Initial Environmental Evaluation

Environmental Impacts of British Antarctic Survey Over-snow Traverse Activities 2022/23 to 2026/27

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

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Cover image: BAS traverse train. Source: British Antarctic Survey

Contents

Contents ii
- Figures v
- Tables vii
- Acronyms and abbreviations viii

Non-Technical Summary 1

1 Introduction 15
- 1.1 British Antarctic Survey 15
- 1.2 Antarctic Research 17
- 1.3 Over-snow traverse capability in Antarctica 18

2 Legal Context and Guidance Material 22
- 2.1 International Requirements 22
- 2.2 National Requirements 23
- 2.3 Applicable ATCM Measures and Resolutions 24
  - 2.3.1 Logistical and operational activities in Antarctica 24
  - 2.3.2 Environmental Management in Antarctica 25
- 2.4 COMNAP guidance material 25

3 Scope of the EIA 26
- 3.1 Geographical scope 26
- 3.2 Temporal scope 27
- 3.3 Activities excluded from the scope of the EIA 27

4 Alternatives 29
- 4.1 Cease all deep field activities: ‘Do nothing’ alternative. 29
- 4.2 Utilise alternative vehicle technologies for traverse activities 30
- 4.3 Support deep field activities by air only. 30
- 4.4 Utilise international partners or contract a specialist provider to support deep field activities. 31
- 4.5 Support deep field activities through a combination of air and traverse capability 32
- 4.6 Summary 32

5 BAS Traverse Activities – Preferred Approach 33
- 5.1 Purpose 33
- 5.2 Vehicles 34
  - 5.2.1 PistenBully 300 Polar 34
  - 5.2.2 Skidoos 36
  - 5.2.3 Environmental aspects from the use of vehicles 36
- 5.3 Towed Loads 37
  - 5.3.1 Environmental aspects from the towing of loads 37

5.4 Traverse Camps 39
5.4.1 Environmental aspects from traverse camps 40
5.5 Waste Management 40
5.5.1 Environmental aspects from the generation and management of waste 40
5.6 Fuel Management and Fuel Transfers 41
5.6.1 Environmental aspects from fuel handling and fuel transfers 42
5.7 Snow moving 42
5.7.1 Environmental aspects of snow moving 43
5.8 Overwintering Depots 43
5.8.1 Environmental aspects from overwintering depots 44
6 Current Environmental State 45
6.1 Climate 45
6.2 Glaciology – West Antarctic Ice Sheet 47
6.2.1 Ice Surface Topography 51
6.2.2 Crevasses 53
6.3 Ice Free Areas 54
6.4 Wildlife 55
6.4.1 Important Bird Areas 56
6.5 Protected / Managed Areas and Historic Sites 59
6.5.1 Protected Areas 59
6.5.2 Managed Areas 60
6.5.3 Historic Sites or Monuments 60
6.6 Human Activity and Antarctic Wilderness 62
7 Assessment of Environmental Impacts 65
7.1 Methods and supporting information 65
7.2 Environmental Aspects 65
7.3 Environmental Exposures 68
7.4 Impacts and Mitigation Measures 70
7.4.1 Impacts that will or may occur to the glaciological environment 71
7.4.2 Impacts that will or may occur to the atmospheric environment 78
7.4.3 Impacts that will or may occur to Antarctic fauna 81
7.4.4 Impacts on Antarctic wilderness values 83
7.4.5 Introduction of non-native species or artificial relocation of native species 84
7.4.6 Cumulative impacts 85
7.5 Summary and evaluation of impact significance 92
8 Monitoring and Record Keeping 98
9 Gaps in Knowledge and Uncertainties 99
9.1 Implications of Antarctic weather 99

9.2 Precise traverse routes to be follow 100
9.3 Precise locations of depots and camp sites 100
9.4 Research needs requiring logistical support 100
9.5 Ship and aircraft rendezvous opportunities 101
10 Summary and Conclusion 102
References 103
Appendices 109
Appendix 1. BAS Traverse Operations Manual V3 2022 (Cover only) 110
Appendix 2. BAS Field Operations Manual 2018 (Cover only) 111
Appendix 3. Heavy Vehicle Traverse Oil Spill Contingency Plan 2021 (Cover only) 112

Figures

Figure 1. Areas of planned traverse activities for BAS operations for the next five years. Areas shaded green indicate areas previously covered by BAS traverse activities. Areas shaded yellow identify areas that have potential to be traversed by BAS tractor trains in the next five summer seasons. Source: BAS. 2

Figure 2. Images showing a range of combinations of towed sledges in BAS traverse trains. Source: BAS. 6

Figure 3: BAS Antarctic Research Stations 16

Figure 4. Royal Research Ship Sir David Attenborough 16

Figure 5: BAS de Havilland Dash 7(a) and Twin Otter (b) 16

Figure 6. Overview of the research themes and teams that constitute BAS's research strategy Polar Science for Planet Earth. Source: www.bas.ac.uk. 17

Figure 7. The Arrol-Johnston car hauling a sledge across sea ice during Shackleton’s 1907-1909 Nimrod Expedition. 18

Figure 8. The Antarctic snow cruiser taken to Antarctic as part of Rear Admiral Byrd's third expedition. Source: C.C. Shirley / United States Antarctic Service. 18

Figure 9. A Trans Antarctic Expedition Tucker Sno-cat. Photographer: Athol R Roberts 19

Figure 10. BAS Tractor Train Traverse 20

Figure 11. Antarctic traverse operations as at 2021. Source: BAS Mapping and Geographic Information Centre. 21

Figure 12. Areas of planned traverse activities for BAS operations for the next five years. Areas shaded green indicate areas previously covered by BAS traverse activities. Areas shaded yellow identify areas that have potential to be traversed by BAS tractor trains in the next five summer seasons. Source: BAS. 26

Figure 13. Example of a vibroseis truck (a) and associated coiled streamer array (b) to be used in a future science traverse. Source: Alfred Wegener Institute 34

Figure 14. A BAS PistenBully 300 Polar on traverse duty in Antarctica. Source: https://www.pistenbully.com..... 34

Figure 15. Technical specifications for the PB300 Polar. 35

Figure 16. PB300 configured with a passenger cab. Source: https://www.pistenbully.com 35

Figure 17. Skidoo based GPR survey. Source: BAS. 36

Figure 18. BAS traverse train with PB300, caboose, Lehman sledge and poly sleds 38

Figure 19. Poly sled with cargo 38

Figure 20. Suggested Camp Layout. Source: BAS Traverse Operations Manual. 39

Figure 21. A Spate PD75 pump used for transferring fuel. Source: BAS Traverse Operations Manual. 41

Figure 22. Transferring fuel between bladders. Source: BAS Traverse Operations Manual. 42

Figure 23. Raised berms used to store fuel (in drums and bladders) during the winter period. Source: BAS Traverse Operations Manual. 43

Figure 24. Waste depot at SB9. Source: BAS. 44

Figure 25. Average temperatures and wind speeds across the Antarctic continent. Source: Morgan, 2007. 46

Figure 26. Map of Antarctica showing the East and West Antarctic Ice Sheets and the dividing Trans-Antarctic Mountains. Source: https://www.grida.no/resources/5339.. 48

Figure 27. The BEDMAP 2 dataset shows how ice thickness across the Antarctic continent is variable, with thin ice over the mountains and thick ice over East Antarctica. The cross section shows how the West Antarctic Ice Sheet (WAIS) is grounded well below sea level. Source: Fretwell et al. 2013. 49

Figure 28. Pine Island and Thwaites Glaciers. Catchment areas and associated ice shelves are shaded. Source: www.add.scar.org.. 50

Figure 29. Eighteen years of change in thickness and volume of Antarctic ice shelves. Circles represent percentage of thickness lost (red) or gained (blue) in 18 years. Background is the Landsat Image Mosaic of Antarctica (LIMA). Source: Paolo et al., 2015. ... 51

Figure 30. Sastrugi on the Antarctic ice sheet surface. Source: a) coolantarctica.com, b) Wikipedia.org ... 52

Figure 31. Blue Ice area adjacent to the Patriot Hills, Ellsworth Mountains, Antarctica. Source: AntarcticScience.com ... 52

Figure 32. Members of the U.S. Antarctic Program's South Pole Traverse team rappel down into a crevasse. Source: https://antarcticsun.usap.gov/science/4454/ ... 53

Figure 33. Exposed rock surfaces in the form of nunataks or volcanic peaks in West Antarctica. Base map: SCAR ADD https://www.add.scar.org/ ... 54

Figure 34. Map of Marie Byrd Land Volcanic Province (MBLVP). Volcanic fields are labelled and volcanoes included in fields are within dashed line polygons. Abbreviations: VF, Volcanic Field; C.I., Cruzen Island; S.I. is Shepard Island; G.I. is Grant Island. Source: Wilch et al., 2021. ... 55

Figure 35. Important Bird Areas identified around Antarctica. Source: Harris et al., 2015. ... 56

Figure 36. Important Bird Areas (yellow dots) that occur in the vicinity of BAS traverse operations. IBA reference source: Harris et al., 2015. ... 57

Figure 37. Antarctic outline showing the location of designated ASPAs. Pink squares contain multiple designations. Source: https://www.ats.aq ... 59

Figure 38. Antarctic outline showing the location of designated ASMAs. Source: https://www.ats.aq ... 60

Figure 39. Antarctic outline showing the location of designated HSMs. Source: https://www.ats.aq ... 61

Figure 40. Inviolate Antarctic wilderness areas defines as large (>10,000km2), contiguous putatively inviolate areas free from human interferences across Antarctica (purple squares). Historical visitation records and traverse routes are shown in red (n=2,698,429 records). Source: Leihy et al., 2019. ... 62

Figure 41. BAS traverse operational areas overlaid with wilderness areas from Leihy et al, 2020. Purple indicates contiguous areas of 10,000km^2 with no historical human activity (1819-2018). ... 63

Figure 42. Established field camps in the area of planned traverse operations. a) ALE Union Glacier Camp, b) WAIS Divide Camp, c) LTG Camp, d) Sky Blu. Some of these camps will be supported by BAS traverse activities. Sources: a) https://icetrek.com/base-camps/union-glacier-camp, b) https://frozenwille.wordpress.com/2016/03/30/overview-of-wais-divide/, c) https://thwaitesglacier.org credit Ted Scambos, d) http://esorekim.blogspot.com/2019/01/sky-blu.html ... 64

Figure 43. Raised footprints on snow surfaces. Source: https://www.amusingplanet.com/2013/04/raised-footprints-in-snow.html ... 73

Figure 44. Returning to a caboose stored on a snow berm over winter showing the extent of snow build up during the winter months. Source: BAS; Damon Davies. ... 74

Figure 45. ITASE traverse routes. Source: Mayewski 2005. ... 87

Figure 46. Overview of logistical support activities for the International Thwaites Glacier Collaboration (ITGC). Source: ITGC Initial Environmental Evaluation ... 88

Tables

Table 1. Overview of those environmental elements that have been identified as potentially being susceptible to the aspects arising from the planned activities. 11

Table 2. Vehicle fuel consumption. Source: BAS Traverse Operations Manual. 36

Table 3: Climate at stations in the operational area (Meteoblue, 2022) (Weatherbase, 2022) 47

Table 4. IBAs in the vicinity of or adjacent to the defined traverse areas. Source: Harris et al., 2015. 58

Table 5. HSMs designated in the vicinity, though outside of the defined area of operations. Source: https://www.ats.aq 61

Table 6: Existing facilities in and around traverse operational area 63

Table 7. Summary of environmental aspects that will or could arise from the planned activities. 67

Table 8. Overview of those environmental elements that have been identified as potentially being susceptible to the aspects arising from the planned activities. Note: The exposure of an activity's aspect may vary in significance in differing environments or at different times of the year. This is not considered in this table. The significance of the impacts is assessed in Section 7.5 of the EIA. 69

Table 9. List of environmental impact assessments relevant to the WAIS region. EIAs identified from the EIA database managed by the Antarctic Treaty Secretariat. https://www.ats.aq/devAS/EP/EIAList?lang=e 89

Table 10. Assessment criteria for evaluating the spatial extent, duration, severity, and likelihood of the potential environmental impacts (modified from Oerter, 2000). 93

Table 11. Risk assessment criteria. 94

Table 12. Summary of identified impacts and assessment of impact significance before and after mitigation measures are applied. 95

Acronyms and abbreviations

ATCM	Antarctic Treaty Consultative Meeting
ATCP	Antarctic Treaty Consultative Party(ies)
ALE	Antarctic Logistics and Expeditions
ASPA	Antarctic Specially Protected Area(s)
ASMA	Antarctic Specially Managed Area(s)
BAS	British Antarctic Survey
CCAMLR	Commission for / Convention on the Conservation of Antarctic Marine Living Resources
CEE	Comprehensive Environmental Evaluation
CEP	Committee for Environmental Protection
COMNAP	Council of Managers of National Antarctic Programmes
EIA	Environmental Impact Assessment
EIES	Electronic Exchange of Information System
FCDO	Foreign, Commonwealth and Development Office
ft	Foot or feet
GHG	Greenhouse gas(es)
GIS	Geographical Information System
GPR	Ground penetrating radar
GPS	Global Positioning System
Gt	Gigatonnes
HSM	Historic Site and Monument(s)
hp	Horsepower
IEE	Initial Environmental Evaluation
IBA	Important Bird Area(s)
ITASE	International Trans-Antarctic Science Expedition
ITGC	International Thwaites Glacier Collaboration
km	Kilometres
km/h	Kilometres per hour
kW	Kilowatts
L	Litre(s)
L/km	Litres per kilometre
LPG	Liquid Petroleum Gas
Mkm^2	Million square kilometres
m	Metre(s)
mm	Millimetres
NERC	Natural Environment Research Council
NEFAB	Trade name for wooden and steel packaging crates
Nm	Newton-metres
rpm	Revolutions per minute
SCAR	Scientific Committee on Antarctic Research
T	Tonne
UN	United Nations
V	Volts
WAIS	West Antarctic Ice Sheet
°C	Degrees Celsius
%	Percent

Non-Technical Summary

Introduction

The British Antarctic Survey (BAS) is the UK's national Antarctic operator, responsible for most of the UK's scientific research in Antarctica.

BAS has a long history of over-snow traverses and has developed a tractor train traverse system for transporting science teams and their equipment across vast areas of Antarctica. A combination of vehicles, sledges and living accommodation towed by tracked vehicles (PistenBully vehicles), allows science and support teams to live and work safely in remote areas a long way from research stations. This over-snow traverse can facilitate research across the West Antarctic Ice Sheet and associated ice shelves.

This environmental impact assessment reviews the significance of the environmental impacts that will or could arise from planned traverse activities and identifies mitigation measures to minimise those impacts.

Legal context and guidance material

All activities in Antarctica are subject to the provisions of a series of international agreements that constitute the Antarctic Treaty System.

The Protocol on Environmental Protection to the Antarctic Treaty (the Protocol) was adopted by the Antarctic Treaty Consultative Parties in 1991. It entered into force in January 1998.

The Protocol sets out environmental principles for the conduct of activities in Antarctica and requires that activities in the Antarctic Treaty area are planned and conducted so as to limit adverse impacts on the Antarctic environment. The Protocol requires an environmental impact assessment to be prepared in advance of any activity taking place in the Antarctic Treaty Area. The level of the environmental impact assessment is determined by whether the activity in question is identified as having 'less than', 'no more than' or 'more than' a minor or transitory impact on the environment.

The EIA provisions of the Protocol are enacted in UK law through the Antarctic Act 1994 and Antarctic Act 2013 and Antarctic Regulations 1995/490 (as amended). The Act applies to both governmental and non-governmental activities in Antarctica.

The environmental impact assessment documented here has been undertaken to meet the requirements of the Protocol and relevant UK legislation.

Scope of the EIA

Geographical scope

Planned traverse activities over the five-year period covered by this environmental impact assessment will be exclusively on snow- and ice-covered areas (see Figure 1), including:

- the Ronne-Filchner Ice Shelf and Berkner Island;
- Ellsworth Land from Sky Blu and the Stange Ice Shelf to Abbott Ice Shelf, Pine Island Glacier and Thwaites Glacier; and
- the West Antarctic Ice Shelf (WAIS) from Institute Ice Stream to WAIS Divide and Siple Dome.

Specific routes within the broad areas shown in Figure 1 cannot be identified at this stage. In any one summer season the precise traverse routes that will be used will be determined by a number of factors including: weather, ice and snow conditions, logistics connections (e.g., coastal locations where ships are able to offload, existing ski ways and blue ice runways) and scientific and operational objectives.

For clarity, the shaded areas in Figure 1 represent a constraint on traverse operations. Should any operational plans require traverse activities to be undertaken outside of these boundaries, BAS Field Operations will be required to consult with BAS Environment Office and additional environmental impact assessment will be undertaken.

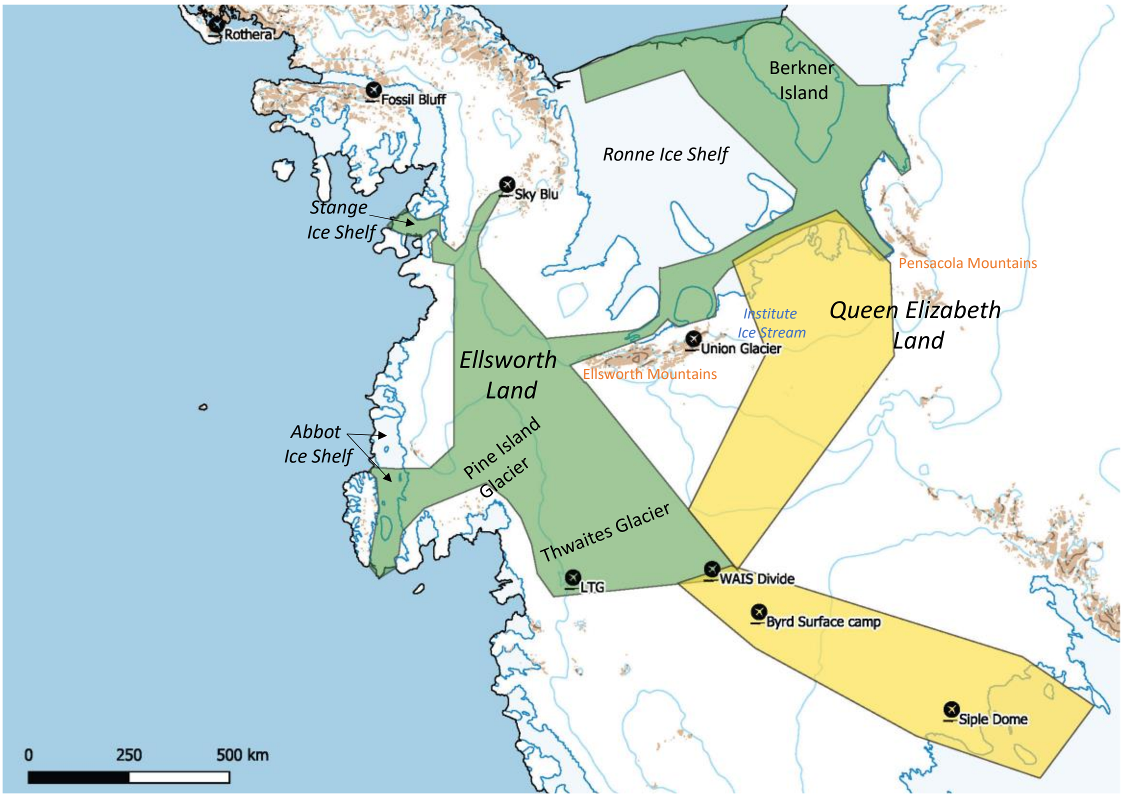


Figure 1. Areas of planned traverse activities for BAS operations for the next five years. Areas shaded green indicate areas previously covered by BAS traverse activities. Areas shaded yellow identify areas that have potential to be traversed by BAS tractor trains in the next five summer seasons. Source: BAS.

Temporal scope

This assessment covers five years of planned traverse activities from the 2022/23 austral summer season to and including the 2026/27 season. The timeframe of this IEE mirrors the timeframe of the BAS Operating Permit granted under Section 3, Section 4, Section 5, Section 6, Section 7, Section 8, Section 9 and Section 10 of the Antarctic Act 1994, which will be valid from 1 October 2022 to 30 September 2027.

Traverse activities occur only in summer months (approximately November to early March (at the latest)), with vehicles and equipment placed in depots for the winter period (approximately March to October).

Activities that are excluded from the scope

This environmental impact assessment does not consider environmental impacts associated with:

- any of the scientific research activities that will be supported by traverses;
- any impacts associated with connecting logistics such as air and ship transport;
- the treatment and handling of waste materials (generated during traverse activities) once it has been removed from the field either by air or by ship.

Alternatives

Several alternatives were considered in the environmental impact process.

Cease all deep field activities – do nothing

Ceasing all deep field activities would eliminate all associated environmental impacts; including those that arise from traverses, aircraft operations and (deep field) scientific research.

Such an approach would also assist in maintaining perceptions of Antarctic wilderness in the interior of Antarctica.

However, this option would be contrary to BAS' vision of being a world-leading centre for polar science and polar operations. It would also severely curtail the UK's ability to undertake globally relevant scientific research, particularly research aimed at understanding Antarctica's response to changing climate conditions, including the behaviour of Antarctica's ice sheets under warming conditions.

The option of ceasing all deep field research was therefore rejected in favour of exploring the most effective means of deploying and recovering deep field research teams and equipment.

Utilise alternative vehicles technologies

Globally there continues to be a shift away from the combustion of fossil fuels to mitigate the harmful effects of greenhouse gases. However, heavier, industrial vehicles utilising electric or low-emission technologies have been slower to emerge. Vehicles capable of meeting the endurance, reliability and towing capacities for safe Antarctic traverse activities are not currently available.

As a result, BAS will continue to use fossil-fuel powered vehicles, whilst monitoring the market and keeping alternative lower-emission vehicles under review as existing plant needs to be replaced.

Support deep field activities by air only

BAS operates five aircraft in Antarctica: four De Havilland DHC-6 Twin Otters and a De Havilland Dash-7 aircraft.

The Twin Otters are extremely versatile and can be modified to allow airborne surveying and other scientific equipment to be fitted. The version operated by BAS is the wheel/ski-equipped aircraft which lands on snow, ice or any other type of hard runways in remote areas.

The larger Dash-7 aircraft can land on ice runways. It is used to move fuel, equipment, and people between Rothera and the BAS field station at Sky-Blu.

The Twin Otter aircraft are already used to support deep field research events by delivering fuel, equipment, and researchers to the field. However, maximum weight requirements limit the combination of fuel, equipment and people that can be carried at any one time and larger field events would require multiple aircraft rotations to establish. The aircraft are also subject to greater restraints on weather conditions which can mean delays in delivering research events or equipment to the field. As a result, BAS would need to greatly reduce its deep field operations each year if only aircraft were available to provide support.

Exclusively using aircraft to support deep field research is also inefficient and requires a larger fuel burn for any unit of weight delivered compared to over-snow vehicles. This alternative was therefore not pursued further.

Utilise international partners or specialist contract providers

To reduce the environmental impacts associated with BAS traverse operations, it could be possible to seek external support for BAS deep field research programmes; either by using assets of other national Antarctic programmes or by using a commercial provider.

However, utilising the assets of other national Antarctic programmes for deep field research would require a substantial reduction in BAS' research ambitions in the interior of Antarctica. The assets of other countries are often fully utilised in meeting their own research and logistical needs, often with limited additional capacity.

A commercial operator could be used to provide traverse capability to meet BAS' research and logistical requirements. BAS have used this option in the past by utilising over-snow traverse support provided by Antarctic operator Antarctic Logistics and Expeditions. However, utilising a commercial provider exclusively would still mean a reduction in BAS' deep field research programme as Antarctic Logistics and Expeditions do not have the capacity to meet all of BAS' research and logistical requirements. Further, using an external provider adds complexity and could impact BAS' current ability to retain flexibility in its delivery of field events as circumstances and conditions change within and between seasons.

Rather than exclusively utilising external providers, BAS' experience has shown that the optimum model is to work cooperatively with other National Antarctic Programmes for mutual benefit, with occasional use of a commercial provider.

Utilise a combination of air and traverse support

BAS' experience to date is that the most efficient use of operational assets to maximise deep field scientific effort in any one austral summer season is to use a combination of aircraft and over-snow traverse capability.

As noted above the Twin Otter aircraft are already utilised to deliver equipment, fuel and personnel to deep field locations. This can be an efficient means of deploying and extracting small-scale research teams with moderate equipment requirements. However, meeting the current scale of research requirements and, in particular the needs of larger scale research programmes, necessitates a combination of air and traverse assets to be used.

Planning for any one austral summer season seeks to maximise the amount of science and research outcomes by optimising the use of available air and over-snow traverse assets.

This is seen as the most effective way of continuing BAS' deep field research programme over the next five years and is the basis for assessing the environmental impacts in this assessment.

BAS traverse activities – preferred approach

The ultimate purpose of BAS' traverse activities over the next five summer seasons is to support globally relevant scientific investigations in the interior of Antarctica.

Tractor traverses are used either logistically focused i.e., involving the relocation or deployment of fuel, cargo and field support equipment in anticipation of future use by science events; or in direct support of science activities i.e., involving following a pre-planned route to allow researchers to undertake a series of measurements over areas of the Antarctic ice sheet or ice-shelves.

Vehicles

Whether the proposed surface traverse is for re-supply or scientific research, over-snow traverses will involve the use of multiple motorised tracked vehicles, towing sleds or trailers containing living and working modules for the traverse crew, fuel for the traverse equipment, as well as payload or cargo.

BAS has five PistenBully 300 Polar vehicles (PB300). These tracked snow-vehicles are used to tow supplies, equipment and portable living and working facilities across the ice.

Two skidoos are typically deployed with each traverse primarily to survey the terrain ahead with ground penetrating radar and avoid crevasses.

Towed loads

The PB300 vehicles are used to tow a variety of sled and sledge mounted equipment and supplies.

BAS has one large caboose, made of two 30 ft containers joined together, and one small caboose utilising a 24 ft container. These are ski-mounted living spaces used during the traverse.

Lehmann Sledges (rated for 10, 15 or 20 T payloads) are used for bulky cargo and may be fitted with high side panels. They can carry up to 60 drums of fuel or other cargo.

Poly sleds are 12 mm thick sheets of high molecular weight plastic that provide a low friction surface and can be used to tow 5,800 L fuel bladders.

Other cargo can also be secured on the poly sleds using platforms such as galvanized pallets and NEFAB crates. Shorter poly sleds can be used to transport four side-by-side skidoos.

Figure 2 shows a number of combinations of towed sledges utilised by BAS traverse trains.

Figure 2. Images showing a range of combinations of towed sledges in BAS traverse trains. Source: BAS.

Traverse camps

Traverse trains can last for several days or weeks depending upon the route, weather conditions or science objectives. Overnight or multi-night camps are established as required.

Camps are set up in a standard arrangement for reasons of efficiency as well as to facilitate known locations of equipment and fuel in low visibility conditions or after periods of significant snow deposition.

In a standard camp arrangement, the cabooses serve as kitchen, accommodation and general living space. Each caboose can sleep four to six people, and additional people may sleep in tents.

Waste management

Waste is separated as it is generated during the traverse and backloaded to BAS' Rothera station when aircraft space is available. Clean, bulk waste (e.g., cardboard, wood, cans or glass) may be stored at logistics depots on the ice sheet for periods of time and driven back to Sky Blu or offloaded to a ship at a later date.

Food and solid human wastes are returned to Rothera in UN plastic drums for incineration. Liquid human waste and sieved grey water are disposed of to the ice.

Fuel management and fuel transfers

The movement and delivery of fuel is a core function of the BAS traverses. The PB300s use Avtur or Avcat, cold blend aviation fuels. Petrol and lubricants are transported in drums.

The PB300s are refuelled using an electric pump and hose reel. The pumping system may also be used to transfer fuel between bladders (e.g., to balance towed loads).

Skidoos are refuelled directly from petrol drums using rotary pumps. Alternatively, drums can be mounted horizontally on the caboose and fitted with drum taps to fill Jerry cans for refuelling of skidoos or small generators.

Aircraft refuelling from fuel drums is via a trigger gun, using the same arrangement as for transferring fuel between bladders.

Standard operating procedures, managed by BAS Field Operations, are used for all refuelling and fuel transfer operations. All fuel use is recorded detailing volume, type of fuel and intended use.

Snow moving

Snow grooming and snow movement is undertaken for several reasons. Trenches or berms are constructed to assist with loading and unloading sledges. Berms are used to elevate equipment and supplies during the winter period to prevent them being buried by snow drifts.

Snow is also collected and melted for water for drinking, cooking and washing.

Overwintering depots

Vehicles, fuel supplies and equipment are overwintered at established sites. These are left securely on 3 m high snow berms to prevent burial in snow drifts. The locations are clearly flagged and recorded for later identification.

Waste items are also stored on the ice shelf until they can be moved to the coast and transferred to a ship for return to Rothera or the UK.

Current environmental state

Climate

Antarctica is the coldest and driest continent on Earth.

Antarctica's average annual temperature ranges from about −10 °C on the coast to −60 °C at the highest parts of the interior. West Antarctica is generally warmer than East Antarctica due to its lower elevation. Monthly average temperatures over the WAIS range from -12°C to -35°C.

Near the coast, the temperature can exceed +10 °C in summer and fall to below −40 °C in winter. Over the elevated inland, it can rise to about −30 °C in summer but fall below −80 °C in winter.

Antarctica's environment has special conditions that make it the windiest continent on Earth. Strong katabatic winds flow downhill from the interior of the ice sheet to the coast with great consistency over large areas. Wind speeds can exceed 100 km/h for days at a time.

The dry, subsiding air over the interior of Antarctica creates little cloud. Around the coast cloudy conditions are more common.

Rain has been observed near the coast, but most precipitation over Antarctica is in the form of snow or ice crystals. Windy conditions make it difficult to measure snowfall accurately. The average accumulation of snow over the whole continent is estimated to be equivalent to about 150 mm of water per year. Over the elevated plateau, the annual value is less than 50 mm. Near the coast, it generally exceeds 200 mm.

Loose snow can be picked up and carried along by the wind, which can reduce visibility significantly and make it challenging to conduct activities including driving vehicles.

Glaciology

The Antarctic continent is divided into East and West Antarctica, both of which are covered by ice. The operational area for activities covered by this environmental impact assessment is on the West Antarctic Ice Sheet (WAIS). The WAIS covers an area of approximately 1.97 Mkm^2 and contains enough ice to raise global sea level by approximately 3 m to 5 m. The WAIS has outlets in the Ross Sea, Amundsen Sea and Weddell Sea.

The WAIS is in places up to 2,000 m thick, with the geological floor well below sea level.

Ice surfaces

Any impacts arising from over-snow traverse activities will be constrained to the surface and upper few metres of the WAIS.

The nature of the ice sheet surface is heavily influenced by snow fall and wind patterns and dominated by surface undulations called sastrugi. Sastrugi can take an almost infinite variety of forms from delicate etchings on a smooth slab of snow, to furrows and grooves up to 1 metre deep, sometimes with overhanging lips. They are highly dynamic and usually form at temperatures of -10 to -20 ^{o}C or lower, when the snow particles are dry. Larger, icy sastrugi can provide significant challenges for surface travel.

In some areas of the ice sheet, persistent winds erode snow year-round and, combined with sublimation create areas of net ablation. These areas of 'blue ice' are characterised by flat, smooth, hard ice. Commonly, such areas occur near mountains or on outlet glaciers at higher elevations. Traversing across blue ice can be easier as the surface is hard and smooth and crevassing easier to identify.

Crevasses

The Antarctic ice sheet flows through a series of ice streams and glaciers from the centre of the ice sheet to the surrounding Southern Ocean. As a consequence of the ice flow, it often splits and cracks to form crevasses. These crevasses vary in size significantly but can be tens of metres deep, tens of metres across, and many kilometres long.

Crevasses can be 'open' and visible, particularly in more rapidly moving parts of a glacier, or they can be covered by snow bridges. Covered crevasses represent a significant danger to vehicle travel across the ice surface.

In recent years improved remote sensing of the polar regions means that crevasse locations can be more readily identified from satellites.

On the ground observations, particularly from ground penetrating radar provides immediate knowledge of crevasse locations. BAS traverses make use of regular crevasse surveys undertaken by Ground Penetrating Radar (GPR) towed by skidoos ahead of the main traverse body. BAS traverse policy is to avoid crevassed areas wherever possible.

Ice-free areas

The operational area for BAS traverse activities is constrained to snow and ice-covered terrain within defined limits. There are ice free areas in proximity to traverse routes including the outer edges of the Ellsworth Mountains and a series of mountain and volcanic peaks throughout Ellsworth Land, Marie Byrd Land and Queen Elizabeth Land.

Within defined boundaries, BAS traverse routes will be selected so as to avoid any contact with ice free areas. BAS traverses will never operate on ice-free ground. There may be occasions when vehicles will approach ice free areas, such as when deploying or collecting a field party. But even in such circumstances, traverse vehicles and any traverse related activities (such as camp sites) will always remain on snow and ice surfaces and, at a minimum, several hundreds of metres away from ice-free terrain.

Wildlife

With a few exceptions (i.e., seabird breeding colonies located a few kilometres from the coast), the majority of Antarctic wildlife is constrained to coastal ice-free regions. Inland areas of the ice sheet support very little life other than microbial communities in some locations.

Whilst the majority of BAS traverse activity will take place well away from coastal regions, there will be occasions when traverse trains will run close to the coast either for the purposes of rendezvousing with a ship (for offloading or onloading cargo and fuel) or when in support of coastal research activities. On such occasions the potential for interaction with wildlife increases.

However, even on such occasions, the vehicles will be constrained to shelf or sea ice and will not venture onto ice-free land. This will minimise the risk of disturbing wildlife, other than the low likelihood of encountering small numbers of penguins and seals that may be occupying the ice.

Important bird areas

A series of 204 Important Bird Areas (IBAs) have been identified across Antarctica. These IBAs represent bird breeding (as opposed to foraging) locations. There is potential for BAS traverse operations to be conducted in the general vicinity of IBAs, although operations are likely to be conducted some distance away (several tens to hundreds of kilometres) in most cases.

Protected or managed areas and historic sites

At the time of preparation of this EIA, 75 ASPAs have been established across Antarctica. The nearest ASPA to the planned activities is ASPA 119 Davis Valley and Forlidas Pond, Dufek Massif. ASPA 119 is some distance away from the area of planned activities and will not be visited by BAS traverse trains.

At the time of preparation of this EIA, 6 ASMAs have been established across Antarctica.

The nearest ASMA is located at the geographic South Pole (ASMA 5). ASMA 5 is well outside of the area of planned activities and will not be visited by BAS traverse trains.

At the time of preparation of this EIA, 95 Historic Site and Monuments (HSMs) have been designated across Antarctica. No HSMs will be visited by BAS traverse trains.

Human activity and Antarctic wilderness

Research studies have estimated that 99.6 % of the Antarctic continent can still be considered wilderness, but pristine areas, free from human interference cover a much smaller area (less than 32 % of Antarctica) and are declining as human activity escalates.

Most of the traverse operations will take place in areas which have had some human activity in the past, including as a result of past traverse activities undertaken by BAS and other National Antarctic Programmes. Several research or logistics facilities are also established in the vicinity although most of these are semi-permanent soft-shell camps.

However, new routes to be used by BAS traverses have the potential to transit areas that have been identified as wilderness because of the lack of previous human activity.

Assessment of environmental impacts

The actual or potential environmental impacts of the activity are assessed by means of a four-step analysis involving:

1. identifying the **aspects** i.e., the physical change imposed on, or an input released to the environment as the result of an action or activity such as emissions, dust, mechanical action on the substrate, fuel spills, etc., arising from the proposed activities;
2. identifying the **exposure** i.e., the interaction between an identified potential output and the receiving environment;
3. identifying the **impacts** i.e., the change in environmental values or resources attributable to the activity;
4. assessing the **significance** of the identified impacts by considering the spatial extent, duration, intensity and likelihood of occurrence of the potential impacts to each environmental element – with reference to the three levels of significance identified in the Protocol (i.e., less than, no more than, or more than a minor or transitory impact).

Identified impacts are summarised in Table 1.

Table 1. Overview of those environmental elements that have been identified as potentially being susceptible to the aspects arising from the planned activities.

<table>
<tr><th rowspan="2">ASPECTS OF ACTIVITIES</th><th colspan="7">ENVIRONMENTAL ELEMENTS THAT WILL / MAY BE IMPACTED</th></tr>
<tr><th>FAUNA AND FLORA</th><th>FRESHWATER (ponds, streams, rivers, lakes)</th><th>MARINE (including sea ice)</th><th>GLACIOLOGICAL (glaciers, ice sheet and ice shelves)</th><th>TERRESTRIAL (ice-free ground, soil and rocks)</th><th>ATMOSPHERE</th><th>WILDERNESS VALUES</th></tr>
<tr><td>Atmospheric emissions</td><td></td><td rowspan="8">No impacts have been identified for freshwater environments</td><td rowspan="8">No impacts have been identified for marine environments</td><td>✓
Particulates in exhaust emissions will settle on ice surfaces</td><td rowspan="8">No impacts have been identified for terrestrial environments</td><td>✓
Gases in exhaust emissions, including GHG, will be released to air</td><td></td></tr>
<tr><td>Noise emissions</td><td>✓
Noise sources have potential to disturb wildlife</td><td></td><td></td><td></td></tr>
<tr><td>Heat emissions</td><td></td><td></td><td>✓
Heat from various sources will be released to air</td><td></td></tr>
<tr><td>Mechanical action</td><td></td><td>✓
Physical disturbance to ice and snow surfaces from vehicle movements; berm creation etc</td><td></td><td></td></tr>
<tr><td>Fuel spills</td><td></td><td>✓
Accidental releases to snow / ice surfaces</td><td></td><td></td></tr>
<tr><td>Wastes
(Including unrecoverable equipment</td><td></td><td>✓
Accidental / deliberate losses to snow / ice environment</td><td></td><td></td></tr>
<tr><td>Introduced species / relocated native species</td><td>See discussion in Section 7.4.5.</td><td></td><td></td><td></td></tr>
<tr><td>Presence / Visual disturbance</td><td>✓
Human presence has potential to disturb wildlife</td><td></td><td></td><td>✓
Human presence and activity may alter perceptions of wilderness</td></tr>
</table>

Given that all activities associated with BAS' traverse activities will be constrained to the ice and snow surfaces, the glacial environment has the potential to be most heavily impacted.

Use of vehicles, generators and heaters creates heat, gas and particulate emissions which impact the immediate snow and ice environment through the release of particulates. Physical disturbance will occur through tracking and movement of snow. Any accidental releases of hazardous substances or waste materials will contaminate the ice sheet environment.

Waste will be generated from the traverses and associated camps, which will need to be managed and removed, with the exception of human liquid waste and grey water which will be disposed to the ice sheet.

Exhaust emissions will also contribute to the release of heat and greenhouse gases into the atmosphere.

Antarctic wildlife could be impacted from traverse noise and presence.

All human activity could impact on perceptions of Antarctic wilderness.

Even with *no* treatments in place, only one activity was assessed as posing a 'high' risk to the environment with impacts potentially being more than minor or transitory, i.e., the potential to impact on perceptions of Antarctic wilderness.

As a general rule BAS aims to prevent or reduce potential environmental impacts from its traverse activities through careful planning, training, execution and the availability of highly experienced personnel. Also, for almost all sources of impact, practicable treatment options to mitigate those impacts have been identified, including:

- Minimising fuel use to the extent practicable, including by using the most efficient fuel options for use in low temperatures, regularly servicing engines and generators, allowing engines to 'warm up' prior to engaging any load, avoiding unnecessary idling, carefully planning traverse routes and evenly distributing loads between towing vehicles to the extent possible;
- Minimising the risk of fuel spills by minimizing the volumes of hazardous liquid substances, including fuel, taken into the field, actively managing and monitoring fuel and other hazardous substances in accordance with standard BAS procedures as set out in the BAS Field Manual and Traverse Operations Manual[1], and using secondary containment to the extent practicable;
- Minimising the impact of spilled fuel by controlled refuelling operations, having spill response equipment available and providing relevant training in oil spill response to the Traverse Leads;
- Managing all waste, including hazardous waste in accordance with the provisions of the Protocol, the BAS Waste Management Handbook and BAS Field Operations Manual and minimising the materials and items taken into the field that will generate waste to the extent practicable;
- Avoiding any known congregations of Antarctic wildlife as well as ice-free areas;
- Reusing previously used traverse routes so as to constrain the spatial coverage of traverse activities to the extent possible.

[1] Currently Version 3, but this is routinely updated.

Provided the mitigation measures identified in this environmental impact assessment are adhered to, the environmental impacts of the planned activities are considered to be largely avoidable or can be minimised to an acceptable level.

Monitoring and record keeping

This assessment has not identified the need for dedicated monitoring to be undertaken. Nonetheless, records will be maintained for post-season reporting purposes, including:

- The volumes and types of fuel burnt during traverse activities.
- Global Positioning System (GPS) records of all traverse routes followed.
- GPS records of camp sites and overwintering storage locations, including the volumes of fuel stored and types and volumes of waste stored.
- GPS records of the location as well as volumes of human liquid waste and grey water disposed to the ice sheet.
- Records of the types and quantities of any materials or equipment that is accidentally lost to the environment.
- Observations of any other environmental incidents such as inefficient burning of fuel resulting in excessive release of airborne pollution.
- Location of any spill events if they occur as well as the volumes and type of fluid lost, and approximate volumes recovered.

Every effort will be made to avoid unnecessary impacts. Where an incident results in impacts, such as disturbance of wildlife or fuel spills, this will be documented and reported to the BAS Environmental Office and to the FCDO in accordance with the conditions of the BAS Operational Permit.

Post season reporting will be undertaken in accordance with BAS requirements.

Gaps in knowledge and uncertainties

No activity in Antarctica can be planned with absolute certainty, due to the extreme, changeable and unpredictable environmental conditions. BAS traverse activities will need to retain a degree of flexibility so as to accommodate changing weather, logistical and scientific requirements.

Accordingly, there remain a number of gaps in knowledge and uncertainties, including:

- The implications of Antarctic weather which can disrupt planned activities in any one season;
- The precise routes that will be traversed in any one season cannot be predicted with certainty and will be determined each season by several operational and research requirements;
- The precise locations of depots and camps, which will equally be determined each year by the routes followed;
- The research events to be supported by BAS traverse activities can change for any one season for several reasons, with implications for the extent to which traverse activities are required and the locations to be accessed;
- Ship and aircraft rendezvous locations and frequency each season will be determined by multiple operational requirements each season.

The uncertainties associated with these factors is assessed as being unlikely to have significant implications for the identified environmental impacts nor for the overall conclusion of the environmental impact assessment.

Summary and conclusion

Surface traverse is considered to be the most efficient and currently viable method to support research on the West Antarctic Ice Shelf.

Overall, this environmental impact assessment considers that the potential environmental impacts arising from the next five years of BAS traverse activities will have **no more than a minor or transitory impact** on the environment.

It is concluded that this level of predicted impact is acceptable given the significant scientific knowledge that will be gained as a result of BAS ongoing programme of globally relevant research in Antarctica.

1 Introduction

1.1 British Antarctic Survey

The British Antarctic Survey (BAS) is the UK's national Antarctic operator, responsible for most of the UK's scientific research in Antarctica. BAS was established in 1962 following the renaming of the Falklands Islands Dependencies Survey, and in 1967 the UK Government transferred the responsibility for BAS from the Colonial Office to the Natural Environment Research Council (NERC).

The BAS Vision is: To be a world-leading centre for polar science and polar operations, addressing issues of global importance and helping society adapt to a changing world.

The BAS Mission is a research-driven organisation recognised for:

- Commitment to excellence in science
- Operational professionalism and innovation in everything we do
- A partner of choice for science, operations and business wherever polar expertise can be applied
- Safely delivering complex operations in extreme environments
- Commitment to environmental stewardship of the polar regions
- Developing our staff to reach their full potential
- Sustaining an active and influential presence in Antarctica on behalf of the UK, and playing a leadership role in Antarctic affairs
- Engagement with policy makers, government and the public.

Operationally, BAS' strategic aim is to provide and operate world-leading research infrastructure that enables scientists from the UK, and colleagues from many nations, to work safely and effectively in the polar regions. A key goal is for BAS to be recognised nationally and internationally as a partner of choice for polar operational expertise wherever it can be applied.

BAS currently operates three research stations in Antarctica (Figure 3): Rothera Research Station on Adelaide Island to the west of the Antarctic Peninsula; Halley VI Research Station on the Brunt Ice-shelf in the Weddell Sea, and Signy Research Station on Signy Island in the South Orkney Islands.

BAS also operates the Royal Research Ship Sir David Attenborough (Figure 4) and an aircraft fleet which currently includes a De Havilland DASH-7 and four De Havilland Twin Otter aircraft (Figure 5).

Figure 3: BAS Antarctic Research Stations

Figure 4. Royal Research Ship Sir David Attenborough

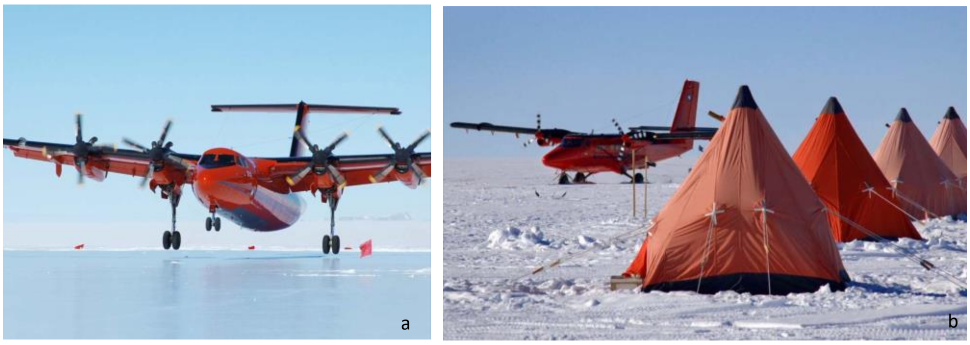


Figure 5: BAS de Havilland Dash 7(a) and Twin Otter (b)

1.2 Antarctic Research

In the context of its published Science Strategy 'Polar Science for Planet Earth', BAS facilitates an array of multi-disciplinary research programmes to investigate and monitor environmental change in Antarctica and the Southern Ocean.

The research strategy focuses on five key themes of global significance (Figure 6) almost all of which require some degree of deep field research.

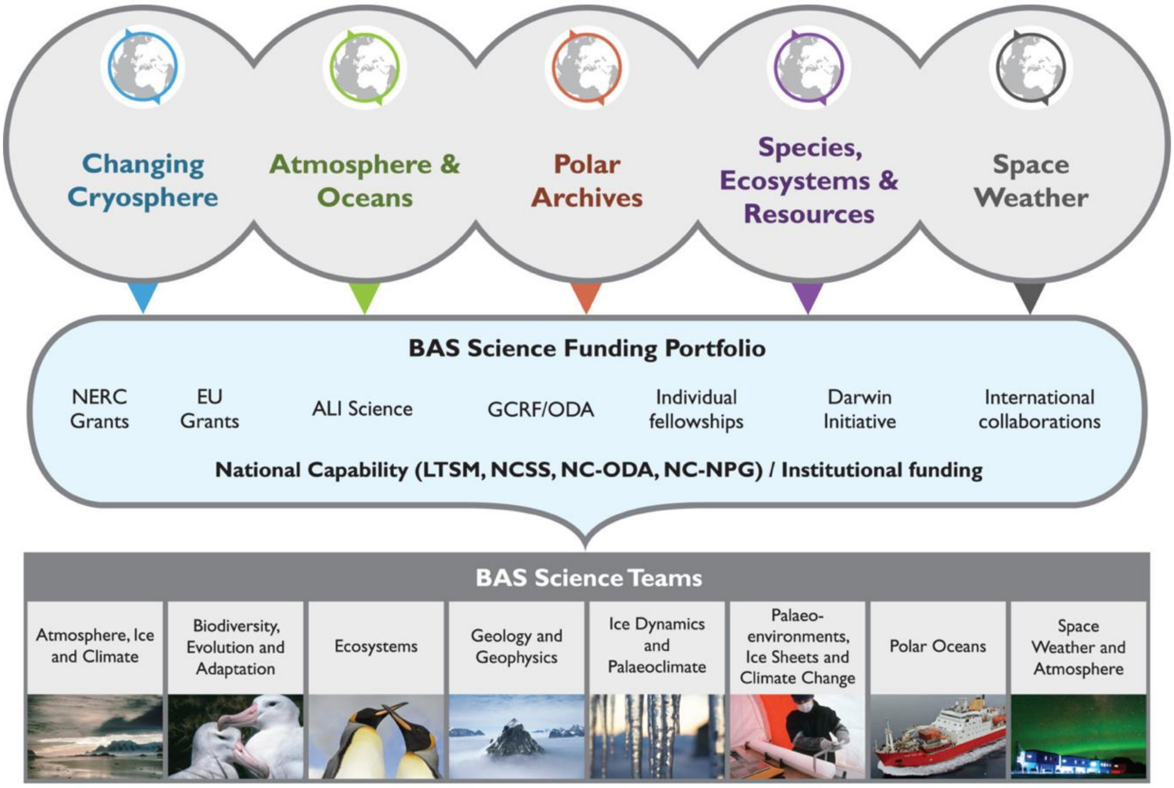


Figure 6. Overview of the research themes and teams that constitute BAS's research strategy Polar Science for Planet Earth. Source: www.bas.ac.uk.

1.3 Over-snow traverse capability in Antarctica

Motorised transport in Antarctica has a long history. The first motorised vehicle used in Antarctica was during Shackleton's 1907-1909 Nimrod Expedition. The Arrol-Johnston car was not a great success, with its activities restricted to moving stores and equipment across the sea ice (Figure 7).

Figure 7. The Arrol-Johnston car hauling a sledge across sea ice during Shackleton's 1907-1909 Nimrod Expedition.

In 1939 a huge snow cruiser was designed for the third expedition to Antarctic lead by Rear Admiral Richard E. Byrd. Resembling a cross between a bus and a tank, the actual cruiser was 55 feet long and 15 feet high (Figure 8). It carried four men inside and was designed to carry a single-engine aircraft on its back.

However, the design proved faulty, and the vehicle performed very poorly in Antarctica. The diesel-electric hybrid powertrain was severely underpowered, and the smooth tires, designed for swampy terrain, offered very little traction, sinking into the snow. Eventually the snow cruiser was abandoned and became buried in the ice.

Figure 8. The Antarctic snow cruiser taken to Antarctic as part of Rear Admiral Byrd's third expedition. Source: C.C. Shirley / United States Antarctic Service.

In 1957/58 modified tracked vehicles including Tucker Sno-cats, Weasels and Muskeg and Massey Fergusson tractors were used for the Commonwealth Trans-Antarctic Expedition which crossed from the Weddell Sea to the Ross Sea via the South Pole (Figure 9).

Figure 9. A Trans Antarctic Expedition Tucker Sno-cat. Photographer: Athol R Roberts

Overland traverses have continued to be used by a range of countries to establish and supply stations and to support field research. The network of current traverse routes is shown in Figure 11.

The current era of traverses includes the following developments:

- Since 1995, the Japanese Antarctic Research Expedition has supported Dome Fuji Station with overland traverses from Syowa Station and conducted research along the route.
- Several long-range science traverses have been conducted since 1999/2000 with the International Trans-Antarctic Science Expedition (ITASE) (Carsey, 2001), which involves around 20 countries.
- Since 2004/05 Concordia Station, jointly operated by the French Polar Institute and the Italian National Antarctic Research Programme, is supplied primarily by overland traverse, with established routes between Concordia, Dumont D'Urville Station and Mario Zuchelli Station.
- The United States Antarctic Program's South Pole Overland Traverse from McMurdo Station has been resupplying South Pole Station since 2005;
- Since 2018, Antarctica New Zealand has operated traverses from Scott Base to the Siple Coast to support a science programme at the ice shelf edge.
- The Australian Million Year Ice Core project will be supported by traverse from Casey Station to Dome C with traverse operations starting in the 2022/23 season.

BAS has a long history of over-snow traverses and has developed a Tractor Train Traverse system for transporting science teams and their equipment across vast areas of Antarctica using (Figure 10).

A combination of vehicles, sledges and living accommodation allows science and support teams to live and work in remote areas a long way from research stations.

Each austral summer season BAS supports an array of scientific research programmes at several field locations across the Antarctic continent for which land-based logistical support is required.

This environmental impact assessment considers the environmental impacts from planned traverse activities for the next five seasons.

Figure 10. BAS Tractor Train Traverse

Figure 11. Antarctic traverse operations as at 2021. Source: BAS Mapping and Geographic Information Centre.

2 Legal Context and Guidance Material

All activities in Antarctica are subject to the provisions of a series of international agreements that constitute the Antarctic Treaty System. These international agreements are enforced through domestic legislation enacted by those countries with active Antarctic involvement, achieved through, for example, the mounting of regular research expeditions and/or establishing a presence in Antarctica through the operation of Antarctic stations or bases.

This Chapter of the EIA:

- describes the relevant international agreements and domestic legislation that will apply to BAS traverse activities, and
- summarises relevant measures agreed under the auspices of the Antarctic Treaty System.

Further details on the scope of this EIA are set out in Chapter 3.

2.1 International Requirements

The Protocol on Environmental Protection to the Antarctic Treaty (the Protocol) was adopted by the Antarctic Treaty Consultative Parties (ATCPs) in 1991. It entered into force in January 1998.

Article 3 of the Protocol sets out environmental principles for the conduct of activities in Antarctica. Article 3 provides that the protection of the Antarctic environment and the intrinsic value of Antarctica, including its wilderness and aesthetic values and its value as an area for the conduct of scientific research, in particular research essential to understanding the global environment, shall be fundamental considerations in the planning and conduct of all activities in the Antarctic Treaty area.

Article 3 also requires that activities in the Antarctic Treaty area are planned and conducted so as to limit adverse impacts on the Antarctic environment and that those activities must be planned and conducted on the basis of information sufficient to allow prior assessments of, and informed judgments about, their possible impacts on the Antarctic environment. Such judgements must take account of:

i. the scope of the activity, including its area, duration and intensity;
ii. the cumulative impacts of the activity, both by itself and in combination with other activities in the Antarctic Treaty area;
iii. whether the activity will detrimentally affect any other activity in the Antarctic Treaty area;
iv. whether technology and procedures are available to provide for environmentally safe operations;
v. whether there exists the capacity to monitor key environmental parameters and ecosystem components so as to identify and provide early warning of any adverse effects of the activity and to provide for such modification of operating procedures as may be necessary in the light

of the results of monitoring or increased knowledge of the Antarctic environment and dependent and associated ecosystems; and

vi. whether there exists the capacity to respond promptly and effectively to accidents, particularly those with potential environmental effects.

Article 8 of the Protocol formalises these requirements by requiring an environmental impact assessment to be prepared in advance of any activity taking place in the Antarctic Treaty Area. The level of the environmental impact assessment is determined by whether the activity in question is identified as having ‘less than’, ‘no more than’ or ‘more than’ a minor or transitory impact on the environment.

The detailed procedures for preparing and processing environmental impact assessments are set out in Annex I to the Protocol. If a proposed activity is determined, by means of a preliminary assessment, to have less than a minor or transitory impact, then it may proceed. If an activity is determined as being likely to have no more than a minor or transitory impact, then an Initial Environmental Evaluation (IEE) must be prepared. If an IEE indicates the potential for the activity to have more than a minor or transitory impact, or if such an impact is otherwise determined to be likely, then a Comprehensive Environmental Evaluation (CEE) must be prepared.

Preliminary assessments and IEEs are processed within the domestic legal and administrative systems of each Antarctic Treaty Party. Draft CEEs are however, required to be made publicly available, and to be made available for consideration by the Antarctic Treaty System’s Committee for Environmental Protection (CEP). The CEP’s advice on the quality of a draft CEE is provided to the Antarctic Treaty Consultative Meeting (ATCM). Comments and advice provided by other Antarctic Treaty Parties and the ATCM must be addressed in a final CEE, which is used as the basis for making a decision about whether and how the activity in question will be conducted.

The Committee for Environmental Protection (CEP) has prepared guidance material to assist those preparing EIAs. The most recent version of these guidelines was adopted by the 39th ATCM (Resolution 1 (2016) refers). These guidelines have been consulted in the preparation of this EIA.

The EIA method used to meet these obligations is outlined in Chapter 7.

2.2 National Requirements

The EIA provisions of the Protocol are enacted in UK law through the Antarctic Act 1994 and Antarctic Act 2013 and Antarctic Regulations 1995/490 (as amended). The provisions of the legislation apply to any person who is on a British expedition to Antarctica, where a British expedition is defined as an expedition “that is organised in the United Kingdom, or the place of final departure for Antarctica of the persons on the expedition was in the United Kingdom”. The Act applies to both governmental and non-governmental activities in Antarctica.

The Act is administered by the Foreign Commonwealth and Development Office (FCDO) and the Secretary of State makes the final determination on whether an activity may proceed taking into account the FCDO’s recommendations. It is an offence under the Act to enter Antarctica without a permit issued by the Secretary of State.

The Act also prohibits the following activities unless a permit is obtained:

- undertaking mineral resource activities
- intentionally, killing, injuring, capturing, handling or molesting any native mammal or native bird
- intentionally disturbing native mammals or native birds
- removing or damaging any native plant so as to significantly affect its local distribution or abundance, or significantly damaging a concentration of native plants
- causing significant damage to the habitat of any native mammal, bird, plant or invertebrate
- introducing any species of non-native animal or plant
- entering an Antarctic Specially Protected Area (ASPA), or an area designated as protected by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR)
- damaging, destroying or removing a designated historic site or monument.

Logistical activities are covered by the BAS Operating Permit, which is organised directly between BAS and the FCDO.

The Secretary of State has discretion under the Act to set conditions regarding the proposed activity. Such conditions may relate to, for example, managing compliance, undertaking environmental monitoring and post-activity reporting. Under the provisions of the Act, non-compliance is an offence carrying a penalty of up to two years imprisonment or a fine or both.

2.3 Applicable ATCM Measures and Resolutions

In addition to the general provisions of the Protocol outlined above, the ATCM has, over time adopted a suite of additional agreements (in the form of Recommendations, Resolutions or Measures) several of which are pertinent to the planned activities in that they relate specifically to the issue of Antarctic logistical and operational activities, or environmental management.

Relevant agreements are highlighted here for completeness and will be considered in this environmental impact assessment and in the conduct of the planned activities.

2.3.1 Logistical and operational activities in Antarctica

Measures related to logistical and operational activities in Antarctic and relevant to traverse activities include:

- Recommendation I-X (1961) – Principle of Emergency Assistance
- Recommendation VII-8 (1972) – Common Transport Facilities
- Resolution 3 (2012) – Improving Co-operation in Antarctica
- Resolution 4 (2013) – Improved Collaboration on Search and Rescue in Antarctica
- Resolution 1 (2014) – Fuel Storage and Handling

2.3.2 Environmental Management in Antarctica

Measures related to environmental management in Antarctica which may be relevant to traverse operations include:

- Recommendation XV-5 (1989) – Environmental Monitoring Activities
- Resolution 2 (2005) – Guidelines for Environmental Monitoring
- Resolution 5 (2015) – Important Bird Areas in Antarctica
- Resolution 1 (2016) – Revised Guidelines for Environmental Impact Assessment in Antarctica
- Resolution 4 (2016) – Non-native Species manual (revised 2019)
- Resolution 1 (2019) – Revised Antarctic Clean-Up Manual
- Resolution 5 (2019) – Reducing Plastic Pollution in Antarctica and the Southern Ocean

2.4 COMNAP guidance material

The Council of Managers of National Antarctic Programs (COMNAP) provides a forum for cooperation among National Antarctic Programs that have responsibility for delivering and supporting scientific research in the Antarctic Treaty Area on behalf of their respective governments. COMNAP guidance material that may be relevant to traverse operations include:

- Checklists for Supply Chain Managers for the Reduction of Risks of Introduction of Non-native Species
- COMNAP Guidelines for Emergency Response and Contingency Planning
- COMNAP Fuel Manual
- COMNAP Practical Guidelines for Developing and Designing Environmental Monitoring Programmes in Antarctica

All of the above obligations and guidance material have been considered in the preparation of this EIA and, where relevant, in the various control measures identified to minimise the impacts of activities undertaken in Antarctica.

Consideration of the additional provisions of the Protocol as they relate to waste management, prevention of marine pollution and area protection and management are considered in later chapters of this EIA.

3 Scope of the EIA

This environmental impact assessment evaluates the environmental consequences that will or could arise from the BAS' planned programme of traverse activities over the next five austral summer seasons (2022/23 to 2026/27).

The planned activities are described in detail in Chapter 5. This Chapter describes the scope of the EIA and provides the rationale for what is and what is not included within the scope.

3.1 Geographical scope

Planned traverse activities over the five-year period covered by this EIA will be exclusively on snow- and ice-covered areas (Figure 12), including:

- the Ronne-Filchner Ice Shelves and Berkner Island;
- Ellsworth Land from Sky Blu and the Stange Ice Shelf to Abbott Ice Shelf, Pine Island Glacier and Thwaites Glacier; and
- the West Antarctic Ice Shelf (WAIS) from Institute Ice Stream to WAIS Divide and Siple Dome.

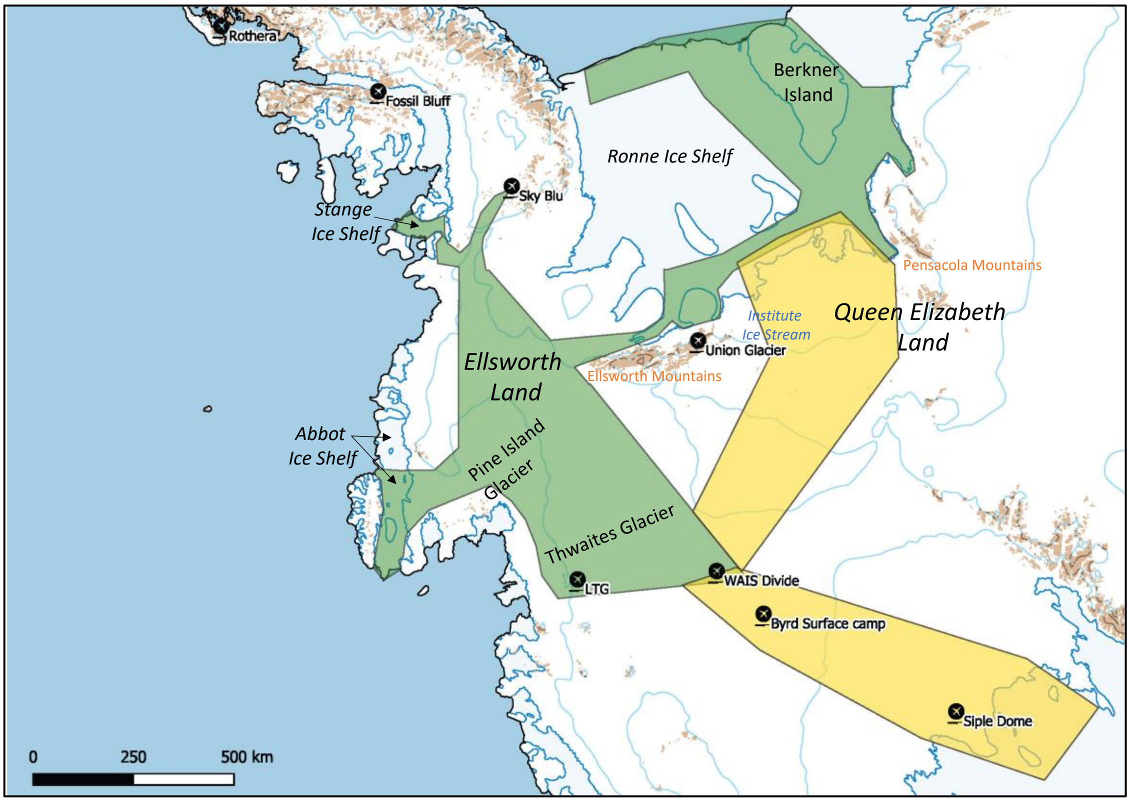


Figure 12. Areas of planned traverse activities for BAS operations for the next five years. Areas shaded green indicate areas previously covered by BAS traverse activities. Areas shaded yellow identify areas that have potential to be traversed by BAS tractor trains in the next five summer seasons. Source: BAS.

Coastal edges of the Abbott Glacier (Belligshausen and Amundsen Seas), the Stange Ice Shelf (Bellingshausen Sea) and the Ronne Ice Shelf (Weddell Sea) may be visited by traverse vehicles in order to facilitate ship offload or onload. Ship rendezvous are anticipated to occur one or two times during the five-year period covered by this EIA.

Specific routes within the broad areas shown in Figure 12 cannot be identified at this stage. In any one summer season the precise traverse routes that will be used will be determined by a number of factors including: weather, ice and snow conditions, logistics connections (e.g., coastal locations where ships are able to offload, existing ski ways and blue ice runways) and scientific and operational objectives.

Nonetheless, the shaded areas in Figure 12 represent a constraint on traverse operations. Should any operational plans require traverse activities to be undertaken outside of these boundaries, BAS Field Operations will be required to consult with the BAS and additional environmental impact assessment will be undertaken.

Traverse activities also will be constrained to snow and ice-covered areas only. Ice free areas such as the Ellsworth Mountains, Pensacola Mountains and any nunataks throughout the planned areas of traverse activity will be avoided and placed 'off-limits' for traverse activities (see mitigation measures in Section 7.4).

3.2 Temporal scope

This evaluation covers five years of planned traverse activities from the 2022/23 austral summer season to and including the 2026/27 season. The timeframe of this IEE mirrors the timeframe of the BAS Operating Permit granted under Section 3, Section 4, Section 6, Section 7, Section 8, Section 9 and Section 10 of the Antarctic Act 1994, which will be valid from 1 October 2022 to 30 September 2027.

Traverse activities only occur during the austral summer months (approximately November to early March at the latest), with vehicles and equipment placed in depots for the winter period (approximately March to October).

3.3 Activities excluded from the scope of the EIA

This EIA considers the actual or potential impacts that will or may arise from the carrying out of over-snow traverses. The EIA does not consider environmental impacts associated with:

- any of the scientific research activities that will be supported by traverses. The impacts of the associated research (including impacts resulting from activities undertaken in snow/ ice free areas) will be addressed entirely separately and will be covered by a Preliminary Environmental Assessment or a separate IEE as required;

- aircraft and vessel activities that will occasionally rendezvous with the traverse, with the exception of the refuelling of aircraft using fuel carried by the traverse which is discussed in this EIA;
- the treatment and handling of waste once it has been removed from the field either by air or by ship.

4 Alternatives

The EIA process needs to consider alternatives in order to identify the optimal way of meeting the need and purpose of the proposal, by enhancing the environmental benefits of the proposed activity or by reducing or avoiding potentially significant negative impacts.

Due consideration of alternatives ensures that the EIA is not simply defending a single project proposal. Instead, the EIA provides the opportunity for an unbiased, proactive consideration of options.

Examples of alternatives include use of different locations or sites for the activity; opportunities for international cooperation; use of different technologies in order to reduce the outputs (or the intensity of the outputs) of the activity, and different timing for the activity.

The alternative of not proceeding with the proposed activity should always be included in any analysis of environmental impacts of the proposed activity (CEP EIA Guidelines, 2016).

This Chapter describes the alternatives that have been (and continue to be) considered as part of BAS' ongoing traverse activities.

4.1 Cease all deep field activities: 'Do nothing' alternative.

Ceasing all deep field activities and limiting scientific research to that which can be supported directly from BAS' main Antarctic stations or the Sir David Attenborough would eliminate all associated environmental impacts; including those that arise from traverse vehicles, associated aircraft operations and (deep field) scientific research.

Such an approach would also assist in maintaining perceptions of Antarctic wilderness in the interior of Antarctica.

However, this option would be contrary to BAS' vision of being a world-leading centre for polar science and polar operations. It would also severely curtail the UK's ability to undertake globally relevant scientific research, particularly research aimed at understanding Antarctica's response to changing climate conditions, including the behaviour of Antarctica's ice sheets under warming conditions.

BAS' scientific research strategy, Polar Science for Planet Earth, sets the strategic direction for British Antarctic Survey and promotes the organisation's mission to deliver excellence, impact and leadership in science. The research strategy focuses on five key themes of global significance (Figure 6) almost all of which require some degree of deep field research.

The option of ceasing all deep field research was therefore rejected in favour of exploring the most effective means of deploying and recovering deep field research teams and equipment.

4.2 Utilise alternative vehicle technologies for traverse activities

Globally there continues to be a shift away from the combustion of fossil fuels so as to mitigate the harmful effects of greenhouse gases in the atmosphere. The vehicle industry has shown a shift towards the manufacture and sale of electric or reduced-emission vehicles.

Light commercial electric vehicles have been tested in Antarctic conditions (see for example Sears et al., 2014) but these have only been used in and around Antarctic stations and bases.

To date heavier, industrial vehicles utilising electric or low-emission technologies have been slower to emerge. Vehicles capable of meeting the endurance, reliability and towing capacities for Antarctic traverse activities are not currently available. Some lower-emission options are beginning to be commercially available (see for example the low-emission PistenBully 600E+ from Kässbohrer) but such vehicles have not been adequately trialled in Antarctic conditions.

Vehicles that are underpowered or without proven reliability under polar conditions could jeopardise safety and reduce the ability to complete operational missions. As a result, BAS will continue to use fossil-fuel powered vehicles, whilst continuing to monitor the market and keep alternative lower-emission vehicles under review as existing plant needs to be replaced.

4.3 Support deep field activities by air only.

BAS currently operates five aircraft in Antarctica: four De Havilland DHC-6 Twin Otters and a De Havilland Dash-7 aircraft (Figure 5).

The Twin Otters are extremely versatile and can be modified to allow airborne surveying and other scientific equipment to be fitted. The version operated by BAS is the wheel/ski-equipped aircraft which lands on snow, ice or any other type of hard runways in remote areas.

The larger Dash-7 aircraft is largely used to provide an intercontinental link between BAS' Rothera Station and the Falkland Islands. It also provides a regular link for spares, urgent supplies and fresh food as well as freeing up the BAS ship, enabling it to spend more time at sea on scientific cruises.

Because the Dash-7 can land on ice runways, it is used to move fuel, equipment and people between Rothera and the BAS field station at Sky Blu.

The Twin Otter aircraft are already used to support deep field research events by delivering fuel, equipment, and researchers to the field.

However, maximum weight requirements limit the combination of fuel, equipment and people that can be carried at any one time and larger field events would require multiple aircraft rotations to establish. The aircraft are also subject to greater restraints on weather conditions which can mean delays in delivering research events or equipment to the field. As a result, BAS would need to greatly reduce its deep field operations each year if only aircraft were available to provide support.

Exclusively using aircraft to support deep field research is also inefficient and requires a larger fuel burn for any unit of weight delivered compared to over-snow vehicles. In their 2004 CEE to assess the development and implementation of surface traverse capabilities in Antarctica, the US noted that: "*When delivering fuel, the LC-130 actually consumes more fuel with each trip than it deposits at the station. Using the example re-supply traverse, compared to a single aircraft, each tractor would deliver to South Pole significantly more material (approximately twice as much) per roundtrip for approximately the same amount of consumed fuel*" (NSF, 2004).

Supporting deep field research activities using only BAS aircraft is not considered to be a viable option and would result in a significant reduction in research effort and greater operational inefficiencies. This alternative was therefore not pursued further.

4.4 Utilise international partners or contract a specialist provider to support deep field activities.

To reduce the environmental impacts associated with BAS traverse operations, it could be possible to seek external support for BAS deep field research programmes; either by seeking the use of assets of other national Antarctic programmes or by using a commercial provider.

Some national Antarctic programmes have pursued this model by utilising the assets of other countries to meet their research needs and thereby avoid cumulative environmental impacts that might occur by deploying their own assets to Antarctica. For many years, BAS have provided annual logistical support at Rothera station to Dutch Antarctic researchers for example.

However, utilising the assets of other national Antarctic programmes for deep field research would require a substantial reduction in BAS' research ambitions in the interior of Antarctica. The assets of other countries are often fully utilised in meeting their own research and logistical needs, often with limited additional capacity.

Such an approach would potentially mean BAS / UK researchers waiting several seasons before assets were available to support their activities.

Alternatively, a commercial operator could be used to provide traverse capability to meet BAS' research and logistical requirements. BAS have used this option in the past by utilising over-snow traverse support provided by Antarctic operator ALE (Antarctic Logistics and Expeditions). ALE have established an air link between South America and their summer field facility at Union Glacier in the Ellsworth Mountains and utilise over-snow traverse capability either for tourism purposes or in support of National Antarctic Programmes (see: https://antarctic-logistics.com/services/overland-transport).

ALE assets have been used at times when BAS' own deep field assets have been over-subscribed. However, utilising a commercial provider exclusively would still mean a reduction in BAS' deep field research programme as ALE do not have the capacity to meet all of BAS' research and logistical requirements. Further, using an external provider adds complexity in terms of planning ability and in-season flexibility. This could impact BAS' current ability to plan and to retain agility and flexibility in its delivery of field events as circumstances and changes occur within and between seasons.

Rather than exclusively utilising external providers, BAS' experience has shown that the optimum model is to work cooperatively with other National Antarctic Programmes for mutual benefit. A recent example of this has been the joint US / UK International Thwaites Glacier Collaboration (ITGC; https://thwaitesglacier.org/). Research aimed at investigating the most unstable parts of the Antarctic ice sheet has required the use of UK and US air and traverse support with research outcomes far greater than would have been possible by one National Antarctic programme operating alone.

4.5 Support deep field activities through a combination of air and traverse capability.

BAS' experience to date is that the most efficient use of operational assets to maximise deep field scientific effort in any one austral summer season is to use a combination of aircraft and over-snow traverse capability.

As noted above the Twin Otter aircraft are already utilised to deliver equipment, fuel and personnel to deep field locations. This can be an efficient means of deploying and extracting small-scale research teams with moderate equipment requirements. However, meeting the current scale of research requirements and, in particular the needs of larger scale research programmes, requires a combination of air and traverse assets to be used.

Planning for any one austral summer season seeks to maximise the amount of science and research outcomes by optimising the use of available air and over-snow traverse assets.

This is seen as the most effective way of continuing BAS' deep field research programme over the next five years and is the basis for assessing the environmental impacts of the traverse component in this EIA.

4.6 Summary

BAS will continue to review options for supporting the deep field research requirements of UK researchers. Following a review of alternatives and based on BAS' many years of experience of undertaking deep field activities in Antarctica, the preferred option is for BAS to continue to support deep field research through a combination of in-house air and traverse capability.

Where possible BAS will continue to explore operational and research collaborations with other National Antarctic Programmes and to utilise commercial providers on an occasional 'as required' basis.

On this basis, this EIA reviews the actual or potential environmental impacts that will or may arise as a result of BAS' planned over-snow traverse operations for the next five summer seasons.

5 BAS Traverse Activities – Preferred Approach

Having considered a range of alternative approaches, the proposed activities associated with the planned over-snow traverse capabilities for both logistical and scientific research applications are described in this chapter.

The purpose for the proposed activities is presented as well as a detailed description of the typical components of a traverse including vehicles used, loads that are towed and associated traverse camps. The chapter also considers associated activities including waste and fuel management, snow moving requirements and the over-wintering of traverse equipment and vehicles.

Whether the proposed surface traverse is for re-supply or scientific research, over-snow traverses will involve the use of multiple motorised tracked vehicles, towing sleds or trailers containing living and working modules for the traverse crew, fuel for the traverse equipment, as well as payload or cargo.

The scope of any one traverse will depend upon the specific or logistical needs of the mission and cannot be definitively stated in this EIA. However, each traverse will be a slight variant on what is presented here.

This chapter also identifies the environmental aspects that will or may arise from the various activities. These aspects or outputs are the ways in which the planned activity will or may interact with the environment. The consequences and significances of these aspects are then assessed in Chapter 7.

5.1 Purpose

The ultimate purpose of BAS' traverse activities over the next five summer seasons is to support globally relevant scientific investigations in the interior of Antarctica.

Tractor traverses are used either logistically focused, i.e., involving the relocation or deployment of fuel, cargo and field support equipment in anticipation of future use by science events; or in direct support of science activities i.e., involving following a pre-planned route to allow researchers to undertake a series of measurements over areas of the Antarctic ice sheet or ice-shelves.

Currently, known science events for which traverse support will be required include the ongoing International Thwaites Glacier Collaboration (involving both logistical support and scientific traverses; https://thwaitesglacier.org/) and a science traverse on the Institute Ice Stream which will involve the towing of a vibroseis truck (planned for the 2025/26 season; Figure 13).

Figure 13. Example of a vibroseis truck (a) and associated coiled streamer array (b) to be used in a future science traverse. Source: Alfred Wegener Institute

5.2 Vehicles

5.2.1 PistenBully 300 Polar

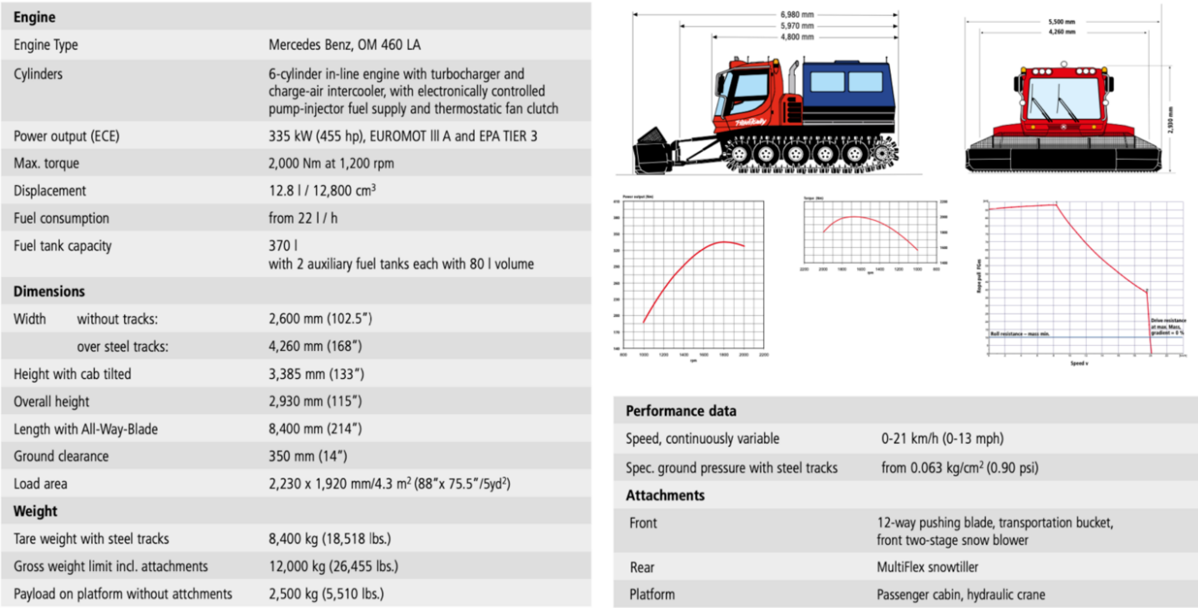
BAS has five PistenBully 300 Polar vehicles (PB300). These tracked snow-vehicles are used to tow supplies, equipment and portable living and working facilities across the ice (Figure 14).

Figure 14. A BAS PistenBully 300 Polar on traverse duty in Antarctica. Source: https://www.pistenbully.com

The vehicles are powered by a Mercedes Benz, OM 460 LA, 6-cylinder engine with turbocharger. The engine provides a power output of 335 kW (455 hp). The vehicle has exceptional towing capacity with a maximum torque of 2,000 Nm at 1,200 rpm. Webasto diesel heaters are used for engine warming.

The PB300 vehicles move at approximately 8-10 km/h, depending upon the load being towed, usually for about 8 hours each day. The average fuel consumption is approximately 7.8 L/km (see Table 2).

The full vehicle specification is shown in Figure 15.



Engine	
Engine Type	Mercedes Benz, OM 460 LA
Cylinders	6-cylinder in-line engine with turbocharger and charge-air intercooler, with electronically controlled pump-injector fuel supply and thermostatic fan clutch
Power output (ECE)	335 kW (455 hp), EUROMOT III A and EPA TIER 3
Max. torque	2,000 Nm at 1,200 rpm
Displacement	12.8 l / 12,800 cm³
Fuel consumption	from 22 l / h
Fuel tank capacity	370 l with 2 auxiliary fuel tanks each with 80 l volume
Dimensions	
Width without tracks:	2,600 mm (102.5")
over steel tracks:	4,260 mm (168")
Height with cab tilted	3,385 mm (133")
Overall height	2,930 mm (115")
Length with All-Way-Blade	8,400 mm (214")
Ground clearance	350 mm (14")
Load area	2,230 x 1,920 mm/4.3 m² (88"x 75.5"/5yd²)
Weight	
Tare weight with steel tracks	8,400 kg (18,518 lbs.)
Gross weight limit incl. attachments	12,000 kg (26,455 lbs.)
Payload on platform without attchments	2,500 kg (5,510 lbs.)

Performance data	
Speed, continuously variable	0-21 km/h (0-13 mph)
Spec. ground pressure with steel tracks	from 0.063 kg/cm² (0.90 psi)
Attachments	
Front	12-way pushing blade, transportation bucket, front two-stage snow blower
Rear	MultiFlex snowtiller
Platform	Passenger cabin, hydraulic crane

Figure 15. Technical specifications for the PB300 Polar.

The PB300 can be configured with a hydraulic crane attachment (Figure 14) or with a passenger cab (Figure 16).

Details of vehicle procedures are provided in the Traverse Operations Manual (Appendix 1). Trained mechanics and operators are part of the traverse personnel. Vehicles are serviced at 250, 500 and 1000 hours of operation and scheduled maintenance carried out. Prestart and shut down checks and procedures are carried out daily.

Figure 16. PB300 configured with a passenger cab. Source: https://www.pistenbully.com

5.2.2 Skidoos

Two skidoos are typically deployed with traverse operations, primarily to survey the terrain ahead with ground penetrating radar and avoid crevasses (Figure 17). Actual fuel consumption depends upon the model of skidoo used (Table 2).

Figure 17. Skidoo based GPR survey. Source: BAS.

Table 2. Vehicle fuel consumption. Source: BAS Traverse Operations Manual.

Vehicle	Average Fuel Consumption
Two PB300 Polars towing 20 tons each	6.6 L per km
Two PB300 Polars towing 40 tons each	8.8 L per km
PB300 Polar moving snow (i.e., berm building and depot work)	14 L per hour
Two V800 skidoos with full tow load	0.46 L per km
Two Alpine III skidoos with full tow load	0.77 L per km

5.2.3 Environmental aspects from the use of vehicles

The aspects from the operation of the over-snow vehicles that will or may interact with the environment include:

- atmospheric emissions of gases including greenhouse gases from the burning of fossil fuels to power the vehicles;
- deposition on snow surfaces of particulates (e.g., black carbon) and trace elements from the incomplete burning of fossil fuels in the vehicles;
- the potential direct release of fossil fuels into the environment if fuel is spilt e.g., during refuelling of the vehicles or as a result of mechanical failure;
- noise from the operation of the vehicles;
- mechanical action on and physical disturbance of snow and ice surfaces.

5.3 Towed Loads

The PB300 vehicles are used to tow a variety of sled and sledge mounted equipment and supplies (Figure 14, Figure 18).

BAS has one large caboose, made of two 30 ft containers joined together, and one small caboose utilising a 24 ft container. These are ski-mounted living spaces used during the traverse (Figure 18).

Lehmann Sledges (rated for 10, 15 or 20 T payloads) are used for bulky cargo and may be fitted with high side panels (Figure 14; Figure 18). They can carry up to 60 drums of fuel or other cargo.

Poly sleds are 12 mm thick sheets of high molecular weight plastic that provide a low friction surface and can be used with 5,800 L fuel bladders (Figure 18).

Other cargo can also be secured on the poly sleds using platforms such as galvanized pallets and NEFAB crates (Figure 19). It is intended also to trial wooden platforms on poly sleds for transporting drummed fuel. Shorter poly sleds can be used to transport four side by side skidoos.

A specialised PB300 recovery sled with track-width poly strips held in place by steel spacers has been designed for towing a PB300 to save fuel or in case of damage or break down.

5.3.1 Environmental aspects from the towing of loads

The aspects from the towing of loads that will or may interact with the environment include:

- mechanical action on and physical disturbance of snow and ice surfaces;
- the potential direct release of fossil fuels into the environment if fuel is accidentally spilt from drums or fuel bladders;
- the potential loss of cargo (including hazardous substances) or equipment to the environment if inadequately secured.

Figure 18. BAS traverse train with PB300, caboose, Lehman sledge and poly sleds

Figure 19. Poly sled with cargo

5.4 Traverse Camps

Traverse trains can last for several days or weeks depending upon the route, weather conditions or science objectives. Overnight or multi-night camps are established as required.

Camps are set up in a standard arrangement every time for reasons of efficiency as well as to facilitate known locations of equipment and fuel in low visibility conditions or after periods of significant snow deposition (Figure 20).

In a standard camp arrangement, the cabooses serve as kitchen, accommodation and general living space. Each caboose can sleep four people, and additional people may sleep in tents. Webasto diesel heaters provide warmth. The smaller caboose kitchen is equipped with an LPG hob, convection microwave oven, snow melter and bread machines. The large caboose is equipped with a two-ring induction hob.

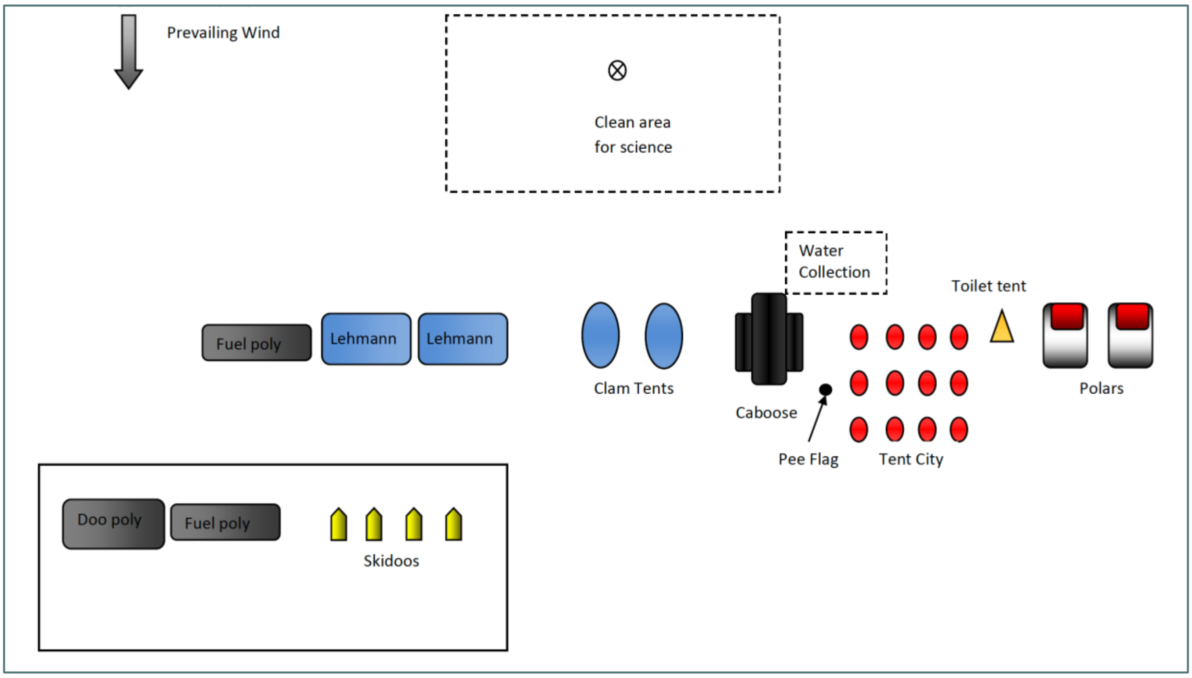


Figure 20. Suggested Camp Layout. Source: BAS Traverse Operations Manual.

12 V and 240 V power is provided to the cabooses from fitted diesel generators. A selection of portable generators is also provided for use around the traverse and science groups.

Snow may be moved using the PB300s, or manually using shovels, to weigh down tent valances and create flat working areas or wind breaks.

5.4.1 Environmental aspects from traverse camps

The aspects from the establishment and operation of traverse camps that will or may interact with the environment include:

- mechanical action on and physical disturbance of snow and ice surfaces from the establishment of tents and people and vehicles moving around the camps;
- the potential direct release of fossil fuels into the environment if fuel is spilt from drums or fuel bladders e.g., when refuelling generators;
- the generation and potential release of waste to the environment if inadequately managed (see Section 5.5 below).

5.5 Waste Management

In accordance with the provisions of Annex III to the Protocol, BAS have well established procedures for separating and retrieving waste from the field to minimise releases to the environment.

Waste is separated into different waste types as it is generated during the traverse and back loaded to Rothera when aircraft space is available or transferred to the *Sir David Attenborough* during a ship rendezvous. Clean and Bulky waste may be stored at logistics depots and driven back to Sky Blu or off loaded to a ship at a later date.

Clean plastics, metals, glass, paper and other recyclable wastes are separated by type and stored in appropriate plastic bags.

Waste Batteries, Oils, Chemicals, and other hazardous materials are returned to Rothera in suitable UN containers, ideally their original packaging, and clearly marked as hazardous.

Food and solid human wastes are returned to Rothera in UN plastic drums for incineration. Liquid human waste and sieved grey water are disposed of in the field and the location marked and recorded for future traverses.

Medical and sanitary wastes are stored in yellow bags, and then added to the human waste drum for incineration.

Clean separated waste is stored in vented and topped fuel drums for ease of storage and transport.

Any waste will be disposed of the UK by licensed waste contractor meeting the requirements of the Waste (England and Wales) (Amendment) Regulations, 2014, the Duty of Care Regulations, 1991, and the Hazardous Waste Regulations, 2005

5.5.1 Environmental aspects from the generation and management of waste

The aspects from the waste generation and management that will or may interact with the environment include:

- the potential release of waste materials to the environment if inadequately managed.

- The potential mis-consignment of waste, incorrect segregation of waste, mixing of hazardous with non-hazardous waste.

5.6 Fuel Management and Fuel Transfers

The PB300s use Avtur or Avcat, cold blend aviation fuels. It is stored in 5,800 L bladders and in 205 L drums. It is kept uncontaminated for use in aircraft also. Petrol and lubricants are transported in drums. The types and volumes of fuel being moved by any one traverse train will vary depending upon the purpose of the traverse.

All fuel use is recorded in a fuel log detailing volume and type of fuel used.

The PB300s are refuelled using an electric pump and hose reel. The hose is connected to a fuel bladder using the dry-break connection; an extension pipe can be fitted for taking drummed fuel. Bulk fuel hoses and pumps are all fitted with dry-break connections.

Great care is taken when bringing PB300s alongside fuel bladders for refuelling as there is a risk of piercing the bladder with the blade or cleated track. A banksman (or spotter) is used to guide manoeuvres and the PB300 is kept at least 3m from the fuel bladders.

If fuel needs to be transferred between bladders (e.g., to balance towed loads) a Spate PD75 pump is used (Figure 21). If the Spate pump is unavailable placing a full bladder on a berm allows gravity to be used.

Figure 21. A Spate PD75 pump used for transferring fuel. Source: BAS Traverse Operations Manual.

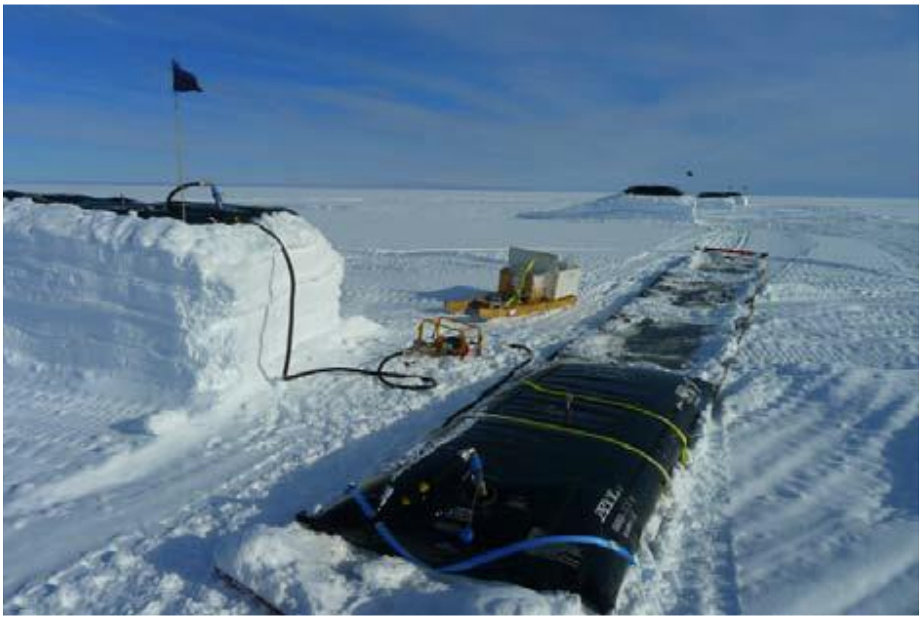


Figure 22. Transferring fuel between bladders. Source: BAS Traverse Operations Manual.

Skidoos are refuelled directly from petrol drums using rotary pumps. Alternatively, drums can be mounted horizontally on the caboose and fitted with drum taps to fill Jerry cans for refuelling of skidoos or small generators.

Aircraft refuelling is via a trigger gun straight from drums, using the same arrangement as for transferring fuel between bladders but with the addition of an inline filter.

Standard operating procedures are used for all refuelling and fuel transfer operations.

5.6.1 Environmental aspects from fuel handling and fuel transfers

The aspects from fuel handling or fuel transfers that will or may interact with the environment include:

- the potential direct release of fossil fuels into the environment if fuel is accidentally spilt.
- in case of fuel spillages, hazardous waste will be created.

5.7 Snow moving

Snow grooming and snow movement is undertaken for several reasons. Trenches or berms are constructed to assist with loading and unloading sledges and used to elevate overwintering equipment and supplies to prevent them being buried by snow drifts.

Snow is also collected and melted for water for drinking, cooking and washing.

5.7.1 Environmental aspects of snow moving

The aspects from snow movements that will or may interact with the environment include:

- mechanical action on and physical disturbance of snow and ice surfaces;

5.8 Overwintering Depots

Vehicles, fuel supplies and equipment are overwintered at established sites and camps such as Sky Blu. These are left securely on 3m high snow berms to prevent burial in snow drifts. The location is clearly flagged and recorded for later identification.

Fuel bladders and drummed fuel are also overwintered on individual snow berms (Figure 23). Checks are made to ensure no potential windblown items or flogging material are present which could puncture or degrade fuel bladders. Depoted bladders are monitored for at least 24 hours to ensure they are secure, and no leaks are detectable.

Rubberised outer bags for the fuel bladders, which provide a secondary containment measure, are being trialled. Fuel drums are stored upright but without secondary containment. Using any form of bund around fuel drums can accelerate the accumulation of snow around the drums.

Figure 23. Raised berms used to store fuel (in drums and bladders) during the winter period. Source: BAS Traverse Operations Manual.

Vehicles are inspected and serviced before being stored for winter. Batteries are disconnected and air intakes and exhaust are sealed to prevent snow ingress. A 500 mm trench is cut between the PB300 tracks to allow wind to scour the tracks free of snow.

Cabooses are cleared of waste, gas and fuels disconnected and air intakes, exhausts and vents are sealed.

All such measures aim to reduce the risk of leaks or damage to equipment.

Waste items may also be overwintered at depots until they can be moved to the coast and transferred to a ship for return to Rothera or the UK (Figure 24).

Figure 24. Waste depot at SB9. Source: BAS.

5.8.1 Environmental aspects from overwintering depots

The aspects from establishing overwinter caches and depots that will or may interact with the environment include:

- the potential loss of items to the environment if they cannot be relocated the following summer season;
- the potential direct release of fuels to the snow/ice environment if fuel drums and bladders leak during the winter period.

6 Current Environmental State

A thorough understanding of the pre-activity (or current) state of the environment is an essential basis for predicting and evaluating impacts, and for identifying relevant and effective mitigation measures.

Consideration of the environment requires the characterisation of all relevant physical, biological, chemical and anthropic values or resources in the area where, and when an activity is proposed. 'Relevant' means all those elements of the environment that the proposed activity might influence, or which might influence the activity, including dependent and associated ecosystems (CEP EIA Guidelines, 2016).

This chapter describes the nature and characteristics of the Antarctic ice sheet where the planned traverse activities will occur.

6.1 Climate

Antarctica is the coldest and driest continent on Earth. Across the continent, high elevations, the prolonged absence of sun, and the high albedo of the ice surface account for low temperatures, and reduced precipitation through the very low moisture-holding capacity of the air.

Antarctica's average annual temperature ranges from about −10 °C on the coast to −60 °C at the highest parts of the interior. West Antarctica is generally warmer than East Antarctica due to its lower elevation (Figure 25). Monthly average temperatures over the WAIS range from -12 °C to -35 °C.

Near the coast, the temperature can exceed +10 °C in summer and fall to below −40 °C in winter. Over the elevated inland, it can rise to about −30 °C in summer but fall below −80 °C in winter.

Antarctica's environment has special conditions that make it the windiest continent on Earth. Antarctica is usually surrounded by a belt of low pressure which contains multiple low centres. This is called the 'circumpolar trough'. But the interior of the continent is dominated by high pressure. These conditions set the scene for the formation of katabatic winds.

Katabatic winds are created when radiative cooling over the elevated Antarctic ice sheet produces very cold, dense air. The cold, dense air flows downhill, and is replaced by subsiding air from above. The resulting katabatic winds accelerate downhill, enhanced by the confluence of glacial valleys and are strongest near to the coast. As the winds move offshore, they lose their driving force and dissipate (Figure 25).

Low-pressure systems near the coast can interact with katabatic winds to increase their strength. Resulting wind speeds can exceed 100 km/h for days at a time. Wind gusts well over 200 km/h have been measured.

The dry, subsiding air over the interior of Antarctica creates little cloud. Around the coast however, more moisture is available and low-pressure systems have a greater influence. This means that cloudy conditions are more common near the coast, particularly in the region of the Antarctic Peninsula.

Rain has been observed near the coast, but most precipitation over Antarctica is in the form of snow or ice crystals.

Windy conditions make it difficult to measure snowfall accurately. The average accumulation of snow over the whole continent is estimated to be equivalent to about 150 mm of water per year. Over the elevated plateau, the annual value is less than 50 mm. Near the coast, it generally exceeds 200 mm, the heaviest being over 1,000 mm for an area near the Bellingshausen Sea.

Loose snow can be picked up and carried along by the wind. When the snow is still below eye level, this is called drifting snow. When it is raised above eye level, it is called blowing snow. Wind speeds of over 30 km/h can lead to drifting snow, while wind speeds over 60 km/h are more likely to produce blowing snow. Blowing snow can reduce visibility significantly and make it challenging to conduct activities including driving vehicles.

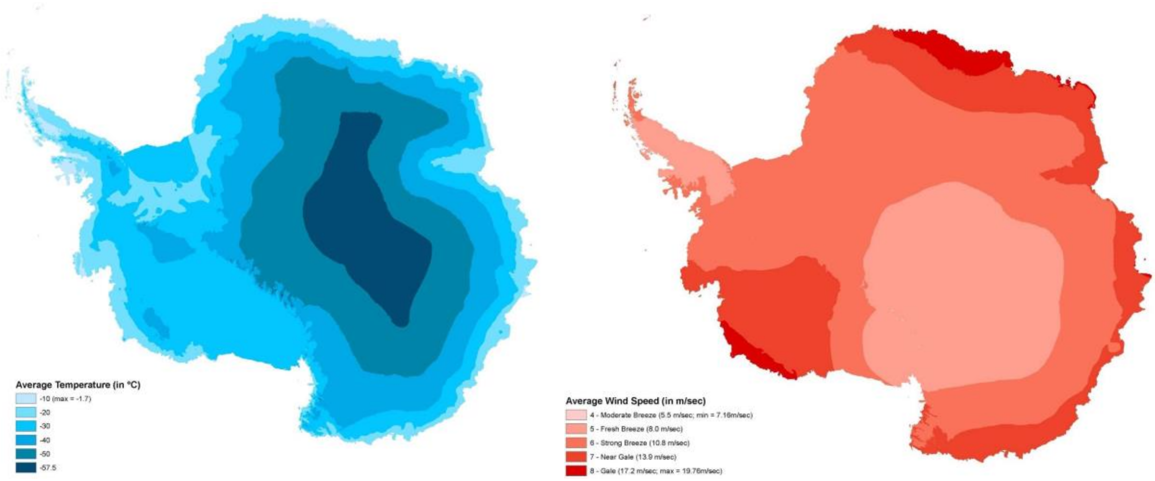


Figure 25. Average temperatures and wind speeds across the Antarctic continent. Source: Morgan, 2007.

When wind speeds are gale force or stronger for at least 1 hour, the temperature is less than 0 °C and visibility is reduced to 100 m or less, it is a Blizzard. These conditions are dangerous and disruptive for outdoor activities. Sometimes blizzards last for days.

Whiteout is an optical phenomenon. Uniform light conditions can make it impossible to distinguish shadows, landmarks or the horizon. This can happen when the snow cover is unbroken and the sky is overcast. Whiteout is a serious hazard as it causes a loss of perspective and direction.

BAS' traverse activities will transit a variety of weather conditions in and between seasons, from the warmer, moister coast to the colder, drier interior (Table 3).

Recent research has focussed on the implications of changing climate conditions on the stability of the WAIS.

The major climate drivers of atmospheric conditions include teleconnection modes such as the Southern Annular Mode, Pacific Decadal Oscillation, and El Niño–Southern Oscillation and the presence and strength of low-pressure systems such as the Amundsen Sea Low. These low-frequency coupled ocean-atmosphere interactions have a range of impacts, including altering rates of snowfall, air temperatures, and sea ice conditions and extent. Changes to surface wind patterns can also alter the degree of upwelling of relatively warm deep-water masses, which is leading to melting of the underside of floating glacier ice (Noble et at., 2020).

Table 3: Climate at stations in the operational area (Meteoblue, 2022) (Weatherbase, 2022)

	Halley Station	Lower Thwaites Glacier	Byrd Surface Station	Union Glacier camp
Elevation above sea level	50m	299m	1515m	732
Average annual temperature	-17.7 °C	-14.7 °C	-27.4 °C	-29.0 °C
Precipitation	398mm	608.3mm	57.8mm	203.8mm

6.2 Glaciology – West Antarctic Ice Sheet

The Antarctic continent is divided into East and West Antarctica, both of which are covered by ice. West Antarctica, to the west of the Trans-Antarctic Mountains, covers an area of approximately 1.97 Mkm^2 (Figure 26).

The operational area is on the West Antarctic Ice Sheet (WAIS) and associated ice sheets, glaciers and ice streams. The WAIS (Figure 26) covers 97 % of West Antarctica and contains enough ice to raise global sea level by approximately 3 m to 5 m (Bamber et al., 2009; Pan et al., 2021). The WAIS has outlets in the Ross Sea, Amundsen Sea and Weddell Sea (Figure 26).

The WAIS is in places up to 2,000 m thick, with the geological floor well below sea level (Figure 27). The marine basins are variable, with both rough mountainous terrain and flat, deep oceanic basins, with a maximum depth of 2,555 m below present sea level (Bindschadler, 2006).

During past interglacial periods, the WAIS has been completely removed (Scherer et al., 1998). During past glacial periods, the WAIS extended as far as the continental shelf edge (Anderson et al., 2002) drained by numerous ice streams (Livingstone et al., 2012).

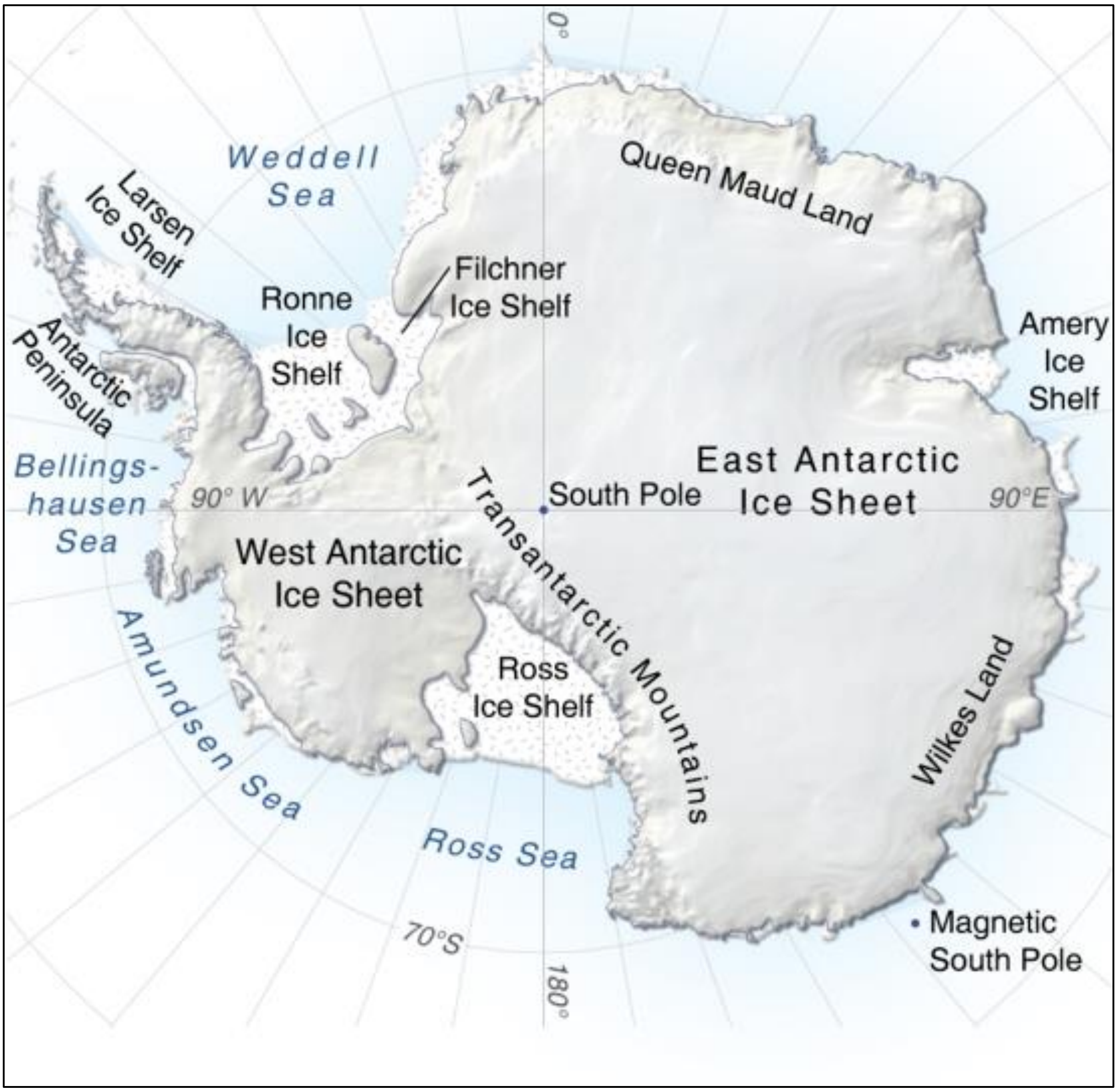


Figure 26. Map of Antarctica showing the East and West Antarctic Ice Sheets and the dividing Trans-Antarctic Mountains. Source: https://www.grida.no/resources/5339

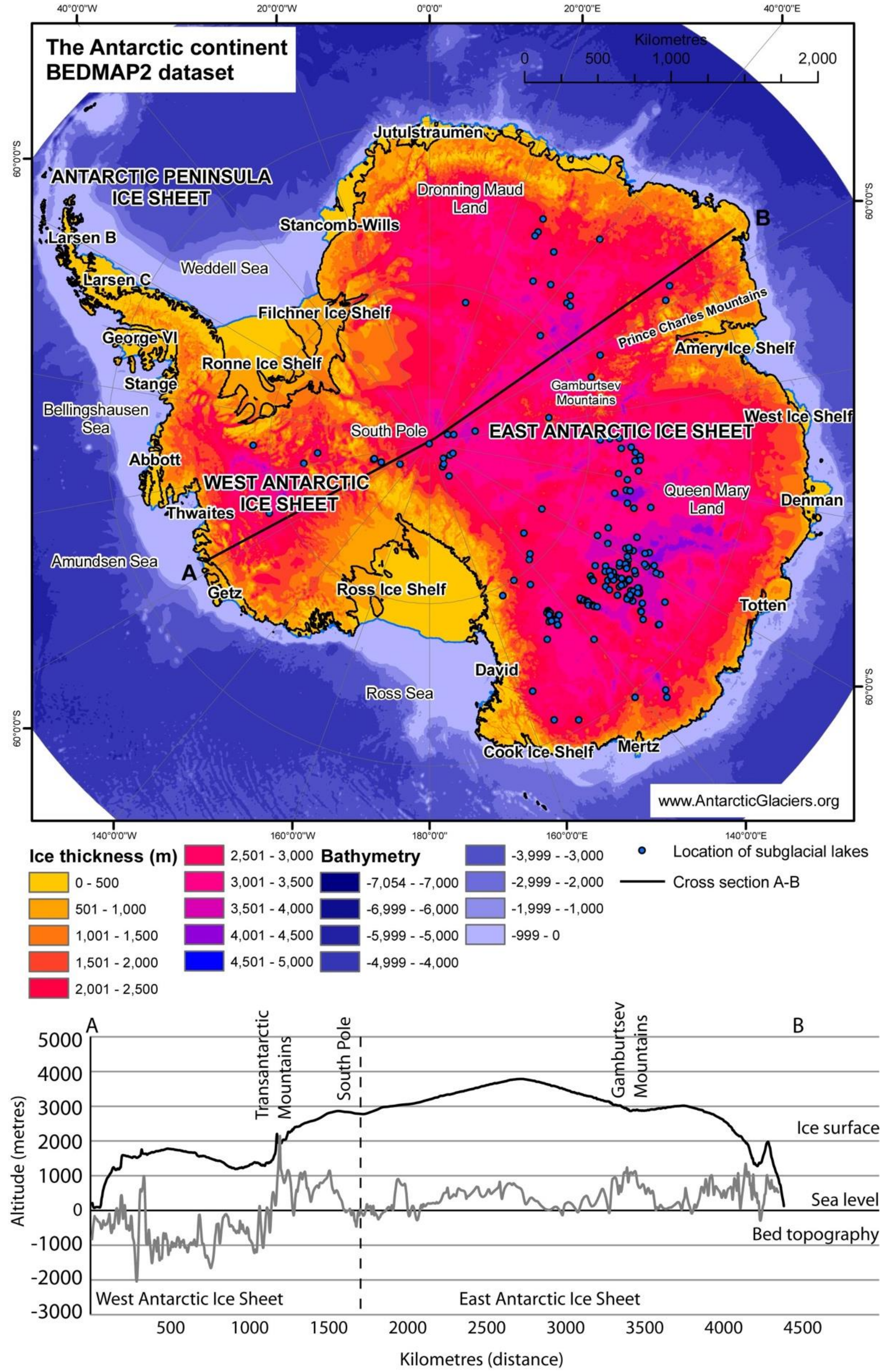


Figure 27. The BEDMAP 2 dataset shows how ice thickness across the Antarctic continent is variable, with thin ice over the mountains and thick ice over East Antarctica. The cross section shows how the West Antarctic Ice Sheet (WAIS) is grounded well below sea level. Source: Fretwell et al. 2013.

The two largest ice streams draining the WAIS are Pine Island Glacier and Thwaites Glacier (Figure 28). The glaciers play a key role in stability of the sheet (Joughin et al., 2021).

The Thwaites Glacier is of particular scientific interest as it is rapidly losing mass with a risk of rapid ocean-driven melting at the grounding zone beneath the glacier.

Thwaites Glacier was first mapped by the United States Geological Survey from surveys and aerial photography in 1959-66 as a floating glacier tongue over 60 km long with a grounded iceberg tongue 110 km long. The Crossen Ice Shelf, Dotson Ice Shelf and Getz Ice Shelf are to the west. Pine Island, Cosgrove and Abbott Ice Shelves are to the east of Thwaites, with the Abbott Ice Shelf extending further to the east into Ellsworth Land, bordered by the Bellingshausen Sea.

Interest in the region increased with the discovery in 1994 that the ice shelf at the terminus of the Pine Island Glacier was melting orders of magnitude faster than the Ross and Filchner-Ronne Ice Shelves, and subsequently that other Amundsen Sea ice shelves have high melt rates and increased velocity of tributary glaciers (Figure 29; Nitsche et al., 2007). Pine Island Glacier is currently Antarctica's fastest melting glacier, retreating at 4km a year with annual discharge of over 130 Gt (Shean et al., 2017).

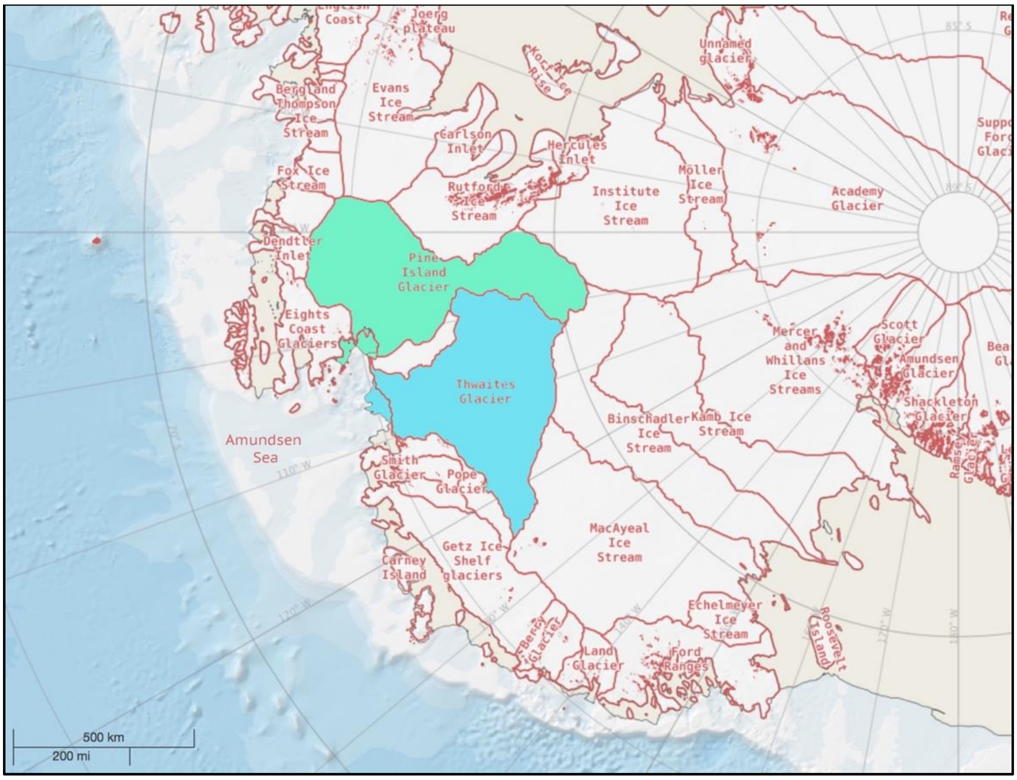


Figure 28. Pine Island and Thwaites Glaciers. Catchment areas and associated ice shelves are shaded. Source: www.add.scar.org

The Thwaites Glacier is also rapidly changing. Throughout the 1990s the flow at its centre remained fairly constant, but it widened along the sides, and increased its 30 ± 15 % mass deficit by a further 4 % in just 4 years (Rignot et al., 2002). Observations show unequivocally that the Thwaites Glacier ice-ocean system is undergoing the largest changes of any ice-ocean system in Antarctica (Scambos et al., 2017).

Glaciological and sub-glacial research is crucial in this region of Antarctica so as to understand the effects of changing atmospheric and oceanic conditions and to better constrain model predictions of future ice sheet responses. Such research will inevitably require the support of over-snow traverse capabilities, which is the subject of this EIA.

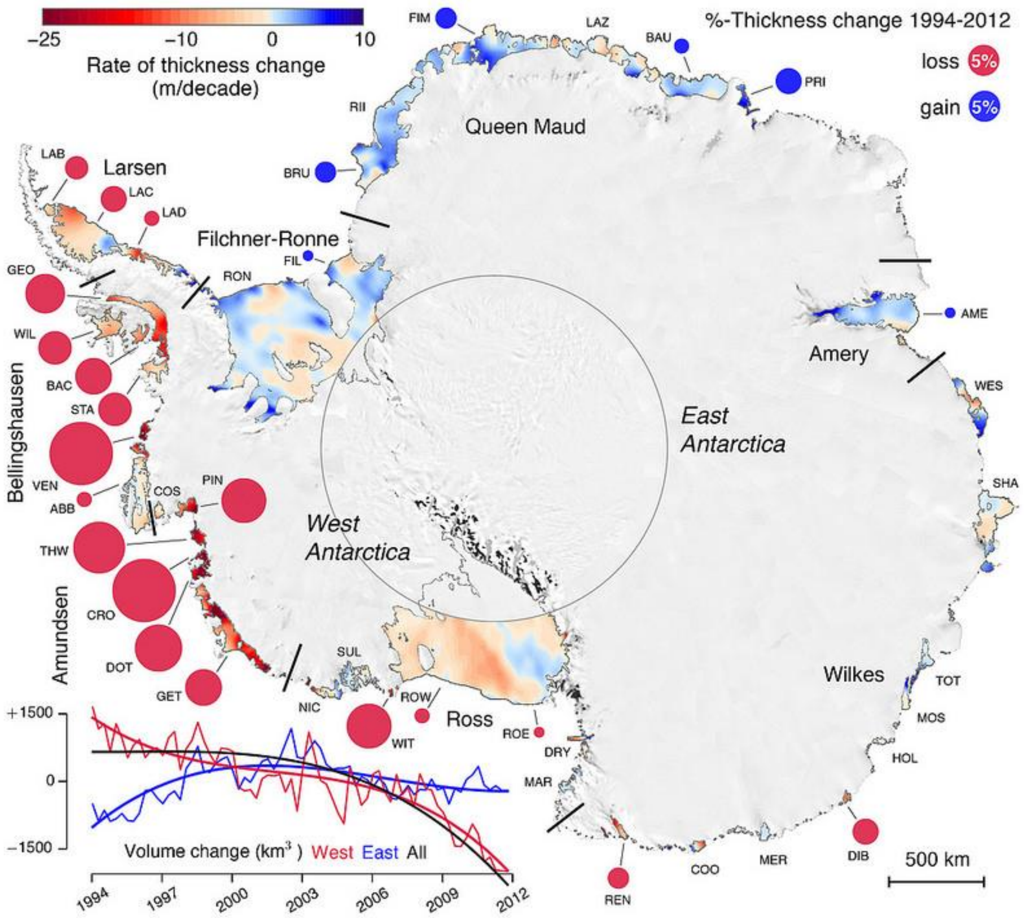


Figure 29. Eighteen years of change in thickness and volume of Antarctic ice shelves. Circles represent percentage of thickness lost (red) or gained (blue) in 18 years. Background is the Landsat Image Mosaic of Antarctica (LIMA). Source: Paolo et al., 2015.

6.2.1 Ice Surface Topography

Any impacts arising from over-snow traverse activities will be constrained to the surface and upper few metres of the WAIS.

The nature of the ice sheet surface is heavily influenced by snow fall and wind patterns and dominated by surface sastrugi (Figure 30). Sastrugi are undulating patterns in the snow surface formed by particles of snow, driven by high winds, scouring the ice surface. The patterns can take an almost infinite variety of forms from delicate etchings on a smooth slab of snow, to furrows and grooves up to 1 metre deep, sometimes with overhanging lips. They are highly dynamic and usually form at temperatures of -10 to -20 °C or lower, when the snow particles are dry. Larger, icy sastrugi can provide significant challenges for surface travel.

The dynamic nature of the ice surface means that physical evidence of vehicle movements is frequently covered in a short period ranging from just a few minutes to a few days depending upon weather and wind conditions.

Figure 30. Sastrugi on the Antarctic ice sheet surface. Source: a) coolantarctica.com, b) Wikipedia.org

In some areas of the ice sheet, persistent winds erode snow year-round. Combined with sublimation this creates areas of net ablation (Winther et al., 2001). These areas are referred to as blue ice areas and are characterised by flat, smooth, hard ice. Commonly, such areas occur near mountains or on outlet glaciers at higher elevations (Figure 31). Traversing across blue ice can be easier as the surface is hard and smooth and crevassing easier to identify.

Figure 31. Blue Ice area adjacent to the Patriot Hills, Ellsworth Mountains, Antarctica. Source: AntarcticScience.com

6.2.2 Crevasses

The Antarctic ice sheet flows through a series of ice streams and glaciers from the centre of the ice sheet to the surrounding Southern Ocean (Figure 28). As a consequence of the ice flow, variable flow rates and the topography over which the ice is flowing, the ice sheet often splits and cracks to form crevasses. These crevasses vary in size significantly but can be tens of metres deep, tens of metres across, and many kilometres long.

Crevasses can be 'open' and visible, particularly in more rapidly moving parts of a glacier, or they can be covered by snow bridges. Snow bridges can vary in thickness from a few metres thick to just a few centimetres thick (Figure 32). Covered crevasses represent a significant danger to vehicle travel across the ice surface.

Figure 32. Members of the U.S. Antarctic Program's South Pole Traverse team rappel down into a crevasse. Source: https://antarcticsun.usap.gov/science/4454/

In recent years improved remote sensing of the polar regions means that crevasse locations can be more readily identified from satellites. Crevasses can be detected at depths of 10 m or more from their satellite radar backscatter signature, offering opportunities to reduce crevasse risk in Antarctic field operations (Marsh et al., 2021).

However, on the ground observations, particularly from ground penetrating radar provide immediate knowledge of crevasse locations. BAS traverses make use of regular crevasse surveys undertaken by GPR towed by skidoos ahead of the main traverse body. BAS traverse policy is to avoid crevassed areas wherever possible, in contrast to other traverse operations which have opted to actively fill crevasses on regularly used routes (see for example the US Comprehensive Environmental Evaluation for Surface Traverse Capability).

6.3 Ice Free Areas

The operational area for BAS traverse activities is constrained to snow- and ice-covered terrain. There are ice free areas in proximity to traverse routes including the outer edges of the Ellsworth Mountains (where Union Glacier airfield is located) and a series of nunataks and volcanic peaks throughout Ellsworth Land, Marie Byrd Land and Queen Elizabeth Land (Figure 33).

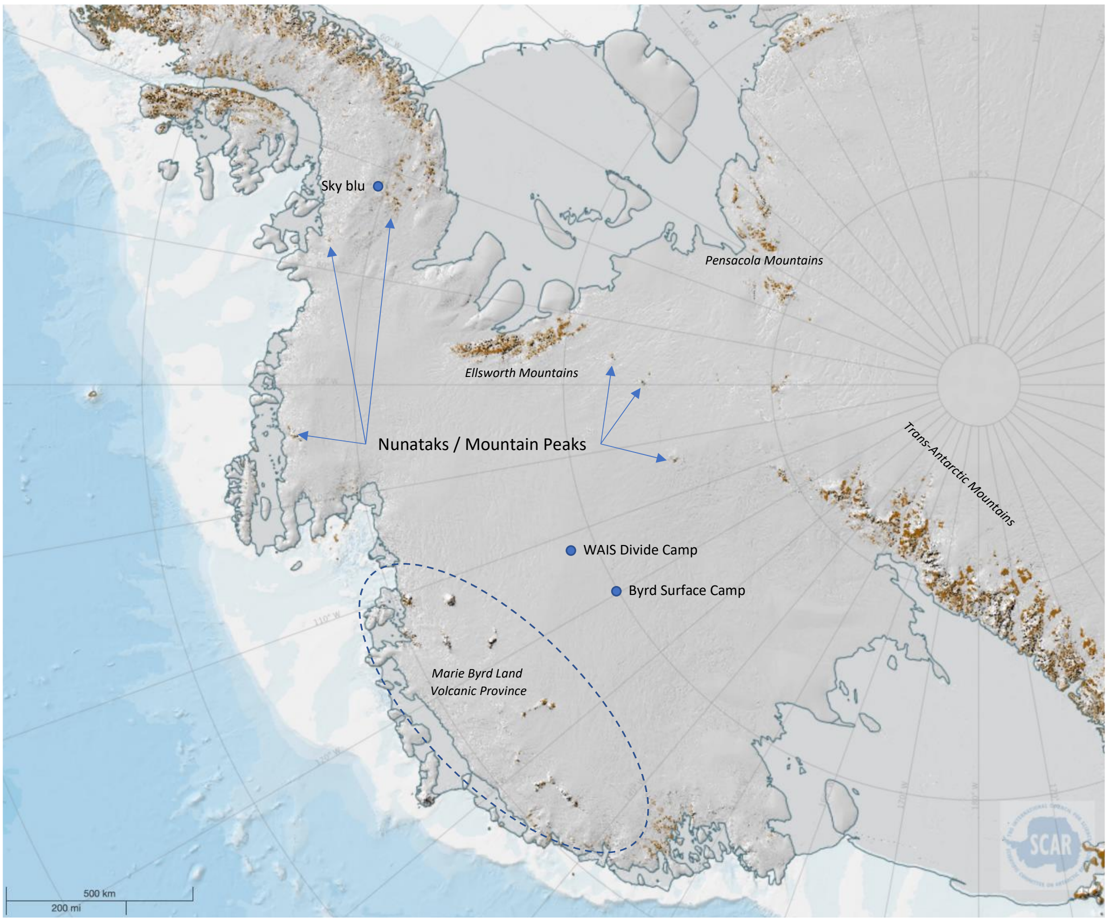


Figure 33. Exposed rock surfaces in the form of nunataks or volcanic peaks in West Antarctica. Base map: SCAR ADD https://www.add.scar.org/

Mountain ranges are exposed towards the coast of Marie Byrd Land where ice thickness is smaller (Figure 34). Prominent ranges include the Ford Ranges in western Marie Byrd Land, The Flood Range, the Executive Committee Range, and the Kohler Range. The Ford Ranges are the most extensive and include more than six individual named mountains groups (Wade et al., 1977). The Executive Committee Range includes five volcanoes, some proposed to be dormant or active. The Flood Range comprises a linear chain of Neogene and Quaternary age volcanoes (LeMasurier, 2013).

The Fosdick Mountains in the northern Ford Ranges are a 30 km long span of Cretaceous metamorphic rocks. Most other exposed rock in Marie Byrd Land is Palaeozoic metamorphosed sedimentary rock and granitoid, and Mesozoic granitoid (Wade et al., 1977).

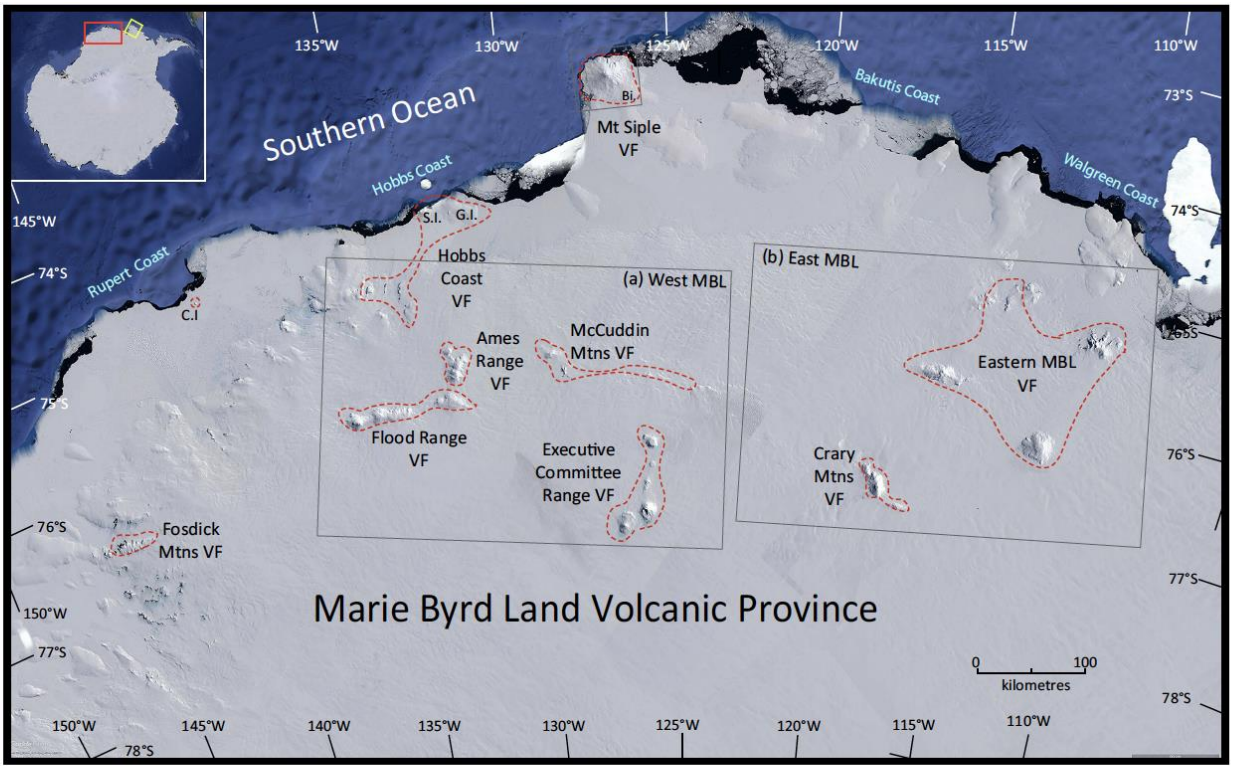


Figure 34. Map of Marie Byrd Land Volcanic Province (MBLVP). Volcanic fields are labelled and volcanoes included in fields are within dashed line polygons. Abbreviations: VF, Volcanic Field; C.I., Cruzen Island; S.I. is Shepard Island; G.I. is Grant Island. Source: Wilch et al., 2021.

BAS traverse routes will be selected so as to avoid any contact with ice free areas. The only occasions when traverse operations would actively operate within the vicinity of exposed rock surfaces would be when supporting the mobilisation or demobilisation of research groups that intend to work or have been working in such locations.

6.4 Wildlife

With a few exceptions (i.e., seabird breeding colonies located a few kilometres from the coast), the majority of Antarctic wildlife is constrained to coastal ice-free regions with inland areas of the ice sheet supporting very little life other than microbial communities in some locations (Anesio et al, 2017).

Whilst the majority of BAS traverse activity will take place well away from coastal regions, there will be occasions when traverse trains will run close to the coast either for the purposes of rendezvousing with a ship (for offloading or onloading cargo and fuel) or when in support of coastal research activities. On such occasions the potential for interaction with wildlife increases.

However, even on such occasions, the vehicles will be constrained to shelf or sea ice and will not venture onto ice-free land. This will minimise the risk of disturbing wildlife, other than the low likelihood of encountering small numbers of penguins and seals that may be occupying the ice.

6.4.1 Important Bird Areas

In 2015, the Antarctic Treaty Consultative Meeting (ATCM) recognised a series of 204 Important Bird Areas (IBAs) across Antarctica (Figure 35), through the application of criteria established by Birdlife International (ATCM Resolution 5 (2015); Harris et al., 2015). These IBAs represent bird breeding (as opposed to foraging) locations.

When compared to the planned areas of traverse operations (Figure 12) a small number of IBAs are within or adjacent to the planned traverse areas. One IBA on Berkner Island (IBA 101) lies within the planned traverse area. Other IBAs are outside of but adjacent to the planned traverse areas; although operations are likely to be conducted some distance away (several tens to hundreds of kilometres) in most cases, with little risk of disturbance.

The IBAs in or adjacent to the planned traverse areas are numbered: 101, 198, 199, 200, 201, 202, 203 and 204 (Figure 36), the details of which are shown in Table 4.

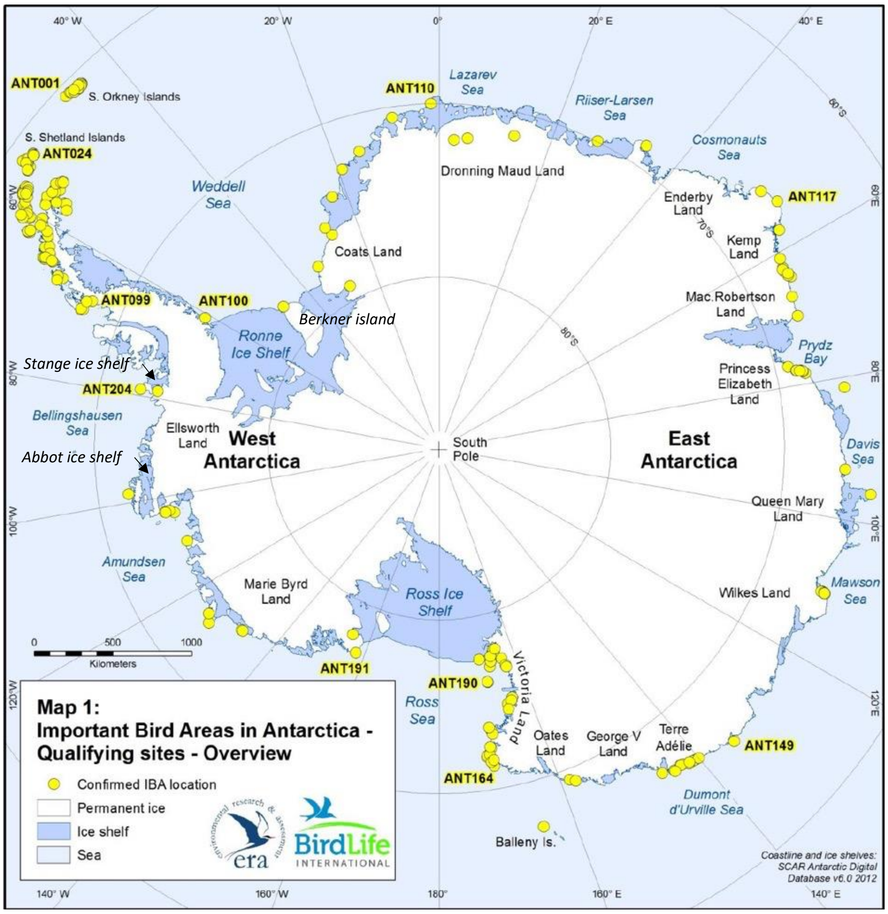


Figure 35. Important Bird Areas identified around Antarctica. Source: Harris et al., 2015.

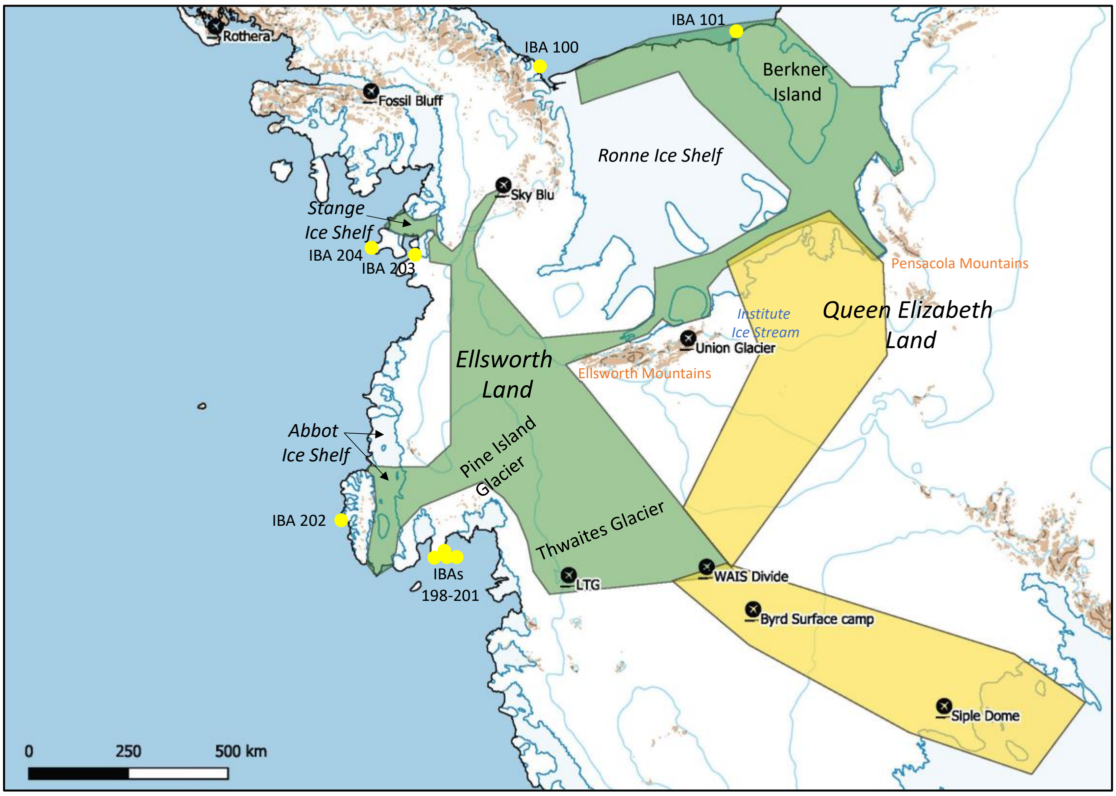


Figure 36. Important Bird Areas (yellow dots) that occur in the vicinity of BAS traverse operations. IBA reference source: Harris et al., 2015.

Table 4. IBAs in the vicinity of or adjacent to the defined traverse areas. Source: Harris et al., 2015.

IBA No.	Location	Details	Comment
101	NW Berkner Island (Gould Bay)	Analysis of a satellite image acquired 14 Oct 2009 (Fretwell *et al.* 2012) indicated 8,242 Emperor Penguins were present at the colony	The Emperor Penguin colony is located on the sea ice in front of the Ronne Ice Shelf. Unlikely to be encountered by any traverse activity which will be constrained to the ice shelf itself.
198	Brownson Islands	Analysis of a satellite image acquired 18 Nov 2009 (Fretwell et al. 2012) indicated that approximately 5,732 Emperor Penguins were present at the colony, although image quality was rated as Poor.	The small group of offshore islands are outside of the planned traverse area and are not accessible by any traverse activity.
199	Edwards Islands	Approximately 58,058 breeding pairs (95% CI: 35,879, 95,740) of Adélie Penguin were present on Edwards Islands as estimated from January 2010 satellite imagery (Lynch & LaRue 2014).	The small group of offshore islands are outside of the planned traverse area and are not accessible by any traverse activity.
200	Schaefer Islands	Approximately 28,033 breeding pairs (CI not available) of Adélie Penguin were present on Schaefer Islands as estimated from March 2011 satellite imagery (unpublished data, H. Lynch & M. LaRue pers. comm. 2014).	The small group of offshore islands are outside of the planned traverse area and are not accessible by any traverse activity.
201	Lindsey Islands	Approximately 52,670 breeding pairs of Adélie Penguin were present on Lindsey Islands as estimated from March 2011 satellite imagery (unpublished data, H. Lynch & M. LaRue pers. comm. 2014).	The small group of offshore islands are outside of the planned traverse area and are not accessible by any traverse activity.
202	Sikorski Glacier, Noville Peninsula	Analysis of a satellite image acquired 17 Nov 2009 (Fretwell et al. 2012) indicated that approximately 3,568 Emperor Penguins were present at the colony, although image quality was rated as Poor.	The Emperor Penguin colony breeds on fast ice north of Sikorski Glacier and on the northern side of Thurston Island. It is outside of the planned traverse area and likely to be inaccessible by traverse.
203	Sims Island	Approximately 14,784 breeding pairs (95% CI: 8,888, 24,254) of Adélie Penguin were present on Sims Island as estimated from December 2012 satellite imagery (Lynch & LaRue 2014).	The colony is outside of the planned traverse area and ship rendezvous have to date occurred in the vicinity of Spaatz Island > 100km to the east.
204	Scoresby Head, Smyley Island	Analysis of a satellite image acquired 12 Nov 2009 (Fretwell et al. 2012) indicated that approximately 6,061 Emperor Penguins were present at the colony.	The Emperor Penguin colony breeds on fast ice that forms on the northern coast of Smyley Island several km east of Scorseby Head. This is outside of the planned traverse area and likely to be inaccessible by traverse.

6.5 Protected / Managed Areas and Historic Sites

Antarctic Specially Protected Areas (ASPAs), Antarctic Specially Managed Areas (ASMAs) and Historic Sites and Monuments (HSMs) can be established under the provisions of Annex V to the Protocol.

6.5.1 Protected Areas

At the time of preparation of this EIA, 75 ASPAs have been established across Antarctica. However, ASPAs are conspicuously absent from West Antarctica (Figure 37). The nearest ASPA to the planned activities is [ASPA 119 Davis Valley and Forlidas Pond, Dufek Massif](). ASPA 119 is designated to protect some of the most southerly freshwater ponds with autotrophic microbial life known to exist in Antarctica, which represent unique examples of near-pristine freshwater ecosystems and their catchments.

ASPA 119 is some distance away from the area of planned activities and will not be visited by BAS traverse trains.

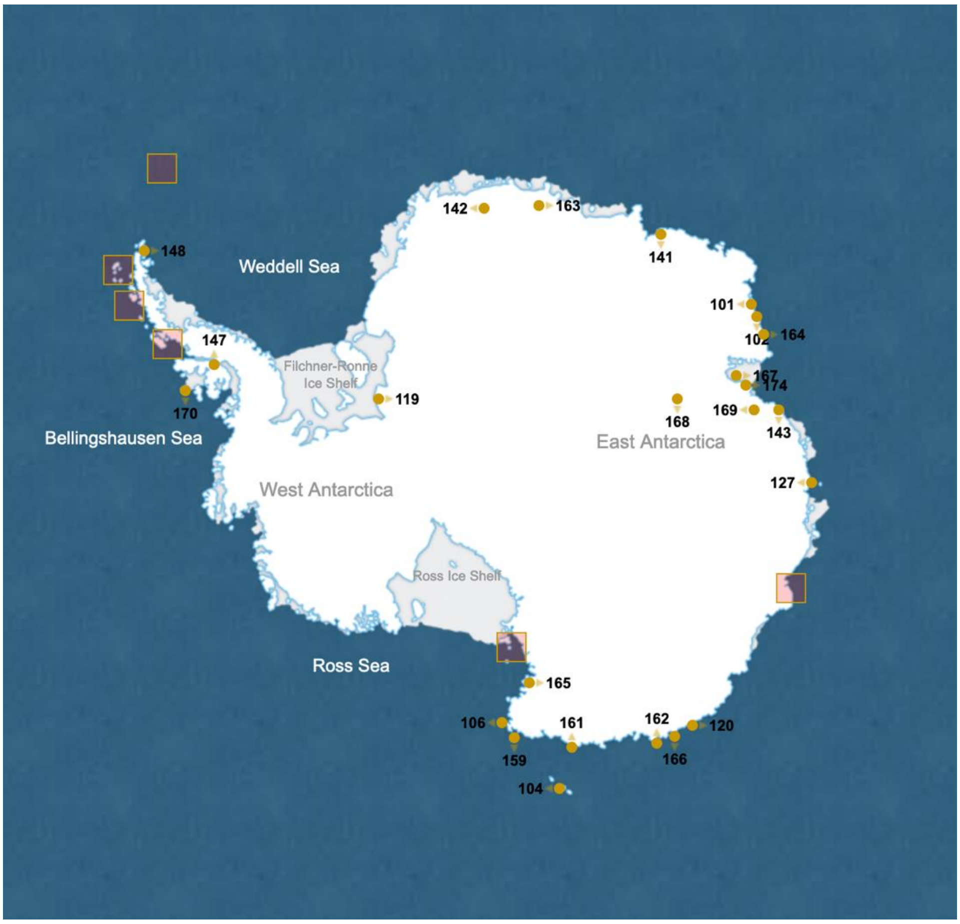


Figure 37. Antarctic outline showing the location of designated ASPAs. Pink squares contain multiple designations. Source: https://www.ats.aq

6.5.2 Managed Areas

At the time of preparation of this EIA, 6 ASMAs have been established across Antarctica (Figure 38).

The nearest ASMA is located at the geographic South Pole (ASMA 5). The South Pole ASMA has been designated in order to maximise the valuable scientific opportunities at the Pole, protect the near-pristine environment and ensure that all activities, including those to experience the extraordinary qualities of the South Pole, can be conducted safely, environmentally responsibly and without disruption to scientific programs.

ASMA 5 is well outside of the area of planned activities and will not be visited by BAS traverse trains.

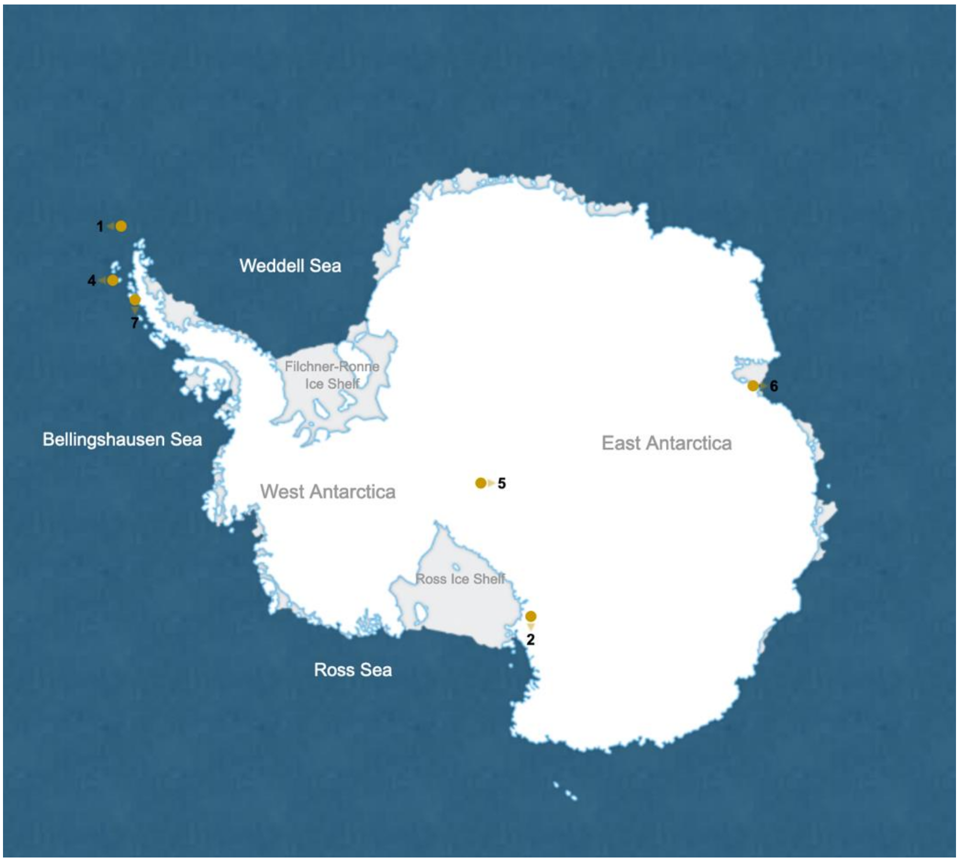


Figure 38. Antarctic outline showing the location of designated ASMAs. Source: https://www.ats.aq

6.5.3 Historic Sites or Monuments

At the time of preparation of this EIA, 95 HSMs have been designated across Antarctica (Figure 39).

The HSMs nearest to the areas of planned activities are shown in Table 5.

None of these HSMs will be visited by BAS traverse trains.

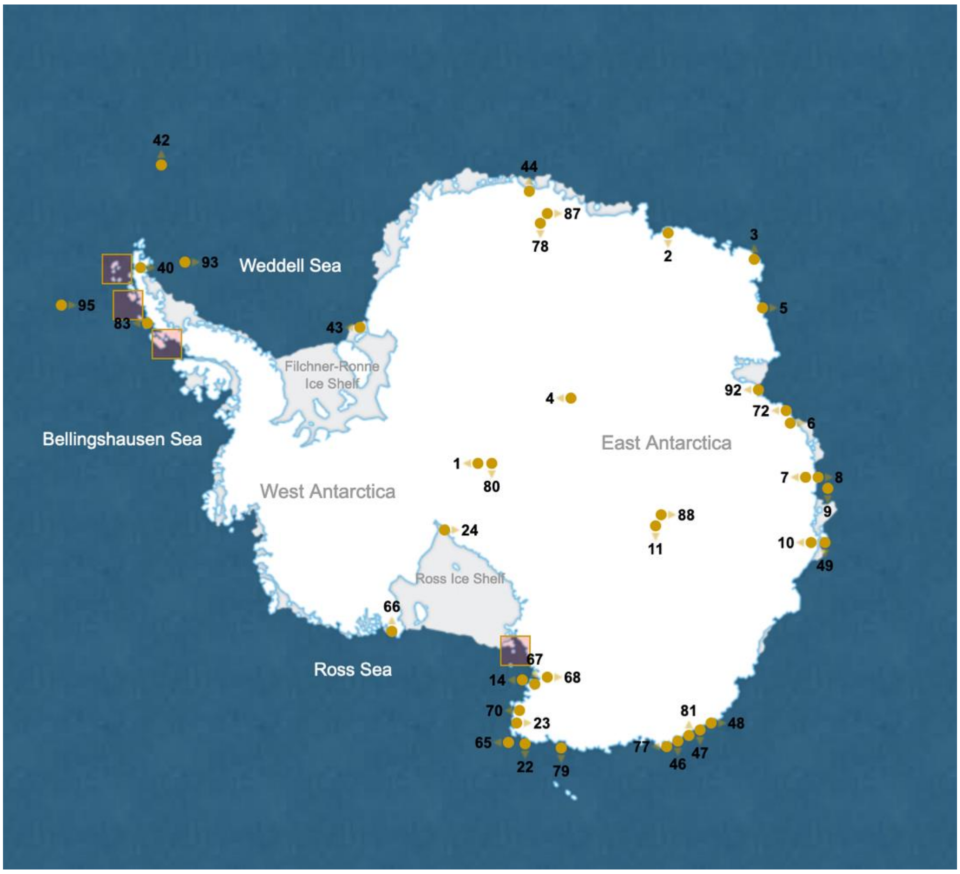


Figure 39. Antarctic outline showing the location of designated HSMs. Source: https://www.ats.aq

Table 5. HSMs designated in the vicinity, though outside of the defined area of operations. Source: https://www.ats.aq

HSM No.	Description
1	Flag mast erected in December 1965 at the South Geographical Pole by the First Argentine Overland Polar Expedition.
24	Rock cairn, known as 'Amundsen's cairn', on Mount Betty, Queen Maud Range erected by Roald Amundsen on 6 January 1912, on his way back to Framheim from the South Pole.
66	Prestrud's Cairn, Scott Nunataks, Alexandra Mountains, Edward VII Peninsula. The small rock cairn was erected at the foot of the main bluff on the north side of the nunataks by Lieutenant K. Prestrud on 3 December 1911 during the Norwegian Antarctic Expedition of 1910-1912.
80	Amundsen's Tent. The tent was erected at 90° by the Norwegian group of explorers led by Roald Amundsen on their arrival at the South Pole on 14 December 1911. The tent is currently buried underneath the snow and ice in the vicinity of the South Pole.

6.6 Human Activity and Antarctic Wilderness

Leihy et al. (2020) estimated that 99.6 % of the Antarctic continent can still be considered wilderness, but pristine areas, free from human interference cover a much smaller area (less than 32 % of Antarctica) and are declining as human activity escalates (Figure 40).

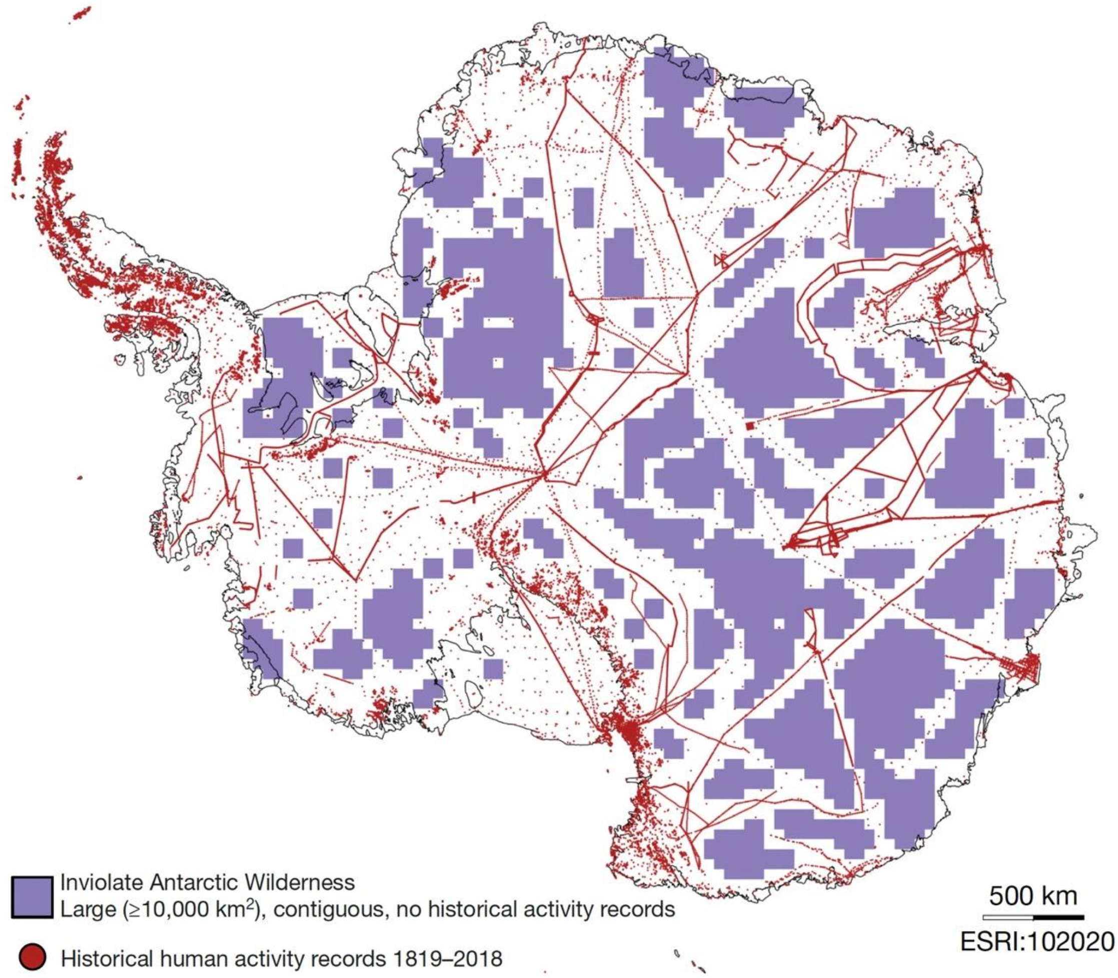


Figure 40. Inviolate Antarctic wilderness areas defines as large (>10,000km2), contiguous putatively inviolate areas free from human interferences across Antarctica (purple squares). Historical visitation records and traverse routes are shown in red (n=2,698,429 records). Source: Leihy et al., 2019.

Most of the traverse operations will take place in areas which have had some human activity in the past, including as a result of past traverse activities undertaken by BAS and other National Antarctic Programmes. Several research or logistics facilities are also established in the vicinity (Table 6; Figure 41; Figure 42), although most of these are semi-permanent soft-shell camps.

However, new routes have the potential to transit areas that have been identified as wilderness because of the lack of previous human activity (Figure 41 overleaf).

Table 6: Existing facilities in and around traverse operational area

Site	Coordinates	Occupation	Facilities
Byrd Surface Camp	80° 0′ 53″ S, 119° 33′ 56″ W	Byrd Station established 1957/58, rebuilt 1960/61. Summer only station opened 1972 Decommissioned 2004/05 Rebuilt 2009/10	50 personnel
Siple Dome	81° 39′ 15″ S, 149° 0′ 18″ W	Established 1973, buried and replaced 1979 New camp established 2009/10	Refuelling 3 personnel
Union Glacier (ALE)[2] **Figure 42a**	Heritage Range 79° 46′ 40″ S, 83° 19′ 15″ W	2008 to present	Blue ice runway
WAIS Divide **Figure 42b**	Marie Byrd Land 79° 28′ 2.9″ S, 112° 5′ 11″ W	Intermittent since 2005/06	Skiway Shelter 13 personnel
Lower Thwaites Glacier (LTG) Camp **Figure 42c**	76.5º S, 108º W (approx.)	Since November 2019	Summer only Tent camp
Sky Blu (UK) **Figure 42d**	Eastern Ellsworth Land 74° 50' 59" S, 71° 34' 0" W	1995 to present	Blue ice runway Summer only

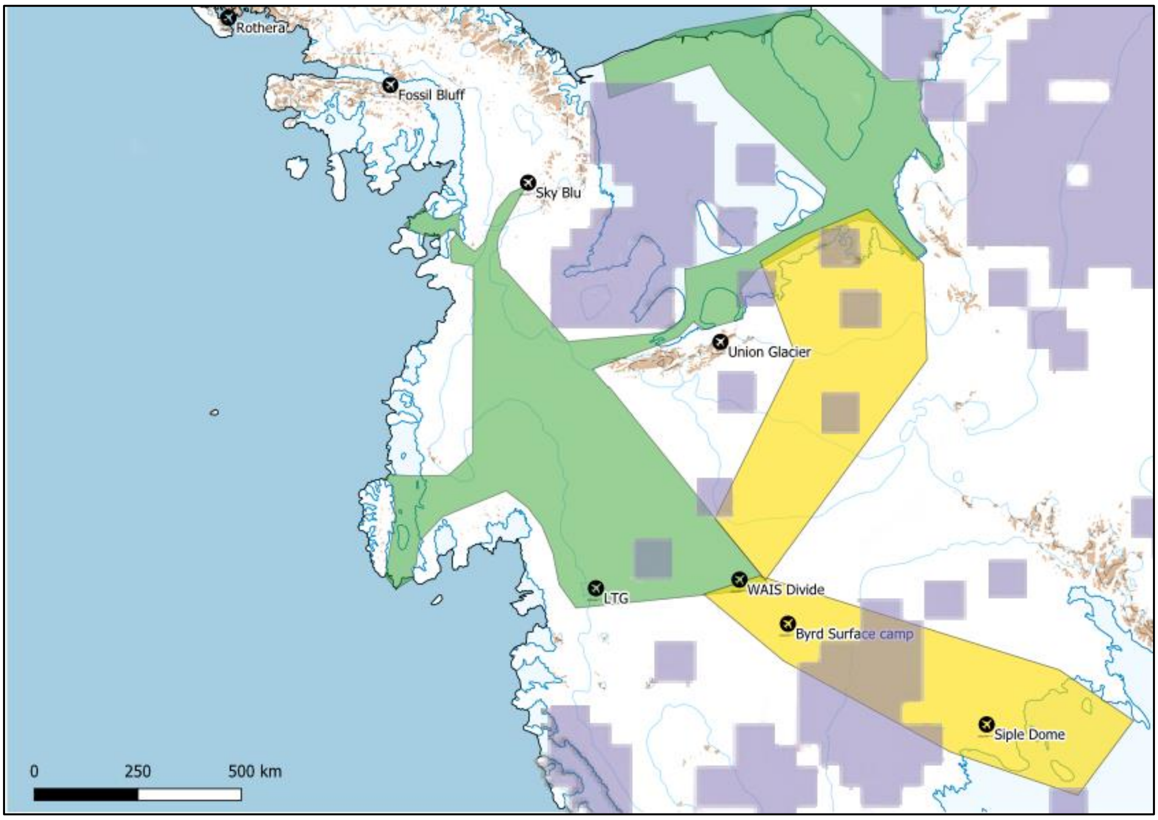


Figure 41. BAS traverse operational areas overlaid with wilderness areas from Leihy et al, 2020. Purple indicates contiguous areas of 10,000km² with no historical human activity (1819-2018).

[2] Operated by Antarctic Logistics & Expeditions LLC, certified by Chilean Directorate General of Civil Aviation

Figure 42. Established field camps in the area of planned traverse operations. a) ALE Union Glacier Camp, b) WAIS Divide Camp, c) LTG Camp, d) Sky Blu. Some of these camps will be supported by BAS traverse activities. *Sources: a) https://icetrek.com/base-camps/union-glacier-camp, b) https://frozenwille.wordpress.com/2016/03/30/overview-of-wais-divide/, c) https://thwaitesglacier.org credit Ted Scambos, d) http://esorekim.blogspot.com/2019/01/sky-blu.html*

7 Assessment of Environmental Impacts

Having described the nature and scale of the proposed activity and reviewed the current environmental state, this chapter assesses the actual or potential impacts that will or could occur as a result of the planned traverse activities.

Consideration is also given here to the cumulative impacts of the planned activities in conjunction with other past, current and reasonably foreseeable activities in the region.

7.1 Methods and supporting information

The actual or potential environmental impacts of the activity are assessed by means of a four-step analysis involving:

1. identifying the **aspects** i.e., the physical change imposed on, or an input released to the environment as the result of an action or activity such as emissions, dust, mechanical action on the substrate, fuel spills, noise, light, wastes, heat, introduced species, etc., arising from the proposed activities described in Chapter 5;
2. identifying the **exposure** i.e., the interaction between an identified potential output and the environment including flora and fauna, freshwater, marine, terrestrial and atmospheric environments;
3. identifying the **impacts** i.e., the change in environmental values or resources attributable to the activity;
4. assessing the **significance** of the identified impacts by considering the spatial extent, duration, intensity and likelihood of occurrence of the potential impacts to each environmental element – with reference to the three levels of significance identified by Article 8(1) of the Protocol (i.e., less than, no more than, or more than a minor or transitory impact).

Information to support the impact assessment is drawn from a number of sources including the academic literature, BAS on-line information and manuals, BAS experts, the Antarctic Treaty Secretariat website, the SCAR website, and the websites of other National Antarctic Programmes.

7.2 Environmental Aspects

As recorded above, an environmental aspect is a physical change (*e.g.* movement of sediments by vehicle passage or noise) or an entity (*e.g.* emissions, an introduced species) imposed on or released to the environment as the result of an action or an activity (CEP EIA Guidelines, 2016).

For the purposes of this environmental impact assessment the planned activities have been divided into the following elements:

- Mobile activities, including the use of skidoos and the movement of the tractor trains during traverse operations.
- Stationary activities, including the establishment and operation of field camps, and over-winter depots.

The environmental aspects of these elements were highlighted in Chapter 5 and are summarised in Table 7. This table records that expected environmental aspects of vehicle activities will include atmospheric emissions, noise, heat, mechanical action on snow and ice surfaces as well as presenting a risk of fuel leaks, which will potentially generate hazardous waste.

Field camps will also produce atmospheric emissions, noise, heat and disturbance to snow and ice surfaces. Fuel spills may also occur at camp locations and camping activities will generate wastes including human waste, which includes the deliberate release of grey water and human liquid waste to the ice sheet.

The over-wintering of vehicles, fuel and traverse equipment will result in disturbance to snow and ice surfaces to build berms and poses the risk of accidental releases of fuel or loss of materials to the ice sheet if equipment cannot be recovered the following summer.

All traverse activities will create visual and audible disturbance and evidence of human presence.

Table 7. Summary of environmental aspects that will or could arise from the planned activities.

ACTIVITY	POTENTIAL ENVIRONMENTAL ASPECTS										
	Atmospheric emissions (burning fossil fuels)	**Noise emissions**	**Light emissions**	**Heat emissions**	**Air turbulence**	**Mechanical action** (physical disturbance to substrate)	**Fuel or hazardous substances release**	**Wastes** (Including unrecoverable equipment)	**Water turbulence**	**Introduction of non-native species or relocation of native species**	**Presence / visual disturbance**
Mobile activities											
Vehicle activities along traverse routes	✓ Fuel burn in skidoos and PBs	✓ Vehicle use	*No light emissions have been identified*	✓ Vehicle engines	*No sources of air turbulence have been identified*	✓ Vehicle & sledge movement over snow / ice surfaces – track development	✓ Spills when refuelling vehicles; mechanical failure; leaks from towed fuel containers	✓ Risk of loss of items in transit, creation of hazardous waste if spills occur	*No sources of water turbulence have been identified*	See Section 7.4.5.	✓ Visible or audible human presence
Stationary activities											
Field camps	✓ Fuel burn in cooking and heating equipment and generators	✓ General camp operations; generators	*No light emissions have been identified*	✓ Operation of generators, cooking and heating equipment	*No sources of air turbulence have been identified*	✓ Establishment of camps, walking tracks	✓ Spills when refuelling generators, cookers or heaters	✓ Food, general & human wastes generated at camp site	*No sources of water turbulence have been identified*	*No risks identified*	✓ Visible or audible human presence
Depoting of fuel and equipment – including over winter						✓ Establishment of raised berms for depoting fuel and equipment	✓ Risk of fuel leaks from depoted containers	✓ Risk of loss of depoted fuel and equipment if it cannot be recovered			✓ Visible or audible human presence

7.3 Environmental Exposures

Exposure is the process of interaction between an identified potential aspect and an environmental element or value (CEP EIA Guidelines, 2016).

The aspects described in Section 7.2 may interact with the environment in several ways. As described above, all traverse activities will occur on snow or ice surfaces and away from ice-free areas and concentrations of wildlife.

Accordingly, the environment that is most exposed to identified aspects is the glaciological environment i.e., ice and snow surfaces of the WAIS. This includes exposure from aspects including particulate emissions from vehicle and generator use, physical disturbance from vehicle movements, and accidental or deliberate releases including waste discharges, and the risk of fuel spills.

The atmospheric environment is exposed from aspects including exhaust and heat emissions.

Antarctic fauna could potentially be exposed to noise and human presence if the traverse worked in a coastal area for ship offload or onload, although traverse vehicles are highly unlikely to be near any established penguin, seabird, or seal colonies. It is not anticipated that any outputs will interact with flora and fauna in ice free areas, as these will be actively avoided.

All traverse related activities have the potential to impact on perceptions of Antarctic wilderness values.

No exposures to marine, terrestrial or freshwater environments are identified from the planned traverse operations.

Table 8. Overview of those environmental elements that have been identified as potentially being susceptible to the aspects arising from the planned activities. Note: The exposure of an activity's aspect may vary in significance in differing environments or at different times of the year. This is not considered in this table. The significance of the impacts is assessed in Section 7.5 of the EIA.

ASPECTS OF ACTIVITIES	**ENVIRONMENTAL ELEMENTS THAT WILL / MAY BE IMPACTED**						
	FLORA AND FAUNA	**FRESHWATER** *(ponds, streams, rivers, lakes)*	**MARINE** *(including sea ice)*	**GLACIOLOGICAL** *(glaciers, ice sheet and ice shelves)*	**TERRESTRIAL** *(ice-free ground, soil and rocks)*	**ATMOSPHERE**	**WILDERNESS VALUES**
Atmospheric emissions		*No impacts have been identified for freshwater environments*	*No impacts have been identified for marine environments*	✓ Particulates in exhaust emissions will settle on ice surfaces	*No impacts have been identified for terrestrial environments*	✓ Gases in exhaust emissions, including GHG, will be released to air	
Noise emissions	✓ Noise sources have potential to disturb wildlife						
Heat emissions						✓ Heat from various sources will be released to air	
Mechanical action				✓ Physical disturbance to ice and snow surfaces from vehicle movements; berm creation etc			
Spills of Hazardous substances				✓ Accidental releases to snow / ice surfaces			
Wastes (Including unrecoverable equipment				✓ Accidental / deliberate losses to snow / ice environment / hazardous waste if fuel spill occurs			
Introduced species / relocated native species	See discussion in Section 7.4.5.						
Presence / Visual disturbance	✓ Human presence has potential to disturb wildlife						✓ Human presence and activity may alter perceptions of wilderness

7.4 Impacts and Mitigation Measures

This section reviews the potential environmental impacts that will or may occur to each of the identified receiving environments as a consequence of the identified aspects and exposures recorded in Sections 7.2 and 7.3 above.

This impact assessment considers the potential worst-case impacts.

The actual or potential impacts are summarised in Table 12 (page 95) which assesses the level of risk associated with the actual or potential impacts according to the spatial extent, duration, severity and likelihood of the impact occurring.

The following definitions are used to describe the different types of impact:

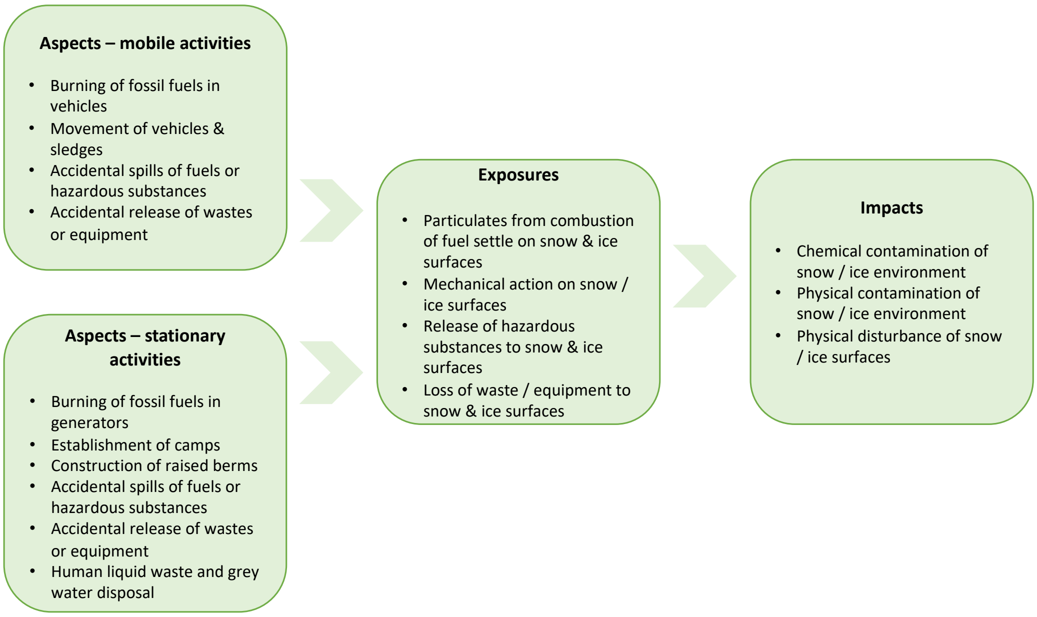
A **direct impact** is a change in environmental values or resources that results from direct cause-effect consequences of interaction between the exposed environment and an activity or action (*e.g.* decrease of a limpet population due to an oil spill, or a decrease of a freshwater invertebrate population due to lake water removal) (EIA Guidelines, 2016).

An **indirect impact** is a change in environmental values or resources that results from interactions between the environment and other impacts - direct or indirect (*e.g.,* alteration in seagull population due to a decrease in limpet population which, in turn, was caused by an oil spill) (EIA Guidelines, 2016). Indirect impacts may not be known until a direct impact occurs.

A **cumulative impact** is the combined impact of past, present and reasonably foreseeable activities. Cumulative impacts may occur over time and should be assessed by looking at other human activities occurring in the proposed locations. As with indirect impacts, cumulative impacts may not be identified until a direct impact has occurred (EIA Guidelines, 2016).

Cumulative impacts are considered in more detail in Section 7.4.6 below.

7.4.1 Impacts that will or may occur to the glaciological environment



Given that all activities associated with BAS' traverse activities will be constrained to the ice and snow surfaces, the glaciological environment has the potential to be most heavily impacted.

Aspects that will or may give rise to impacts to snow / ice environments have been identified as:

a. Particulates and other organic compounds released in exhaust emissions from the incomplete burning of fossil fuels in engines, power units, cooking and heating equipment settling on the snow and ice surface;

b. Mechanical action and physical disturbance to snow and ice surfaces from the movement of vehicles, the creation of berms and from field camp operations;

c. Potential for the accidental release of hazardous substances (e.g., spills of fuel from mobile and stationary containers);

d. Potential for the accidental release of wastes and the deliberate release of human waste and grey water at field camp locations, as well as the risk of release of other items and equipment through accidental loss (e.g., in windy conditions).

7.4.1.1 Release of particulates and organic compounds to the glacial environment

Impact description

The burning of fossil fuels in vehicle engines as well as in generators will result in emissions to air of a range of gases as well as other compounds including volatile organic compounds, heavy metals and particulates such as black carbon (arising from incomplete combustion of fossil fuels).

Particulates, heavy metals and organic contaminants will deposit on and contaminate the local snow and ice surface with the spatial extent of deposition largely determined by wind conditions.

Long-range atmospheric transport and ocean current transport from other continents are generally considered to be the principal source of contaminants that can be detected in Antarctic snow and ice (Vecchiato et al., 2015; Cheng et al., 2013), although local sources such as emissions from Antarctic scientific stations, over-snow vehicles and marine vessels cannot be discounted (Xie, et al., 2020; Kukučka et al., 2010).

Contaminant concentrations in Antarctic snow and ice are generally low and have little direct impact other than providing evidence of human presence (Xie, et al., 2020). Black carbon deposited on snow and ice can decrease albedo and increase surface melting. However, concentrations of black carbon in Antarctic snow and ice are also generally very low (Kang et al., 2020).

The additional contributions to snow and ice contamination from BAS traverse activities are considered to be negligible.

Impact type: direct and cumulative

Particulate emissions to the snow and ice surface will be a direct source of contamination of the ice sheet and add to any contamination already captured by the ice from local and global sources.

Treatment and Mitigation

- Vehicle engines, generators and fuel burning equipment are regularly serviced and maintained to maximise efficiency of operation;
- Vehicle engines and generators will be allowed a 'warm up' period prior to engaging any load;
- Sledge loads are evenly distributed between towing vehicles to the extent possible;
- The fuel types selected are the most efficient for use in low temperature conditions;
- All fuel burning will be minimised to the extent practicable.

Monitoring or Record keeping

Snow and ice contamination levels are not proposed to be monitored as part of BAS traverse activities.

Volumes and types of fuel uses will be recorded as part of BAS' annual fossil fuel and carbon emissions monitoring.

7.4.1.2 Mechanical action and physical disturbance to the glacial environment

Impact description

The surface of the ice sheet will be physically disturbed during traverse operations in a number of ways, including from: the movement of vehicles and the dragging of sledges; the digging of snow to create berms for overwinter depots or to create pits to assist with servicing vehicles; the movement of snow when establishing camps, and tracking caused by people walking around camp sites.

Such physical disturbance will be temporary. The surface of the ice sheet is a highly dynamic environment as a result of ice movement, precipitation and wind action (refer Section 6.2).

Accordingly, evidence of disturbance to the snow surface is likely to be erased in time frames ranging from minutes to weeks depending upon the weather conditions – wind conditions in particular. Wind flow across the ice sheets can attain hurricane force and blow for several days. As such, the snow present in Antarctica is almost always airborne. Snow lifted from the surface and carried aloft by wind is known as drifting snow (snow transported at heights <2 m) or blowing snow (snow transported at heights >2 m) (Palm et al., 2018).

In some areas it is feasible that tracks made in the snow can become raised as a consequence of less tightly bound snow being blown away from the more compressed snow where tracks have been made (Figure 43). Eventually, the hardened snow will also be eroded, though this can take days or weeks depending upon conditions.

Figure 43. Raised footprints on snow surfaces. Source: https://www.amusingplanet.com/2013/04/raised-footprints-in-snow.html

Evidence of the dynamic conditions can be seen when returning to raised berms used to store vehicles and equipment overwinter on the ice sheet surface (Figure 44). Even when equipment and vehicles are stored on berms built up to three metres high, it has been known for them to be totally buried and vehicle cabs to be full of snow when returning the next season on some parts of the continent.

Consequently, the impacts for the ice sheet from the physical disturbance to otherwise highly dynamic snow and ice surfaces is considered to be less than minor and transitory.

Impact type: direct

Disturbance will occur though effects will be transitory.

Treatment and Mitigation

No mitigation measures are considered necessary.

Traverse routes will be carefully selected on an annual basis albeit for reasons of operational efficiency and for reducing fuel costs, rather than avoiding physical impacts to the ice sheet.

Monitoring or Record keeping

Records will be maintained on routes followed, camp sites used, and locations used for over-wintering vehicles and equipment – though not specifically for the purposes of recording disturbance.

Figure 44. Returning to a caboose stored on a snow berm over winter showing the extent of snow build up during the winter months. Source: BAS; Damon Davies.

7.4.1.3 Accidental release of hazardous substances (fuel)

Impact description

Accidental releases of fuel, or other hazardous substance being transported by a traverse, could occur either when transferring the liquids between containers (e.g., during refuelling) or as a result of damage to or failure of a fuel bladder, drum or container.

The fate of fuel or other liquid substances accidentally released to the glacial surface will depend upon the nature of the snow or ice. Any liquid substances spilt on lightly packed snow or firn[3] is challenging to recover. Liquids can penetrate quickly into the firn layer and their distribution will depend upon the conditions at the time. During warmer temperatures the ice is more porous, and liquids will flow quickly through the firn. Under colder conditions the ice is less porous and spilt fuel will migrate less (Raymond et al., 2017).

Any liquid substances spilt on to hard, blue ice, which is much less porous than snow or firn, may be easier to recover.

[3] Firn is usually defined as snow that is at least one year old and has therefore survived one melt season, without being transformed to glacier ice. Firn is transformed gradually to glacier ice as density increases with depth, as older snow is buried by newer snow falling on top of it.

Unrecoverable liquids will remain in the snow / ice as a contaminant and will add to previous fuel spill events that have occurred in Antarctica. This will have no implications for ice sheet behaviour. Contaminated sites could be detectable in any future scientific ice coring or sampling programme with negative implications for the research in question; though the likelihood of a glaciological research programme encountering an historic spill event is considered to be extremely low.

Any spill event is also likely to create hazardous waste items *e.g.,* contaminated spill response equipment.

Impact type: Direct and cumulative

Any hazardous liquid spilt on snow and ice will directly contaminate the area that it penetrates to.

If a spill event were to occur, any unrecoverable liquid will add to previous fuel spill events that have occurred in Antarctica.

Treatment and Mitigation

- Volumes of hazardous liquid substances, including fuel taken into the field will be minimised to the extent that is safe and practicable;
- All fuel and other hazardous substances will be managed in the field in accordance with standard BAS procedures as set out in the BAS Field Manual and Traverse Operations Manual;
- Hazardous liquid substances (fuel and oils) will be stored in secondary containment e.g., drip trays, to the extent practicable and regular checks on the integrity of the drums and storage containers will be undertaken;
- When overwintering bladdered fuel:
    - All ports are inspected to ensure they are closed to avoid the weight of snow forcing fuel out of the bladder;
    - Bladders are monitored for a few days to check for the risk of windblown debris, flogging material or other possible causes of puncture, and to ensure no leaks are occurring.
- Trained and experienced operators will oversee equipment and manage refuelling activities;
- Refuelling operations will be undertaken by a minimum of two people using spill mats, absorbent wipes etc. in accordance with standard BAS field practices;
- All hose connections are dry break connections meaning no fuel is lost when hoses are disconnected;
- Fuel spill response training will be provided to those undertaking fuel handling in the field;
- Fuel bladder repair kits (containing glue, patches and clamps) will be carried on all traverses;
- Spill kits will be readily available at locations where fuel is stored, transported or transferred. Any fuel (except petrol) spilt will be cleaned up to the extent practicable in accordance with the BAS Field Manual (Appendix 2) and Oil Spill Contingency Plan for Heavy Vehicle Traverses (Appendix 3). Recovered liquids and contaminated absorbents will be treated as hazardous waste and will be contained, marked as hazardous and transported to Rothera for appropriate handling and disposal.

Monitoring or Record keeping

Any fuel or other hazardous liquid substances spill event will be recorded and reported in accordance with BAS requirements, including volume and type of substance spilt, the location of the spill and the approximate volume that was recovered.

7.4.1.4 Accidental and deliberate releases of wastes or cargo to the glacial environment

Impact description

Accidental loss of cargo

The type and volume of equipment carried on sledges in a traverse will vary depending upon the traverse purpose. There is a risk that items could be lost to the environment if not properly secured, particularly when traversing over uneven snow / ice surfaces.

Any unrecovered items lost to the environment are likely to become buried in snow and lost to the ice sheet environment. Such items will gradually become encapsulated in the ice. This will have no immediate impacts on the ice sheet itself other than any local contamination that may occur. Over long time frames (hundreds of years) such lost equipment will be transported to the Southern Ocean in accordance with natural rate of flow of the ice.

Human waste and grey water

BAS policy requires all solid human waste to be removed from the field. Plastic UN approved drums are provided for this purpose. Solid human waste is returned to Rothera for incineration. There is negligible risk of solid human waste being released to the glacial environment.

Liquid human waste will be disposed of to the ice environment. This is an unavoidable impact. Liquid human waste is more difficult to transport and to process at Rothera.

Small volumes of grey or waste-water will also be disposed of at field camp sites. Such grey water is generated from cleaning plates and dishes, brushing teeth etc.

Human liquid waste and grey water will be disposed of to the ice / snow at identified locations. It is normal practice to dig small pits for such disposal. The disposed liquid waste will melt into the ice pit, but quickly freeze over. Once the field camp is disestablished the pits will quickly fill in as a result of ice movement, precipitation and wind-blown snow.

Food and general waste

Food waste and general waste, such as food packaging, paper and glass as well as (potentially) some hazardous wastes such as medical wastes and batteries, will be generated at field camps and during traverse operations. If un-managed, such items could be released to the glacial environment where they are likely to blow around or become trapped in the ice causing localised contamination.

Annex III of the Protocol provides for Parties to reduce the quantity of waste produced and or disposed of in Antarctica in order to minimise any impact on the environment. Emphasis is placed on the storage, disposal and removal of waste from the Antarctic Treaty area, as well as recycling and source reduction.

BAS complies with the requirements of the Annex by means of conditions attached to the Operating Permit granted by the FCDO.

BAS has prepared a Waste Management Handbook that guides the management of waste on its ships, stations and in the field in accordance with best practice and UK waste legislation

Impact type: Direct and cumulative

Any cargo or waste released to the environment will have a direct localised impact, and will add to the volumes of items, equipment and materials lost to the Antarctic environment over the decades of human activity in the region.

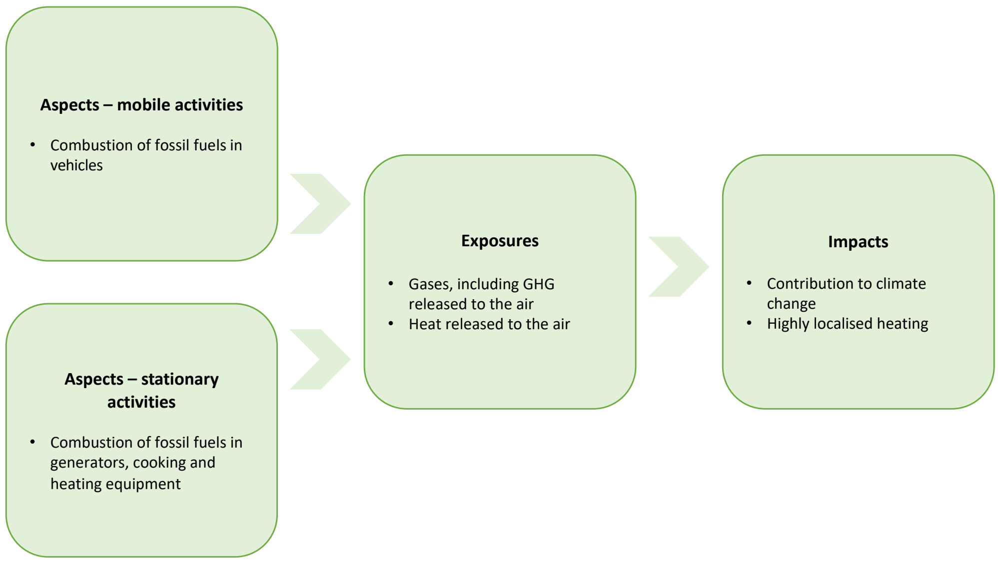
Treatment and Mitigation

- Payloads for all sledge types are known and adhered to so as to prevent overloading;
- Sledge loads and configurations are fully inspected daily prior to departure to ensure all cargo is secure;
- Tractor trains travel side by side or slightly offset from each other, allowing regular inspections of sleds and load by the opposite tractor train;
- Waste generated in the field, including any hazardous waste, is managed in accordance with the provisions of Annex III to the Protocol, the BAS Waste Management Handbook and BAS Field Operations Manual;
- All food and general waste is separated into waste streams and removed from the field for correct handling at Rothera;
- Human liquid waste and grey water are disposed of in ice pits at specifically identified locations only. Solid human waste is removed from the field;
- Grey water production at the camp is minimised to the extent practicable;
- Careful planning seeks to minimise the materials and items taken into the field that will generate waste.

Monitoring or Record keeping

Any items accidentally released to the environment and which are unrecoverable will be recorded and reported in accordance with BAS incident reporting requirements.

7.4.2 Impacts that will or may occur to the atmospheric environment



There are a number of aspects that will or may give rise to impacts on the atmosphere. These include:

a. Release of gases including greenhouse gases as a result of the combustion of fuel in vehicles, generators, cooking and heating equipment;

b. The release of heat from engines, generators, cooking and heating equipment.

7.4.2.1 Release of gases and greenhouse gases.

Impact description

Emissions to air from the burning of fossil fuels will occur throughout all seasons of planned traverse activities. Exhaust gases will be quickly dispersed depending upon the weather and particularly wind conditions at the time. The emission of gases will pass into the atmosphere and add to regional and global atmospheric pollution.

In the 2021/22 austral summer season, the traverse fuel burn was 57.9 m^3 Avtur or Avcat (cold blend aviation fuels). This was the total fuel burn for five PistonBully vehicles doing 2,554 km each plus depot work. This equates to approximately 147 tCO_2e[4].

It is difficult to accurately predict the amount of fuel used and emissions released for any one traverse season as the number of PistenBully vehicles and total distance vary in any given season. In order to reflect the highly variable fuel usage, figures for volumes of fuel used are given for distance and

[4] Tonnes of CO_2 equivalent. tCO2e emission factors taken from https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2021.

number of vehicles at the low end, i.e., 4 PistenBully vehicles doing 1500km, and the high end, i.e., 5 PistenBully vehicles doing 2500km. Considering that one PistenBully burns 5.5 L per km, the total fuel burn per one season is likely to range between 33 m^3 and 67 m^3. The anticipated carbon emissions associated with the Traverse vehicles are highly variable but are expected to fall between 84 and 171 tCO_2e[5].

In addition, fuel use in generators is between 1-3 drums of petrol (between 205 and 615 L). Cooking is on LPG and consumption is one 44kg gas bottle per season. This equates to between approximately 0.44 to 1.33 tCO_2e and 0.13 tCO_2e, respectively.

Overall, the anticipated carbon emissions for one season are expected to range between approximately 85 and 173 tCO_2e.

Releases of gases from Antarctic activities make only a minor contribution to global pollution, and current technology has yet to provide sufficiently reliable alternatives to the burning of fossil fuels in the harsh Antarctic environment (particularly for remote field activities); although sustainable energy options continue to be explored (Dou et al., 2019; Bustos et al., 2021).

It is now well established that anthropogenic releases of greenhouses gases from the burning of fossil fuels and other sources, is the major contributor to measurable changes in the global climate (IPCC, 2014).

As noted above, the behaviour of the WAIS under pressure from changing climate conditions, and in particular the contribution that the WAIS may make to global sea level rise, is a major focus of research for BAS and other National Antarctic Programmes.

The climate change implications for Antarctica and Antarctic biodiversity are also a major focus of the ATCPs and the CEP.

Impact type: Indirect and cumulative

This will be an unavoidable impact. Emissions of gases from the burning of fossil fuels will occur and will be transported into the atmosphere and indirectly and cumulatively contribute to regional and global atmospheric pollution, and climate change; though the contribution from BAS traverse activities will be negligible.

Treatment and Mitigation

- All engines, generators and fuel burning equipment are routinely serviced and maintained to ensure they run and operate as efficiently as possible;
- Emissions are minimised by only burning fossil fuels when required. Equipment is not left idling unnecessarily;
- Traverse routes are planned to maximise efficient movements of people, fuel and cargo;
- Sledge loads are carefully balanced between tractor trains to maximise efficient vehicle use;

[5] Tonnes of CO_2 equivalent. tCO2e emission factors taken from https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2021.

- Vehicle engines and generators are allowed a ‘warm up’ period prior to engaging any load;
- Sledge loads are evenly distributed between towing vehicles to the extent possible;
- The fuel types selected are the most efficient for use in low temperature conditions;
- All fuel burning is minimised to the extent practicable.

Monitoring or Record keeping

Volumes and types of fuel uses are routinely recorded as part of BAS’ annual fossil fuel and carbon emissions monitoring.

7.4.2.2 Release of heat.

Impact description

Heat will be generated from a range of sources throughout BAS’ planned traverse activities, including from vehicles, generators and cooking and heating equipment. Any heat generated will rapidly dissipate in the cold Antarctic atmosphere, particularly so at times when the wind is blowing.

No discernible impacts are likely to arise from heat emissions.

Impact type: Direct

Heat will be lost directly to the atmosphere, but with no discernible impacts.

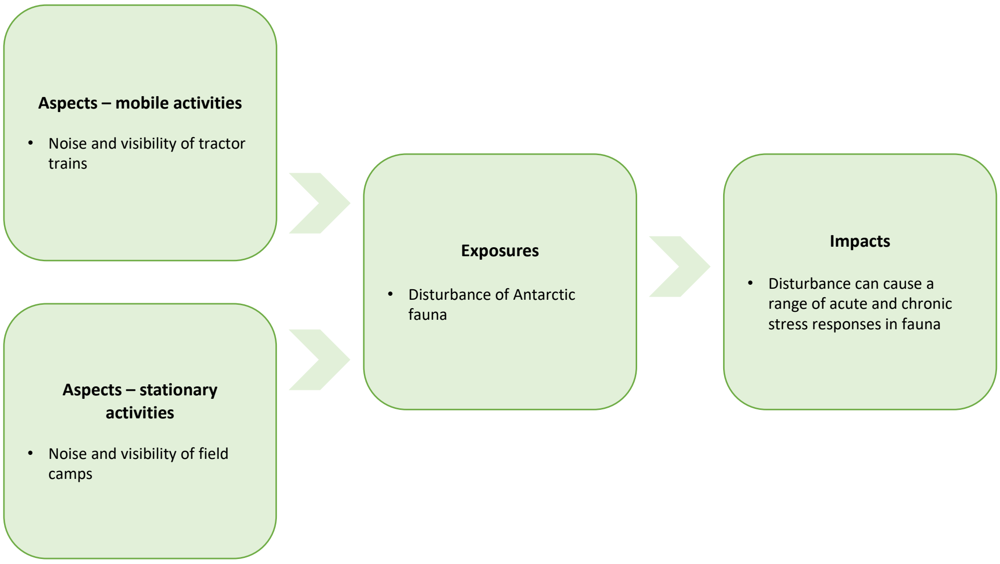
Treatment and Mitigation

None required; though fuel burn is generally kept to the minimum required.

Monitoring or Record keeping

None required.

7.4.3 Impacts that will or may occur to Antarctic fauna



Impacts to Antarctic flora will not occur as a result of BAS traverse activities. All traverse activities, field camps and over-winter depots will occur on snow and ice surfaces and will avoid ice-free locations where plant life occurs. This section therefore considers the risk that traverse activities pose to Antarctic fauna only.

As identified in the assessment above, there are a number of aspects that could give rise to impacts on Antarctic fauna. These include:

a. The creation of noise from the operation of vehicles and people moving and talking as well as visible disturbance arising from the presence of vehicles, sledges, tents and people.

Impact description

Human disturbance to Antarctic wildlife is summarized in the Antarctic Environments Portal by Coetzee and Chown (2014), (www.environments.aq). They note that sustained disturbance can vary significantly, depending upon the species, the location, the time and the nature of the disturbance. Human disturbance to Antarctic wildlife can cause declines in breeding success (Tin et al., 2009; Ellenberg et al., 2007; McClung et al., 2004), and induce physiological stress (McClung et al., 2004; Regel and Putz, 1997) which can cause behavioural changes (Weimerskirch et al., 2002; Engelhard et al., 2002), and could be the cause of direct mortality (Cooper et al., 1994). In some cases, wildlife can become accustomed to human activity and be relatively unaffected by it. Some well-studied populations show no major observable changes following disturbance (Burger and Gochfeld, 1994). In other cases, human activities have been shown to cause significant disturbance to wildlife (Cooper et al., 1994; Saraux et al., 2011; Rounsevell and Binns 1991).

Coetzee and Chown (2014) report that an individual animal's response to stress can vary widely as a function of extrinsic factors such as the type of disturbance, its form and its magnitude. Disturbance also varies with intrinsic factors such as the species, colony size and breeding stage, and different individual responses. Few studies have considered all of these factors, making it difficult to draw conclusions or conduct a meta-analysis of the results across the diverse range of studies (de Villiers 2008).

Research to date likely underestimates the potential impacts of human disturbance to wildlife as behavioural responses may obscure more subtle and potentially severe physiological responses (Fowler 1999; Coetzee and Chown, 2016).

The above notwithstanding, the majority of BAS' traverse activities will occur in the interior of the Antarctic ice sheet and well away from any known wildlife concentrations. For the majority of traverse activities, interactions with wildlife are considered to be highly unlikely and restricted to rare sightings of individual or small numbers of seabirds that occasionally fly into the Antarctic interior (see for example Burton, 2015).

Encounters with seals, penguins and seabirds could occur when a traverse train meets up with a ship at the coast for the purposes of offloading or onloading cargo, people and waste. Currently used rendezvous locations do not occur in the vicinity of any known breeding colonies although encounters with individuals or small numbers of seals and birds could occur at these coastal locations.

Impact type: Direct and indirect

Disturbance events are assessed as being highly unlikely and if they were to occur encounters are likely to be restricted to individuals or very small numbers of birds or seals in coastal environments. If disturbance events were to occur impacts could include acute immediate effects as well as longer-term chronic impacts.

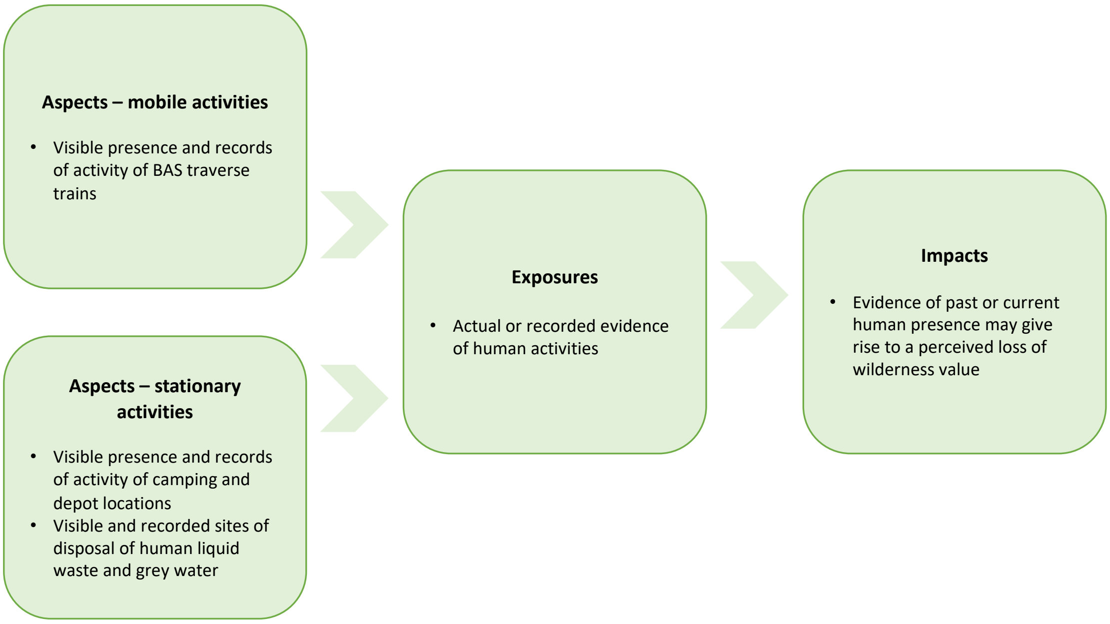
Treatment and Mitigation

- Avoidance of know congregations of Antarctic wildlife is a factor in selecting sites for connecting with ships at the coast;
- All traverse activities, including field camps and overwinter depots are conducted on ice and snow surfaces. Ice-free areas in mountainous areas as well as nunataks will be avoided at all times;
- All traverse activities will be constrained to the defined areas that have been stipulated in this EIA.

Monitoring or Record keeping

Any observed disturbance events will be recorded and reported in accordance with BAS incident reporting requirements.

7.4.4 Impacts on Antarctic wilderness values



Aspects that will or may give rise to impacts to wilderness values have been identified as:

a. Visible or recorded human presence at locations across the Antarctic ice sheet.

7.4.4.1 Visible or recorded human presence

Impact description

The Protocol provides for the "*protection of the Antarctic environment …. and the intrinsic value of Antarctica, including its wilderness and aesthetic values*" and requires that such values "*shall be fundamental considerations in the planning and conduct of all activities in the Antarctic Treaty area*".

Activities must be planned and conducted so as to avoid "*degradation of, or substantial risk to, areas of …. aesthetic or wilderness significance*".

However, the term 'wilderness' is not defined in the Protocol and to date the Antarctic Treaty Parties have not formed a collective view as to how the term should be defined. This makes it challenging to assess the impacts of activities on wilderness values in an Antarctic context.

Leihy et al. (2020) assembled a comprehensive record of human activity and used it to quantify the extent of Antarctica's wilderness. Drawing from definitions determined in the academic literature Leihy et al. showed that 99.6 % of the continent's area can still be considered wilderness, even when transitory human activity and cumulative impacts are taken into account. They noted however that pristine areas, free from recorded human interference, cover a much smaller area (less than 32% of Antarctica) and are declining as human activity escalates.

As recorded above, BAS traverse activities have the potential to impact upon wilderness values as a consequence of visible human presence and by traversing through areas that appear to have had no recorded human presence to date (Figure 41).

The latter is likely to be of most significance. Visible human presence as a result of traverse activities and associated camps and depots will only be transitory. As noted above, the surface of the Antarctic ice sheet is highly dynamic. Following the removal of vehicles and traverse assets any disturbed areas will be covered or weathered in a very short period of time, erasing any visible traces of human activity. However, records of traverse activities and human presence will cumulatively add to all past records of human presence with potential to further erode areas that can be regarded as pristine.

Impact type: Indirect and cumulative

Recorded human activities (*e.g.,* traverse routes, camp sites, depots) have the potential to impact on perceived wilderness values in Antarctica and cumulatively add to the erosion of pristine areas of the Antarctic continent. Loss of pristine areas (even due to records of human presence) could be regarded as permanent.

Treatment and Mitigation

There are few mitigation measures that can be used to reduce the impacts on wilderness values. However, traverse activities will be constrained to the defined areas that have been stipulated in this EIA and all practicable efforts will be made to:

- Reuse previously used traverse routes so as to constrain the spatial coverage of traverse activities;
- Constrain the areas used when establishing field camps and depots;
- Minimise disposal to the ice environment and ensure all waste materials (except for human liquid waste and grey water) are removed from the field.

Monitoring or Record keeping

All locational information will be recorded and reported at the end of each operational season. This includes traverse routes followed, camp site locations, disposal sites of human liquid waste and grey water and locations used to depot equipment. This information will be recorded in BAS' Operational GIS.

7.4.5 Introduction of non-native species or artificial relocation of native species

As recorded above all traverse activities will be confined to ice and snow surfaces and will not venture onto ice-free areas, where introductions and establishments of non-native species are more likely to occur.

Consequently, traverse activities are assessed as posing no risk for the introduction of non-native species. However, it should be acknowledged that in moving scientists and equipment around Antarctica (particularly science events moving to or between ice-free locations) traverse activities could, indirectly play a role in the introduction of non-native species or the artificial relocation of native species.

Assessing this risk is out of scope for this EIA, but places emphasis on the importance of pre-deployment screening and cleaning of all clothing and equipment prior to deployment to Antarctica, as well as cleaning protocols when moving research groups between ice-free locations by aircraft. Any equipment, cargo or waste packaging must be checked before they are loaded onto the aircraft from snow/ ice-free areas to ensure that they are not contaminated with any soil, plant fragments, or invertebrates.

However, traverse staff must remain vigilant when reloading from aircraft onto traverse vehicles, and make best efforts to remove any soil, plant material or invertebrate contamination from loads as much as feasible.

7.4.6 Cumulative impacts

Cumulative impacts occur as a result of the combined impacts of past, present and reasonably foreseeable activities. Cumulative impacts may occur over time and should be assessed by looking at other human activities occurring in the proposed locations. As with indirect impacts, cumulative impacts may not be identified until a direct impact has occurred (EIA Guidelines, 2016).

Cumulative impacts may occur during the research project as well as in combination with past and reasonably foreseeable activities in this region of Antarctica.

Accessing information to support cumulative impact assessments in an Antarctic context can be challenging given that the international community has placed limited emphasis on monitoring and assessing incremental, but nonetheless cumulative impacts, across broader spatial and temporal scales (Tin et al., 2009).

The qualitative method used here to assess cumulative impacts has been to:

- identify activities that have occurred or are ongoing in the area covered by this EIA. This has been constrained to the last two decades (although it is noted that activities have occurred in West Antarctica since as early as the 1930s);
- identify activities that are planned to take place in the area covered by this EIA, over the same five-year time period as this EIA;
- identify the primary impacts that have occurred or are anticipated to occur from these past and planned activities;
- assess the key impacts to which BAS' planned traverse activities will cumulatively contribute.

Data sources that were searched to assess past, current and planned activities in the area covered by this EIA include:

- Web of science[6]
- Google Scholar[7]
- The Environmental Impact Assessment database (EIA database) maintained by the Antarctic Treaty Secretariat[8]
- The Electronic Exchange of Information System (EIES)[9] database maintained by the Antarctic Treaty Secretariat, and
- A general web search.

A number of geographical locations were used as search terms, including, for example: 'West Antarctic Ice Sheet', 'Ellsworth Land', 'Queen Elizabeth Land', 'Thwaites Glacier', 'Pine Island Glacier', 'Ellsworth Mountains', 'Ronne Ice Shelf', 'Berkner Island' and 'Institute Ice Stream'.

7.4.6.1 Science activities

A search of the Web of Science and Google Scholar indicates a number of activities that have or continue to occur in the region.

Over several decades an array of geological research and associated sampling has been undertaken in the Ellsworth Mountains. In a review paper, Webers and Splettstosser (2007) noted that [to that point] geologic investigations in the Ellsworth Mountains have yielded a treasure-trove of paleontological information, with 27 localities yielding 17 fossil faunas and one fossil flora. The majority of these sampling locations having been in the Heritage Range (see for example: Yergeau et al., 2007; Sugden et al., 2017).

The Pensacola Mountains have also attracted significant research interest over the years with the majority of research being geological in nature (see for example: Curtis, 2004; Balco et al., 2016; Bentley et al., 2017).

The WAIS has been and continues to be the subject of a wide range of glaciological and subglacial research initiatives including, for example:

- the ITASE which aimed to collect and interpret a continent-wide array of environmental parameters, and which involved a number of scientific traverses in West Antarctica (Figure 45), (Mayewski et al., 2005);
- the BAS BEd Access, Monitoring and Ice Sheet History'(BEAMISH) project in the 2018/19 field season which drilled three holes in West Antarctica to gather data on basal conditions of the Rutford Ice Stream;

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6 https://www.webofknowledge.com

7 https://scholar.google.co.nz

8 https://ats.aq/devAS/EP/EIAList?lang=e

9 https://ats.aq/devAS/InformationExchange/LatestReports?lang=e

- the programme of research aimed at penetrating and sampling subglacial Lake Ellsworth during the 2011/12 and 2012/13 austral summers (Siegert et al., 2014), involving tractor traverses from Union Glacier;
- the programme of glaciological survey undertaken by Chile's Centro de Estudios Científicos (CECs; Centre for Scientific Studies) in January 2014 which discovered subglacial Lake CECs (Rivera et al., 2015);
- the US Whillans Ice Stream Subglacial Access Research Drilling project, which was developed to explore the hydrology, biogeochemistry, microbiology, and geology of a large West Antarctic ice stream (Fisher et al., 2015), including the programme of research to penetrate and sample sub-glacial Lake Whillans (Priscu et al., 2013; Christner et al., 2014; Vick-Majors et al., 2020)
- airborne geophysical surveys that have been undertaken over the Institute Ice Stream (Siegert et al., 2016; Rippin et al., 2014);
- ice penetrating radar studies of selected WAIS ice streams and glaciers (Ashmore et al., 2020; Bingham et al., 2012);
- surveys of subglacial topography using ground-based and aero-geophysical radio-echo sounding surveys (Ross et al., 2014);
- ice coring and ice temperature measurements in the area of the WAIS divide (Ahn et al., 2012; Orsi et al., 2012; Koutnik et al., 2016);
- the multi-season International Thwaites Glacier Collaboration programme which aims to improve our understanding of the stability of the Thwaites Glacier and hence of the WAIS itself. The ITGC involves significant deployment of assets and equipment throughout the five-year campaign and will be supported by BAS traverse activities (Figure 46).

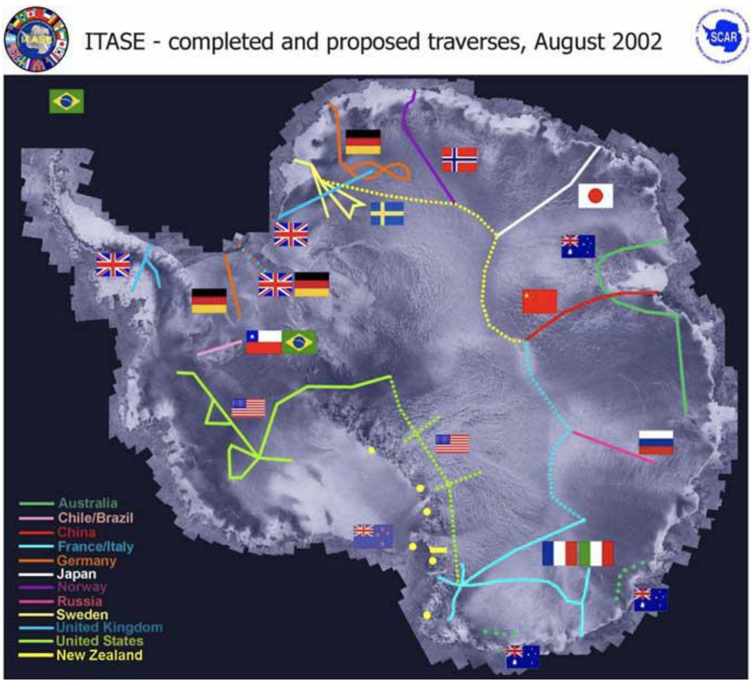

Figure 45. ITASE traverse routes. Source: Mayewski 2005.

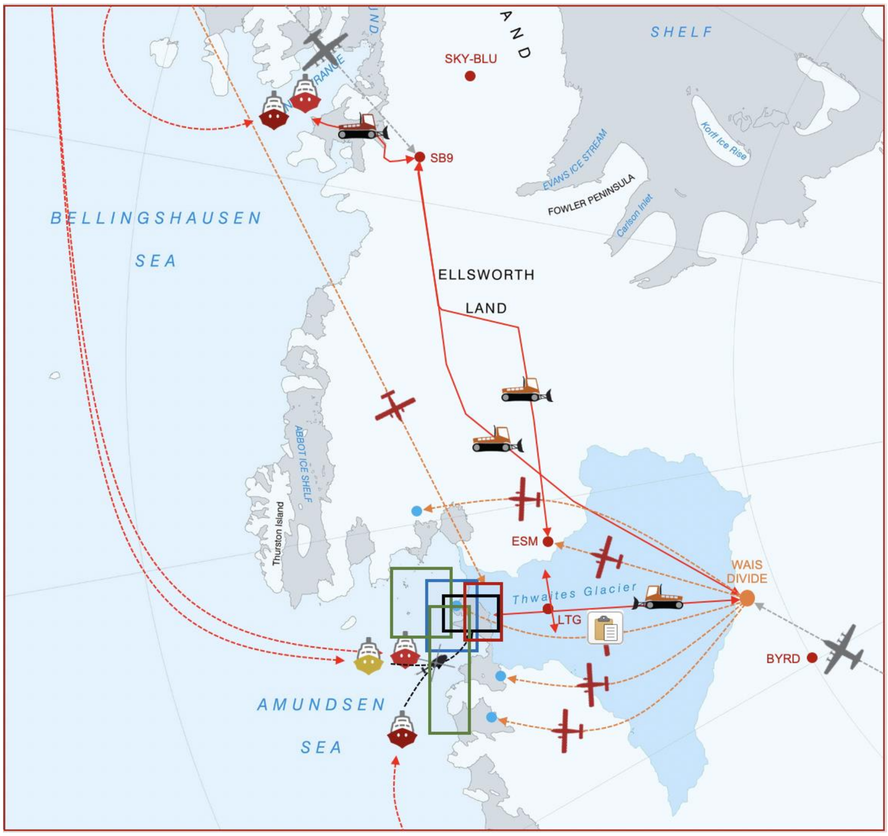

Figure 46. Overview of logistical support activities for the International Thwaites Glacier Collaboration (ITGC). Source: [ITGC Initial Environmental Evaluation]

7.4.6.2 Other activities

Between 1996 and 2014 the Chilean Antarctic Institute (Instituto Antártico Chileno) operated a research facility in the Patriot Hills area of the Ellsworth Mountains from which a range of research activities were supported throughout the Ellsworth Mountains and surrounding ice streams.

In 2014, the facility was moved to Union Glacier and renamed Estación Polar Científica Conjunta Glaciar Unión with ongoing geological, glaciological and meteorological studies conducted in the region.

The private tour operator and logistics provider Antarctic Logistics and Expeditions (ALE) has operated from its Union Glacier camp in the Ellsworth Mountains for the last two decades (Figure 42). ALE offers air and over-snow transportation, camping support, and guided experiences for those venturing to the interior of Antarctica.

7.4.6.3 Activities subject to EIA

A review of the EIA database revealed a number of EIAs submitted since 1998 for activities in the WAIS region (Table 9).

Table 9. List of environmental impact assessments relevant to the WAIS region. EIAs identified from the EIA database managed by the Antarctic Treaty Secretariat. https://www.ats.aq/devAS/EP/EIAList?lang=e

Country	Activity (Tile)	IEE or CEE	Period of activity
New Zealand	Investigate the rate-determining processes associated with deglaciation in the Ross Sea region of West Antarctica, via Hot Water Drilling.	IEE	2021 to 2025
Brazil	Chemical and Climatic variability in the ice cores records of Pine Island Glacier - West Antarctic Ice Sheet (Brazilian National Institute for Science and Technology of the Cryosphere).	IEE	2019 - 2020
UK	Deep Core Drilling Project On Sherman Island, Antarctica	IEE	2019 - 2020
UK	International Thwaites Glacier Collaboration.	IEE	2018 to 2023
UK	Basal Conditions on the Rutford Ice Stream: Bed Access, Monitoring and Ice Sheet History.	IEE	2016 to 2019
US	Subglacial Antarctic Lakes Scientific Access (SALSA): Integrated study of carbon cycling in hydrologically active subglacial environments in West Antarctica.	IEE	2018 - 2019
UK	Science Projects on the Filchner-Ronne Ice Shelf, Antarctica	IEE	2014 - 2018
UK	Ice Sheet Stability Programme	IEE	2013 - 2015
Chile	Initial Environmental Impact Assessment for the Joint Polar Research Station at Union Glacier.	IEE	2013/2014
US	A series of IEEs in relation to the Recovery of a Deep Ice Core from the West Antarctic Ice Sheet Ice Flow Divide (WAIS Divide).	IEE	2005/06 to 2014/15
US	A series of IEEs in relation to the US CReSIS programme (Characterize West Antarctic Ice Sheet using Multidisciplined Geophysical Survey Techniques to Support the Center for Remote Sensing of Ice Sheets).	IEE	2007/08 to 2013/14
US	Development and Implementation of Surface Traverse Capabilities.	CEE	2004/05
US	Establishment of Three Temporary Field Camps for Logistical Support of a Large-Scale Airborne Geophysical Survey of the Amundsen Sea Embayment, Antarctica (AGASEA).	IEE	2004/2005
UK	Deep Ice Core Drilling Project on Berkner Island	IEE	2001

7.4.6.4 Potential future activities

A review of the EIES database revealed that no countries have submitted information for the five season period covered by this EIA. Ordinarily pre-season information is only required to be submitted for the immediate forthcoming season and not for future seasons.

Searches of the websites for National Antarctic Programmes that have operated across the WAIS in the past did not reveal any specific information about future planned activities in the WAIS.

It is known that BAS will be supporting a subglacial geological drilling project, which will be sampling at the edge of the Ellsworth Mountains in the 2022/23 season and at the edge of the Pensacola Mountains in the 2023/24 season. This project will not require traverse support and will be input by air in both seasons.

7.4.6.5 Summary of cumulative impacts arising from this research project

The assessment in Section 7.4.6 above clearly outlines that the WAIS has supported and continues to support a wide range of activities from several National Antarctic Programmes and private operators.

All of the activities identified above will have been or continue to be supported with an array of over-snow traverse and aircraft assets and the establishment of field camps. Accordingly, impacts associated with these activities will parallel those identified in this EIA, i.e., emissions to glacial and atmospheric environments through the combustion of fossil fuels, waste production, as well as impacts arising from the deployment of research equipment including, for example, glacial and subglacial geological drilling activities.

There are therefore a number of cumulative impacts that can be identified, to which BAS traverse activities will contribute including (see also Table 12 below):

a) **Contamination of the glacial environment** with particulates from the combustion of fossil fuels in vehicle engines and generators etc. BAS traverse activities will contribute to particulates that become trapped in the ice from other local as well as global sources;
b) **Contamination of the glacial environment** from the accidental release of hazardous substances including spillage of fuels. With effective implementation of the identified mitigation measures, this should not occur in the case of BAS traverse activities, but if a spill event were to occur then the contamination would add to other spill events that have occurred historically across Antarctica (Aislabie et al., 2004). It is noted that there are poor records for such events on a continental scale.
c) **Contamination of the glacial environment** through the release of waste, including the accidental release of waste items. With effective implementation of the identified mitigation measures this should not occur in the case of BAS traverse activities, other than the deliberate release of small volumes of human liquid waste and grey water. Should any items accidentally be released to the environment, this will add to other losses that have occurred historically across the WAIS. Here also there are no records of such events that are maintained on a continental scale.
d) **The release of gases, including greenhouse gases** from the combustion of fossil fuels will add to other atmospheric releases from stations, bases, vehicles, and vessels in the same seasons and from previous activities in the region.

e) Records of human presence in the areas of activity, and any materials inadvertently left in situ has the potential to add to the further **loss of wilderness values in Antarctica**.

There are no comprehensive databases of human impacts in Antarctica that can be accessed to support an effective quantification of cumulative impacts. Accordingly, cumulative impacts can only be qualitatively assessed here.

Using the assessment criteria set out in Table 10 and Table 11 below, it is noted that:

Spatial extent of cumulative impacts: LOW. Whilst human activities have been undertaken across large areas of the WAIS, impacts that have occurred are likely to be constrained to the immediate areas of activity. No impact is known to have occurred on a large spatial scale on the WAIS. No impacts from the planned BAS traverse activities are likely to have widespread impact.

Duration of cumulative impacts: HIGH. Most impacts to the WAIS will be of very short duration e.g., physical disturbance of snow and ice surfaces, however some impacts will be much longer-lasting, e.g., contamination of snow and ice surfaces from the burning of fossil fuels will be detectable for years to decades as well as the loss of perceptions of wilderness value.

Severity of cumulative impacts: LOW. Impacts from human activities across the WAIS are considered unlikely to have caused any disruption to the natural functions and processes of the WAIS environment.

Likelihood of cumulative impacts: HIGH. Impacts from past, present and reasonably foreseeable human activities across the WAIS are known to have occurred and further impacts are likely, including those that will be contributed by BAS traverse activities.

Overall, the cumulative impacts of past, present and reasonably foreseeable activities across the WAIS are considered to be no more than minor. Some impacts will be transitory, whilst others will be more than transitory. Of particular note is that accumulating evidence of human activity across the WAIS will continue to erode perceptions of Antarctic wilderness, which could be considered to be more than minor and transitory.

The contribution of BAS traverse activities to these cumulative impacts is considered to be less than minor, with some impacts being more than transitory.

7.5 Summary and evaluation of impact significance

Section 7.4 has identified the potential (direct, indirect and cumulative) impacts of planned traverse activities. This section evaluates the significance of the identified actual or potential impacts taking into account the three levels of significance identified in Article 8(1) of the Protocol.

In order to evaluate the significance of a given potential impact, the spatial extent, duration, severity (which also includes a level of reversibility) and likelihood of the identified potential impacts are considered so as to evaluate the overall significance of the identified impact of each activity.

Table 10 overleaf outlines the assessment criteria and definitions that have been used when evaluating the spatial extent, duration, intensity and likelihood of the identified potential impacts for the environmental elements (table and methodology modified from Oerter, 2000).

In each case the spatial extent, duration, severity and likelihood are scored 1 to 4 depending on whether each is considered to be 'low', 'medium', 'high' or 'very high' against the described criteria. An overall risk score (before and after treatment) is then calculated as follows:

Risk score = spatial extent score x duration score x severity score x likelihood score

The risk score determines whether the overall risk level is 'low', 'medium', 'high' or 'very high' as set out in Table 11 (page 94).

Table 12 (page 95) summarises the findings by setting out the identified impacts, assessing the raw risk with not control measures in place and the residual risk after the control measures have been applied. The residual risk level is then compared to the three levels of significance set out in Article 8(1) of the Protocol as per Table 11.

		Criteria for assessment			
Impact	**Environment Element**	**Low (1)**	**Medium (2)**	**High (3)**	**Very High (4)**
SPATIAL EXTENT OF IMPACT Area or volume where changes are likely to occur	***Freshwater*** ***Marine*** ***Terrestrial*** ***Atmosphere***	*Local extent*	*Partial extent*	*Major extent*	*Entire extent*
		Confined to the site of the activity.	*Some parts of an area are partially affected.*	*A major sized area is affected.*	*Large-scale impact; causing further impact.*
	Flora and Fauna	*Confined disturbance of fauna and flora within site of activity, e.g., individuals affected.*	*Some parts of the community are disturbed.*	*Major disturbance in community, e.g., breeding success is reduced.*	*Impairment at population level.*
DURATION OF IMPACT Period of time during which changes in the environment are likely to occur	***Freshwater*** ***Marine*** ***Terrestrial*** ***Atmosphere***	*Short term*	*Medium term*	*Long term*	*Permanent*
		Several weeks to one season; short compared to natural processes.	*Several seasons to several years; impacts are reversible.*	*Decades; impacts are reversible.*	*Environment will suffer permanent impact.*
	Flora and Fauna	*Short compared to growth period/ breeding season.*	*Medium compared to growth/ breeding season.*	*Long compared to growth/ breeding season.*	*Permanent*
SEVERITY OF IMPACT A measure of the amount of change imposed on the environment due to the activity	***Freshwater*** ***Marine*** ***Terrestrial*** ***Atmosphere***	*Minimal Affect*	*Affected*	*High*	*Irreversible*
		Natural functions and processes of the environment are minimally affected. Reversible.	*Natural functions or processes of the environment are affected but are not subject to long-lasting changes. Reversible.*	*Natural functions or processes of the environment are affected or changed over the long term. Reversibility uncertain.*	*Natural functions or processes of the environment are permanently disrupted. Irreversible or chronic changes.*
	Flora and Fauna	*Minor disturbance. Recovery definite.*	*Medium disturbance. Recovery likely.*	*High levels of disturbance. Recovery slow and uncertain.*	*Very high levels of disturbance. Recovery unlikely.*
LIKELIHOOD *Chance of the occurrence of the impact*	***All elements***	*Should not occur under normal operation and conditions.*	*Possible but unlikely.*	*Likely to occur during span of project. Probable.*	*Certain to occur / unavoidable.*

Table 10. Assessment criteria for evaluating the spatial extent, duration, severity, and likelihood of the potential environmental impacts (modified from Oerter, 2000).

Risk score	Risk level	Description	Ref Article 8(1) of the Protocol
1 to 15	Low	Acceptable under most circumstances. Impact likely to be managed through normal operating procedures.	Less than minor or transitory
16 to 35	Medium	May be acceptable under certain circumstances. Impact requires ongoing monitoring and possible further treatment.	No more than minor or transitory
36 to 143	High	Unacceptable in most circumstances. Senior Management to be notified. Further treatment options must be explored.	More than minor or transitory
144 to 256	Very High	Unacceptable. Senior management to be alerted. Significant further treatment must be explored. Only senior management can approve proceeding if risk cannot be further treated to reduce risk level.	

Table 11. Risk assessment criteria.

Table 12. Summary of identified impacts and assessment of impact significance before and after mitigation measures are applied.

Environment type	Environmental Aspect	Potential Impact(s)	Type of Impact (Direct, Indirect, Cumulative)	Pre-treatment risk assessment: Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment (Preventative or Mitigating Measures)	Post-treatment risk assessment: Extent	Duration	Severity	Likelihood	Residual Risk Level	Ref Article 8 of the Protocol
Glacial Environment	Burning of fossil fuels in engines, generators etc. releasing particulates to snow / ice surface	Contamination of snow / ice surface along routes of the traverse or around camp sites	Direct / Cumulative	1	2	1	4	8 Low	• Vehicle engines, generators and fuel burning equipment are regularly serviced and maintained to maximise efficiency of operation; • Vehicle engines and generators will be allowed a 'warm up' period prior to engaging any load; • Sledge loads will be evenly distributed between towing vehicles to the extent possible; • The fuel types selected are the most efficient for use in low temperature conditions; • All fuel burning will be minimised to the extent practicable.	1	2	1	4	8 Low	Less than minor or transitory
	Mechanical action on snow / surface from: vehicle use; camp establishment; creation of berms for overwinter storage	Physical disturbance to snow / ice surface	Direct	1	2	1	4	8 Low	Any such impacts are likely to be negligible and transitory and no mitigation measures are considered to be required.	1	2	1	4	8 Low	Less than minor or transitory
	Accidental release of hazardous liquid substances e.g., from fuel spill events	Contamination of local ice environment	Direct / Cumulative	1	2	2	3	12 Low	• Volumes of hazardous liquid substances will be minimised to the extent practicable; • All fuel / hazardous substances will be managed in accordance with standard BAS procedures as set out in the BAS Field Manual and Traverse Operations Manual; • Hazardous liquid substances will be stored in secondary containment e.g., bunds, to the extent practicable and regular checks on the integrity of containers will be undertaken; • When overwintering bladdered fuel: o All ports will be inspected to ensure they are closed; o Bladders will be monitored for a few days to check for the risk of puncture, and to ensure no leaks are occurring. • Trained and experienced operators will oversee equipment and manage refueling activities; • Refuelling operations will be undertaken by a minimum of two people using spill mats, absorbent wipes etc. in accordance with standard BAS field practices; • Fuel spill response training will be provided to those undertaking fuel handling in the field; • Fuel bladder repair kits will be carried on all traverses; • Spill kits will be readily available at locations where fuel is stored and transferred. Any hazardous substance spilt[10] will be cleaned up to the extent practicable in accordance with the BAS Field Manual and Traverse Oil Spill Contingency Plan. Recovered liquids and contaminated absorbents will be contained, labelled as hazardous and flown to Rothera for disposal.	1	2	1	2	4 Low	Less than minor or transitory

[10] Other than petrol. Generally, it is BAS policy not to contain and recover petrol but allow it to evaporate. Petrol spills must be reported in accordance with the Traverse Oil Spill Contingency Plan to review whether a passive response is the correct response (this depends on volume/sensitivity of spill site).

Environment type	Environmental Aspect	Potential Impact(s)	Type of Impact (Direct, Indirect, Cumulative)	Pre-treatment risk assessment: Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment (Preventative or Mitigating Measures)	Post-treatment risk assessment: Extent	Duration	Severity	Likelihood	Residual Risk Level	Ref Article 8 of the Protocol
Glacial Environment	Release of human liquid waste and grey water, or accidental loss of wastes and items of cargo or equipment	Contamination of local ice environment	Direct / Cumulative	2	2	1	4	16 Medium	• Human liquid waste and grey water are disposed of in ice pits at specifically identified locations only; • Grey water production at camps will be minimised to the extent practicable; • All food and general waste is separated into waste streams and removed from the field for correct handling at Rothera; • Waste generated in the field, including hazardous waste is managed in accordance with the provisions of Annex III to the Protocol, the BAS Waste Management Handbook and BAS Field Operations Manual; • Payloads for all sledge types are adhered to so as to prevent overloading; • Sledge loads and configurations will be inspected daily to ensure all cargo is secure; • Tractor trains travel side by side to allow for ongoing observation of sled loads by the opposite tractor train; • Careful planning seeks to minimise the materials and items taken into the field that will generate waste.	1	2	1	3	6 Low	Less than minor or transitory
Atmospheric Environment	Release of gases including greenhouse gases from combustion of fossil fuels in vehicles, generators, cooking and heating equipment	Pollution of atmosphere and contribution to climate change	Direct / Cumulative	2	2	1	4	16 Low	• Vehicle engines, generators and fuel burning equipment are regularly serviced and maintained to maximise efficiency of operation; • Emissions will be minimised by only burning fossil fuels when required. Equipment is not left idling unnecessarily; • Traverse routes will be planned to maximise efficient movements of people, fuel and cargo; • Sledge loads will be carefully balanced between tractor trains to maximise efficient vehicle use; • Vehicle engines and generators will be allowed a 'warm up' period prior to engaging any load; • Sledge loads will be evenly distributed between towing vehicles to the extent possible; • The fuel types selected are the most efficient for use in low temperature conditions; • All fuel burning will be minimised to the extent practicable.	1	2	1	4	8 Low	Less than minor or transitory
	Release of heat from vehicles, generators, cooking and heating equipment	Highly localised and temporary heating of air adjacent to equipment	None identified	1	1	1	4	4 Low	Heat will be lost directly to the atmosphere, but with no discernible impacts. No mitigation is considered necessary.	1	1	1	4	4 Low	Less than minor or transitory

				Pre-treatment risk assessment						Post-treatment risk assessment					
Environment type	Environmental Aspect	Potential Impact(s)	Type of Impact (Direct, Indirect, Cumulative)	Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment (Preventative or Mitigating Measures)	Extent	Duration	Severity	Likelihood	Residual Risk Level	Ref Article 8 of the Protocol
Native Antarctic Fauna	Noise emissions from equipment and vehicles and human activity	Disturbance resulting in acute or chronic effects	Direct / Indirect	1	2	2	2	8 Low	• Avoiding known congregations of Antarctic wildlife will be a factor in selecting sites for connecting with ships at the coast; • All traverse activities, including field camps and overwinter depots will be conducted on ice and snow surfaces. Ice-free areas in mountainous areas as well as nunataks will be avoided at all times; • All traverse activities will be constrained to defined areas as stipulated in this EIA.	1	1	1	1	1 Low	Less than minor or transitory
Antarctic Wilderness	Human presence and all activities associated with the research project at each location and across both seasons	Reduction in wilderness values in these areas of Antarctica	Indirect / Cumulative	2	3	3	3	54 High	• All traverse activities will be constrained to defined areas as stipulated in this EIA; • Previously used traverse routes will be used as far as practicable so as to constrain the spatial coverage of traverse activities; • Areas used for field camps and depots will be constrained to the extent practicable; • Disposals to the ice sheet will be restricted to small volumes of human liquid waste and grey water. All other wastes will be removed from the field.	2	2	2	3	24 Medium	No more than minor. Any loss of areas considered 'pristine' will be more than transitory

8 Monitoring and Record Keeping

This assessment has not identified the need for dedicated monitoring to be undertaken. Nonetheless, records will be maintained for post-season reporting purposes. These records will include:

- The volumes and types of fuel burnt during traverse activities. Measuring fuel burn and the emissions associated with BAS logistics is an important part of BAS Net Zero Carbon Strategy 2020-2040 and is required under the conditions placed by the FCDO on the BAS Operating Permit (2022-2027).
- GPS records of all traverse routes followed. This data will be input into the BAS operational geographical information system. This will be an important source of operational information, but the data also has value with respect to understanding and recording impacts on wilderness values.
- GPS records of camp sites and overwintering storage locations, including the volumes of fuel stored and types and volumes of waste stored.
- GPS records of the location as well as volumes of human liquid waste and grey water disposed to the ice sheet.
- Records of the types and quantities of any materials or equipment that is accidentally lost to the environment.
- Observations of any other environmental incidents such as inefficient burning of fuel resulting in excessive release of airborne pollution.
- Location of any spill events if they occur as well as the volumes and type of fluid lost, and approximate volumes recovered.

Every effort will be made to avoid unnecessary impacts. Where an incident results in impacts, such as disturbance of wildlife or fuel spills, this will be documented and reported to the BAS Environmental Office via the BAS Incident Reporting System Maximo and to the FCDO in accordance with the conditions of the BAS Operating Permit.

Post activity reporting will be undertaken in accordance with BAS requirements and the conditions placed on the BAS Operating Permit (2022-2027) issued by the FCDO.

9 Gaps in Knowledge and Uncertainties

No activity in Antarctica can be planned with absolute certainty, due to the extreme, changeable and unpredictable environmental conditions.

Albeit constrained to the areas identified in Figure 12, BAS traverse activities will need to retain a degree of flexibility (e.g., with regard to precise routes followed and activities undertaken) so as to accommodate changing weather, logistical and scientific requirements.

Accordingly, there remain a number of gaps in knowledge and uncertainties. These are interlinked and are discussed below.

9.1 Implications of Antarctic weather

The weather in Antarctica can be highly variable both within and between summer seasons. Conditions can also change dramatically in short periods of time. This variability and unpredictability may require a number of adjustments to operational plans.

Weather conditions have the potential to impact on the schedule of the traverse programme in a number of ways. Inter- and intra-continental flights as well as ship itineraries may be delayed due to poor weather conditions at points of departure or destination which may have implications for the location and timing of aircraft and vessel rendezvous plans with the traverse team in the field.

Weather conditions may also influence the selection of traverse routes across the WAIS as well as the extent of any travel that can be achieved (particularly during storm events). Seasons with poor weather may also limit what can be achieved in any one season with the implication that some operational objectives will need to be moved to another season.

Weather uncertainties have implications for some environmental aspects including the:

- volumes of fuel burnt in any one season and hence the impacts on glaciological and atmospheric environments;
- locations that are visited and the actual traverse routes that are taken in any one season as well as the locations of camp sites and overwintering depots, and hence physical impacts on snow and ice surfaces;
- volumes and types of materials and equipment, as well as waste that will need to be overwintered.

The uncertainty associated with the unknown implications of Antarctic weather, is unlikely to have significant implications for the identified environmental impacts nor for the overall conclusion of the EIA.

9.2 Precise traverse routes to be follow

The precise traverse routes that will be taken cannot be predicted with certainty. Traverse routes to be taken will be determined by a number of factors including weather conditions that are encountered in any one season, (see Section 9.1 above), safety considerations, as well as research and operational priorities, which may change (See Section 9.4 below).

Consequently, this EIA has only been able to identify broad areas of the WAIS within which BAS traverse activities will be constrained.

The uncertainties associated with the inability to predict the precise traverse routes may have implications for some environmental aspects including the:

- records of human presence and consequently the impacts on wilderness values;
- volumes of fuel burnt in any one season and hence the impacts on glaciological and atmospheric environments;
- locations of camp sites and overwinter depots and hence physical impacts on snow and ice surfaces.

The uncertainty associated with the unpredictable traverse routes, is unlikely to have significant implications for the identified environmental impacts nor for the overall conclusion of the EIA.

9.3 Precise locations of depots and camp sites

As recorded in Sections 9.1 and 9.2 above, one of the implications of unpredictable weather conditions and unpredictable traverse routes is that the locations to be used for camping or overwintering fuel and traverse equipment cannot be predicted with certainty.

The uncertainties associated with the inability to predict the precise locations of camp sites and overwintering depots may have implications for some environmental aspects including the:

- risks of losing equipment to the environment or the risk of spill events occurring where fuel is used or stored. This has some implications for the assessment of the impacts of any emergency events (such as fuel spills).

The uncertainty associated with the unpredictable locations of camp sites and depots, is unlikely to have significant implications for the identified environmental impacts nor for the overall conclusion of the EIA.

9.4 Research needs requiring logistical support

Whilst research programmes and associated logistical support activities are planned in advance, these can be amended for any one season for several reasons.

Such changes may have secondary implications for planned traverse activities including for the locations of traverse activities and the extent and type of research programmes to be supported.

As with other uncertainties, this can have implications for some environmental aspects including the:

- volumes of fuel burnt in any one season and hence the impacts on glaciological and atmospheric environments;
- locations that are visited and the actual traverse routes that are taken in any one season as well as the locations of camp sites and overwintering depots, and hence physical impacts on snow and ice surfaces;
- volumes and types of materials and equipment, as well as waste that will need to be overwintered.

The uncertainty associated with variations to planned research activities, is unlikely to have significant implications for the identified environmental impacts nor for the overall conclusion of the EIA.

9.5 Ship and aircraft rendezvous opportunities

Several factors, including weather conditions and changes to research and operational priorities (see Sections 9.1 and 9.4 above), can influence the number and location of rendezvous opportunities with ships and aircraft.

This in turn has implications for the:

- traverse routes that are followed in any one season and hence the impacts that occur to glaciological and atmospheric environments;
- the type and quantities of fuel, waste and equipment that needs to be overwintered and hence the physical impacts on snow and ice surfaces, including risks of fuel spills.

The uncertainty associated with variations to rendezvous with ships and aircraft, is unlikely to have significant implications for the identified environmental impacts nor for the overall conclusion of the EIA.

10 Summary and Conclusion

This EIA has considered a number of alternatives to BAS traverse activities (Chapter 4); described the preferred approach to be taken (Chapter 5); described what is known about the current environmental state in the planned areas of activity (Chapter 6); assessed the potential environmental impacts that will or could arise (Chapter 7); outlined the mitigation measures to prevent or minimise any potential environmental impacts that may occur (Chapter 7); described the records that will be maintained of any environmental impacts that do occur (Chapter 8), and identified remaining unknowns and uncertainties (Chapter 9).

Surface traverse is the most fuel efficient currently viable method to support research on the West Antarctic Ice Shelf. Use of vehicles, generators and heaters creates heat, gas and particulate emissions which impact the immediate snow and ice environment, and local air quality. Tracking and movement of snow will also occur. These expected impacts will be minor and short lived, with the exception of the cumulative impact of greenhouse gas emissions and the accumulation of particulates in glacial surfaces.

This assessment was undertaken on a worst-case scenario evaluation. Even with *no* treatments in place, only one activity was assessed as posing a 'high' risk to the environment with impacts potentially being more than minor or transitory, i.e., the potential to impact on perceptions of Antarctic wilderness.

As a general rule BAS aims to prevent or reduce potential environmental impacts from its traverse activities through careful planning, training, execution and the availability of highly experienced personnel. And for almost all sources of impact, practicable treatment options to mitigate those impacts have been identified.

British Antarctic Survey has many decades of experience of operating in the region. Provided the mitigation measures described in Section 7.4 (summarised in Table 12) are adhered to, the environmental impacts of the planned activities are considered to be largely avoidable or can be minimised to an acceptable level.

Overall, this EIA considers that the potential environmental impacts arising from the next five years of BAS traverse activities will have **no more than a minor or transitory impact** on the environment.

It is concluded that this level of predicted impact is acceptable given the significant scientific knowledge that will be gained as a result of BAS ongoing programme of globally-relevant research across the WAIS.

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Appendices

Appendix 1. BAS Traverse Operations Manual V3 (Cover only)
Appendix 2. BAS Field Operations Manual (Cover only)
Appendix 3. BAS Oil Spill Contingency Plan for Heavy Vehicle Traverse 4th Edition (Cover only)

Appendix 1. BAS Traverse Operations Manual V3 2022 (Cover only)

Traverse Operations Manual V3 (Reviewed by Ben Norrish 01-09-2020, J Wake 05-08-22)

Traverse Operations Manual

Version 3

For review post 22/23 season

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

1

Appendix 2. BAS Field Operations Manual 2018 (Cover only)

Appendix 3. Heavy Vehicle Traverse Oil Spill Contingency Plan 2021 (Cover only)

Oil Spill Contingency Plan

Heavy Vehicle Traverse

BAS Environment Office

4th Edition, 2021

Revision No.	Revision description	Revision date
1	Review and restructure of plan based on Oil Spill Response capability review	October 2021

British Antarctic Survey,
High Cross, Madingley Road,
Cambridge, UK, CB3 0ET.

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL