# Sherman Island
# Initial Environmental Evaluation

**BAS Environment Office**

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British Antarctic Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL

Initial Environmental Evaluation
Proposed Deep Ice Drilling Project
On Sherman Island, Antarctica

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### 1. Introduction

This Initial Environmental Evaluation (IEE) has been carried out by the British Antarctic Survey (BAS) for a proposed deep ice core drilling project on Sherman Island, Antarctica, during the 2019/20 field season.

The IEE has been prepared in accordance with Annex I of the *Protocol on Environmental Protection to the Antarctic Treaty* (1998).

This IEE also reviews the compliance with the associated drilling project that occurred on the Skytrain Ice Rise during the 2018/19 season, which was subject to a separate IEE. These two drill projects comprise the WACSWAIN project.

### 2. Description of the Proposed Activity

During the 2019/20 season BAS, in collaboration with the Department of Earth Sciences, Cambridge University, plans to carry out a deep ice core drilling project using its unique RAID (Rapid Access Isotope Drill) drilling technology on Sherman Island, Antarctica, situated in the Abbot Ice Shelf, inland from Thurston Island, and close to the Amundsen and Bellingshausen Seas. The project is funded in full by the European Research Council Advanced Grant to Prof. Eric Wolff (University of Cambridge), with partner Dr Robert Mulvaney (UKRI-BAS).

The chosen drilling site (S72°40.2’, W099°42.8’) is on a local dome of altitude 415 m above sea level, where ice approximately 430 m thick sits on a flat basal topography approximately 15 m below sea level. Rather than recover an ice core, as is normal for ice drilling to access palaeoclimate records, the aim is to retrieve only ice chippings from the full ice column through to the base of the ice rise. For this project, we will use the unique BAS-developed RAID (Rapid Access Isotope Drill) drilling system, which was developed to recover a full ice column of ice chips alone, using an auger enclosed in a barrel. The drill system was built specifically for recovering the stable water isotopes which are used to reconstruct climate history – hence the name of the drill system. No sampling of the basal sub-ice material is intended. The ice chippings will be transported frozen to the UK and sampled and distributed amongst the collaborating institutes for laboratory analysis. The objective is to obtain a new, and definitive, palaeoclimate record of stable water isotopes and chemistry from a region close to where the West Antarctic Ice Sheet (WAIS) drains into the Amundsen Sea, complementing the deep ice core obtained from Skytrain Ice Rise (located to the south of the Ronne Ice Shelf) which was recovered in 2018/19 season as part of the same EU-funded WACSWAIN project.  It complements too the UK deep ice cores from Berkner Island (located centrally in the Ronne), Fletcher Promontory (located at the south western corner of the Ronne) ice cores and those of the WAIS ice core programme of the USA. The drilling project on Sherman Island is planned to be carried out at a temporary field camp over the austral summer season 2019/20.

The project team also plan to revisit the Skytrain Drill site to take measurements from and retrieve equipment deployed last season.

**3. Description of the Environment**

Sherman Island is an ice-covered island about 50 km long and 19 km wide, lying south of Thurston Island in the middle of Peacock Sound. It is within environment domain M in the Antarctic Environmental Domains Analysis and consists of continental mid-latitude sloping ice.
There is no ice-free ground in the local vicinity, and no known biota; the nearest ice-free ground is on Thurston Island, more than 25 km from the proposed drill site.  The drilling project does not require visits to any ice-free areas elsewhere in the region. The site is not believed to have been previously visited and is therefore unlikely to have been subjected to human disturbance.  Site choice was informed by a single US airborne radar profiles that crossed the site.  There are no protected areas on the Sherman Island.

**4. Alternatives to the Proposed Activity**

Three alternatives have been examined:

i) Do nothing
ii) Drill Elsewhere in Antarctica
iii) Use Alternative Drilling Technologies

All three alternatives were considered not viable for scientific, technical or health and safety reasons.

**5. Impact Assessment**

The area likely to be impacted by the deep drilling project is estimated at approximately 0.5 $km^2$ for the field camp, and a 430 m 82.5 mm borehole. All drilling infrastructure will be input by BAS Twin Otter aircraft.  The three science personnel will be transported to and from the site by Twin Otter, while the two Field Guides supporting the project will travel by skidoo from the Thwaites Glacier project and return the same way. Unlike deep ice-core drilling projects, no drilling fluid will be used in this RAID drilling project as the RAID drill is designed to be used in a dry borehole.  Once drilling is finished, the borehole will naturally close up under the influence of ice flow.

In addition, minor environmental impacts may occur as a result of the field camp, including the production of a small quantity of hazardous and non-hazardous waste including sewage, possible contamination of snow caused by minor spills and leaks of fuel, and air pollution and particulate deposition from aircraft, generator and skidoo emissions. The likelihood of non-native species becoming established as a result of this project is very low.

**6. Mitigating Measures**

An environmental briefing has been given by the BAS Environment Office to all those taking part in the proposed deep ice core drilling project on Sherman Island.

Appropriate measures are recommended to mitigate any adverse impacts from the proposed activity. These include:

- **Site selection**: There will be no visitation of ice-free ground. There are no protected areas on the Sherman Island
- **Drilling methods**: Drilling will be carried out using the BAS RAID drill, in a dry borehole, which will close naturally on completion of the drilling, and within a few months.
- **Biosecurity**: The provisions of the BAS Biosecurity Regulations will be followed wherever applicable. All equipment will be checked prior to deployment from Rothera Station to ensure that it is free of soil and non-native biota.
- **Waste management**: All waste, other than grey water and urine, will be correctly packaged and labelled in accordance with the BAS Waste Management Handbook, and removed from Antarctica.
- **Spill response**: Spill kits including absorbents will be available for use to respond to some spills of fuel. However petrol spills will be allowed to evaporate naturally. Spills will be avoided by the use of funnels when e.g. refilling generators.
- **Air quality**: Daily visual checks of generator exhausts will be carried out, and maintenance will be undertaken as required to reduce the impact of atmospheric emissions.
- **Aesthetics/Wilderness:** The location of the camp, depots and associated traverses will be recorded on the Ops GIS. The accidental loss of any equipment or waste to the environment will be prevented by sound drilling methods and experienced operatives, and good camp management. Any loss event will be recorded.

**7. Environmental Monitoring and Management**

During the deep ice drilling project, compliance with BAS environmental policy and the mitigation measures outlined in this IEE will be the responsibility of the BAS Field Leader, Dr Robert Mulvaney.

## 8. Conclusion

This Initial Environmental Evaluation indicates that the proposed deep ice core drilling project on Sherman Island is likely to have no more than a minor or transitory impact on the Antarctic environment, provided the recommended mitigation measures identified in this report are carried out. It is therefore concluded that this activity should be allowed to proceed, and that a Comprehensive Environmental Evaluation (CEE) is not required.

The IEE for the associated drilling exercise on the Skytrain during 2018/19 has been reviewed. Whilst most of the impacts were correctly predicted, some impacts were greater than anticipated such as the loss of some of the drilling fluid. The mitigation method required to recover the drill fluid failed and lessons have been learnt for future projects using this method. Equipment was also deployed that was not described in the IEE and its retrieval is planned during 2019/20.

**Initial Environmental Evaluation**
**Proposed Deep Ice drilling Project**
**On Sherman Island, Antarctica**

# 1. INTRODUCTION AND SCOPE

This Initial Environmental Evaluation (IEE) has been carried out by the British Antarctic Survey (BAS) for a proposed deep ice drilling project on Sherman Island, Antarctica, during the 2019/20 field season.

It has been prepared in accordance with Annex I of the *Protocol on Environmental Protection to the Antarctic Treaty* (1998). The Revised Guidelines for Environmental Impact Assessment in Antarctica (Resolution 1, 2016) were also consulted during its preparation.

This IEE also reviews the compliance with the associated drilling project that occurred on the Skytrain Ice Rise during the 2018/19 season, which was subject to a separate IEE. These two drill projects comprise the WACSWAIN project.

# 2. Review of Compliance with 2018/19 IEE

The Skytrain IEE was prepared to assess the impacts of the 2018/2019 field season and agree the mitigation measures required. The BAS Operating Permit requires that "compliance with the EIA must be reviewed by the BAS Environment Office post season and findings shared with the permitting authority".

This review is covered in this document and is based on information gathered during a site Environmental Management System (EMS) audit by a BAS Environmental Manager during the Skytrain field activity and through a review meeting with the Principal Scientist on completion of the field season.

The BAS Internal EMS Audit report is included as an appendix to this report. In summary, its findings were that the overall impression of the field camp was that it was well organised and there was a high degree of awareness of environmental management practices and generally these were being well implemented. There were some areas which could be improved and included segregation of domestic waste and the day to day management of hazardous substances in the generator tent.

The review meeting with the Principal Scientist confirmed that many of the activities were carried out as planned, with the associated impacts as predicted. However the following issues altered the environmental impact from that predicted in the IEE:

- A generator failure hampered the full recovery of the drill fluid, meaning that up to a third of the drill fluid 1450 L remained in the drill column and will have become frozen in to the environment. This risk was predicted in the IEE but the planned mitigation measures failed. The lesson learnt from this incident for future drilling projects (using drill fluid) is that the generator provided needs to be fit for its intended purpose and serious consideration should be given to provision of a back-up generator as added resilience.

- The team also installed 15 No. 4m long metal glacio poles, 6 No. bamboo canes and cabling in the borehole which was not described in the IEE for use in the GPS and radar survey. The cabling consisted of 3 cables; a fibre optic cable and a copper cable to the base of the borehole, and a copper cable to 100m depth. It is likely that the cables and glacio poles will be removed during the 2019/20 season although this assumes they have not become excessively frozen in.

- The potential loss of the poles and cables to the environment will impact the wilderness potential of the site. The follow up process of this Sherman IEE will investigate what poles/cables remain in the field and the BAS Lost Equipment Log will be updated accordingly.

# 3. DESCRIPTION OF THE PROPOSED ACTIVITY

3.1 LOCATION OF THE PROPOSED ACTIVITY

The proposed deep ice drilling will take place at a site on Sherman Island, Antarctica, an elongated ice rise situated in the Abbot Ice Shelf, inland from Thurston Island, and close to the Amundsen and Bellingshausen Seas. The chosen drilling site (S72°40.2’, W099°42.8’) is on a local topographic dome with an altitude of about 415 m, where ice approximately 430 m thick sits on a flat basal topography approximately 15 m below sea level (Figure 1).

## 3.2 PRINCIPAL CHARACTERISTICS OF THE PROPOSED ACTIVITY

### 3.2.1 Aim and objectives

The proposed activity is a collaborative project between BAS and the University of Cambridge.

The project aims to drill through the ice sheet to bedrock, retrieving an ice chippings from the entire ~430 metres. The ice chips will be transported frozen to the UK and distributed amongst the collaborating institutes for laboratory analysis. The principal scientific objective is to obtain a new, and definitive, palaeoclimate record from a region where the West Antarctic Ice Sheet (WAIS) drains into the Amundsen Sea. The project will also involve revisiting the Skytrain site to take measurements from and recover the poles and cables installed last season.

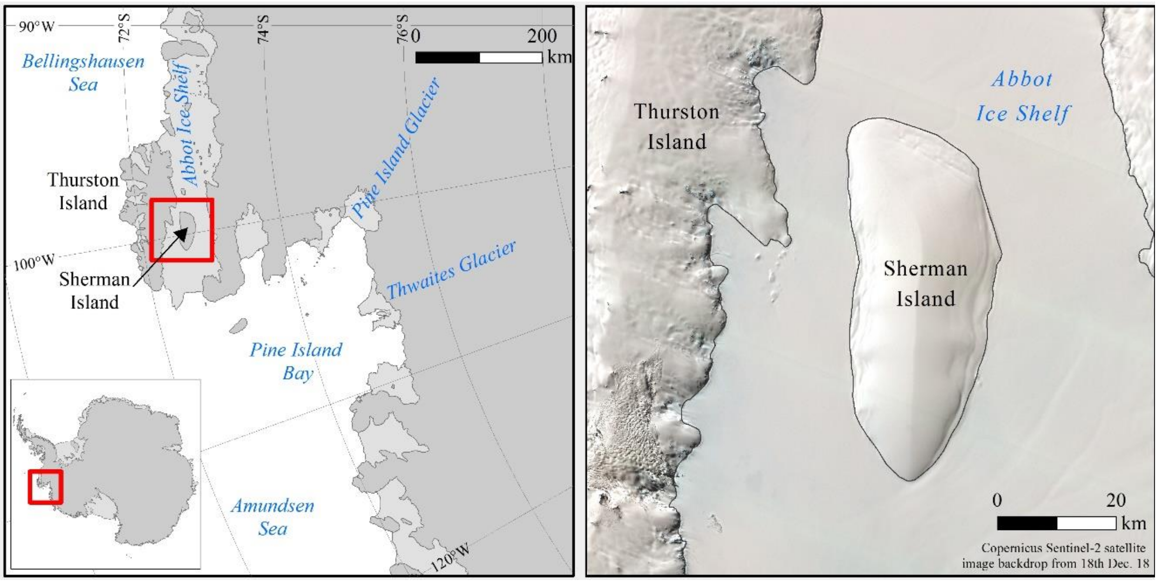


**Figure 1** Location of proposed drilling site on Sherman Island.

### 3.2.2 Field Camp

A field camp will be established on a local topographic ridge ~415 m above sea level close to the centre of Sherman Island. The logistic operation to establish the camp will be via BAS Twin Otter aircraft operating out of Rothera and the Sky Blu blue ice runway. To limit the need for Twin Otter flights, the majority of camp infrastructure will be transported over-snow (by skidoo) from the Thwaites Glacier project. Additional camp and drilling infrastructure will be deployed by Twin Otter. Uplift of equipment at the end of the project will be mainly by BAS Twin Otter to Rothera. Only three input flights and four uplift flights are anticipated, and no refuelling of aircraft at the field camp will be required.

The camp will consist of a maximum of 2 or 3 pyramid tents for accommodation, a toilet tent and two work tents for messing and for drilling controls.

Two 2 kVA petrol generators will be installed at the field camp to operate the drilling equipment and to supply power to the field camp.

### 3.2.3 Drilling methodology

The deep drilling will be carried out during one austral summer field season using the BAS RAID (Rapid Access Isotope Drill) electromechanical drill, described in Rix et al., (2019).

The drill consists of a drilling head with an ice cutting auger mounted on a rotating outer barrel driven by an electric motor. An inner rod with a continuous spiral flight transport ice chips generated by the auger is housed within an outer barrel – in this sense the drill can be considered as an Archimedes screw. The inner screw is connected to an anti-torque device, designed to grip the borehole walls to counter the rotational torque generated by the drilling action. Ice chippings generated by the drilling are carried up the Archimedes screw until the outer barrel is full, at which point the drill is returned to the surface and emptied by rotating the barrel in the reverse direction.

The drill is suspended by a wire cable with internal conductors carrying power from the snow surface to the drill. The drill has an overall length of 6.4 m and weighs 50 kg. It is capable of taking chippings from approximately 1.3 m of ice on each drilling run, in a borehole 82.5 mm diameter. Raising and lowering the drill in the borehole is controlled by a winch and a 9m tall mast and sheave wheel at the surface. Power is provided by the two linked 2 kVA petrol generators.

A typical drilling run, which includes lowering the drill to the bottom of the borehole, drilling 1.3 m of ice, then returning the drill to the surface, and removing the chippings, takes approximately 12 minutes at 300 m depth. Drilling to 430 m is expected to take approximately 40 hours of continuous (24 hours per day) drilling.

The drill has successfully reached 461 m at Little Dome C on the East Antarctic Plateau, operated by Dr Robert Mulvaney.

### 3.2.4 Drilling fluids

In conventional deep ice core drilling, a drilling fluid is used to combat borehole closure due to ice deformation.

The speed of drilling with the RAID drill, 24-hour drilling operation, and the use of a reamer to open the borehole if creep closure is expected, means that drilling fluid is not used.

Thus, no drilling fluid has been supplied for this project.

#### 3.2.5 Termination of drilling operations

Once recovered, the ice chips will be sampled into sample bags, and will remain depoted on site until an opportunity arises to fly them to freezer storage at Rothera using BAS Twin Otter aircraft. Later, the boxes of ice samples will be shipped via the BAS research vessel *RRS James Clark Ross* to the UK for analysis.

Following the drilling, a combination of cables will be lowered into the borehole to measure the borehole temperature in order to estimate the geothermal heat flow. The cabling is similar to that used on Skytrain Ice Rise in 2018/19, and consists of three cables; a fibre optic cable and a copper cable to the base of the borehole, and a copper cable to 100m depth. Over two or three days, the cables will be logged to measure the borehole temperature. On completion of the measurements, the cables will be removed from the borehole, and from Antarctica,

When all operations have been completed, the field camp, drilling equipment, unused fuel, and any remaining waste, will be removed from Antarctica for reuse or safe disposal mainly via Twin Otter to Rothera; ice samples will be flown to Rothera.

#### 3.2.6 Revisit of Skytrain site

The Skytrain drill site will be revisited during the 2019/20 season to take measurements from and retrieve the glacio poles and cables that were installed last season. Any materials not recovered will be reported to BAS Environment Office and recorded in the Lost Equipment Log.

### 3.3 AREA OF DISTURBANCE OF THE PROPOSED ACTIVITY

The area of disturbance at the drill site is estimated at a maximum of 0.5 $km^2$, including the field camp and fuel depot. The borehole will penetrate to a depth of ~430 m and will be 82.5 mm in diameter over most of its depth on completion, but will close naturally under ice deformation over a few months after drilling.

The location of the associated skidoo traverse used to transport Field Guides and some camp infrastructure is recorded on the BAS Operations GIS.

The Skytrain site will be visited is the same location as described in the previous IEE for the 2018/19 season.

### 3.4 DURATION AND INTENSITY OF THE PROPOSED ACTIVITY

No depot work has been carried out at the proposed site prior to the 2019/20 field season.

The proposed drilling project is planned to be undertaken during one single austral summer season 2019/20. The field party will be input to Sherman Island in late January 2020. A temporary field camp will be established which will remain for the duration of the project, after which it will be removed. The drilling infrastructure will be mostly in the open, with the winch and drill tower mounted on a single plywood sheet on the snow surface. A small 'pop-up' tent, and two wind breaks will provide minimal shelter for the drilling operation.

Five personnel will spend a total of 20 days in the field. At the end of this season, the field camp and drilling infrastructure, including any plywood sheets, will be removed from Sherman Island, as well as all empty fuel drums, unused fuel, ice samples and waste.

## 4. DESCRIPTION OF THE LOCAL ENVIRONMENT

Sherman Island is an ice ridge within the Abbot Ice Shelf. Abott ice shelf is 400 km long and 65 km wide, bordering Eights Coast from Cape Waite to Phrogner Point. Thurston Island lies along the north edge of the western half of the ice shelf with other sizable islands (including Sherman, Carpenter, Dustin, Johnson, McNamara, Farwell and Dendtler) lie partly or wholly within it.

The chosen drill site is on a local topographic dome with a surface altitude of around 415 m metres above sea level, and a flat base about 15 m below sea level. There is no ice-free ground in the vicinity, and there are no known biota present.

Sherman Island is an ice-covered island about 50 km long and 19 km wide, lying south of Thurston Island in the middle of Peacock Sound. The feature rises above Abbot Ice Shelf which occupies the sound. The island was delineated from aerial photographs taken by USN Operation HighJump in December 1946. It was named by US-ACAN for Admiral Forrest Sherman, USN, Chief of Naval Operations, 1949-51, when preparations were being made for U.S. Naval support during the forthcoming IGY operations.

Sherman Island is within environment domain M in the Antarctic Environmental Domains Analysis and consists of continental mid-latitude sloping ice. Environment M is an expansive ice sheet environment that covers four distinct areas all focused around the 75°S parallel. Environment M (902 626 km2) is the sixth largest on the continent. The environment consists entirely of ice sheet and contains no mapped geology. Climatically the environment is cool in comparison to the other environments. Environment M is the ninth coldest in average air temperature (–22.76°C) and the seventh largest seasonal range (–20.62°C). The average wind speed within the environment is moderate, ranking 12thout of 21 environments (12.14 m/sec). The environment is not steep with an average slope of only 7.38°. Well-known locations the environment covers include David and Lambert Glaciers, Maudheimvidda, Coates Land, northern Berkner and Roosevelt Islands and Ellsworth Land.

Results from radar surveys show that Sherman Island has approximately 430 m depth of ice sitting over flat bedrock topography, an accumulation rate equivalent to approximately 30 cm of water per year, a surface temperature of -21°C and a bedrock temperature of around -6°C.

No areas of ice-free ground are known within Sherman Island and, as a consequence, no geological or botanical records exist for the area. The nearest ice-free ground is located on Thurston Island, 25 km to the north.

There are no protected areas (ASPAs, ASMAs or HSMs) on Sherman Island.

The site is not believed to have been previously visited and is therefore unlikely to have been subjected to human disturbance. No surface borne radar studies have been carried out by BAS in earlier seasons, and the only known radar track across the island came from a US airborne radar survey.

# 5. ALTERNATIVES TO THE PROPOSAL

## 5.1 DO NOTHING

This alternative has been considered and rejected on the grounds of the highly important scientific benefit that will be gained from carrying out the project. The significance of the project has been verified as of exceptional importance by the award of €3.1 M grant for the project (Sherman Island drilling, and the earlier Skytrain Ice Rise drilling) in the highly-competitive European Research Council Advanced Grants to the project PI Prof Eric Wolff (Cambridge University) and partner Dr Robert Mulvaney (BAS).

Continuous depth analysis of deep Antarctic ice provides the best possible records of the history of climate change and atmospheric composition. Major deep ice drilling projects (greater than 500m in depth) have been carried out at more than twelve locations in Antarctica since 1968. Figure 2 shows the locations of previous deep ice drilling sites in Antarctica.

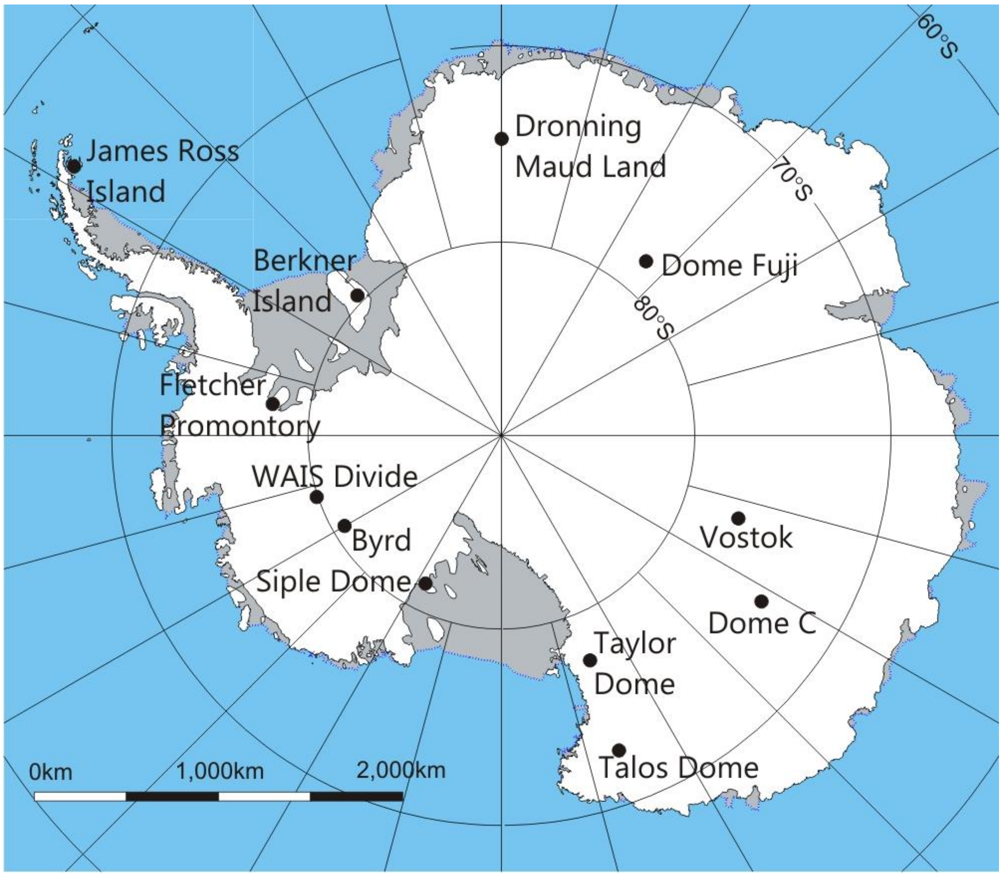


**Figure 2.** The location of previous ice core drilling sites (>500m depth) in Antarctica (plus the UK 364m site on James Ross Island).

The IPICS (the SCAR International Partnerships in Ice Core Sciences) white paper on deep ice core research outlines the climate history provided by the longest records of Antarctic deep ice core drilling projects (Vostok, Dome C and Dome F), and makes the specific recommendation that these should now be complemented by understanding how climate changes have affected different regions of Antarctica. The WAIS Divide ice core, which spans a timescale of almost 70,000 years, shows similar climate patterns to the longest cores, but with important differences during rapid climate change (such as the last deglaciation). Indeed, the analysis of other coastal cores of a similar timescale, such as Berkner Island, Fletcher Promontory, Taylor Dome, Siple Dome and Talos Dome suggest that Antarctic climate did not follow a single or uniform pattern of change. This apparent discontinuity with central East Antarctic records poses severe tests on existing models of climate change. It is also clear from Figure 2 that the drilling of a deep ice at Sherman Island for the palaeoclimate record will complement geographical coverage of the WAIS and Ronne sectors of Antarctica.

## 5.2 DRILL ELSEWHERE IN ANTARCTICA

This alternative has been considered and rejected on the grounds that the Sherman Island ice cap has been selected as the one of the best sites in the coastal region of the West Antarctic Ice Sheet for obtaining a high resolution climate record of this region using the ice drilling capabilities of the UK. Results from radar surveys by BAS show that Sherman Island has approximately 430 m depth of ice sitting over flat bedrock topography, an accumulation rate equivalent to approximately 30 cm of water per year, a surface temperature of -21°C and a bedrock temperature of around -6°C. Experience from Berkner Island and Fletcher Promontory suggests that drilling on Sherman Island should capture the climate record of this sector of Antarctica over the past >70,000 years, and may even incorporate the period of the Last Interglacial when the climate was warmer than our present interglacial climate, sea levels were 6-9m higher and the WAIS might have collapsed.

The International Partnerships in Ice Core Sciences (IPICS), endorsed by SCAR and officially approved as an IPY project by the IPY Committee, has released five White Papers describing the science strategy for ice core research over the 10 to 15 years. One of these White Papers, entitled "History and Dynamics of the Last Interglacial period from Ice Cores" (http://pastglobalchanges.org/ini/end-aff/ipics/documents) calls for additional ice core drilling site to expand the number of regional ice cores from Antarctica (see Figure 3). Skytrain Ice Rise and Sherman Island were chosen, and funded by the highly competitive ERC funding mechanism, to complement particularly the UK Weddell Sea deep ice cores, and the US WAIS ice core, to understand the extent of ice loss from the WAIS region under a warm interglacial, and the impact on sea level rise.

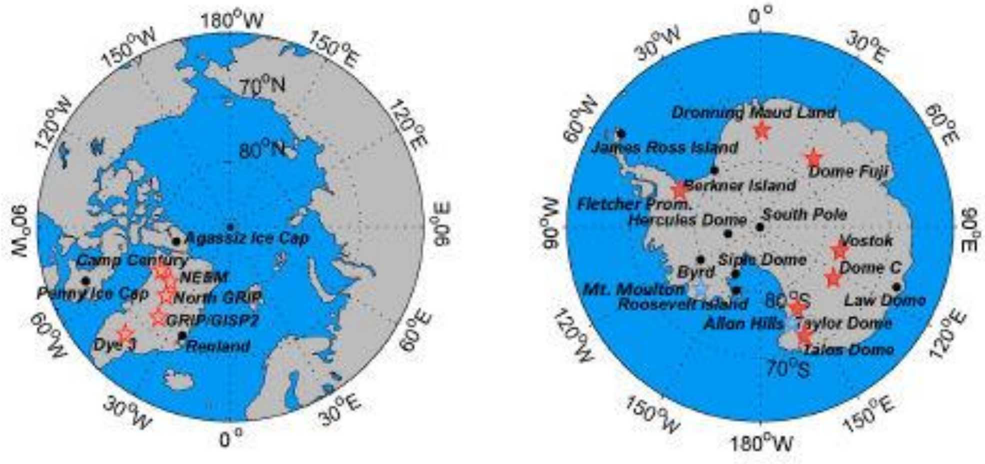


**Figure 3.** Locations of deep ice cores containing sections from the last interglacial are shown with red stars. Filled star indicates complete intact Eemian record; open star indicates records that contain Eemian ice but are either not complete or not stratigraphically intact (that is, sections are missing and/or not in order).

## 5.3 USE ALTERATIVE DRILLING TECHNOLOGIES

Two alternative drilling technologies have been considered.

### 5.3.1 Thermal Drilling

This alternative is capable of collecting deep ice cores, but has been considered and rejected on the grounds that it:

- may result in a poor-quality ice core;
- is more energy intensive than electro-mechanical drilling;
- is a slow drilling method, and would take longer than the short field season envisaged.

Thermal drilling replaces the cutter head, as used in an electro-mechanical drill, with an annular ring of electrically heated wires that melt an annulus of ice. The melt water is mixed with antifreeze and drawn away from the head of the drill into a chamber. Using thermal drilling, the borehole must also be filled with bulk drilling fluid to avoid hole closure. Thermal drilling usually requires a strong ethylene glycol mixture, or pure ethanol, as the drilling fluid.

The major scientific disadvantage of thermal drilling is the thermal shock applied to the ice core, which initiates the cracking of the ice, damaging the core, and commonly soaking the core with contaminated liquid which is miscible with the ice. This can result in a poor-quality ice core, which will compromise the quality of the chemical analysis, and hence the climate record, obtained.

Thermal drilling is also more energy-intensive, requiring greater quantities of fuel, with a resulting increase in atmospheric emissions and the deposition of particulates in the immediate surface snow layer, while returning a scientifically compromised ice core that is unlikely to meet the quality criteria for the range of analyses planned. It is also a slow drilling technology, better suited to long field seasons with a large party.

Poor quality core, and the energy intensive nature of thermal drilling, mean that this technique is now rarely used in Antarctica where an ice core is to be recovered.

### 5.3.2 Ice Core Drilling with a Drilling Fluid

This alternative is the standard method by which BAS (and others) have collected ice cores for palaeoclimate research (Mulvaney et al., 2002, 2007, 2014). It has been considered and rejected on the grounds that:

- a drilling fluid is required to reach 430 m;
- the specific science project on Sherman Island calls only for continuous ice chippings, and on this occasion a full ice core for multiple analytical procedures is not required;
- drilling a core would require a larger party, and a full/long field season, with considerably greater commitment of infrastructure and logistics.

The main purpose of this science project is to recover a continuous profile of ice chips for stable water isotope analysis (which is the basis for the climate record), and for a limited range of chemical analysis designed to determine the extent and proximity of open sea water at the last interglacial, and during the glacial period.  We do not intent to measure the gas composition of trapped air bubbles in an ice core, nor to measure the full range of analytes available to us from ice cores.

# 6. IDENTIFICATION AND PREDICTION OF IMPACTS, AND MEASURES TO MINIMISE OR MITIGATE THOSE IMPACTS

The following predicted impacts and mitigating measures are based upon BAS experience of operating similar deep ice core drilling projects (for example, Berkner Island 2002-2006, James Ross Island, 2007/08, Fletcher Promontory 2011/12), Skytrain Ice Rise (2018/19).

## 6.1 USE OF DRILLING FLUID

We will not use a drilling fluid for this RAID drilling project.

## 6.2 ATMOSPHERIC EMISSIONS

Air pollution will result from the input of the field party by aircraft and skidoos, and the use of unleaded petrol generators at the field camp. Fuel consumption from the generators used on-site during the field season is estimated at 410 L of petrol. 80 l kerosene will also be required to cooking and heating purposes in the field camp. Emissions will include carbon monoxide, carbon dioxide, nitrous oxides, sulphur dioxide, heavy metals and particulates. Using UK Government Guidelines for Greenhouse Gas Reporting (2019) (see https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019) the use of petrol in the generators will give rise to a combined total emission of greenhouse gases of approximately 949 kg $CO_2$e (carbon dioxide equivalent). The emissions from the kerosene will give rise to a combined total emission of greenhouse gases of approximately 203 kg $CO_2$ e.  Emissions resulting from the fuel used e.g. in aircraft associated with the projects logistics will be calculated and reported in the BAS Annual Environmental Report as part of the overall BAS carbon footprint.

Emissions will generally be rapidly and thoroughly dispersed by the strong and regular winds. There will be some fallout of pollutants in the local area. Heavy larger particles, such as soot, are likely to have relatively short maximum transport distances, with background levels in surface snow samples probably being reached within 2 km downwind of the drill site. Heavy metals would have greater transport distances. Based on monitoring results from Halley IV Station, it is possible that background levels of heavy metals (e.g. lead) in surface snow samples would be exceeded up to a maximum of 10 km downwind of the site (Suttie and Wolff, 1993).

### 6.2.1 Mitigating Measures

Daily visual checks are to be made of generator exhausts. Any maintenance to reduce atmospheric emissions will be carried out as required. The generators will be shut down when not required.

## 6.3 WASTE

A very minor increase in the quantity of hazardous and non-hazardous waste produced by BAS in Antarctica is expected as a result of the drilling project. Hazardous waste may comprise empty drums, used absorbents, batteries and clinical waste. Non hazardous waste is likely to comprise paper, glass, metal and plastic.

Batteries will be returned to Rothera: rechargeable batteries will be taken from the Rothera battery store at the start of the season, and returned to the store at the end of the season for use by other projects. Primary cells will be taped, and flown to Rothera and safely removed from Antarctica for disposal.

Approximately 30 kg of waste plastic and paper is generated by the drilling project, and will be removed to Rothera and absorbed into the Rothera waste management system

Based upon an estimated 0.23 kg of waste (excluding sewage and grey water) produced per person per day (derived from Lewis, 1994), it is estimated that a maximum of 23 kg of general waste will be produced by the field party during the one austral summer season.

The field party will also produce sewage, food waste and grey water. Based upon an average adult excreting 1.8 litres of urine and faeces per day, the field party will produce approximately 180 litres of sewage during the season.

### 6.3.1 Mitigating Measures

Staff involved in the Sherman Island Drilling Project will comply with BAS waste management policy and will follow the procedures outlined in the BAS Waste Management Handbook (BAS, 2019). The camp will be cleared of any rubbish or debris each day. All waste, other than grey water and urine, will be removed from the site to Rothera, where it will be removed from Antarctica for safe and controlled disposal. Open burning of waste is prohibited.

All BAS field parties are supplied with a copy of the Field Operations Manual, colour coded waste sacks for the separation and disposal of wastes, and solid human waste drums that are UN approved for clinical waste.

## 6.4 MINOR SPILLS OF FUEL

A further, but localised possible impact, could be ice or snow contamination caused by minor spills and leaks of fuel. The maximum quantity of fuel that is likely to be spilled at any one time is 205 L, due to a punctured drum. Spilled

fuel would pass quickly through the surface layer of snow, and be absorbed by it. A small quantity may also evaporate.
There would be no biological effect of a minor fuel spill or leak close to Sherman Island.

### 6.4.1 Mitigating Measures

BAS makes every effort to prevent accidental fuel spills through careful attention to fuel management, at its stations and in the field. There is no need to refuel aircraft at the Sherman Camp, so the volume of fuel is minimised and includes only low volumes of petrol and kerosene.

Members of the field party will be expected to take all reasonable precautions to ensure that minor fuel leaks and spills do not occur. Any minor fuel spills should be stopped as quickly as possible such as by righting a drum or jerry, and patching it with Pig Putty. A drum funnel will be provided to prevent spills. Absorbent mats and pads will be provided for immediate response to minor fuel spills of kerosene, though most of the spillage is likely to be lost in the firn. Used absorbents may be drummed and removed to Rothera for safe disposal. Any petrol spilt would be left to evaporate naturally, to avoid the H&S risks associated with flying with used absorbents.

A log of any fuel spills is to be kept and recorded on the BAS accident reporting (AINME) system.

## 6.5 INTRODUCTION OF NON-NATIVE BIOTA

There is a very small risk of the introduction of non-native biota, particularly micro-organisms, because of the importation of materials. This risk is very low of species becoming established as the camp is being set up on an ice dome, approximately25 km from the nearest ice-free ground on Thurston Island or other islands on the Abott ice shelf.

### 6.5.1 Mitigating Measures

All equipment and materials required for the drilling project will be thoroughly cleaned before dispatch to Antarctica. All timber used for the drilling rig infrastructure will be new and comply with the International Standards for Phytosanitary Measures No. 15 (ISPM 15).

All items of cargo will be checked for soil or non-native species prior to being flown from Rothera. The advice and procedures contained within the BAS Biosecurity Regulations will be followed where applicable.

## 6.6 CHANGES IN LOCAL TOPOGRAPHY AND WILDERNESS/AESTHETIC VALUES

BAS logistics and science operations have an impact on the wilderness and aesthetic values in Antarctica.

### 6.6.1 **Mitigating Measures**

The site is not believed to have been previously visited and is therefore unlikely to have been subjected to human disturbance. Log of depots, camps and associated traverse routes to be kept at BAS for future reference

Care will be taken to avoid loss of equipment and waste at the field camp/drill site, and any accidental loss will be recorded on the AINME system. The cables installed into the boreholes are only intended to remain in the boreholes for a few days before their planned removal.

Snow drifts which have accumulated as a result of the field camp will generally dissipate through natural processes once the field camp is removed.

The route for the skidoo traverse (from Thwaites to Sherman Island is approximately 350km long and is estimated to take 4 days to complete. To minimise the risk to wilderness values and wildlife disturbance, the route will be recorded on the Ops GIS, it is all on ice (with no requirement to visit ice-free ground or areas with concentrations of wildlife). Standard poo bins will be provided for use (to ensure no waste is left in the field). Refuelling of skidoos will only likely occur at the camp sites, whose locations will also be recorded on the Ops GIS.

## 6.7 ENVIRONMENTAL EDUCATION

It is BAS policy to brief all new recruits on Antarctic Environmental Protection before they travel to Antarctica. An environmental briefing will be given by the BAS Environment Office to those personnel involved in the drilling project during the BAS Pre-Deployment Training.

## 6.8.1 IMPACT MATRIX

Table 1 shows a summary of how the predicted environmental impacts which may result from the drilling project, and how BAS plans to minimise or mitigate these impacts.

| Activity | Output | Possible Impact | Probability of impact occurring | Severity of impact | Preventative or mitigating measures |
|---|---|---|---|---|---|
| Ice Core Drilling | Possible loss of drill | Non –recovery of drill from Sherman Island | Slight | Low | Safe drilling procedures to be followed at all times to reduce risk of loss of drill. Only experienced operatives will use the drill.<br><br>The loss of any equipment will be reported in the AINME system for inclusion in the BAS Lost Equipment Log. |
| Importation of cargo to Sherman Island | Introduction of non-native species | Ecosystem alteration if species became established. Increased competition and spread of non-native disease. | Very low | Very Low (if 1 or small number of individuals)<br><br>High (if species become established) | BAS Biosecurity Regulations will be followed where appropriate.<br><br>All procedures include measures to ensure that soils, seeds and propagules are not transported to Antarctica.<br><br>Cargo, vehicles and personal clothing must be cleaned prior to importation. All equipment to be thoroughly cleaned before packing, and checked at Rothera before flying into the field.<br><br>All equipment to be flown directly to camp via Sky Blu, and not offloaded on ice-free ground.<br><br>If soil, seeds or propagules are accidentally imported they must be carefully collected and removed. Disposal may include incineration at Rothera or removal from Antarctica.<br><br>All timber to be new and compliant with ISPM 15. |
| Operating field camp and the supporting logistics | Waste (hazardous and non/hazardous) | Danger to wildlife if scattered by wind. | Low | Very Low | Environmental briefing for all staff.<br><br>All waste to be correctly packaged, labeled and |

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| | | | | | removed from Sherman Island for safe disposal, in line with BAS Waste Management Handbook.<br><br>Site to be cleared each day to prevent wind scatter. |
| | Minor fuel spills and leaks from generators or skidoos | Chemical contamination of ice | Low | Very Low | Careful attention to fuel handling and management. Low volumes of fuel required minimise storage requirements and risk of spills.<br><br>Use of drip trays and funnels to prevent leaks.<br><br>Any minor leaks to be sealed immediately<br><br>Minor spills to be cleaned up with absorbents (unless petrol which will be left to evaporate).<br><br>Any spill event to be reported on the BAS AINME system. |
| | Atmospheric emissions from generators, skidoos and aircraft | Very minor but cumulative contribution to regional and global atmospheric pollution including greenhouse gas emissions.<br><br>Particulate fallout. | Certain | Very low | Daily checks of vehicles / generator emissions.<br><br>Maintenance to be carried out as necessary.<br><br>Carbon emissions from fuel use to be recorded in the BAS carbon footprint and reported in Annual Environmental Report. |
| | Snow drifts around temporary field camp structures | Changes in local topography | Certain | Very low | Drifts will dissipate naturally in time. |
| | BAS Operational footprint | Aesthetic Damage<br>Reduction of wilderness and pristine nature of localities<br>Impact on future science | High | Low | Log of depots, camps and traverse routes to be kept at BAS for future reference<br><br>Log to be kept of any equipment accidentally lost |

**Table 1 Impacts associated with the Proposed Deep Ice Drilling programme, and preventative or mitigating measures**

# 7. ASSESSMENT AND VERIFICATION OF IMPACTS

## 7.1 ENVIRONMENTAL MONITORING

The BAS Field Leader (Dr Robert Mulvaney) will be responsible for the daily on-site supervision of the project, and for implementing the measures to be taken to minimise or mitigate the adverse environmental impacts which may result from the proposed deep ice core drilling project (Table 1). Photographs and video will be taken of the site at all major stages of drilling project, including the clean-up and removal of the camp during the final season.

Any environmental incident such as fuel spill, poor waste handling, loss of equipment to the environment will be reported on the BAS AINME system for investigation by Environment Office.

# 8. CONCLUSIONS

This Initial Environmental Evaluation indicates that the proposed deep ice core drilling project on Sherman Island is likely to have no more than a minor or transitory impact on the Antarctic environment, provided the recommended mitigation measures identified in this report are carried out. It is therefore concluded that this activity should be allowed to proceed, and that a Comprehensive Environmental Evaluation (CEE) is not required.

The IEE for the associated drilling exercise on the Skytrain during 2018/19 has been reviewed. Whilst most of the impacts were correctly predicted, some impacts were greater than anticipated such as the loss of drilling fluid. The mitigation method required to recover the drill fluid failed and lessons have been learnt for future projects using this method. Equipment was also deployed that was not described in the IEE and its retrieval is planned during 2019/20.

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## 9. AUTHORS OF THE IEE

This Initial Environmental Evaluation was prepared by Dr Robert Mulvaney and Rachel Clarke, British Antarctic Survey.

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## 10. ACKNOWLEDGEMENTS

We are grateful to MAGIC for preparing the location map of Sherman Island.

# 11. Appendix A

BAS Internal EMS Audit Report

**BAS Internal EMS Audit Report**

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| **Audit Location /Scope:** | WACSWAIN Field Camp, Sky train Ice Rise, Ronne Ice Shelf. |
| **Auditor(s):** | Clare Fothergill |
| **Audit Host(s):** | Rob Mulvaney (RM) Principal Scientist |
| **Date of Audit:** | 26.12.2018 |
| **Summary of Audit** | A one hour visit to the WACSWAIN field camp was completed. The overall impression of the field camp was that it was well organised and there was a high degree of awareness of environmental management practices and generally these were being well implemented. There were some areas which could be improved and included segregation of domestic waste and the day to day management of hazardous substances in the generator tent. Recommendations have been provided in the body of this report.<br><br>This was the second field camp audit undertaken by BAS Environment Office as part of the BAS EMS and ISO14001 requirements. As such there will be an internal Environment Office review to determine if the process of completing field audits can be improved. |
| **Element of ISO 14001:2015 being audited:** | 6.1 Compliance obligations<br>7.2 Competence<br>7.3 Awareness<br>8.1 Operational planning & control<br>8.2 Emergency preparedness and response<br>9.1.2 Evaluation of compliance |
| **Compliance Obligations: Element 6.1** | • Skytrain IEE 2018<br>• Environmental Protocol (1991) – Annex's I, II, III, IV and VI<br>• Antarctic Act (1994, 2013)<br>• BAS Waste Management Handbook<br>• BAS Field Operations Manual<br>• BAS Biosecurity Regulations<br>• Control of Substances Hazardous to Health (COSHH)<br>• Oil Spill Contingency Plan<br>• Section 6 of the Antarctic Act 1994 (Permit No.2/2017) letter of authorisation (BAS-S6-2018/11) |
| **Audit Area** | **Audit Findings** |
| Ski way | • Approximately 30 x 205l drums of AVTUR fuel were located at the ski way. An oil spill kit was present. No refuelling was undertaken during the audit. |
| Drill Tent | • The WACSWAIN field camp is a deep ice core drilling project located on the Ronne Ice Shelf. The intention is to retrieve an ice core which is the full depth of the glacier (approx. 600m) and to obtain a sample of the |

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| | basal material underneath it. At the time of the audit 6 personnel were on site.<br>• The main environmental impact identified in the IEE was the use of Exxsol D60 drilling fluid. During the site visit RM explained how the drill was operated and the procedure for reusing the drill fluid. RM explained that due to the cost and potential environmental impact of the drill fluid every attempt was made to recover, reuse and recycle it. He confirmed that approximately 15% of the fluid used would be lost at the end of season despite plans to pump out any remaining fluid from the bore hole. The recovery of the fluid was anticipated to take at least 7 days at the end of the season once the ice core drilling was complete.<br>• Exxsol D60 drilling fluid is a highly volatile substance which will rapidly evaporate and degrade in the atmosphere. It is readily biodegradable and has a low eco-toxicity.<br>• The drill tent was well organised and there was a comprehensive system in place to minimise the impact of the loss of any drill fluid. Each time the corer was retrieved from the bore hole there was the potential for drill fluids to be spread. Oleophilic spill mats were actively being used to absorb the drill fluid from around the bore hole, the corer bench and underneath the cable spool. See Photos 1 & 2. Once saturated the spill mats were being recycled by placing them in the centrifuge and removing as much drill fluid as possible.<br>• In addition any snow that had been contaminated by drill fluid was also processed through the centrifuge. Visually and to the touch, it appeared very clean. See Photos 3 & 4.<br>• Segregation of waste packaging materials such as card and plastic was evident in the drill tent and was being well managed. This was packaged up and returned to Rothera for consignment back to the UK. |
| Generator Tent | • RM confirmed that the generator was the ‘dirtiest’ part of the operation and contaminated snow was visible around the generator as a result of emissions. See Photos 5 & 6.<br>• Small quantities of fuel and oils were being stored here in jerry cans and plastic containers. Whilst spill mats were in use underneath these containers there was no hard barrier between the containers and the snow. RM raised concerns over the use of traditional drip trays which could become a hazard in high winds. Plant nappies which can be tethered to an anchor (e.g. an ice screw) would resolve this issue.<br>**Improvement Action:**<br>**It is recommended that BAS Operations undertake a review of current procedures for handling and storing fuel drums, jerry cans and other hazardous substances (oils, hydraulic fluids etc.) in the field and whether an improved and** |

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| | **more robust method of bunding can be implemented. E.g. using drip trays or plant nappies underneath generators when refuelling, and portable bunds for fuel drums. This could ensure compliance with COSHH and oil storage regulations.** |
| Mess tent | • The mess tent was well organised as a communal space. RM advised that there was little to no food waste.<br>• Segregation of waste packing and other materials had been seen in other parts of the camp. A bag for contaminated food packaging was in use in the mess tent and it was confirmed that this was sent to Rothera for final disposal in landfill. RM confirmed that plastics, metals, paper and card were being segregated and where possible using colour coded bags. RM suggested that if specific containers/bins were provided it would make it easier to segregated waste.<br>**Improvement Action:**<br>**Waste management in the field should be co-ordinated by the Field GA but is the responsibility of all members of the field team. The FOM needs to ensure that the process for managing waste as set out in the Field Operations Manual is communicated effectively to the Field GAs and the appropriate equipment provided. As per the Field Operations Manual and the BAS Waste Management Handbook, waste should be segregated effectively in the field. A review of the procedure as set out in the Field Operations Manual and the BAS Waste Management Handbook is recommended in conjunction with the BAS Environment Office.** |
| Toilet Tent | • The honey bucket toilet system appeared to be working well and RM advised that he thought it was effective. Three 'pee flags' were in use outside and a dedicated pee drain had been created inside the toilet tent. No issues were reported or seen with regard this system. |
| Ice Core Storage | • Once the ice cores had been cut into smaller sections they were being bagged up and placed inside plastic boxes (lined with polystyrene insulation). These were then placed inside the ice core storage 'cave'. This was an underground storage area which kept the cores frozen until they were collected and transported back to Rothera. There were no environmental risks in this storage area.<br>• RM confirmed that it was imperative that the boxes remained horizontal as far as possible and were treated with care to avoid damaging the cores. There had been some confusion amongst staff at Sky Blu, which was being used as an interim storage site, over whether the priority was to keep the cores below a certain temperature or to minimise movement of the cores. The issue being that access to the underground store at Sky Blu was extremely constrained. Clarification of the requirements to those staff operating at Sky Blu may ensure that the cores are managed appropriately. |

<table>
<tr><th>Photos</th><th></th></tr>
<tr><td>Photo 1. Ice Core Drill Operations<br></td><td>Photo 2. Drill rig cable with spill mat underneath and tray to catch contaminated snow.<br></td></tr>
<tr><td>Photo 3. Centrifuge for cleaning spill mats and contaminated snow<br></td><td>Photo 4. Contaminated snow post cleaning<br></td></tr>
</table>

Photo 5. Generator

Photo 6. Contaminated snow in generator tent

Photo 7. Storage of fuels and oils for daily use (small quantities)

Photo 8. Mixed contaminated food packaging

Photo 9. Ice Core Storage

| **Actions & Non conformities** | **Action to be completed by:** |
|---|---|
| Improvement Action:<br><br>It is recommended that BAS Operations undertake a review of current procedures for handling and storing fuel drums, jerry cans and other hazardous substances (oils, hydraulic fluids etc.) in the field and whether an improved and more robust method of bunding can be implemented. E.g. using drip trays or plant nappies underneath generators when refuelling, and portably bunds for fuel drums. This could ensure compliance with COSHH and oil storage regulations. | BAS Operations: Field Operations Manager and Vehicle Operations |
| Improvement Action:<br><br>Waste management in the field should be co-ordinated by the Field GA but is the responsibility of all members of the field team. The FOM needs to ensure that the process for managing waste as set out in the Field Operations Manual is communicated effectively to the Field GAs and the appropriate equipment provided. As per the Field Operations Manual and the BAS Waste Management Handbook, waste should be segregated effectively in the field. A review of the procedure as set out in the Field Operations Manual and the BAS Waste Management Handbook is recommended in conjunction with the BAS Environment Office. | Field Ops Manager &<br><br>Environment Office |

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|---|---|
| Audit report completed by:<br><br>Clare Fothergill | Date: 26.12.2018 |
| Audit report reviewed by:<br><br>Rachel Clarke | Date: 30.05.2019 |