was used to collect 1 vertical and 2 oblique photographs to provide horizon to horizon views (called trimetrogon photographs).

Ground level photographs come from a variety of sources. Some are from Operation Deep Freeze Yearbooks and others terrestrial photographs from an online historical photography collection assembled by the US Antarctic Program.

A number of Ob hill shots came from Bill Spindler who produces the southpolestation.com website.

Some of the 1955-1956 photographs came from a collection given to the Byrd Polar Institute Library by David Grieze.

R.L. Horton a member of the Old Antarctic Explorers Association has also kindly provided some images and aerial shots he made

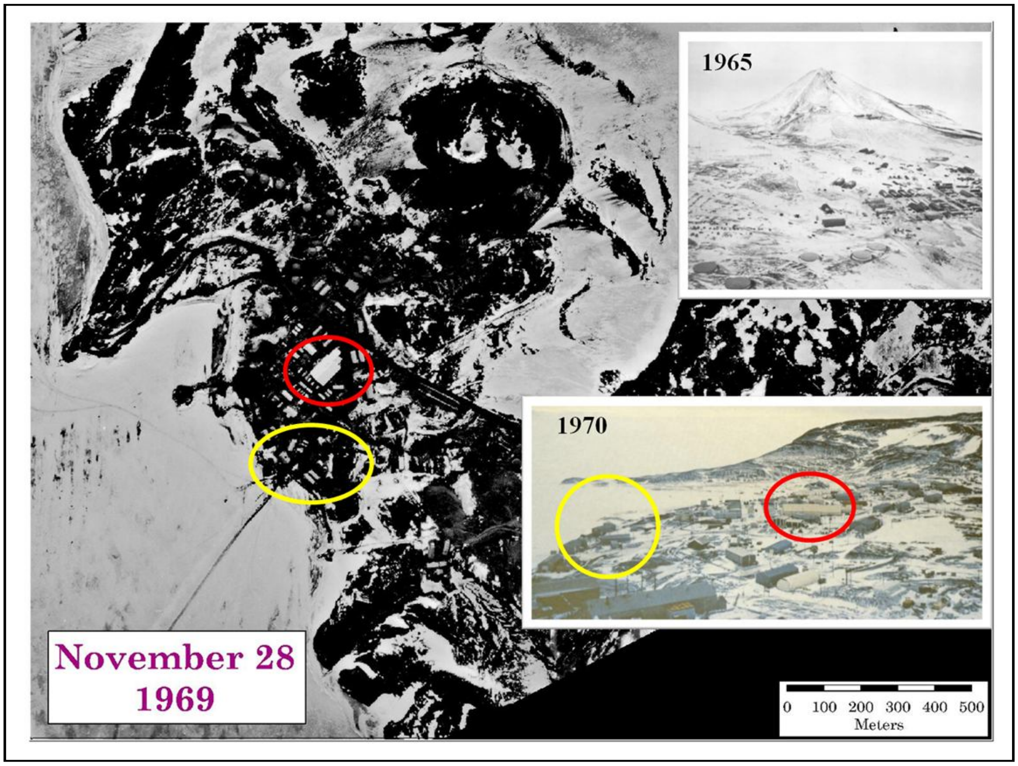


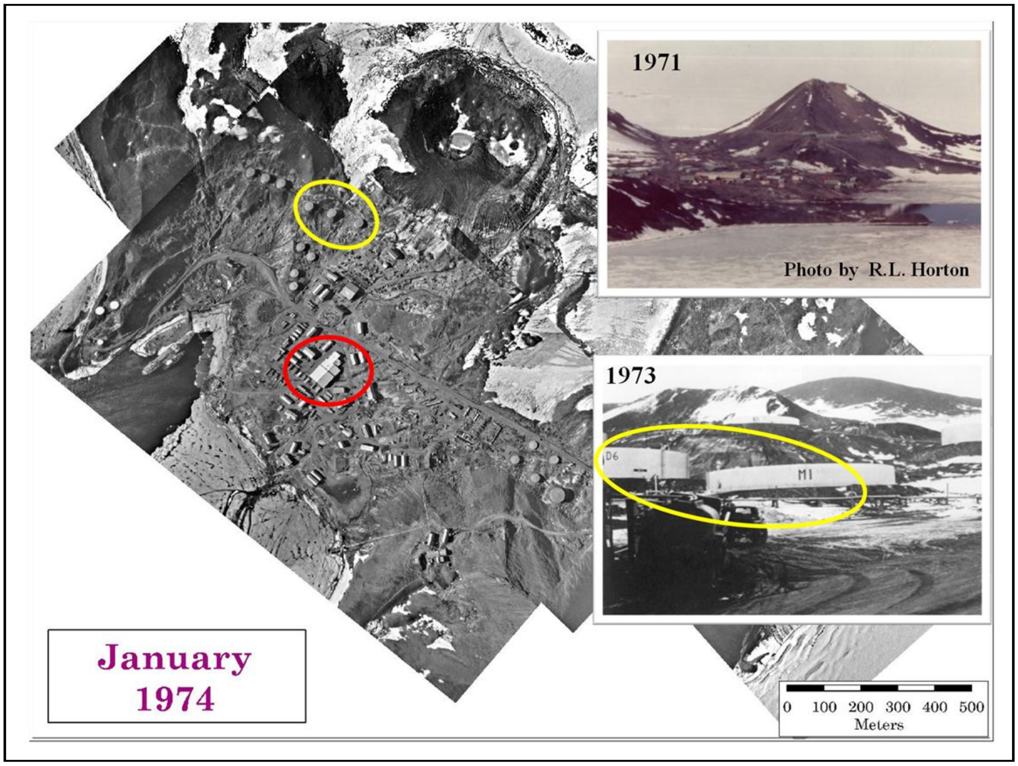
THE EARLY YEARS – Beginning of permanent buildings

Established in 1956, it has grown from an outpost of a few buildings to a complex logistics staging facility of more than 100 structures including a harbor, an outlying airport (Williams Field) with landing strips on sea ice and shelf ice, and a helicopter pad.

Ground level pictures in 1960 – Called the Naval Air Facility, McMurdo Sound

Arial view November 1963


1965
1970
November 28
1969
0 100 200 300 400 500
Meters


1971
Photo by R.L. Horton
1973
D6
M1
January
1974
0 100 200 300 400 500
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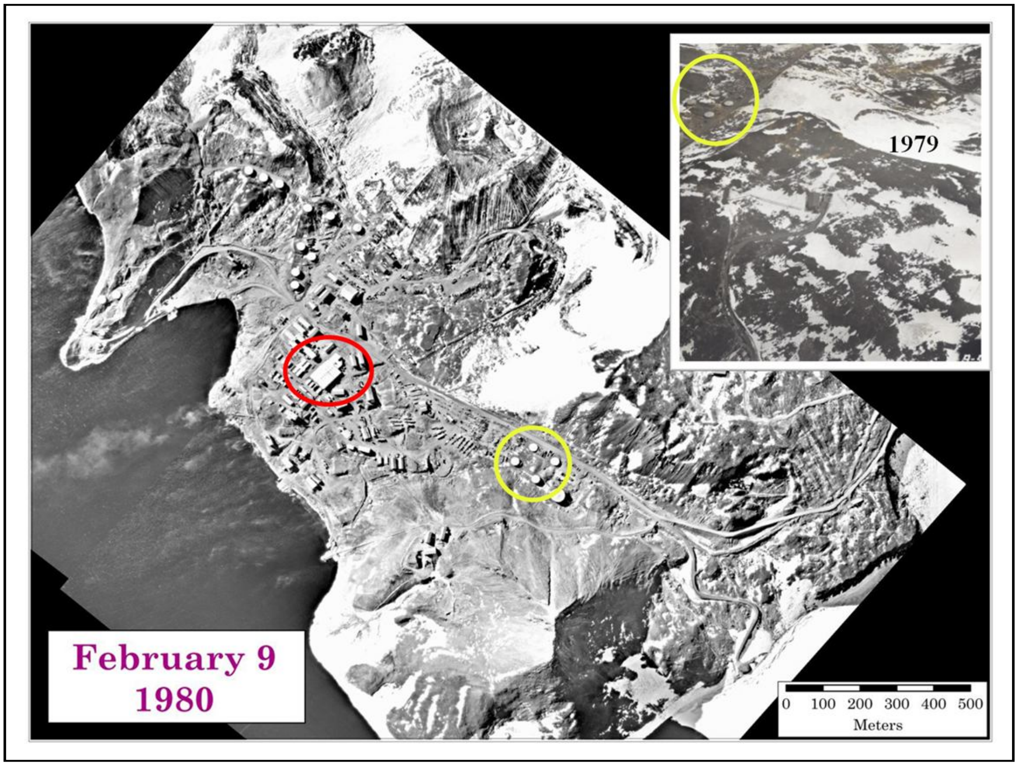
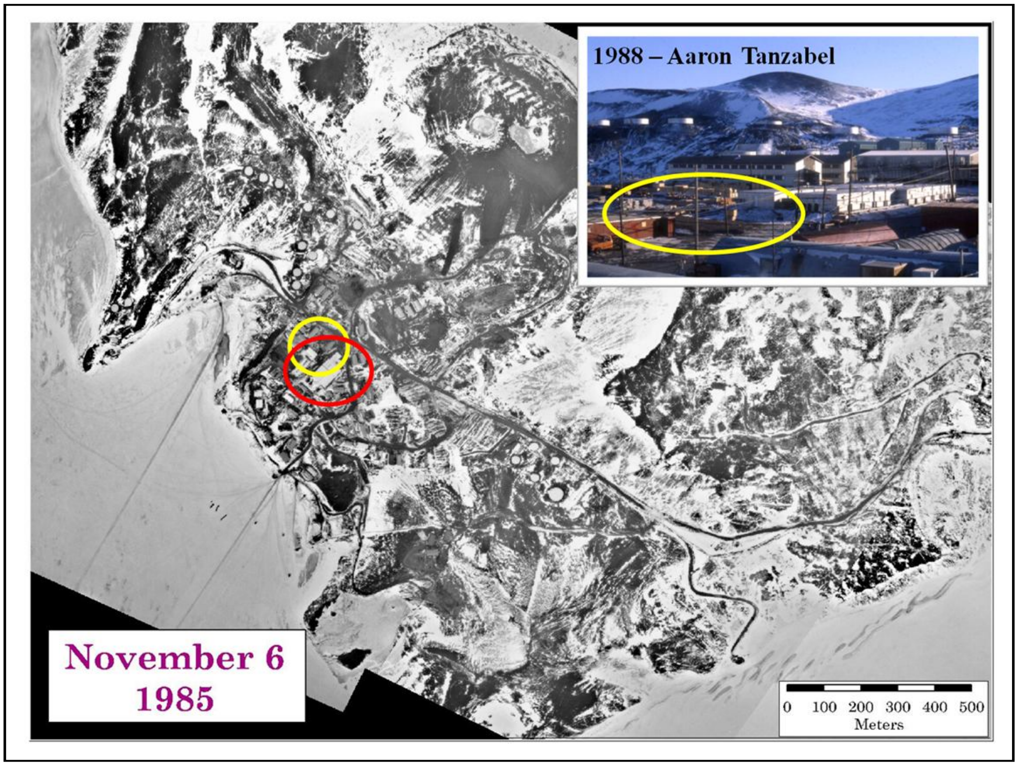
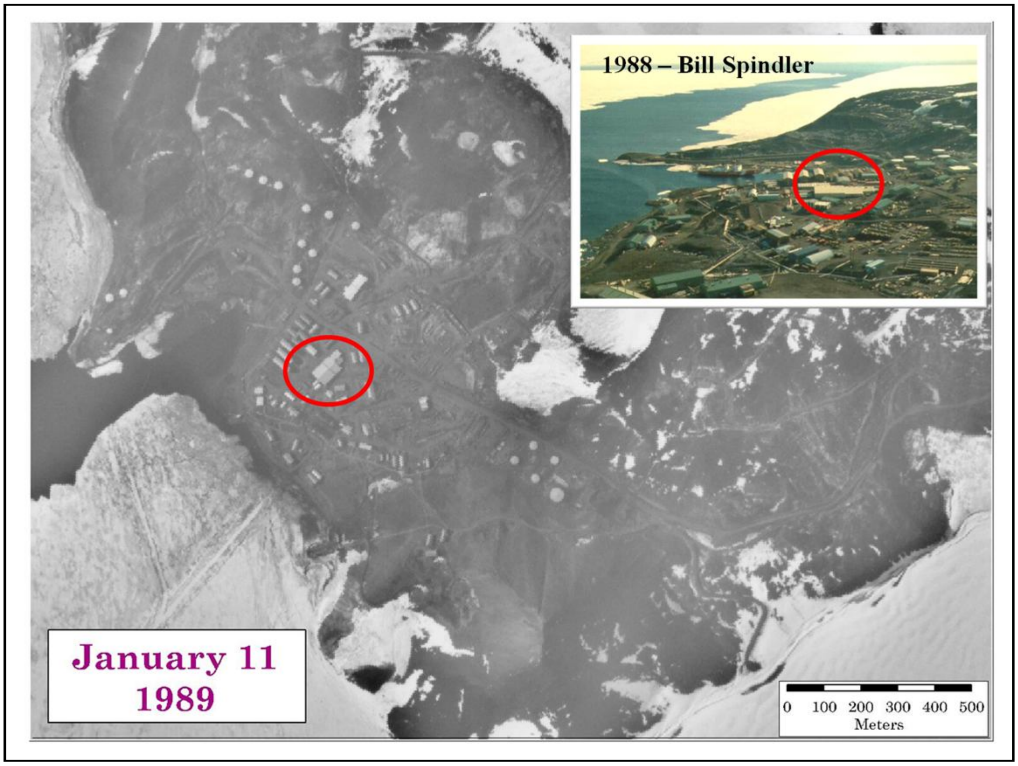
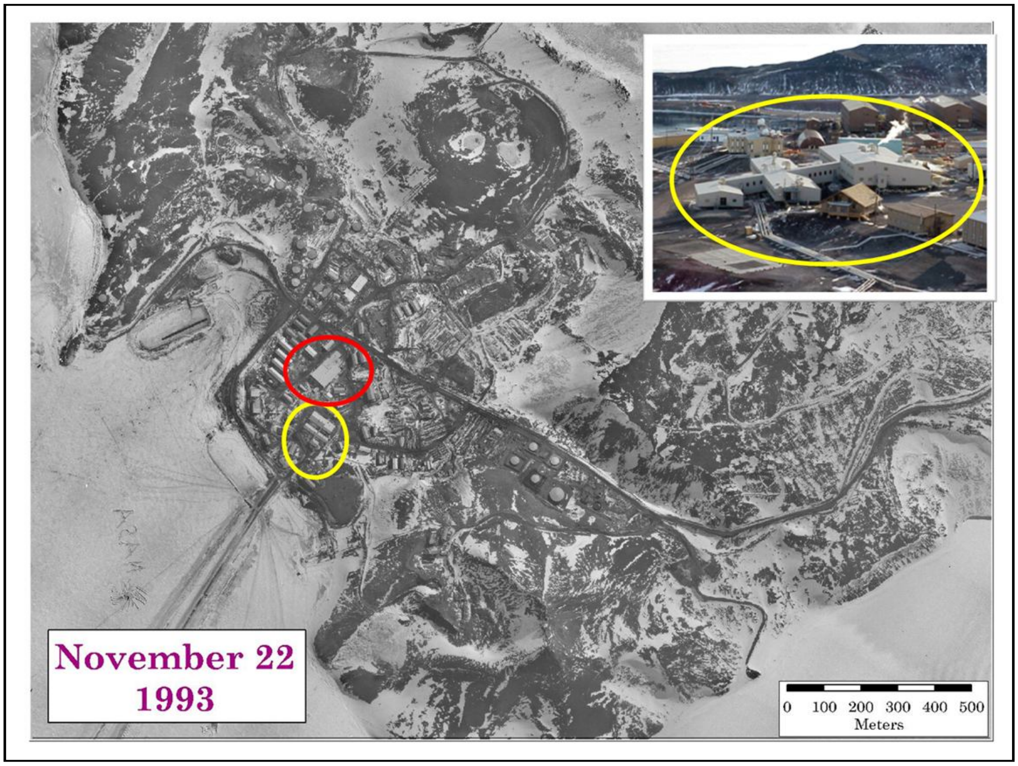


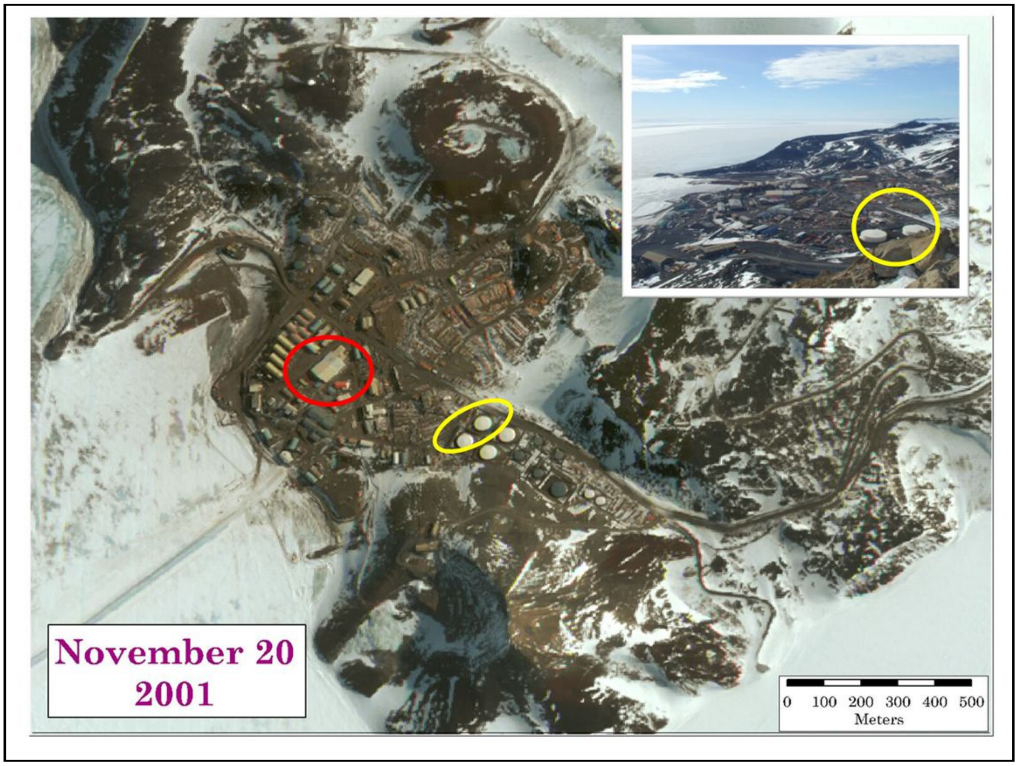
Fix This ONE!


1988 – Aaron Tanzabel
November 6
1985
0 100 200 300 400 500
Meters

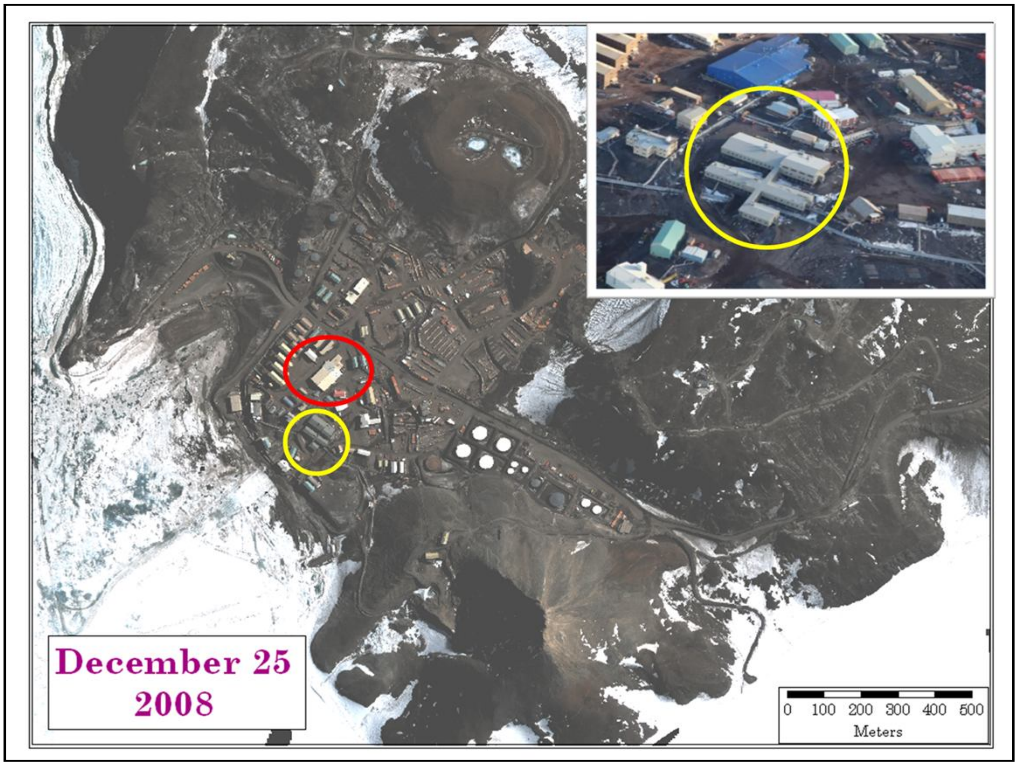

1988 – Bill Spindler
January 11
1989
0 100 200 300 400 500
Meters



The Albert P. Crary Science and Engineering Center at McMurdo Station was dedicated in November 1991. The laboratory is named in honor of geophysicist and glaciologist Albert P. Crary (1911-1987), the first person to set foot on both the North and South Poles.The laboratory contains state-of-the-art instrumentation to facilitate research and to advance science and technology. It contains modern personal computers and workstations, a computer-based geographic information system (GIS), and a local area network. It has laboratory space, analytical instrumentation, and staging areas for a wide range of scientific disciplines. The laboratory also supports special activities, including environmental monitoring, snow and ice mechanics, and meteorology. The facility replaces outdated science buildings that were built as early as 1959.



Images later than 2001 were acquired from the Quickbird Satellite by Digtial Globe. The 2010 aerial photograph came from the I drive at McMurdo and the origins are unknown.


December 25
2008
0 100 200 300 400 500
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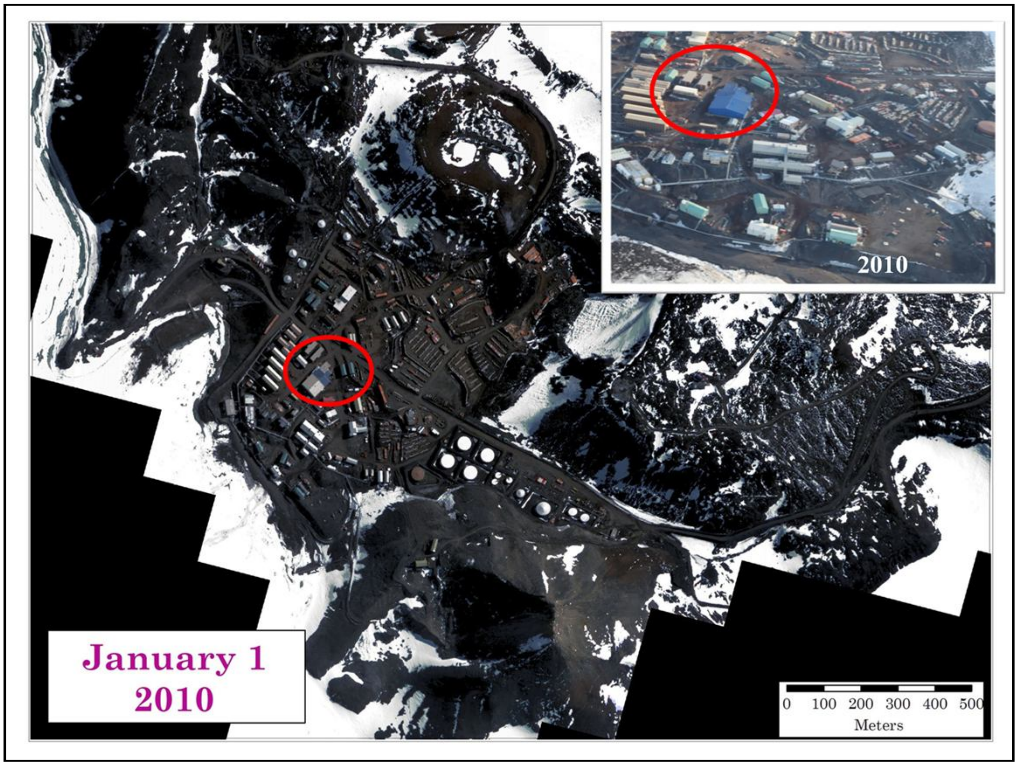
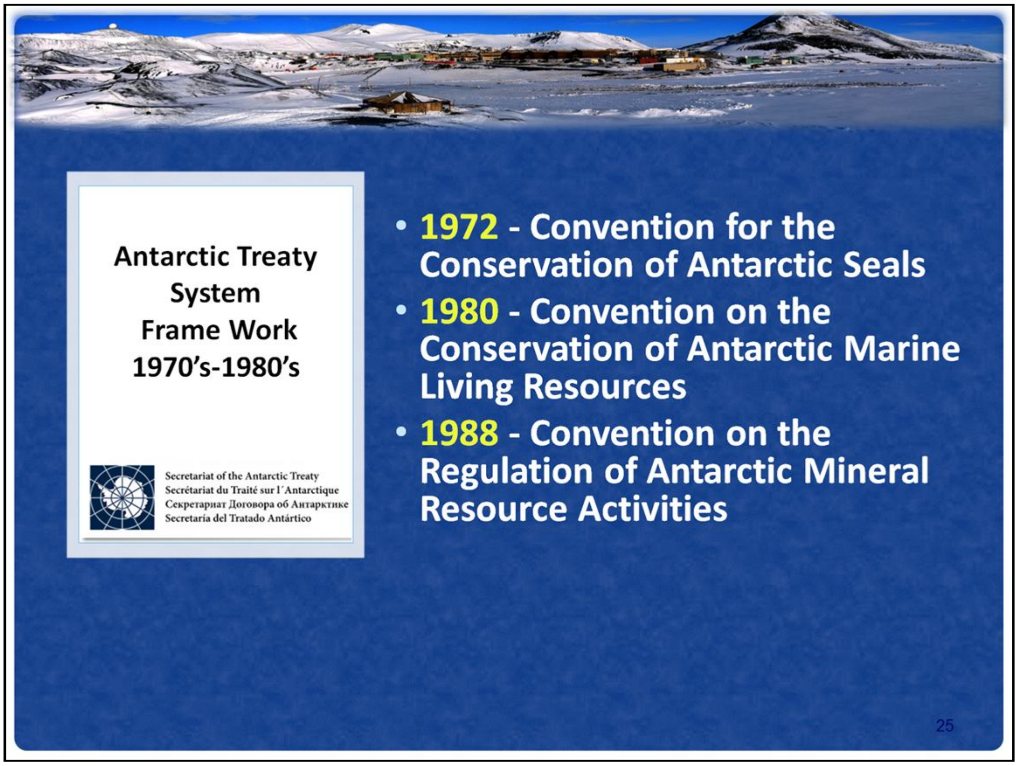
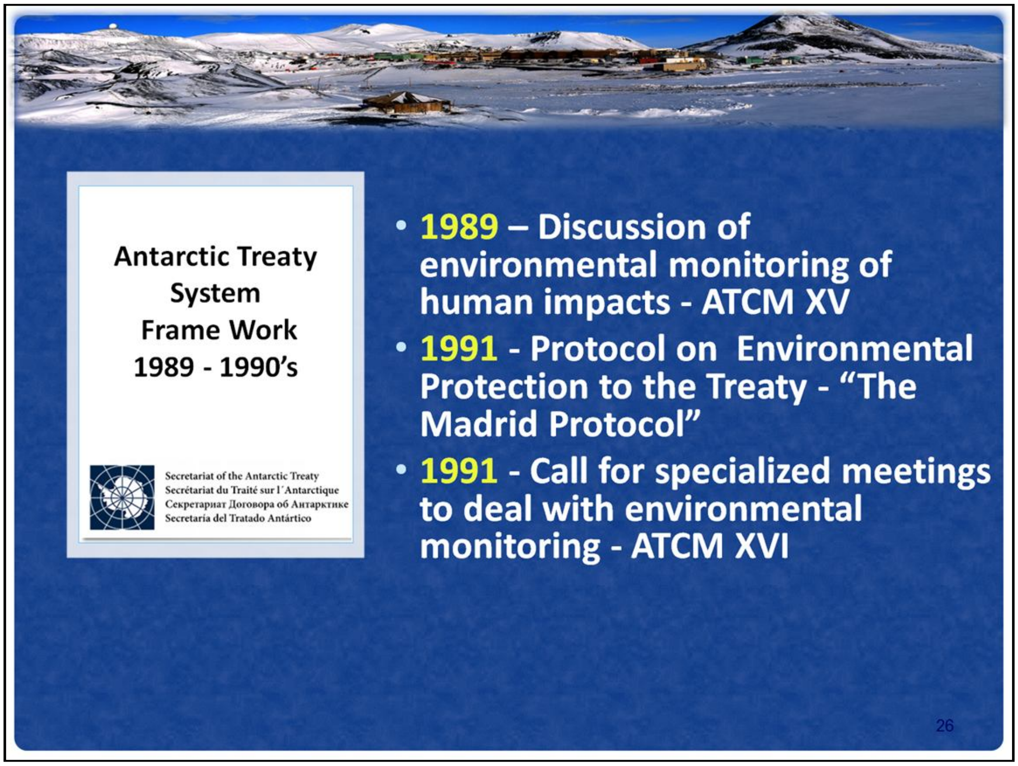

2010
January 1
2010
0 100 200 300 400 500
Meters

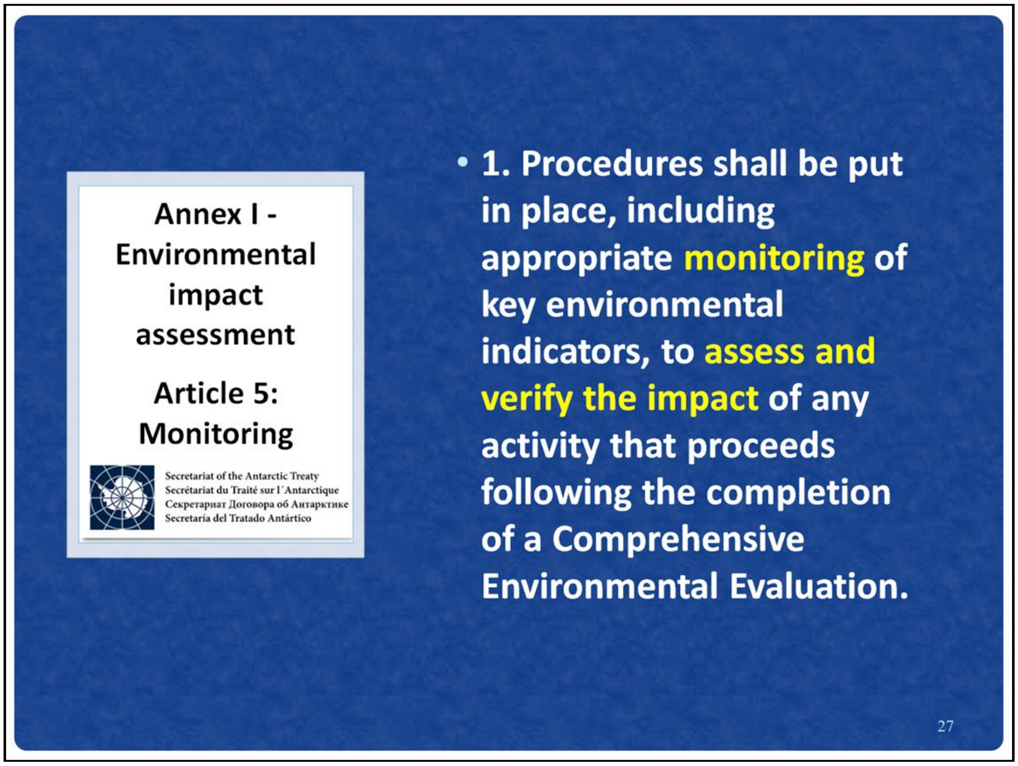
Environmental monitoring has it foundations in Antarctic Treaty System documents dating back to the 1970's. The adoption of Conventions and Annexes adopted over the years laid the ground work for the Environmental Protocols that formalized the role of monitoring in environmental protection of Antarctica.



Two conventions one on seals and one on marine living resources were adopted in the 1970'2 to 1980's.While unratified, important discussions about environmental protection were begun during consideration of the Convention on Antarctic Mineral Resources.



The Protocol on Environmental Protection to the Treaty - explicitly sets forward obligations for environmental monitoring.

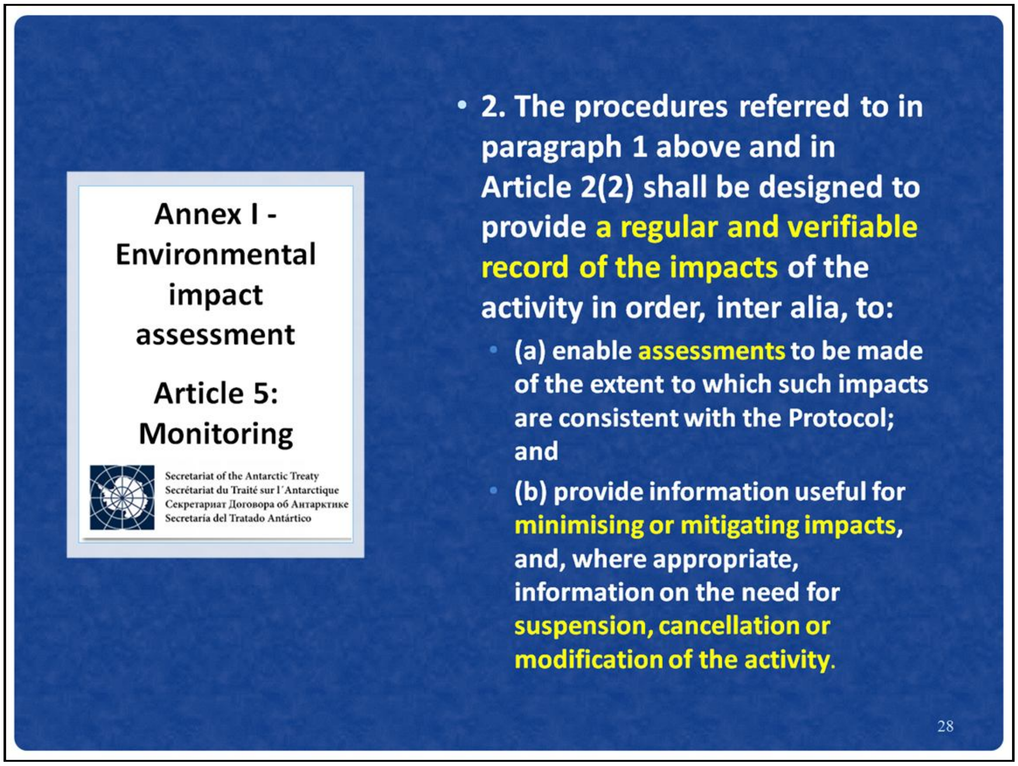


Protocol on the Environmental Protection to the Treaty

Annex I - Environmental impact assessment

Article 5: Monitoring

Procedures shall be put in place, including appropriate monitoring of key environmental indicators, to assess and verify the impact of any activity that proceeds following the completion of a Comprehensive Environmental Evaluation.



Annex I - Environnemental impact Assessment

Article 5: Monitoring

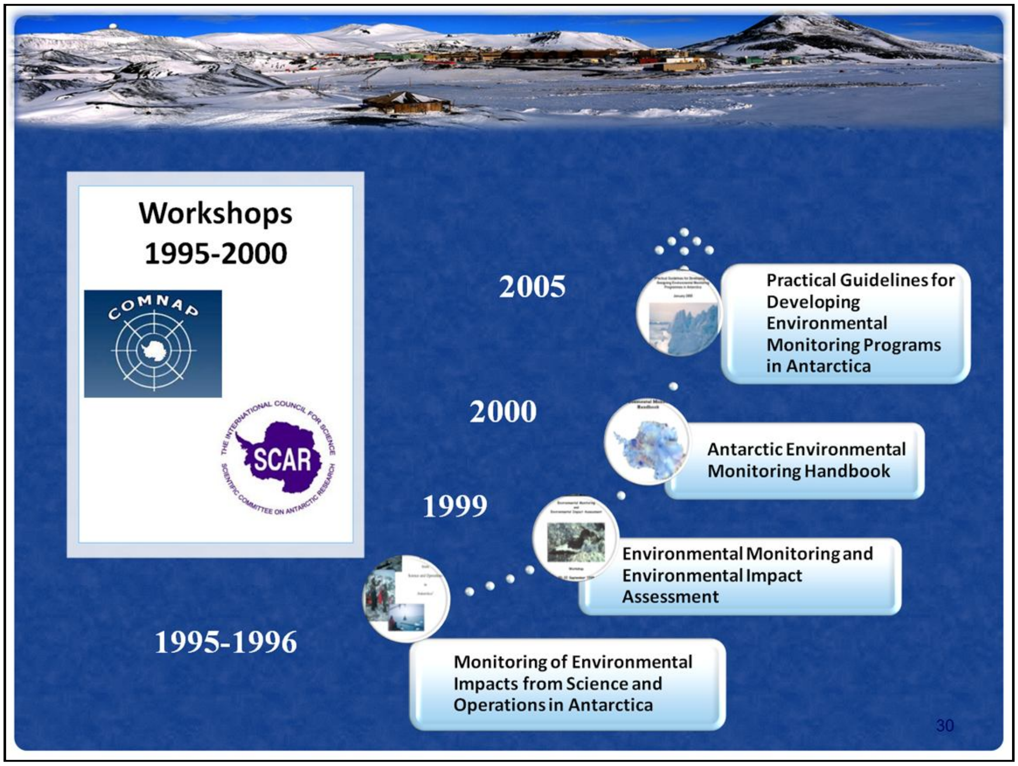
The procedures referred to in paragraph 1 above and in Article 2(2) shall be designed to provide a regular and verifiable record of the impacts of the activity in order, inter alia, to:

(a) enable assessments to be made of the extent to which such impacts are consistent with the Protocol; and

(b) provide information useful for minimizing or mitigating impacts, and, where appropriate, information on the need for suspension, cancellation or modification of the activity

The Protocol on the Environment explicitly sets forward obligations for environmental monitoring.

1992 – First Meeting of Experts in Buenos Aires, Argentina



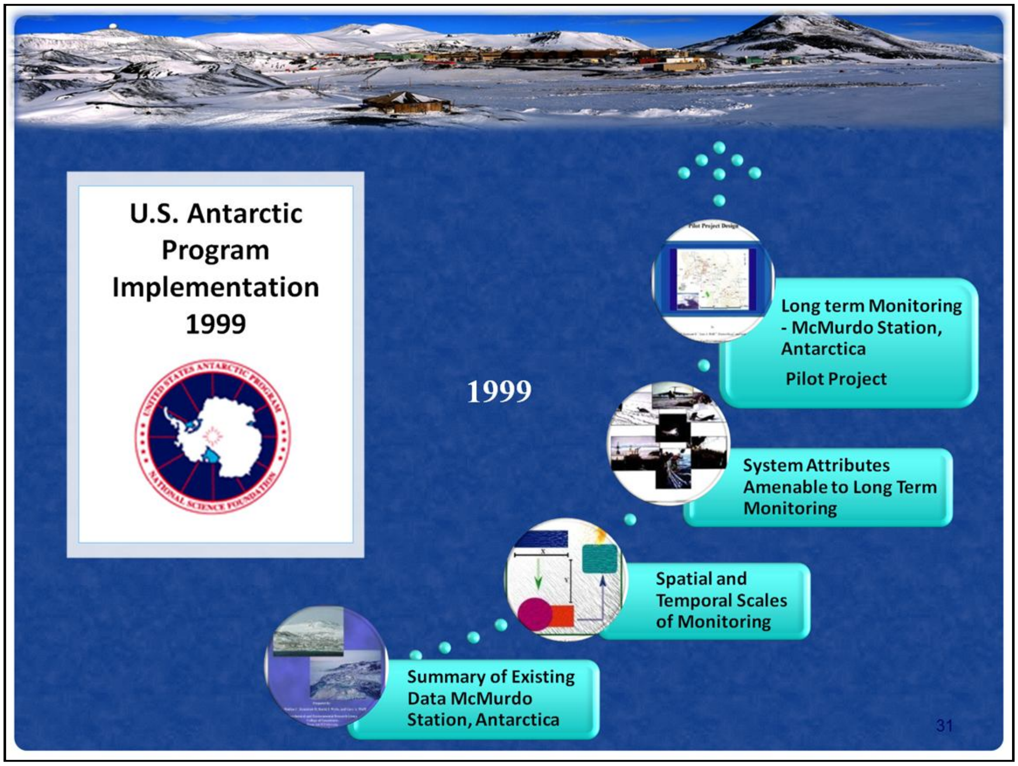
This was followed with a series of workshops and products produced by SCAR and COMNAP:

Two workshops I 1995 and 1996 - one in Oslo and one in College Station, TX - that produced the report - “Monitoring of Environmental Impacts from Science and Operations in Antarctica”

An assessment of filed EIAs - Environmental Monitoring and Environmental Impact Assessment – by COMNAP’s Antarctic Environmental Officers Network (AEON) in 1999.

An Antarctic Environmental Monitoring Handbook commissioned by COMNAP in 2000 and produced by my group.

Ana 2005 report - Practical Guidelines for Developing Environmental Monitoring Programs in Antarctica – commissioned by COMNAP



During this time the US Antarctic Program began to implement the recommendations coming from the various workshops and meetings.

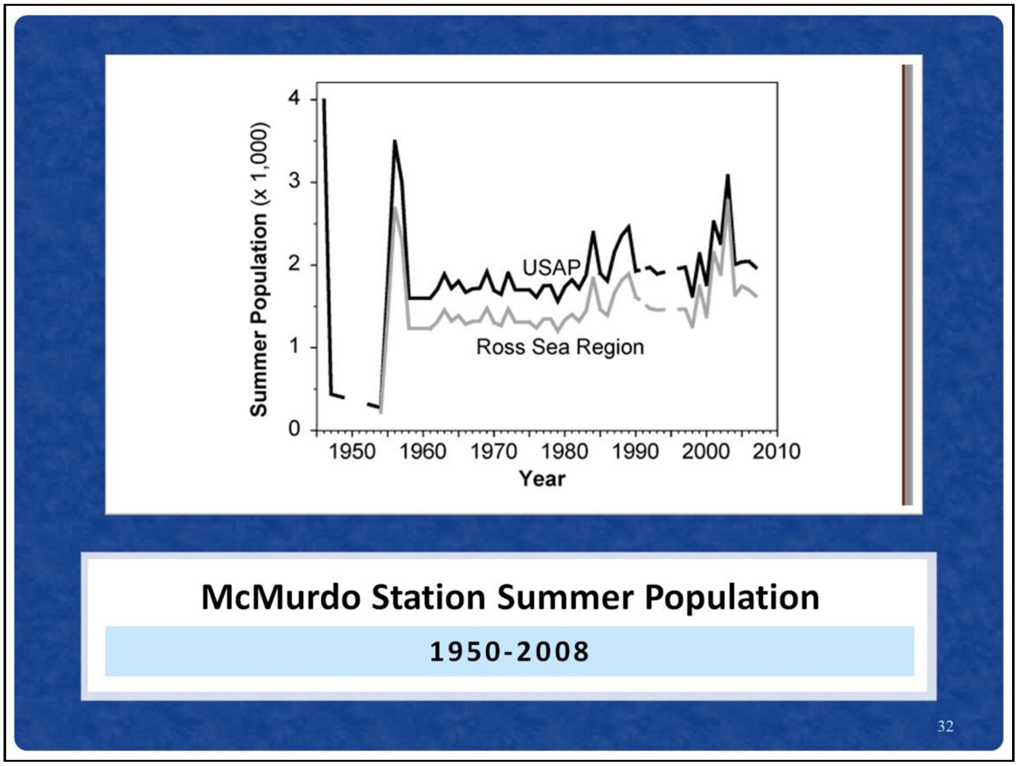
This resulted in the production of four reports in 1999 that laid out the details of a design plan for a long term monitoring program to document human impacts. These reports concentrated on McMurdo Station as the location of the largest human presence for the US Antarctic Program.

The first report summarized existing environmental data collected at McMurdo Station. The various design elements – density of samples, frequency, variables, measured, etc. were then tested for applicability during a three-year pilot project.

The second report considered the spatial and temporal scales of monitoring using historical data to statistical methods to determine the necessary density and frequency of sampling necessary to be able to recognize human disturbance above natural variability in terms that would provide adequate information for management decisions.

The third report considered what parameters could be measured that would directly indicate the extent and intensity of human impact. The feasibility and availability of standard protocols were considered including cost.

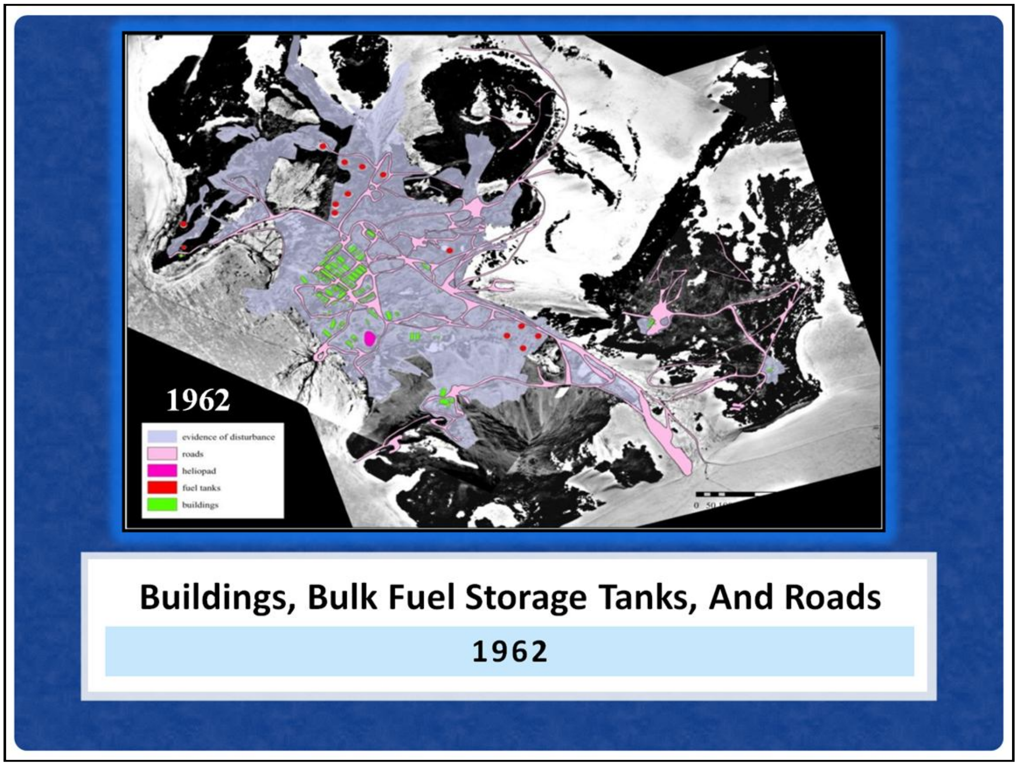
The fourth and final report combined all of the information from the previous reports and international workshops and meeting and proposed a design for a long term monitoring program at McMurdo Station.



First I would like to describe what we learned from looking at the photographic record of the station evolution and previously collected environmental data. Basic parameters indicative of the presence of humans can be derived form the “paper record” of the history of the station that assist in interpreting data collected on human impacts.

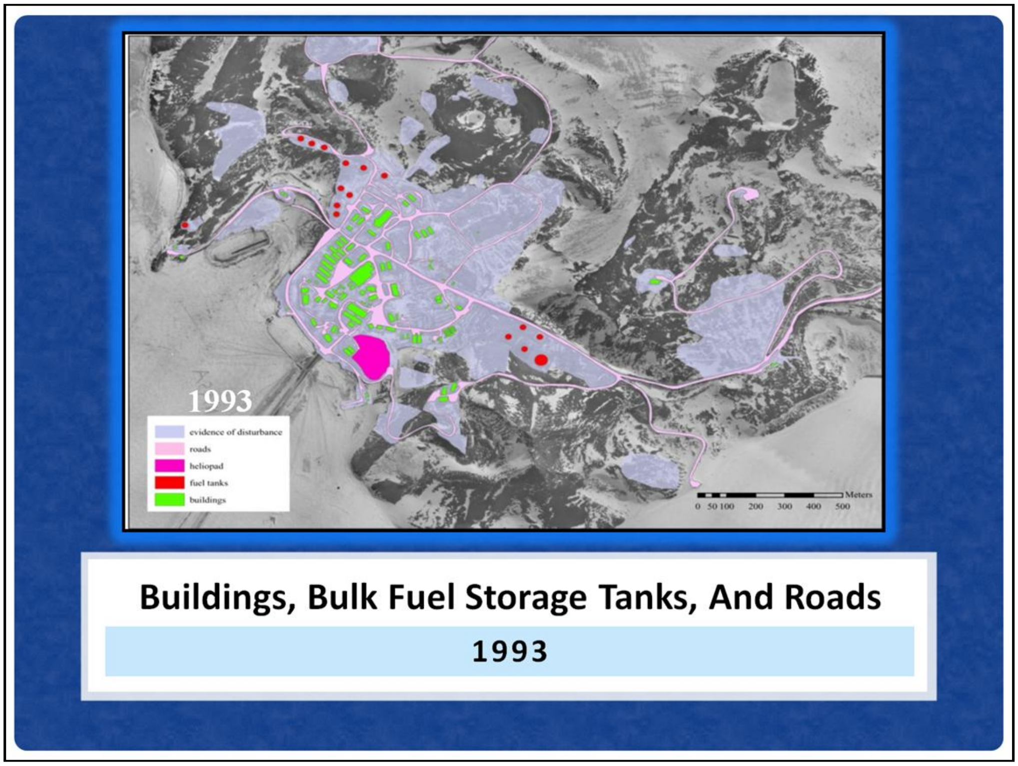
In this figure we see the summer population at the Station. One for the first observations is that the largest population at McMurdo Station was during the IGY in the 1950’s when the station was first begin established. Station population settled into a some what stable period of about 1000 persons and this fluctuated over the years gradually increasing to about 1200 persons this last season. Winter populations reduce to a few hundred personnel.

USAP and Ross Sea Region Population. Populations prior to the 1989└1990 season are taken from Beltramino (1993). More recent population totals are taken from annual Antarctic Treaty Information Exchange documents (http://nsf.gov/od/opp/antarct/treaty/index.htm). The Ross Sea Region’s population includes all USAP personnel with the exception of those at Palmer Station and aboard ships.

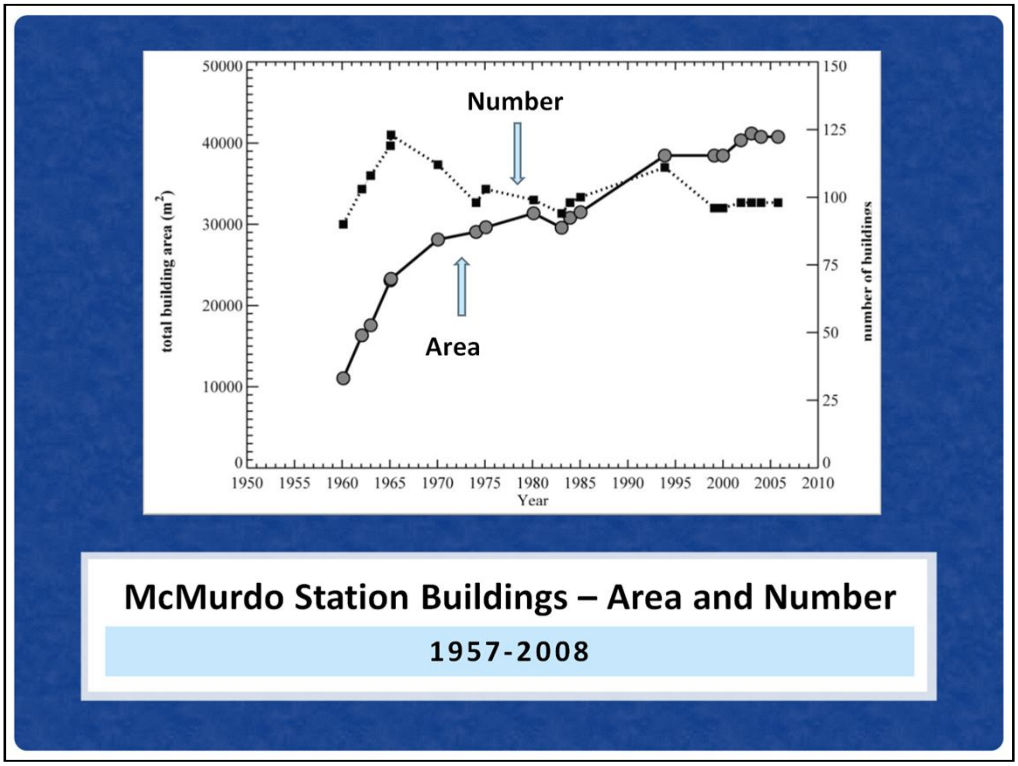


Arial photography can be classified as to the types of facilitates including buildings, fuel storage tanks, and roads. This can be visually displayed as well as quantified to show trends in the development of the station.

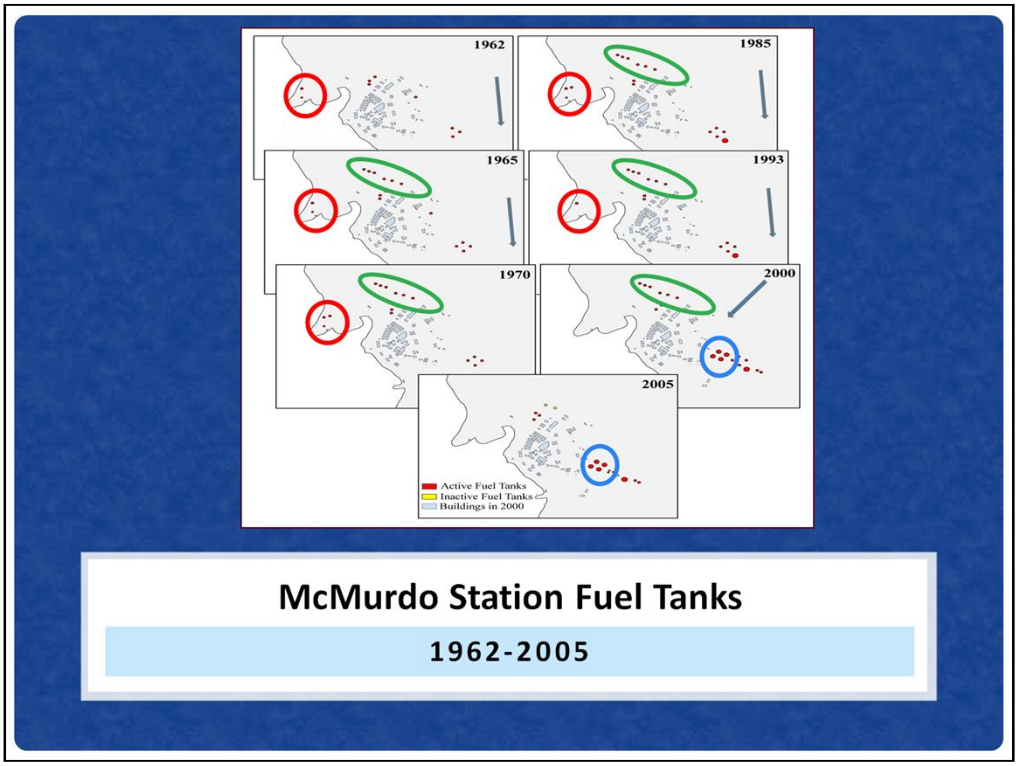
This first figure shows these facilities in 1962. Note that the basic configuration of the station is et early in its development.



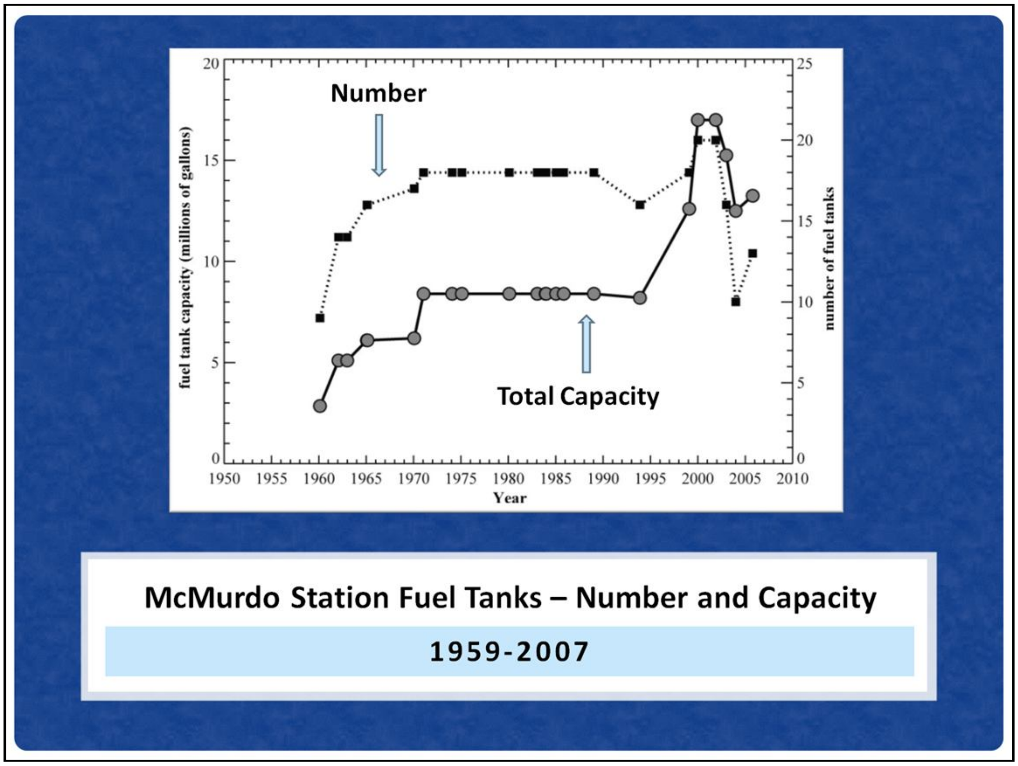
A second photograph show the same types of facilities in 1993.Iti s evident hat roads are more organized, there are more buildings, and the helicopter pad had expanded in area since the 1960's.



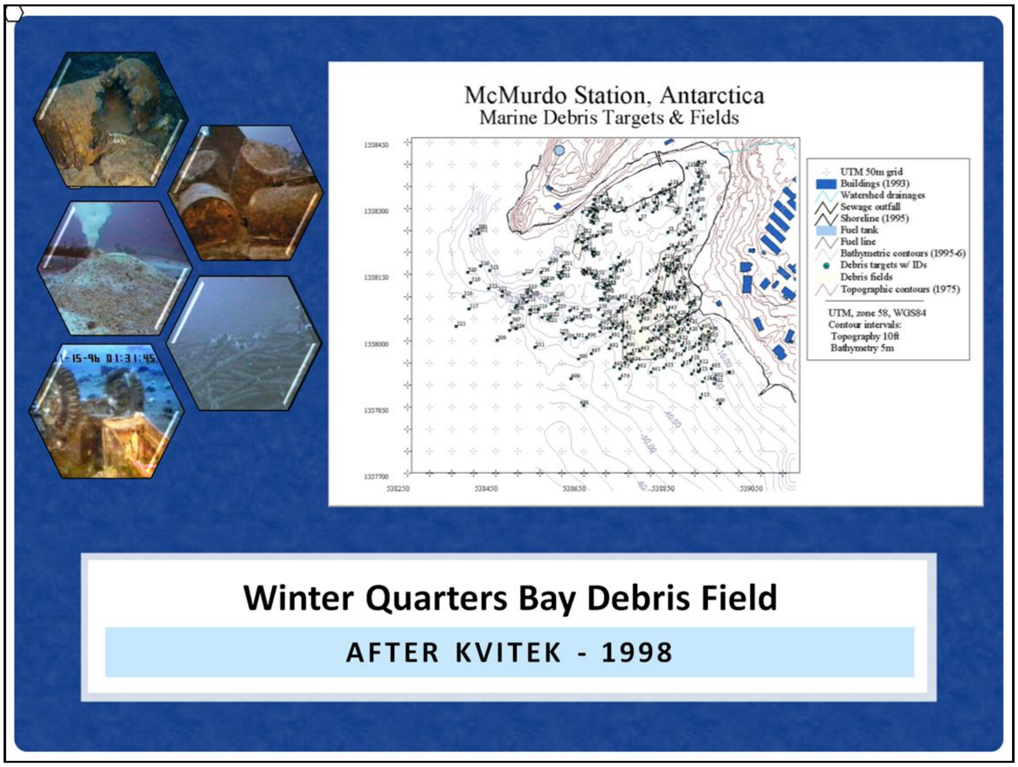
These photos are digitized and translated into quantitative measures of human presence – numbers of buildings and area covered by buildings. The same can be done fro km's of road, etc. note again that the basic structure of the station is established early in its history and the number and area of building becomes relatively stable in the early 1970's.



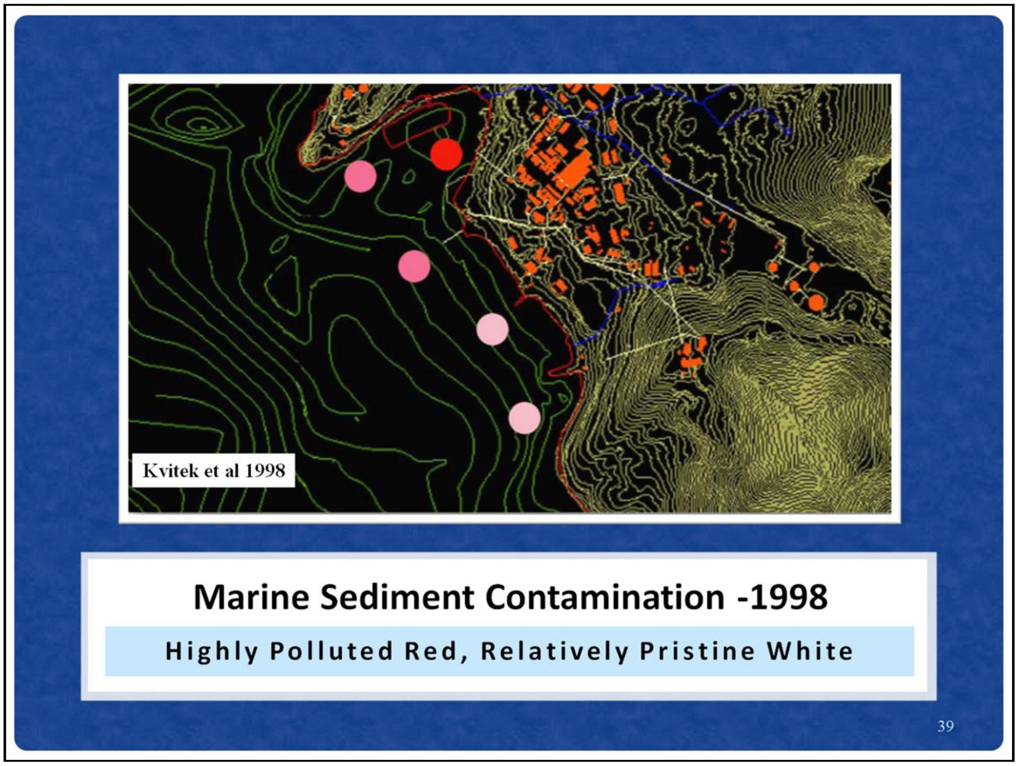
The history of fuel storage can also be traced by identifying the presence of storage tanks. Over time storage tanks are commissioned and e-commissioned and storage tanks are consolidated. During this time storage tanks were bermed (cntained) and flexible hosing was replaced by hardened transfer systems to decrease accidental spills.



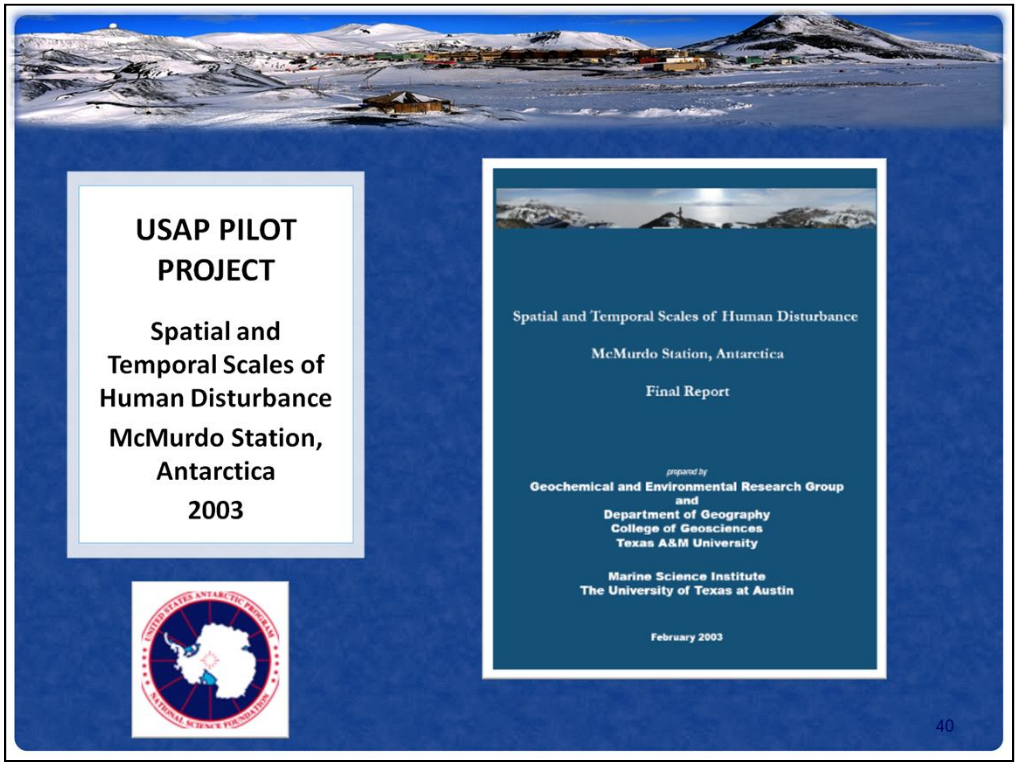
The number of fuel storage tanks and capacity can be traced over time.



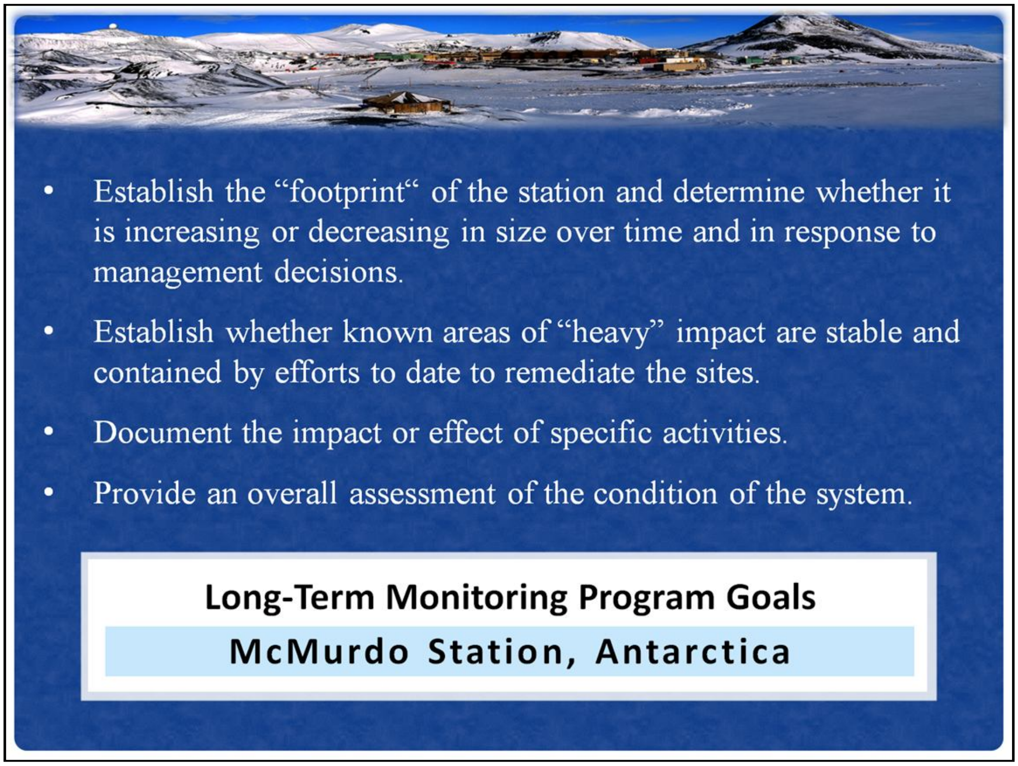
There was also remotely operated vehicle survey of the debris field offshore of McMurdo station in 1998. This revealed and extensive area disturbed offshore due to past disposal practices. At the time it was determined that less impact would result by leaving the material in place rather than dredging and hauling away which would have resulted in a much wider distribution of debris and contaminants in the marine environment. In contract, at this same time, onshore disposal areas were remediated and materials were collected and returned to the United States.



These studies also confirmed the presence of significant chemical contamination in marine sediments that I will describe in much greater detail based on recent long term monitoring. Again, these human disturbances are legacies of disposal practices that were in common use decades ago.



Based on a three pilot project, a revised long term monitoring program was implemented in 2003. The final part of my presentation reports the findings of the pilot project and nearly 8 years of routine annual monitoring efforts at McMurdo Station.



The long term monitoring program at McMurdo Station has the following goals:

•Establish the "footprint" of the station and determine whether it is increasing or decreasing in size over time and in response to management decisions.

•Establish whether known areas of "heavy" impact are stable and contained by efforts to date to remediate the sites.

•Document the impact or effect of specific activities.

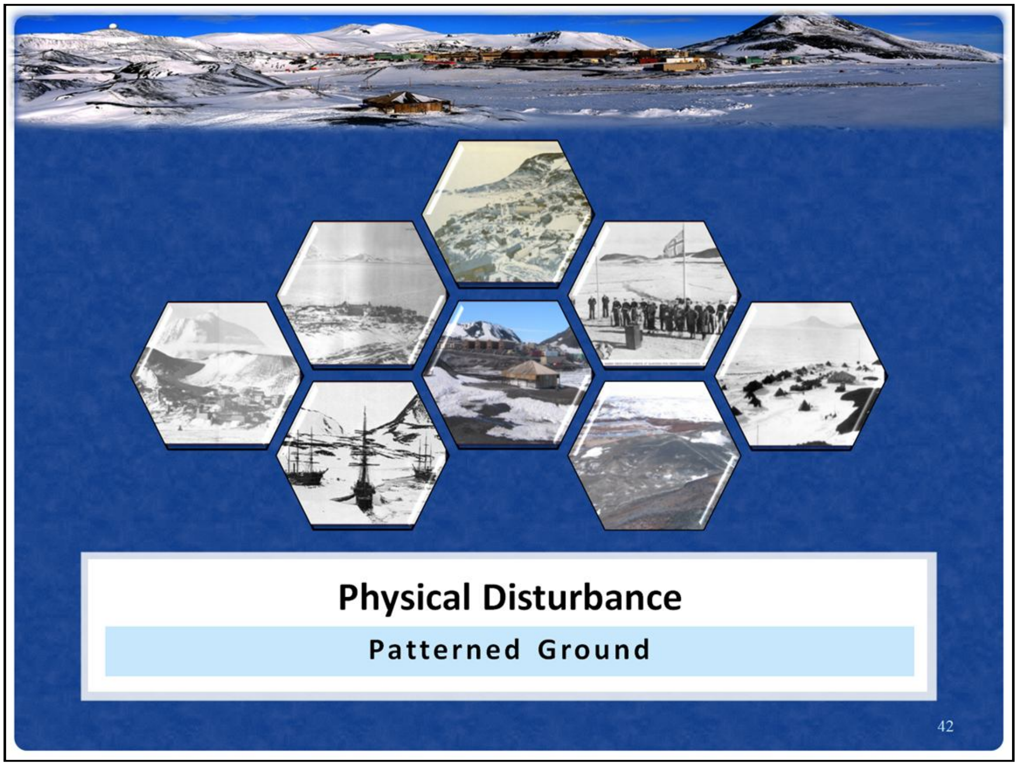
•Provide an overall assessment of the condition of the system

It is expected that this program will continue as long as humans are present at the Station.

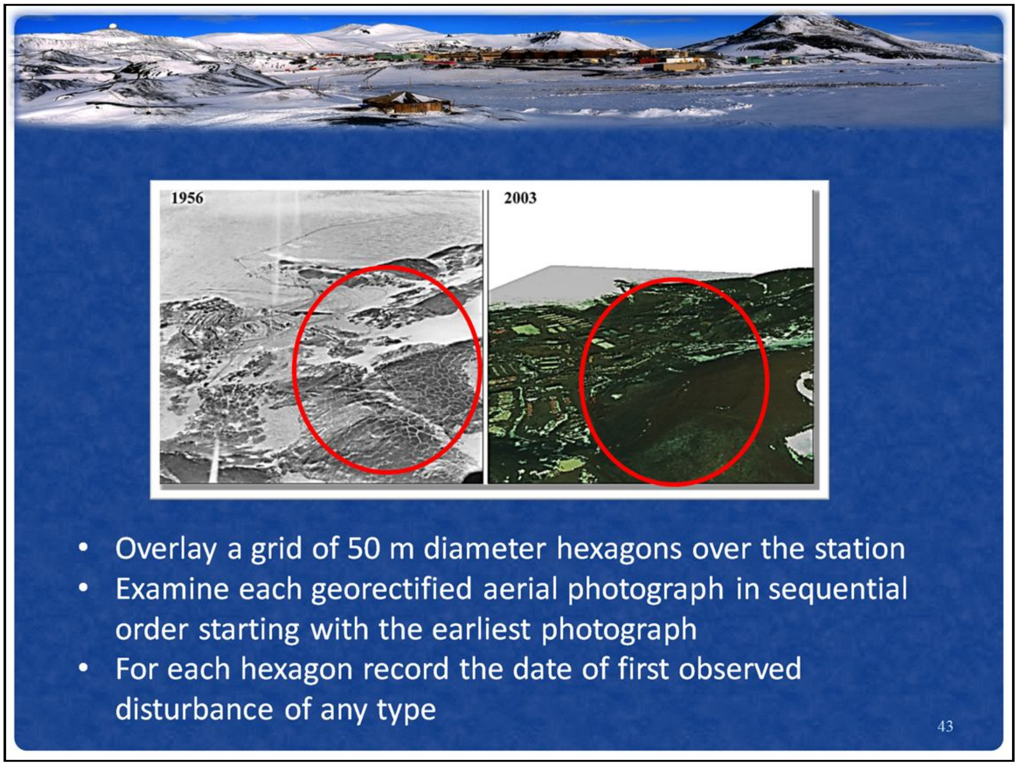
There are 3 major elements to the program based on the 3 major types of disturbance detected:

1. Physical Disturbance
2. Terrestrial soil contamination
3. Marine environment disturbance

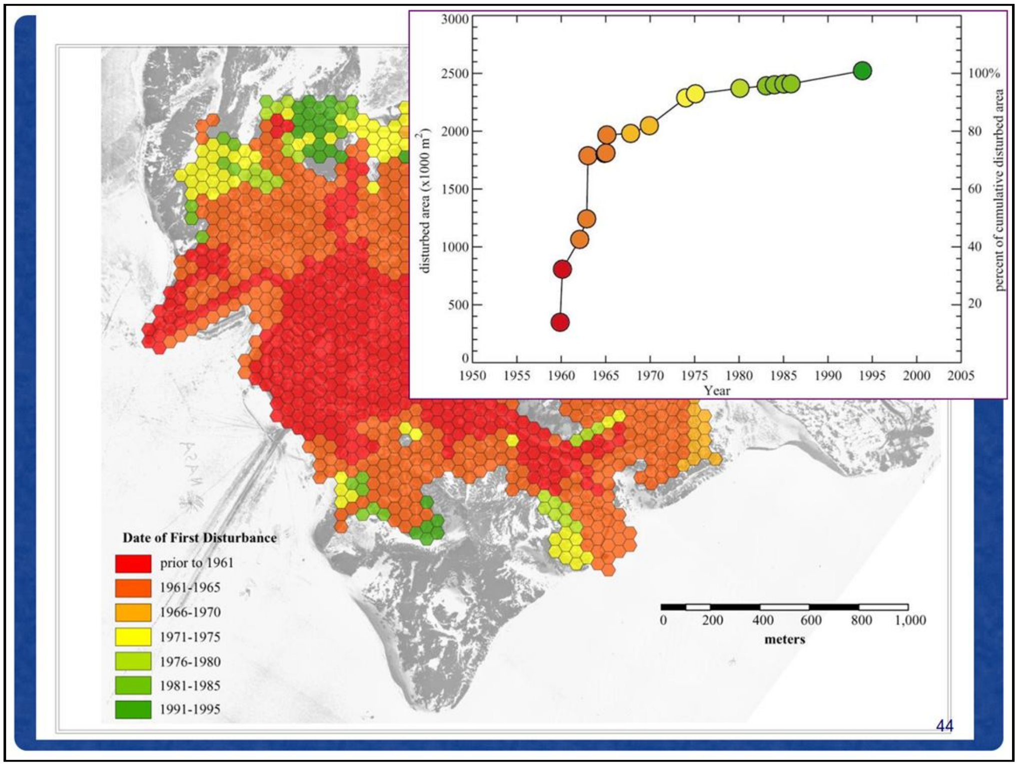
Each type of disturbance is monitored base donits characteristics and uses different techniques and study designs.



Physical disturbance is monitored based on the loss of patterned ground.



Patterned ground is natural phenomena in cold regions that is created over long periods of time by repeated cycles of thawing and freezing. It is recognizable from photographic surveys and is quantified based on its loss due to physical disturbance such as physical scraping or trampling of land surfaces.

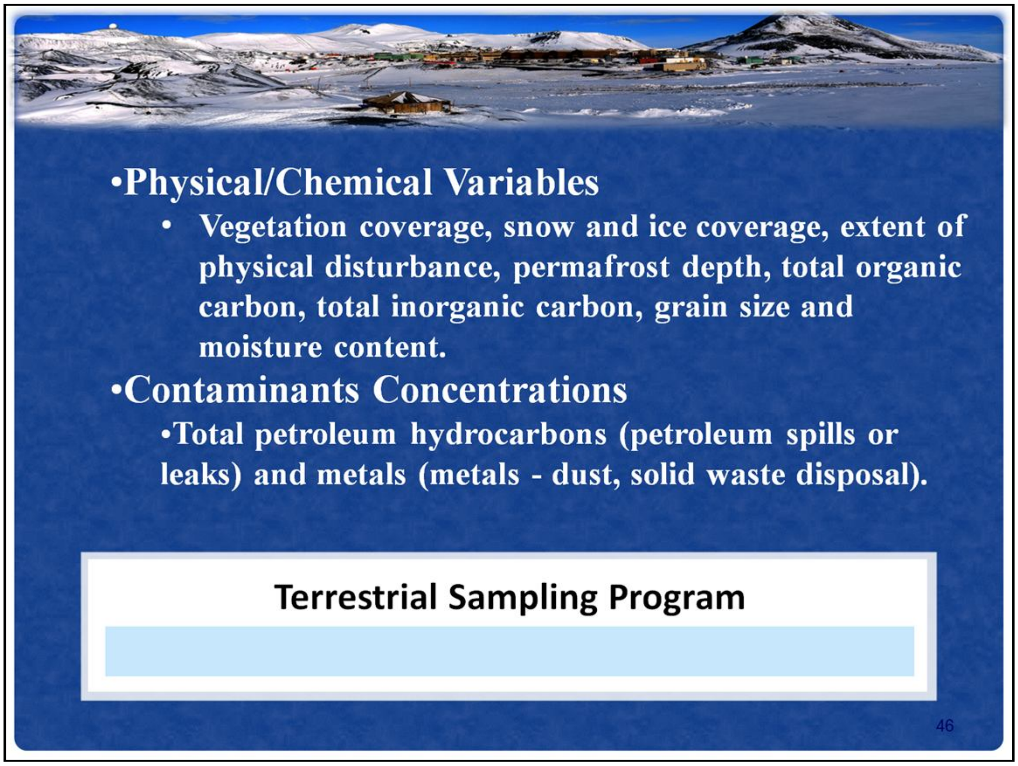


Physical disturbance is measured by overlaying a grid of 50 m diameter hexagons over the area of interest, examining each georectified areal photograph and recording the date of the first observed disturbance. This provides of time series of observations that quantifies the degree of physical disturbance on the area due to the presence of humans.

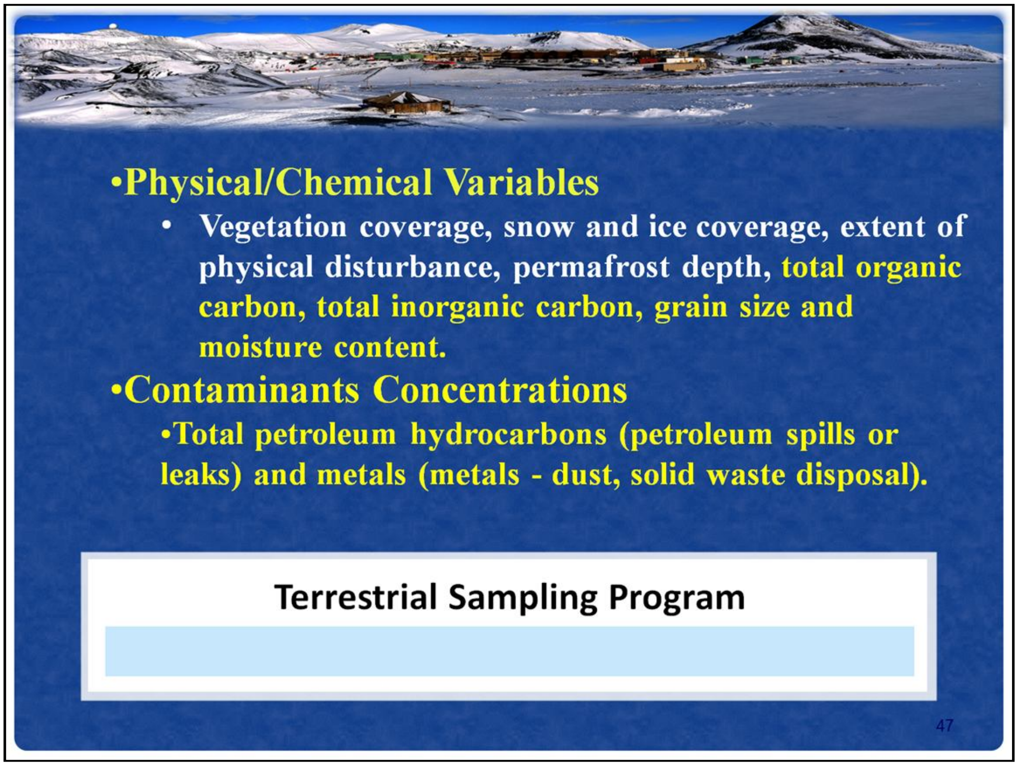
Note that once again the extent of physical disturbance is established early in the history of the station. This is to be expected as the affected areas are greatest when buildings and roads are first established and the practice that once established most new buildings and changes occur within the are already disturbed.

Terrestrial physical disturbance was restricted to a few square kilometers near the station (figure 3). Most disturbance of the surface had occurred by the 1970s as major construction to establish a permanent station had been completed. Construction relied on local sources of building fill. In many cases, surfaces were scraped to prepare building sites and the surroundings were contoured to accommodate the station. Scrapping of the surface in later years was mostly confined to already disturbed areas. The spatial extent of physical disturbance has been stable for more than 30 years. Indications are that disturbed land surfaces will not recover for many tens, if not hundreds, of years or more. Once disturbed, land surfaces are slow to recover because run-off is negligible since temperatures are perennially cold limiting the presence of liquid water and landforms take years to develop because natural processes are slow to redistribute material.

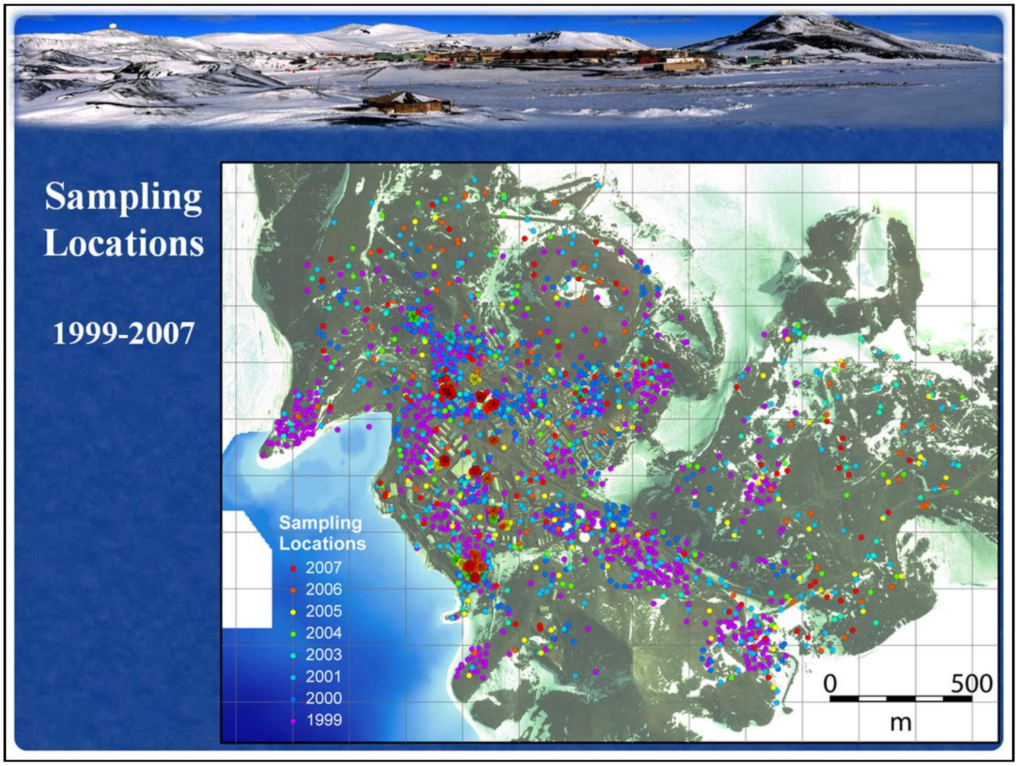
Monitoring on the land is primarily based on measuring the chemicals that are released by human activities. At McMurdo Station there was little indigenous biological populations that could be used effectively for monitoring. There were few if an animals present and vegetation was sparse and what was there was removed early in the station's history. Soil micro fauna and microbial communities were not a target of monitoring.



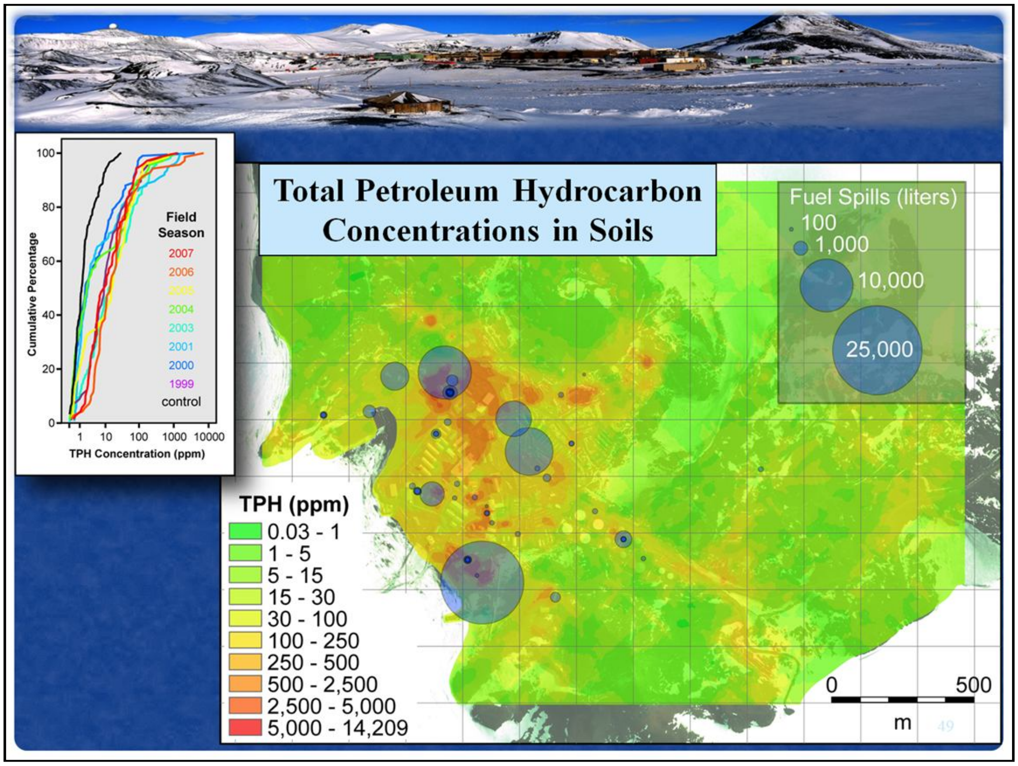
During the Pilot Project a set of variables was established based previous studies and experience from temperate climates. This is the list of initial variables for the land based sampling program. Based on 3 years of data collection this list was reduced to those variables that provided the most useful information for detecting changes related to human disturbance.



This is the reduced set of variables measured for land-based monitoring. In particular chemical contaminants related to fuel usage and materials - for example metals – were most indicative of human disturbance.



Samploign locations across McMurdo Station from 199-2007

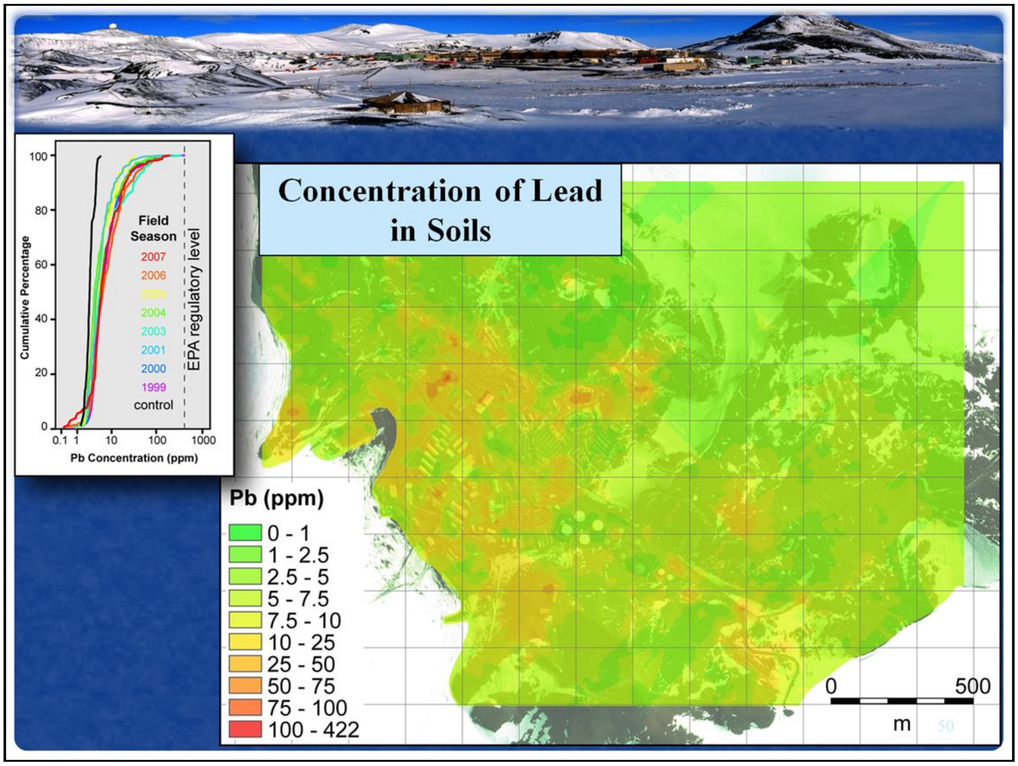


Petroleum hydrocarbons from fuel are the largest volume of potential contaminants brought to and used at Antarctic scientific stations. Correspondingly the most prevalent contaminant detected in surficial soils at McMurdo Station is fuel-related petroleum hydrocarbons (figure 4).

Petroleum hydrocarbon concentrations derived from release of fuels are presented in this figure. Statistical measures are sued to produce a surface that shows the presence of fuel across the station. Hydrocarbon contaminants were highest in areas where fuel was utilized or stored such as refueling stations, the helicopter pad, vehicular traffic routes and parking areas, and the vehicle maintenance facility (indicated by the concentrated sampling efforts in figure 2). Highest TPH concentrations were associated with recently spilled fuel. Ongoing activities in these areas pose a risk for continuing contamination (figure 4). There was little evidence of the redistribution of fuel spills away from the point of release since run-off events are few and remedial activities rapid.

In this figure the location and volume of accidental spills are indicated. In most instances accidental spills are quickly remediated reducing soil levels. Correlation of soil fuel contamination and spill locations is confounded as spills are often remediated and contaminated soil removed.

It should be noted that the levels detected are in most instances close to background levels and consistently below levels expected to cause biological effects. This type of information assists management in addressing practices and locates sites for possible remediation.



Metal concentrations on the land surface were usually at or near background concentrations. Arsenic, cadmium, copper, lead, and zinc exceeded background concentrations at a few sites. In general, the spatial patterns of metal contamination were similar to those of petroleum hydrocarbons suggesting an anthropogenic origin.

A typical contaminant metal associated with human presence is lead. Elevated lead concentrations may be a legacy of leaded fuel use or be derived from other anthropogenic sources such as paint, plumbing materials, and solder [44–48]. Most surficial soils at the station contained metal concentrations below levels known to elicit biological changes in temperate climates. Human activities, such as scraping and construction, can result in a redistribution or mobilization of naturally occurring metals affecting their bioavailability.

The third aspect of the long term monitoring program is sampling in the marine environment adjacent to the station.

The Challenges of Monitoring in Antarctica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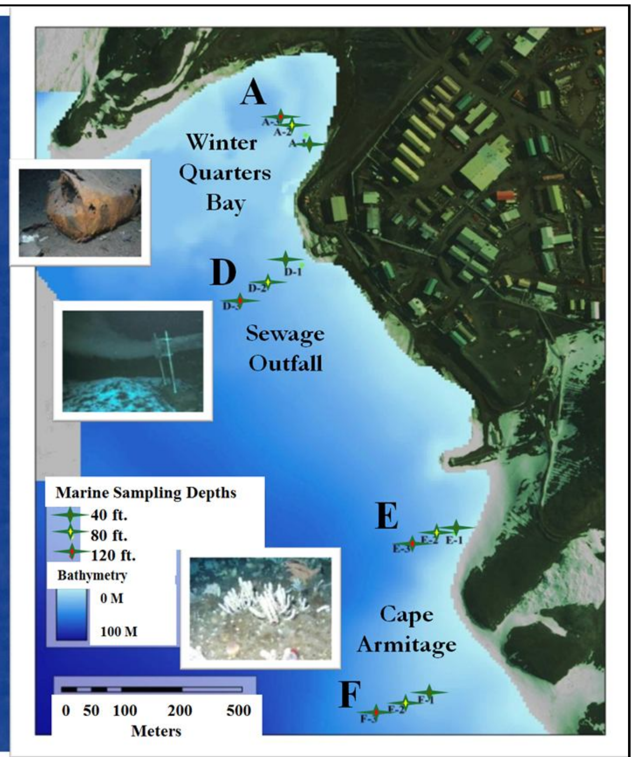
Marine Transects and Sediment Sample Locations



Marine Sampling Program

- Contaminants in sediments: hydrocarbons, PCBs, metals, and sediment toxicological tests.
- Biological tissues: hydrocarbons, metals and PCBs.
- Benthic infaunal communities: community structure, species diversity, abundance and biomass, photo-documentation of epibenthic community structure, species diversity, and abundance.
- Marine sediments: coliform bacteria, grain size, total organic carbon content, and percent moisture.

55

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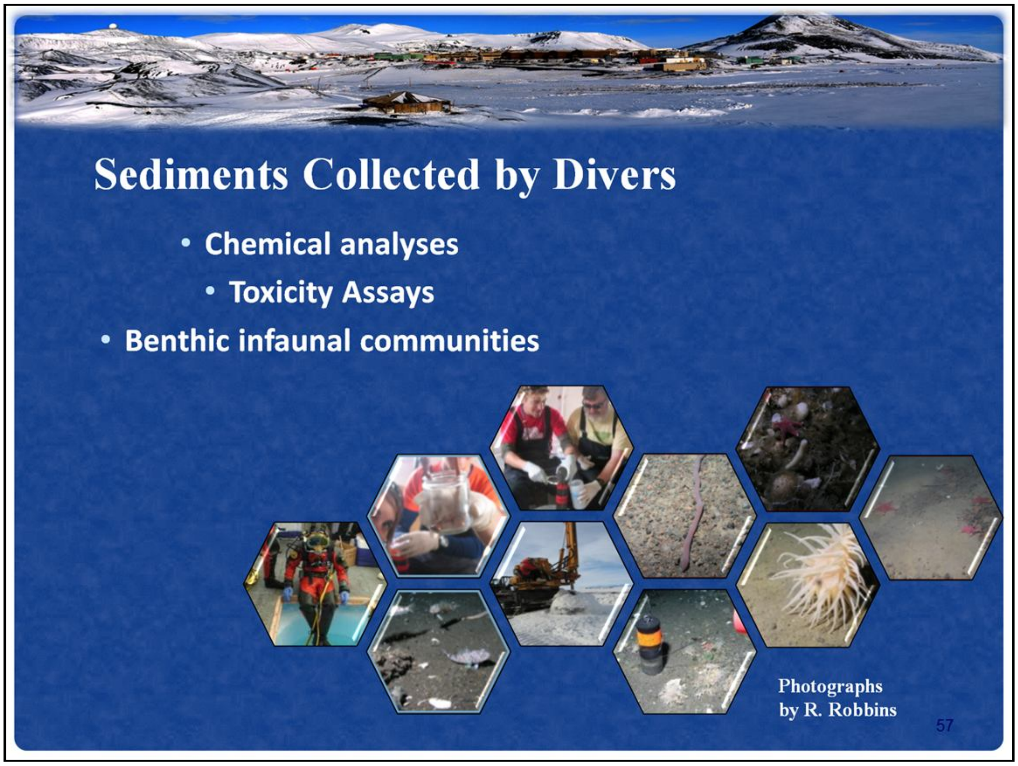
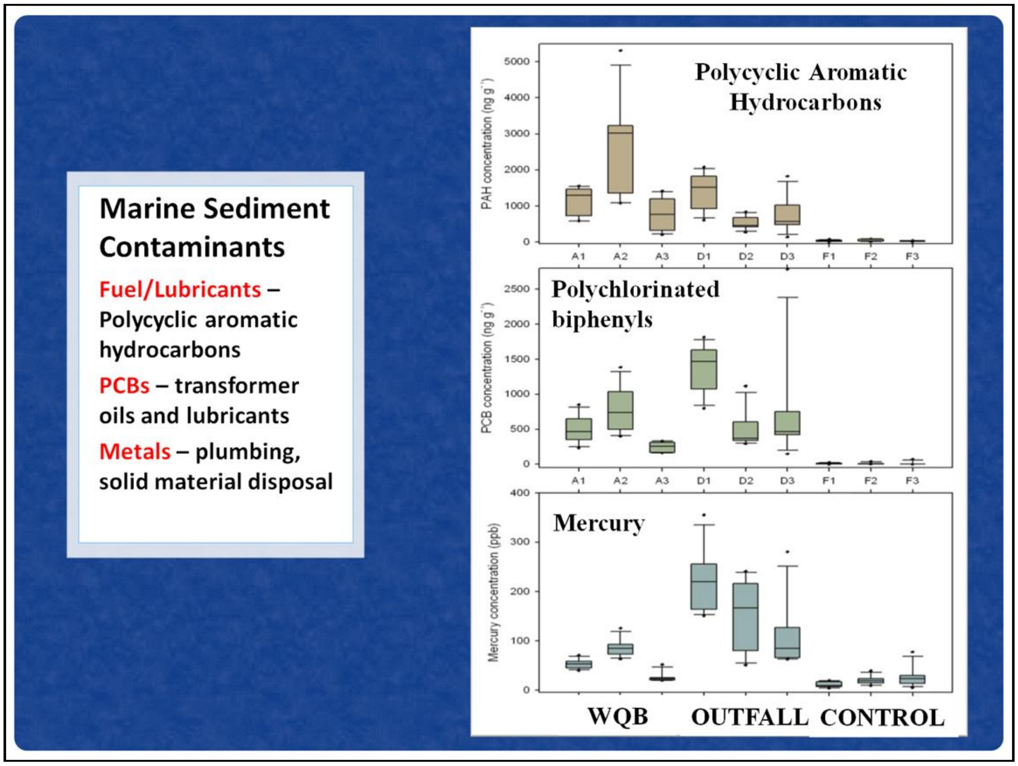


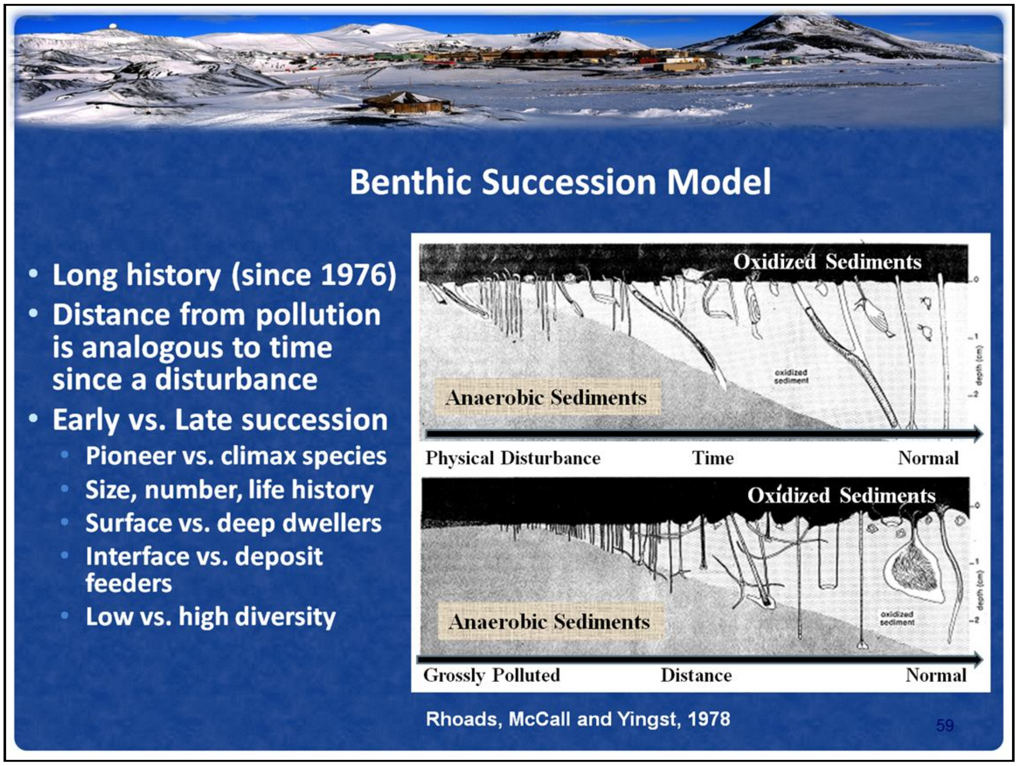
Indicator use

SQT

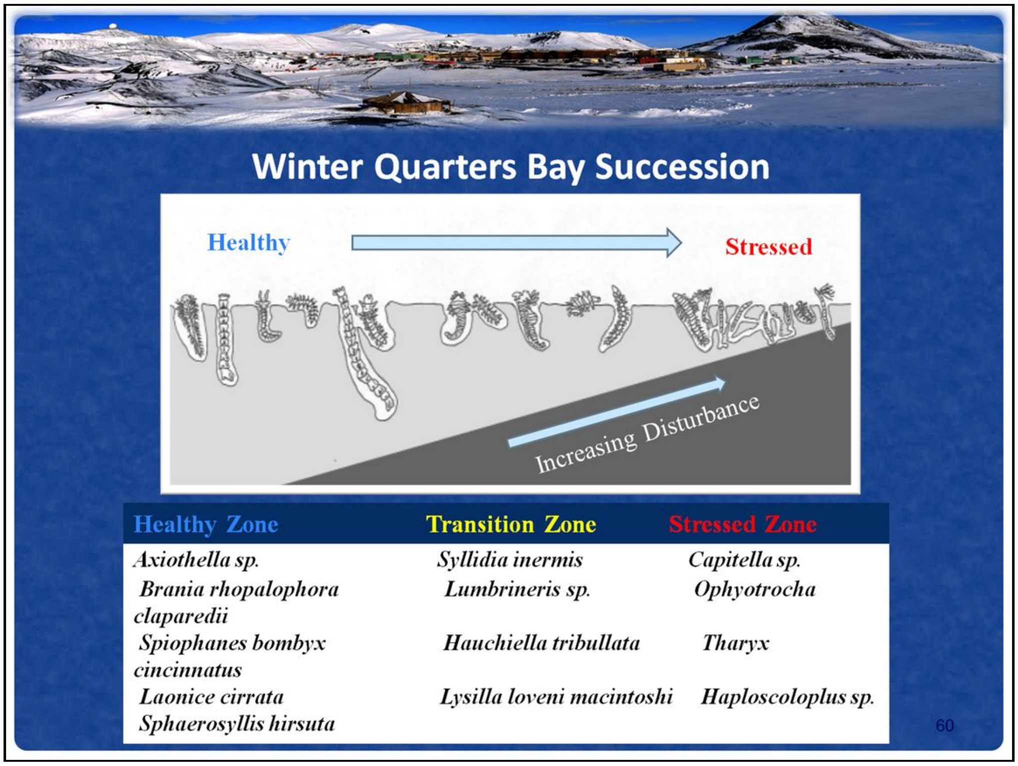


Past disposal practices have resulted in an area of several hundred square meters of contaminated sediments in Winter Quarters Bay (WQB) [25, 27]. PCB contamination in WQB was first documented in the late 1980s [22]. While localized in a restricted area of WQB, PCB concentrations were similar to those at some of the most contaminated sites in temperate climates. An unusual contamination by polychlorinated terphenyls, of unknown toxicity, was also present suggesting that several kilograms of a concentrated mixture of chlorinated compounds were disposed of in the bay at some time in the past (pre-1980). Previous assessments concluded that dredging and removal of these sediments is cost prohibitive and might result in a wider dispersal of contaminants in the area since WQB sediments are stabilized behind a sill.

The concentrations and spatial patterns of contaminants at McMurdo Station were similar over nine years. Recent additions of contaminants appeared to be minimal due to the more stringent environmental controls adopted in the 1980s but more definitive studies of run-off patterns and contaminant loads are needed. Contaminant hydrocarbons were biodegraded in both the terrestrial and marine setting indicating an indigenous population of hydrocarbon-degrading bacteria had altered releases over time [49, 50]. However, rates of degradation in cold climates are expected to be slower than in temperate climates [15, 50–53]. The unaltered nature of PCBs indicates in situ microbes have limited capacities to degrade synthetic chemicals suggesting that released synthetic chemical contaminants will persist for tens if not hundreds of years if natural processes are the only removal process [54].

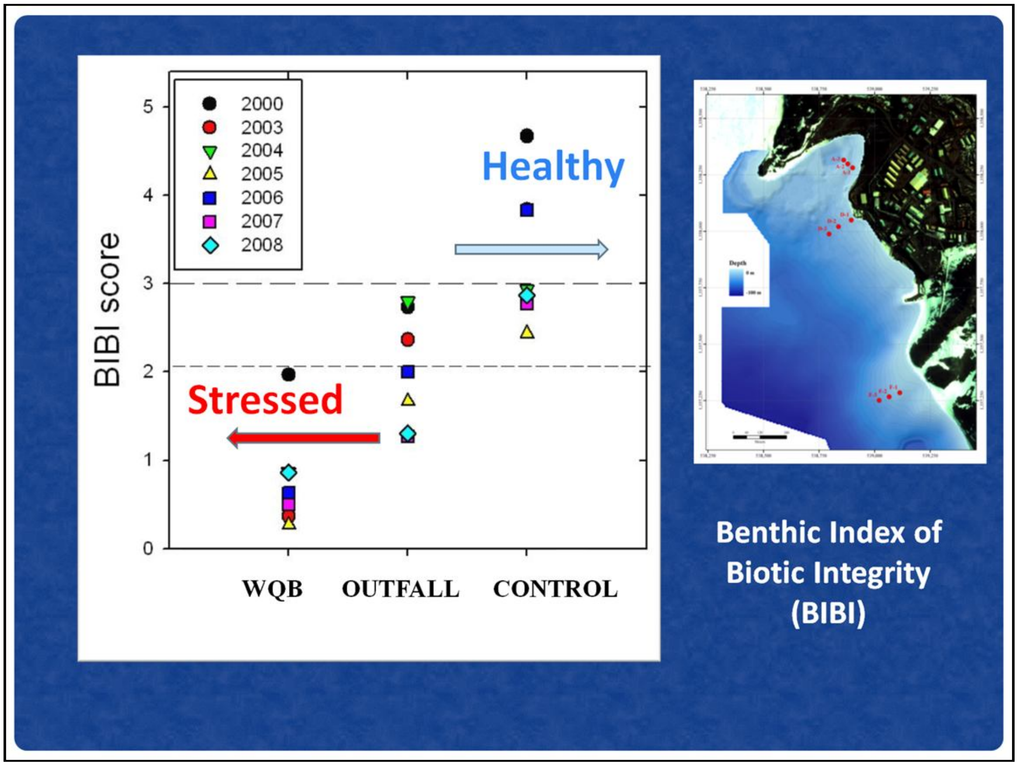


There is an abundant benthic community in marine areas adjacent to McMurdo Station suggesting biological indicators of human impact used in other climates might be applicable as indicators at McMurdo Station [59–61]. The changes in marine benthic communities in response to carbon enrichment and the toxicity of chemical contaminants is based on more than 3 decades of data collected in temperate climates. These responses are well known and predictable and can be used to indicate if a marine environment is suffering stress due to human disturbance.

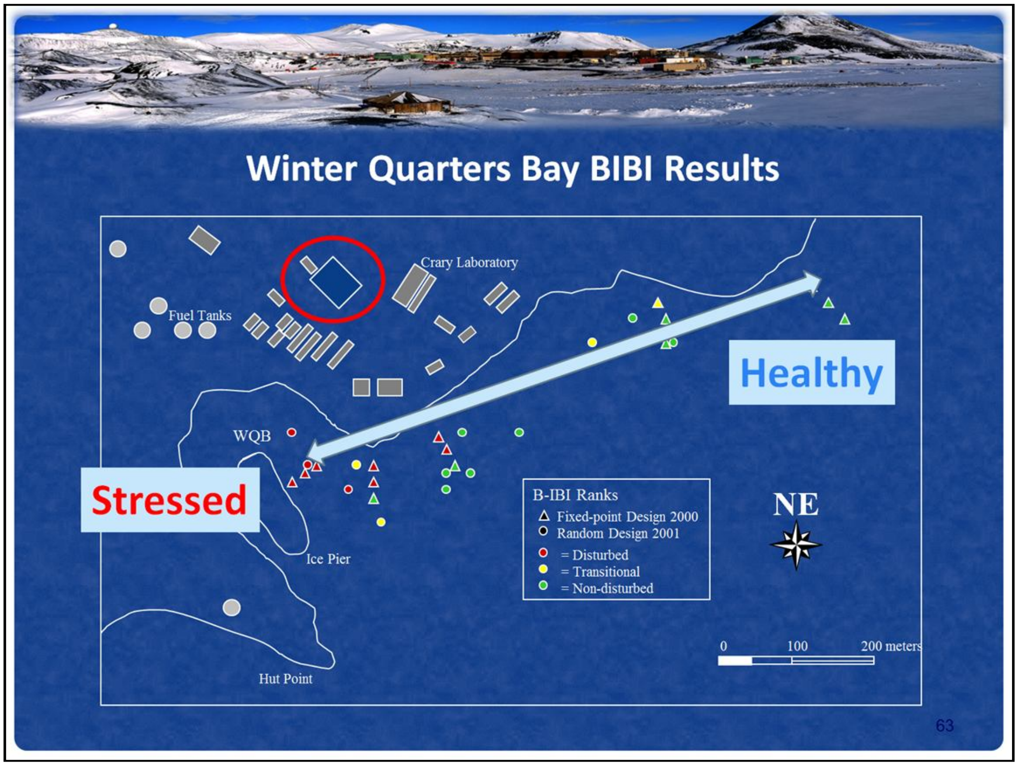


Based on these well known responses to stress the benthic ecology the "health" of Antarctic marine environments can be assessed and environments that are under stress form human disturbances can be recognized.

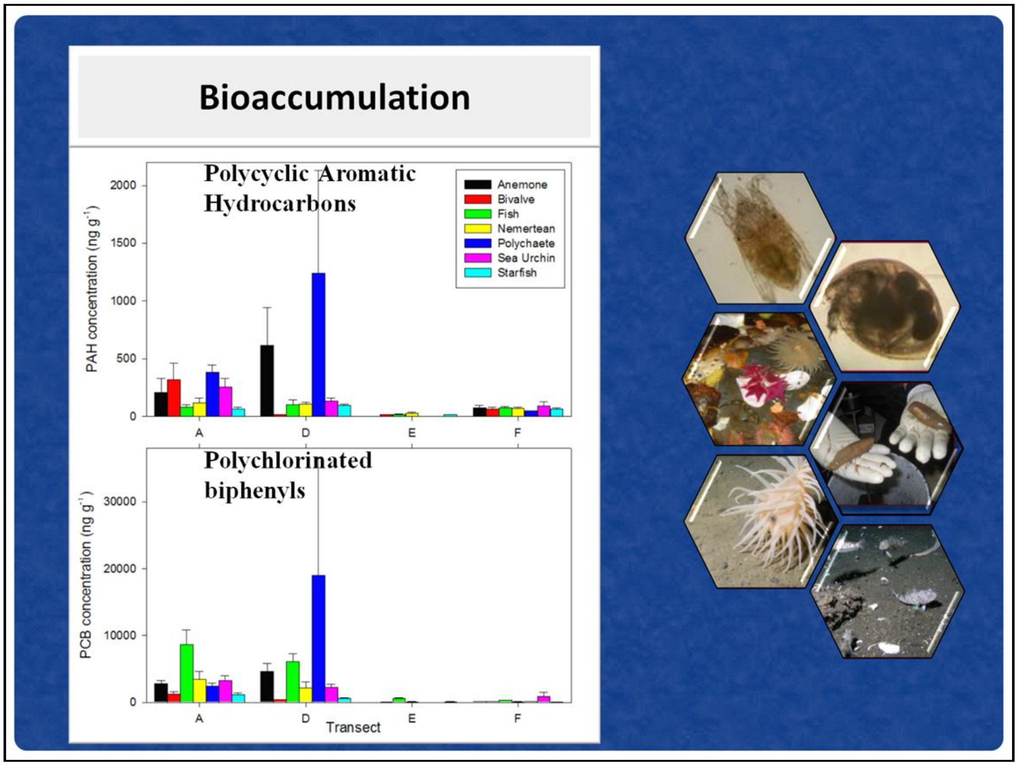
Complex benthic biology data sets can be reduced to s ingle variable that measures the health of the benthic community and the extent to which is has been disturbed by human activities.



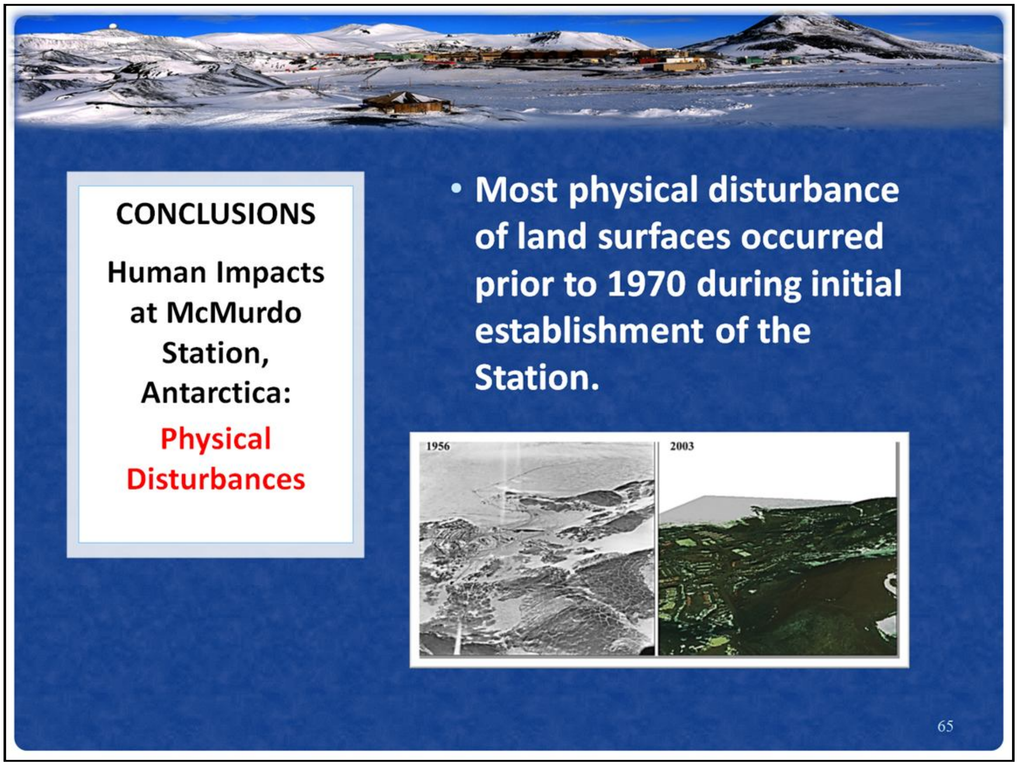
Date from 3 transects adjacent to McMurdo Station show classic patterns of reduced health due to exposure to chemical contaminants. The Benthic Index of Biotic Integrity is lower in close proximity to the Station and chemically contaminated sediments.



Marine benthic disturbance is mostly restricted to within 100’s of meters of the station – the discharge point.

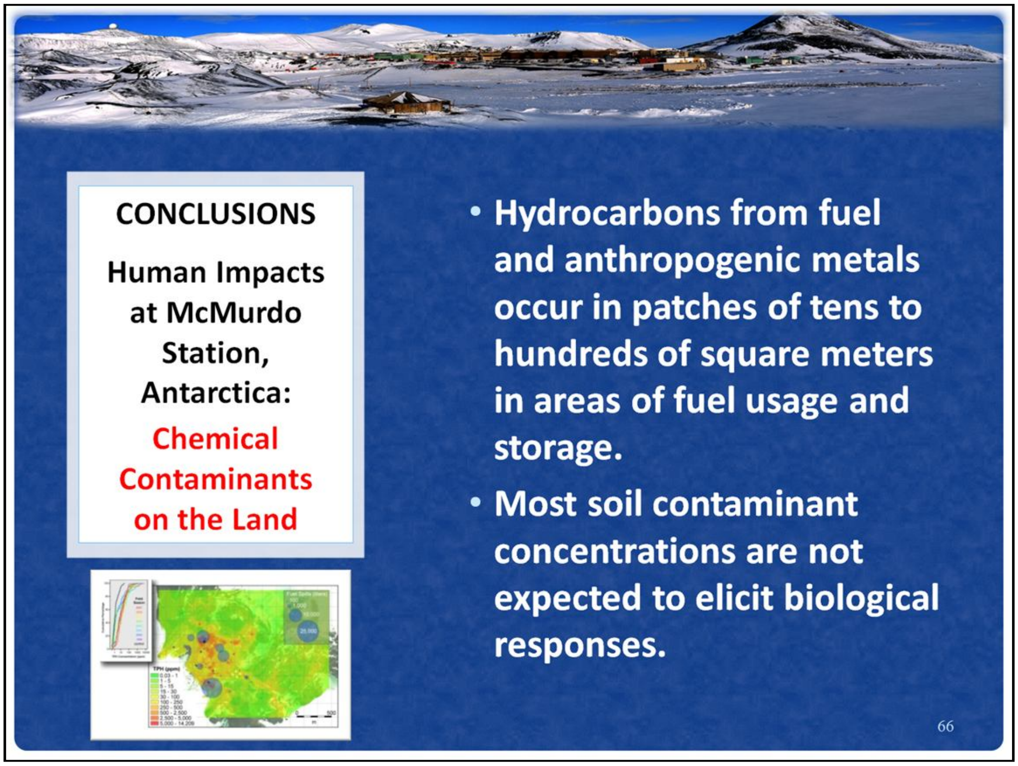


In addition to changes in marine benthic ecology, monitoring also demonstrated that the chemicals present are biologically available and that they are accumulating in biological tissues of indigenous species.



PHYSICAL DISTRUBANCE - LEGACIES

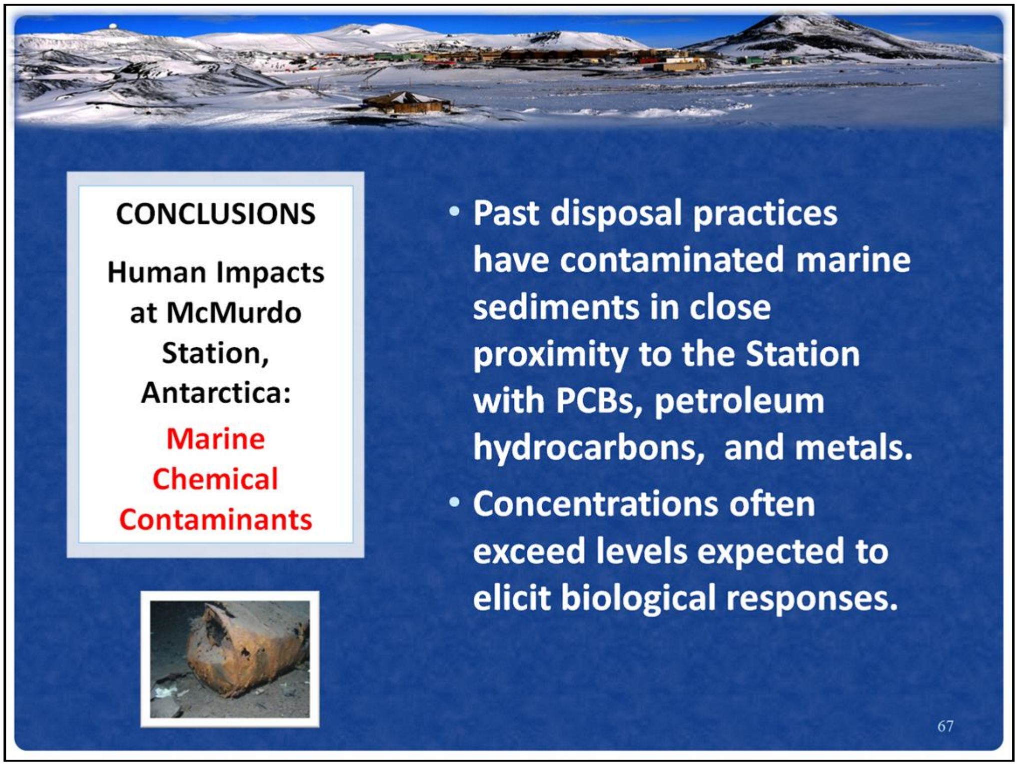
Most physical disturbance of land surfaces occurred prior to 1970 during initial establishment of the Station.



CHEMicAL CONTAMINANTS ON LAND

Hydrocarbons from fuel and anthropogenic metals occur in patches of tens to hundreds of square meters in areas of fuel usage and storage.

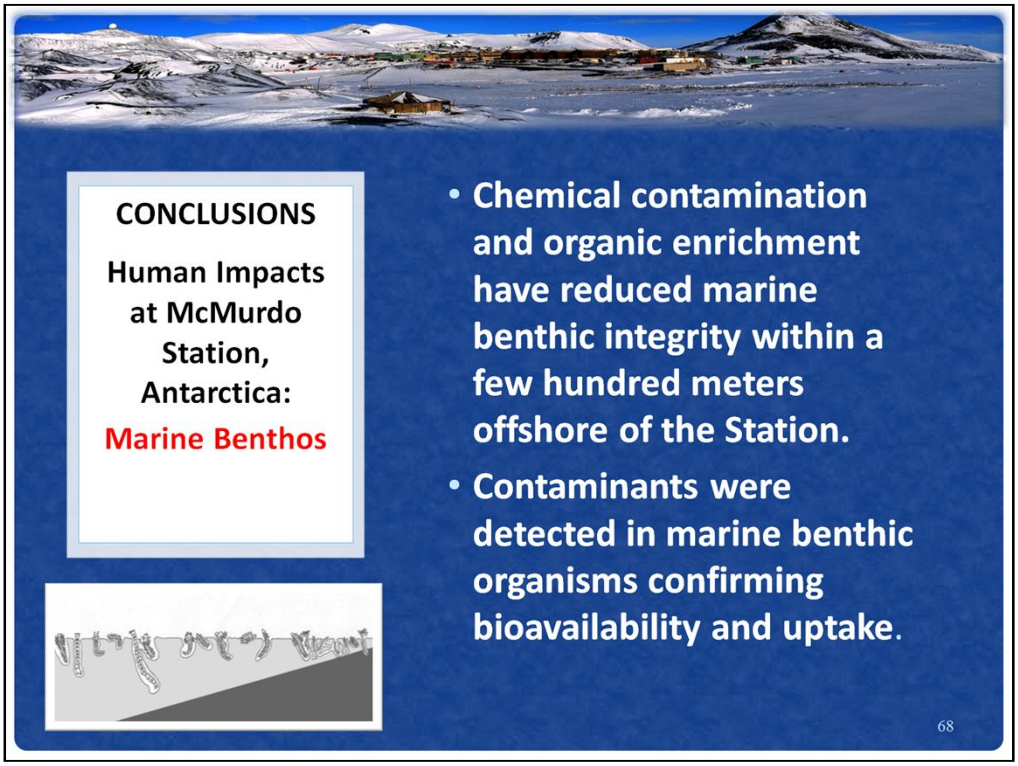
Most soil contaminant concentrations are not expected to elicit biological responses.



MARINE CHEMCIAL CONTAMINANTS

Past disposal practices have contaminated marine sediments in close proximity to the Station with PCBs, petroleum hydrocarbons, and metals.

Concentrations often exceed levels expected to elicit biological responses.

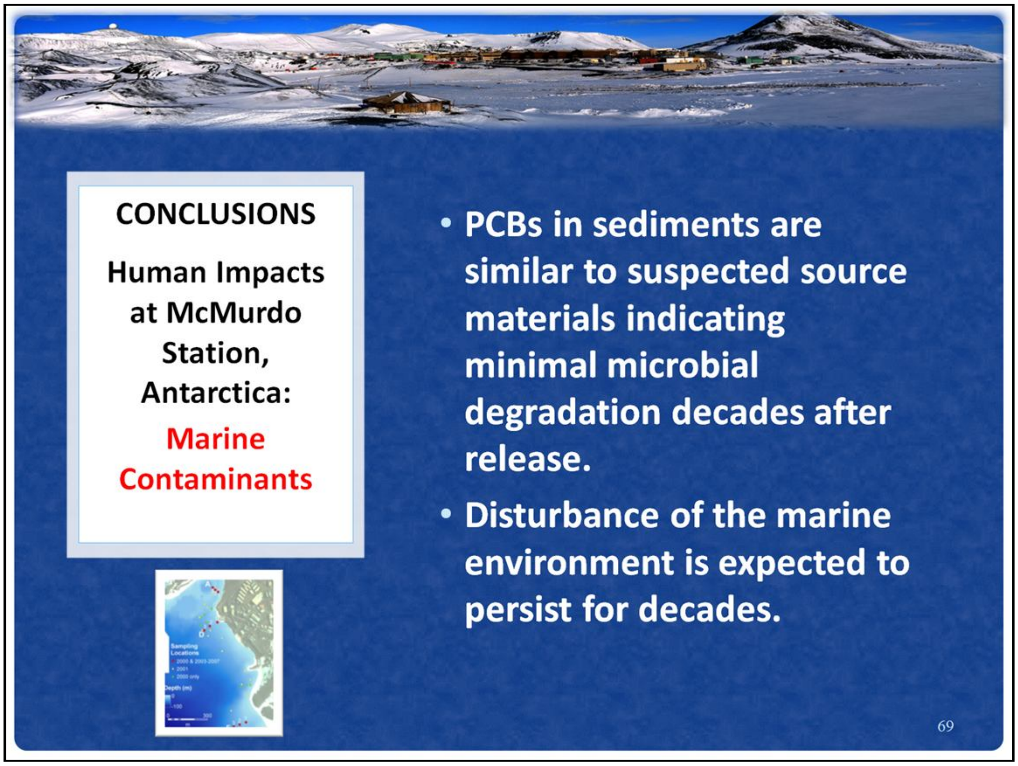


MARINE BENTHIC DISTRUBANCES

Result of past disposal practices in the pre-1980's

Chemical contamination and organic enrichment have reduced marine benthic integrity within a few hundred meters offshore of the Station.

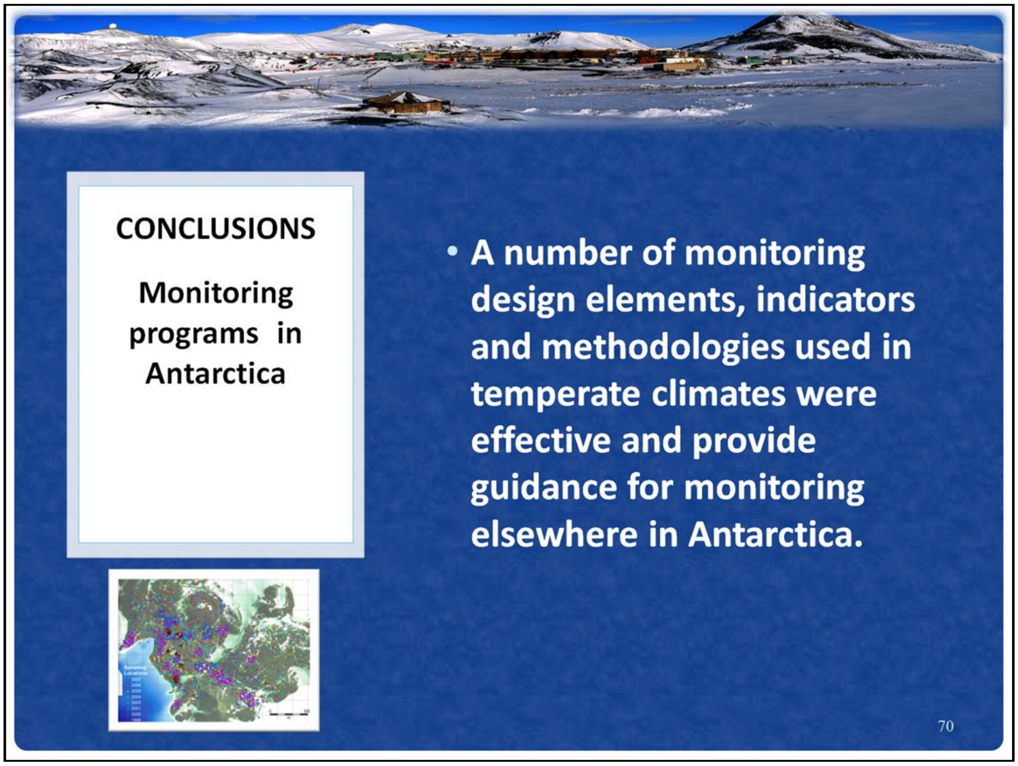
Contaminants were detected in marine benthic organisms confirming bioavailability and uptake.



MARINE CONTAMINANTS

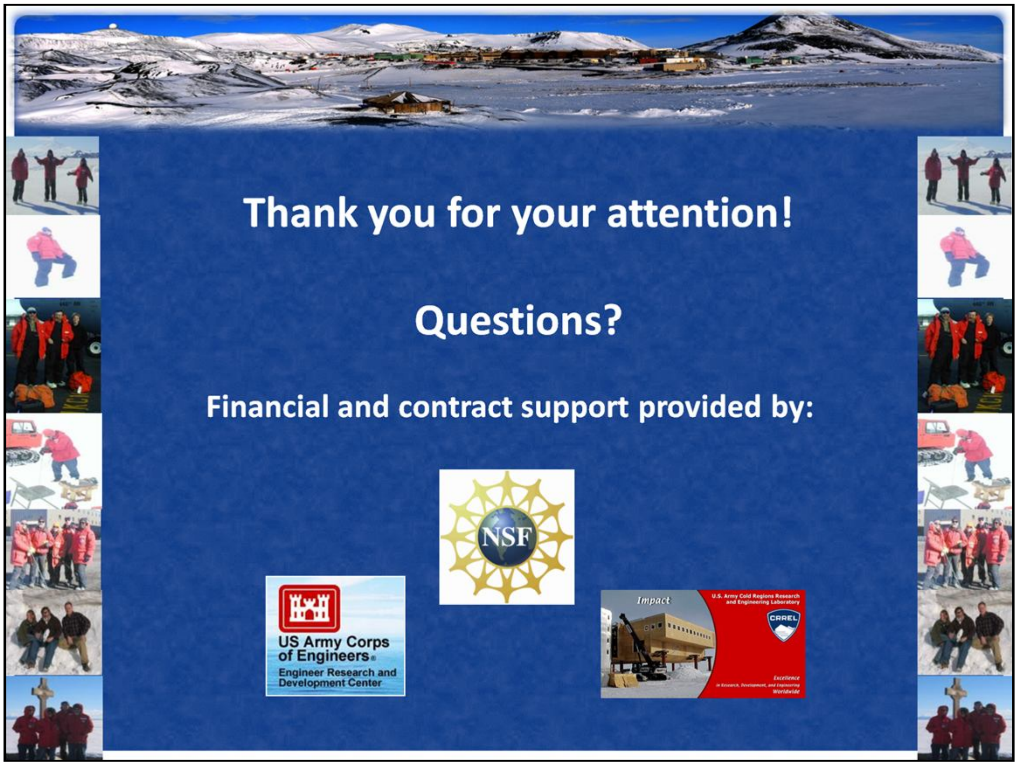
PCBs in sediments are similar to suspected source materials indicating minimal microbial degradation decades after release.

Disturbance of the marine environment is expected to persist for decades.



CONCLUSIONS

A number of monitoring design elements, indicators and methodologies used in temperate climates were effective and provide guidance for monitoring elsewhere in Antarctica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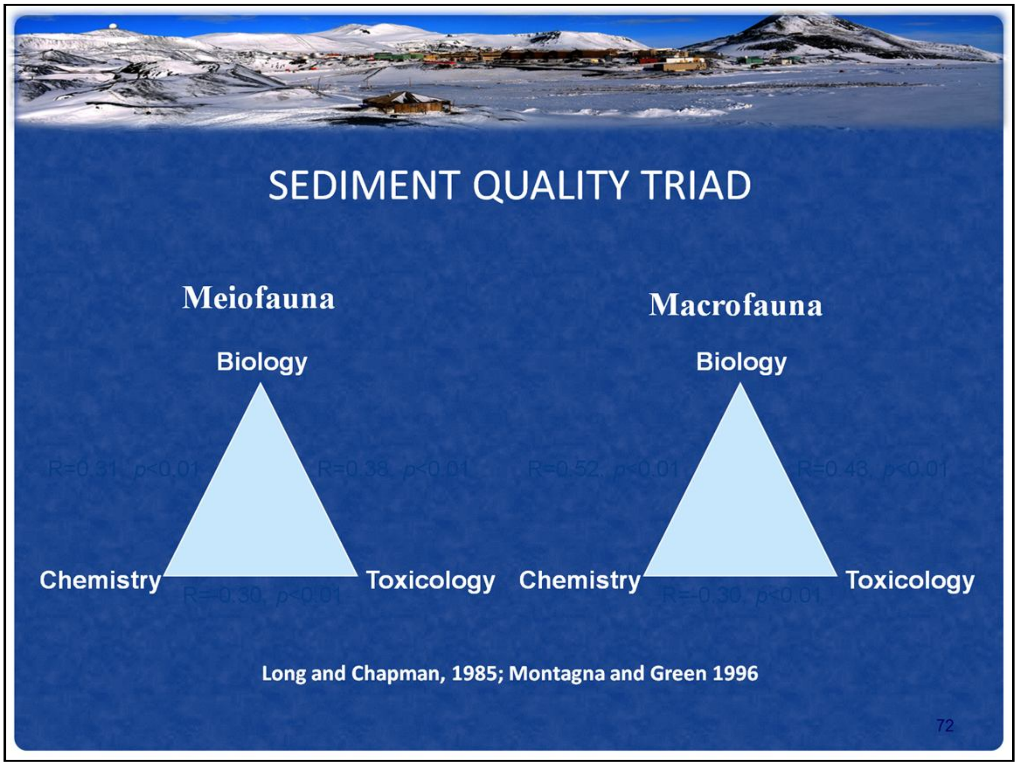
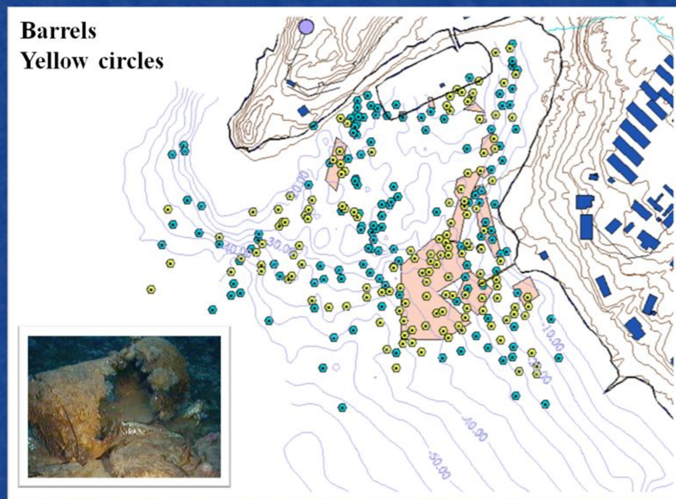
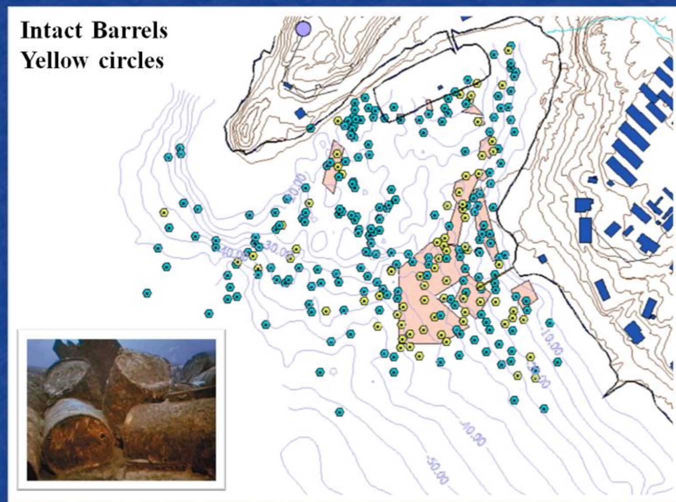

SEDIMENT QUALITY TRIAD
Meiofauna
Biology
R=0.31, p<0.01
R=0.38, p<0.01
Chemistry
Toxicology
R=-0.30, p<0.01
Macrofauna
Biology
R=0.52, p<0.01
R=0.43, p<0.01
Chemistry
Toxicology
R=-0.30, p<0.01
Long and Chapman, 1985; Montagna and Green 1996
72



Marine Debris Distribution

1998

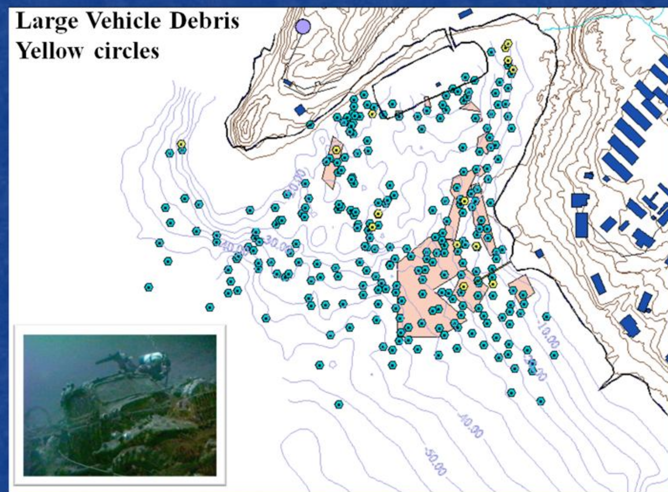
73



Marine Debris Distribution

1998

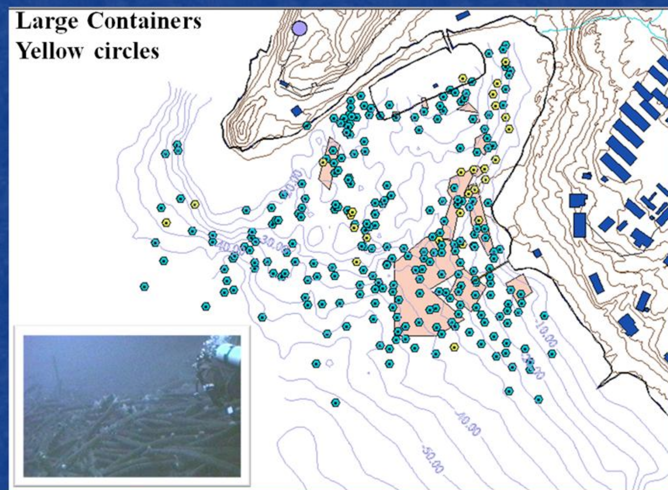
74



Marine Debris Distribution

1998

75



Marine Debris Distribution

1998

76