BEAMISH
Initial Environmental Evaluation

BAS Environment Office
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British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Contents

Non-Technical Summary

Introduction

The project "Basal conditions on Rutford Ice Stream: Bed Access, Monitoring and Ice Sheet History" (BEAMISH) aims to improve the understanding of the uncertainty in predicting future sea level rise associated with the melting of the Antarctic and the Greenland ice sheets. Through measurements taken at the ice surface and by drilling to the bed of Rutford Ice Stream, the project will set out to establish how long ago the ice sheet last disappeared completely, and how water and soft sediments underneath it help the ice move fast on its journey to eventually melting in the sea.

The British Antarctic Survey (BAS) is leading the BEAMISH project, with collaborations from a number of UK and overseas organizations. These include the Universities of Swansea, UCL, Bristol and Aberystwyth and The Pennsylvania State University.

This Initial Environmental Evaluation has been prepared in accordance with Annex I of the Protocol on Environmental Protection to the Antarctic Treaty (1991).

Project Description

The project involves using a variety of sampling techniques in order to collect data and samples from the surface of Rutford Ice Stream, from within it and from the sediment beneath it. It is proposed that ice and sediment cores will be taken from four sites on the glacier using a hot water drill. Seismic and radar surveys will be undertaken across the whole of the study area. GPS receivers and seismic monitoring stations will be deployed temporarily on the ice stream for several months each season.

The purpose of these activities is to study the flow of the Rutford Ice Stream and to map the topography and variations in basal water and sediment in the area around the drill holes. The GPS receivers will track the motion of the ice surface whilst a seismometer will detect the noise bursts emitted as the ice stream grinds over the underlying bed. The seismic surveys will enable maps to be produced identifying variations in the bed sediment. The radar surveys will map the bed topography and reflect where water beneath the glacier is concentrated or distributed. Two additional GPS stations, on Fletcher Promontory and in the Ellsworth Mountains, will act as stationary control-points, used to improve the accuracy of the GPS results acquired on the moving ice stream.

In the initial season a tractor traverse will support the project by transporting fuel across the Ronne Ice Shelf and creating a depot on the Rutford Ice Stream. In the main science season, 2017-2018, approximately 40,000 litres of this fuel will be used to power the hot water drill.

Project Schedule

BEAMISH will operate over a period of four years commencing in November 2016 and is anticipated to be complete by early 2019.

- Season 1 – 2016 -2017
    - Radar surveys and GPS deployment. Field party of two. Approx 90 days.
    - Tractor traverse to BEAMISH depot. Team of four. November – February.
- Season 2 – 2017-2018
    - Hot water drilling, radar and seismic surveys, deployment of all equipment. Field party of ten personnel. Approx 100 days.
- Season 3 – 2018-2019
    - Seismic surveys, data download recovery of temporary equipment. Field party of two. Approx 100 days.

Description of the Environment
Rutford Ice Stream is a typical fast-flowing, dynamic Western Antarctic ice stream. It is approximately 180 miles long and over 15 miles wide and drains south easterly between the Sentinel Range of the Ellsworth Mountains and Fletcher Promontory, into the southwest part of Ronne Ice Shelf.

There are no known habitats for any flora or fauna on Rutford Ice Stream.

There are no known subglacial lakes in the immediate vicinity of the study area. The closest known lake is Subglacial Lake CECs more than 150km away, on the other side of the Ellsworth Mountains. The shortest flow-line distance to the nearest subglacial lake is many hundreds of kilometres.

Microbial life and micro invertebrates are typical of life in the areas of the proposed Nunatak. Higher plant life is absent and mosses are extremely rare.

There are no protected areas within the vicinity of the BEAMISH drill sites, survey areas or proposed tractor traverse routes.

Alternatives
Four alternative options have been examined these are;

- Do Nothing
- Do the activity elsewhere
- Do the activity with alternative science
- Do the activity with alternative logistics

All four alternatives were considered not viable for scientific, technical or practical reasons.

Impact Identification and Mitigation
BEAMISH covers a wide array of activities which could give rise to a multitude of environmental impacts. Where potential negative environmental impacts have been identified mitigation measures have been proposed to reduce, minimise or avoid these impacts. The activities which have the potential to result in a medium to high severity of environmental impact are listed below and the relevant mitigation measures to reduce the impact have been outlined.

(i) **Hot Water Drilling –** There is potential that if the hot water drill enters a pristine subglacial environment this could result in contamination of sediments and water. The proposed drilling locations however are on the periphery of the grounded ice sheet, 40km upstream of the grounding line in areas modulated by the ocean tides. The hydraulic gradient of the ice stream will ensure that if any drilling water enters the basal hydrological system it would be driven in the same direction and will enter the ocean at the grounding line. Evidence suggest that the proposed drilling site is a marginal location and is not considered to be a pristine, isolated subglacial environment.

(ii) **Non retrieval of temporary equipment-** Due to the number and complexity of the different instruments that will be deployed there is the potential for equipment to become disengaged and/or permanently lost during deployment. This could result in unnecessary waste and pollution being left in the field. There are a number of mitigation measures to avoid this occurring. Firstly equipment has been designed to be robust for the conditions and duration of deployment. All equipment will be tested prior to deployment and only equipment that has a proven track record will be used. Only experienced trained staff will be involved in the deployment of equipment using established proven techniques supported by risk assessments. All equipment left for any length of time will be logged with a GPS and marked with additional visual markers. A record of any equipment which is unintentionally left in the field will be made by the PI and submitted to the BAS Environment Office.

(iii) **Non retrieval of permanent equipment –** Some of the equipment will be permanently deployed in the ice stream. This is an unavoidable result of this type of equipment being used in the Antarctic environment. For practical as well as environmental reasons, this equipment has been designed to be as small, simple and low-power as possible. A record of equipment which is deployed and left in the field permanently by design will be made by the PI and logged on the BAS Operations GIS database.

(iv) **Fuel Transfers** - Large quantities of fuel will be transported and stored in the field during the project. This increases the risk of a fuel spill occurring in the field and impacting on what is currently a pristine environment. Robust and reliable transfer and storage equipment has been sourced for this project. Personnel involved in fuel transfer will be trained in the correct transfer procedures and spill response. A spill kit will be carried with the tractor train at all times. Fuel stores left overwinter will be well marked and have individual GPS positions recorded. Methods to recover fuel bladders and drums are set out in the BAS Traverse Operations Manual. Carbon emissions associated with the fuel use are unavoidable but have been minimised through good planning, and using efficient means of transportation. Carbon emissions will be calculated for inclusion in the BAS carbon report.

(v) **Importation of Cargo -** Through the unintentional importation of non-native species carried on equipment and general cargo, the local ecosystems (particularly in ice free areas) within Antarctica could be impacted if any non-native species become established. Whilst there is a very low probability of this occurring even on the ice free nunataks, if the impact were realised the severity could be significant. All equipment and materials required for the proposed activity will be thoroughly cleaned before dispatch to Antarctica. Practices in the BAS Bio-security Handbook and SCAR's Environmental Code of Conduct for terrestrial scientific field research in Antarctica will also be followed.

Conclusion

This IEE indicates that the proposed BEAMISH project is likely to have no more than a minor and transitory impact on the Antarctic environment, provided the recommended mitigation measures identified are carried out. It is concluded that this activity should be allowed to proceed, and that a Comprehensive Environmental Evaluation (CEE) is not required.

1. Introduction

1.1. Background to Project

The polar ice sheets play a major role in controlling the Earth's sea level and climate, but scientists' understanding of their history and motion is poor. The biggest uncertainty in predicting future sea level comes from the Antarctic and the Greenland ice sheets where the rate of sea level rise is increasing much faster than anticipated. The melting on both continents has the potential to trigger irreversible changes to sea levels that could continue for many centuries. Reducing this uncertainty is currently one of the biggest challenges in glaciology.

The project "Basal conditions on Rutford Ice Stream: Bed Access, Monitoring and Ice Sheet History" (BEAMISH) aims to improve understanding of two aspects of this uncertainty; first, the past behaviour of the West Antarctic Ice Sheet (WAIS), and second, the flow of the fast "ice streams" that drain it. Through measurements taken at the ice surface and by drilling to the bed of Rutford Ice Stream, the project will set out to establish how long ago the ice sheet last disappeared completely, and how water and soft sediments underneath it help the ice move fast on its journey to eventually melting in the sea.

The British Antarctic Survey (BAS) is leading the BEAMISH project, with collaborations from a number of UK and overseas organizations. These include the Universities of Swansea, UCL, Bristol and Aberystwyth and The Pennsylvania State University.

1.2. Statutory Requirements

To ensure the protection of the Antarctic environment, the Antarctic Treaty nations adopted the Protocol on Environmental Protection to the Antarctic Treaty in 1991 (hereafter referred to as the Environmental Protocol). The UK enforces the provisions of the Protocol through the 'Antarctic Act 1994 and Antarctic Act 2013' and 'Antarctic Regulations 1995/490 (as amended).

<u>Annex I – Environmental Impact Assessment (EIA)</u>
One of the guiding principles of the Environmental Protocol is that an EIA be carried out before any activity is allowed to proceed. It states that activities should be planned and conducted on the basis of *'information sufficient to allow prior assessments of, and informed judgements about, their possible impacts on the Antarctic environment'* (Article 3, Environmental Protocol).

Annex I of the Environmental Protocol sets out the detailed regulations for EIA in Antarctica, and establishes a three-stage procedure based on different levels of impact. The levels are:

1. Preliminary Environmental Assessment (PEA);
2. Initial Environmental Evaluation (IEE); and
3. Comprehensive Environmental Evaluation (CEE).

An IEE is for activities, which are likely to have a minor or transitory impact on the Antarctic environment. It is considered that an IEE is appropriate for the BEAMISH project. In the UK the IEE is subject to review by the Foreign and Commonwealth Office (FCO), which also makes the final decision on whether the activity should proceed.

Specialist Activity Permits

The Environmental Protocol also states that certain activities within Antarctica require a permit before being undertaken. Those activities relevant to the BEAMISH project include mineral resource activities for scientific research. The relevant permit application for this activity will be submitted to the FCO early in 2017, for the 2017-2018 season.

Other logistical activities associated with the BEAMISH project will be covered by the BAS Operating Permit, which is organised directly between BAS and the FCO.

1.3. Purpose and Scope of Document

The purpose of this IEE is to provide sufficient information on the BEAMISH project for an informed judgement by the FCO to be made on the possible environmental impact of these activities on the Antarctic environment and whether they should proceed. The scope of this document covers the BEAMISH project and directly-associated logistics.

The document has been split into the following sections;

- Section 1 introduction
- Section 2 provides a description of the overall project;
- Section 3 describe the current environmental conditions
- Section 4 outlines the alternatives considered at the outset of the project;
- Section 5 identifies the potential environmental impacts and outlines the mitigation measures that are proposed to minimise and avoid those impact; and
- Section 6 provides the conclusions of the IEE.
- Section 7 references
- Section 8 acknowledgements

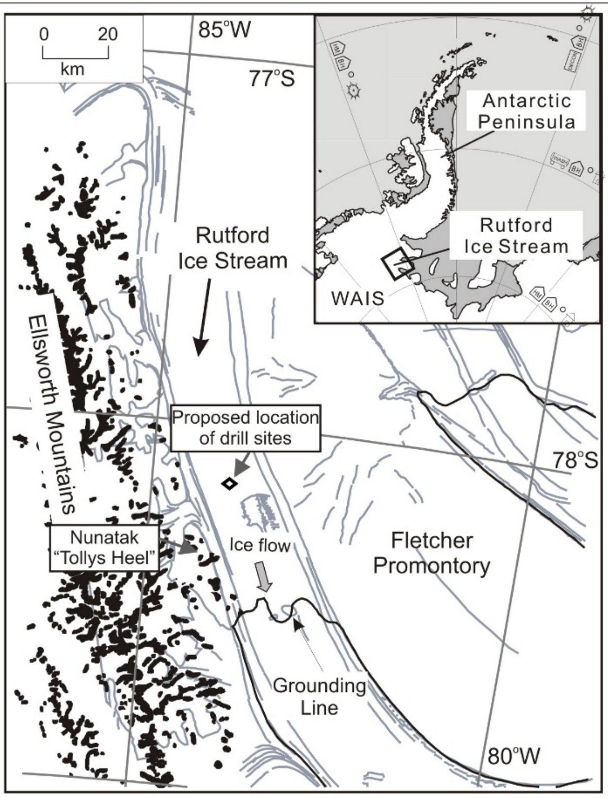
A non-technical summary has been included at the beginning of the document to provide an overview of the IEE in a clear, concise and non-technical manner as well as outlining the conclusions achieved.

2. PROJECT DESCRIPTION

2.1. Project Overview

BEAMISH aims to improve the understanding of the uncertainty in predicting future sea level rise associated with the melting of the Antarctic and the Greenland ice sheets.

Rutford Ice Stream, the proposed location of the project, is one of the fast-flowing glaciers that drain the West Antarctic Ice Sheet (WAIS) and delivers ice to the ocean. The field work for the BEAMISH project will focus on a 20km area centred on the location S78° 08.383' W083° 54.901'. Some activities may extend as far as 50km downstream of the glacier to the grounding line and 100km upstream to the onset region. All proposed locations have been visited on many occasions by BAS personnel in the past 40 years. The main work location is also the site of a long term BAS fuel and science depot, formerly known as RABID, now called BEAMISH.



BEAMISH location map. Black areas are rock outcrop, thin black line is the grounding line, grey lines show ice flow and structural features. Proposed drill location area is indicated. Geophysical surveys will mostly be concentrated in the area surrounding the drill holes.

Figure 1. Location Map

The project involves using a variety of sampling techniques in order to collect data and samples from the surface of Rutford Ice Stream, from within it and from the sediment beneath it. Ice streams are regions of ice sheets which move significantly faster than the surrounding ice. A typical feature of Antarctic ice sheets, the ice streams account for the majority of ice leaving the ice sheet. Most ice streams have some water at their base, which lubricates and speeds up the flow of the ice. The type of bed also affects the flow with soft, deformable sediments resulting in faster flow than hard rock.

It is proposed that ice and sediment cores will be retrieved from four sites on the glacier using a hot water drill. Seismic and radar surveys will be undertaken across the whole of the study area. GPS receivers and seismic monitoring stations will be deployed temporarily on the ice stream for several months each season. During the main fieldwork period in 2017/18, additional GPS stations may be installed at the sides of the ice stream, one at a nunatak on the Northeast edge of the Ellsworth Mountains (unofficial name "Tollys Heel") and one of the ice sheet of nearby Fletcher Promontory.

The purpose of these activities is to study the flow of the Rutford Ice Stream and to map the topography and variations in basal water and sediment in the area around the drill holes. The GPS receivers will track the motion of the ice surface whilst a seismometer array will detect the noise bursts emitted as the ice stream grinds over the underlying bed. The seismic surveys will enable maps to be produced identifying variations in the bed sediment. The radar surveys will map the bed topography and reflect where water beneath the glacier is concentrated or distributed. The two additional GPS stations, on Fletcher Promontory and in the Ellsworth Mountains, will act as stationary control-points, used to improve the accuracy of the GPS results acquired on the moving ice stream.

2.2. Project Schedule

BEAMISH will operate over a period of four years commencing in 2016 and is anticipated to be complete by early 2019.

The initial field season will commence in November 2016 and will involve the completion of radar surveys and the deployment of GPS stations and long term monitoring equipment to support the seismic and radar work. This is anticipated to involve two personnel (one scientist and one field guide) over a three month period.

The main field season is anticipated to last approximately 100 days between November 2017 and February 2018 will involve a field party of up to ten people. All ice and sediment core drilling activities will occur during this season and the permanent monitoring instruments will be installed inside the bore holes. Additional temporary seismic and GPS equipment will be installed and the long term installations repositioned. Radar and seismic surveys will also be undertaken.

The final field season also anticipated to last 100 days will occur between November 2018 and January 2019. A field party of two will undertake seismic surveys, download the data from the permanent instruments and remove and uplift the long term installations. At the end of this season the project will be demobilised and most of the equipment and vehicles, unless allocated to other projects, will be removed from the deep field and returned to Rothera or the UK.

If the permanent instruments continue to function beyond the three year period, it is possible that an additional site visit by BAS Field Operations in Year 4 might be requested to recover data.

Table 1. Summary of Project Schedule

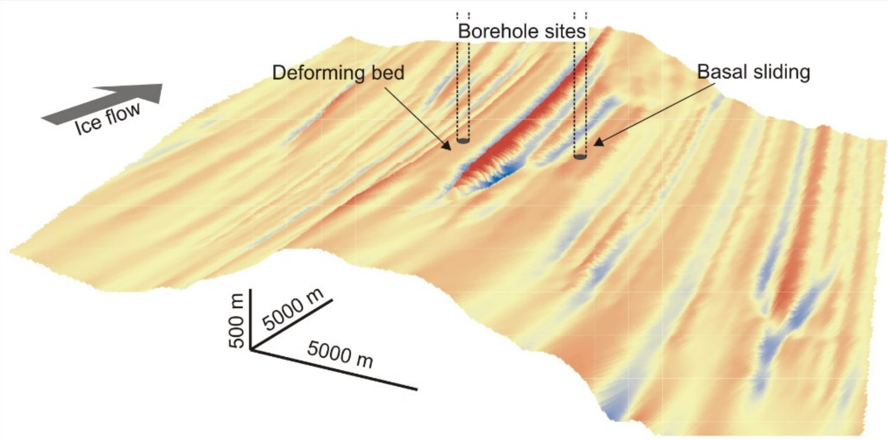
Project	BEAMISH			
Season	**Personnel Involved**	**Location**	**Duration of Activity**	**Brief Summary of activity**
2016 -2017 (austral summer)	• Alex Brisbourne (BAS), Co-I. Field Team Leader • Polar Guide (BAS; formerly "Field Assistant, or FGA")	Rutford Ice Stream. Work will centre around location: S78° 08.383' W083° 54.901'. Possible overland travel up to ~50 km downstream and ~100 km upstream.	• 90 days	• Radar survey. Grids of survey lines towing ice-sounding radar by skidoo. • Temporary GPS installations (up to 2) • Long term installations: seismic, GPS and radar
2017 -2018 (austral summer)	• Andy Smith (BAS), PI. Field Team Leader • Tavi Murray (Swansea University), Co-I • Keith Nicholls (BAS), Co-I • Keith Makinson (BAS), Co-I • Alex Brisbourne (BAS), Co-I • Paul Anker (BAS), Drilling Engineer • Polar Guide (BAS) • PhD student (Swansea University; recruit) • Vehicle Engineer (BAS) • Sridhar Anandakrishnan (Penn State Univ, USA), Collaborator	As above. Also air-supported visits to the Ellsworth Mountains & Fletcher Promontory	• 100 days	• All drilling activities (ice and sediment cores) • All permanent deployments • All transient deployments • Temporary installations (seismic & GPS) • Radar and seismic survey lines • Long term installations repositioned and re-deployed
2018-2019 (austral summer)	• Andy Smith (BAS), PI. Field Team Leader • PDRA (BAS; new recruit) or Polar Guide (BAS)	As above	• 100 days	• Seismic survey lines • Temporary installations (some seismic & GPS) • Download data from permanent installations • Recover and uplift long term installations
2019-2020	**TBC**	As above		If the permanent instruments continue to function, it is possible that an additional site visit in Year 4 might be requested to recover data

2.3. Description of the Project

2.3.1. Hot water drilling, Ice and Sediment Cores

Using a hot-water drill the project team intend to drill four bore holes, in the vicinity of the main study location (S78° 08.383’ W083° 54.901’). There will be two main drilling sites 2km apart and at each site the bore holes will be located 10m apart. Each hole will be up to approximately 30cm wide and up to 2.2km deep; each hole will reach the ice stream bed. A suite of instruments will be available to deploy in the boreholes, some transient and some for permanent installation. It is expected that a different set of instruments will be used in each hole, the details of which are still being determined.

The precise location of the two main drilling sites is still being finalised but they will definitely be located in the main study location noted above. From existing seismic data, it is known that the ice stream bed in this area has two different sediment types, one softer than the other, interpreted respectively as “deforming bed” and “basal sliding”; the two drill locations will target these two bed types. The current proposed locations are shown in the figure below.



Drill hole locations. Perspective view of Rutford Ice Stream bed topography (derived from radar surveys). Heavier shading picks out high and low topography, relative to regional trends, showing subglacial bedforms. Proposed drilling locations are shown; final, precise locations are still being determined.

Figure 2. Drill hole locations

Due to the thickness of Rutford Ice Stream which is greater than 2km thick in places, it could take two days for the drill to reach the base of the ice stream. No drilling fluids will be used during the procedure, only hot water which will be melted from the surrounding snow and ice. Approximately 40,000 litres of AVTUR (aviation grade kerosene) will be burned in the heat exchange process.

Hot water drilling has been identified as the most effective means of obtaining rapid access to the bed of Rutford Ice Stream. The technique has been used routinely by BAS for over 20 years to reliably provide access holes through ice shelves up to a 1000 m thick. Readily available industrial equipment is used to build the drilling system and a schematic of the drilling system is shown in Figure 3 and equipment photos in Figure 4.

Local snow is initially melted and the water stored in a number of large surface storage tanks. The water is then pumped at high pressure and heated via heat exchangers. It is then pumped through the single length 2.3km drill hose to a nozzle that jets hot water to melt the ice. The hose and nozzle are lowered slowly to form a very straight borehole, using gravity as the steering mechanism. (Borehole logging instrumentation will confirm the verticality of the holes). The drill water from the nozzle and the subsequent melt water will return towards the surface via the melted borehole.

A water recirculation cavity will be created near the surface, but below the local hydrological level (200-275m below the ice surface, between the ice floatation pressure or sea level pressure). See Figure 3. Two submersible borehole pumps will be installed in the cavity and will return water to the surface storage tanks. These tanks will be maintained at several degrees above freezing using the heat recovered from the water heater exhausts. The water is then reused by the hot water drill. Several small generators will also provide electrical power for the drill.

During drilling, the water flow, pressure and temperature will be approximately 160l min^{-1}, 1000psi, and 90 °C, while the drilling speed is varied between 2.0m s^{-1} and 0.75m s^{-1}. This will create a hole that will have a uniform diameter of about 30 cm at the end of the drilling process. Creating the water recirculation cavity and a ~2160m access hole to the ice stream bed will take around 2 days.

Detecting when the drill reaches the ice base will be achieved using pressure sensors close to the submersible pumps in the recirculation cavity. These will monitor the water level adjustment when the hydraulic connection between the bore hole and the subglacial hydraulic system is made. The drill will then be recovered and the hole made available for sampling and instrument deployments. Closure of the bore hole, because of refreezing, reduces the diameter at a rate of ~ 0.5cm per hour, resulting in a limited time when the hole will remain large enough to deploy equipment. If additional subglacial access time is required, the hole can be reamed for as long as fuel remains available.

The electrical generators are standard off-the-shelf three-phase 15KVA units, housed in acoustic cabinets and fuelled by unleaded petrol. There will be seven generator units available for powering the hot water drill, which includes provision for spare capacity. Each unit uses up to 7l hr^{-1}, with a total petrol consumption per hole of approximately 1,800l.

The four water heaters, each with exhaust heat recovery units, provide the 1MW of heating capacity for the drill. Secondary heaters are used to provide heat to the submersible borehole pumps. In total approximately 7500l of AVTUR will be used per hole for heating drill water.

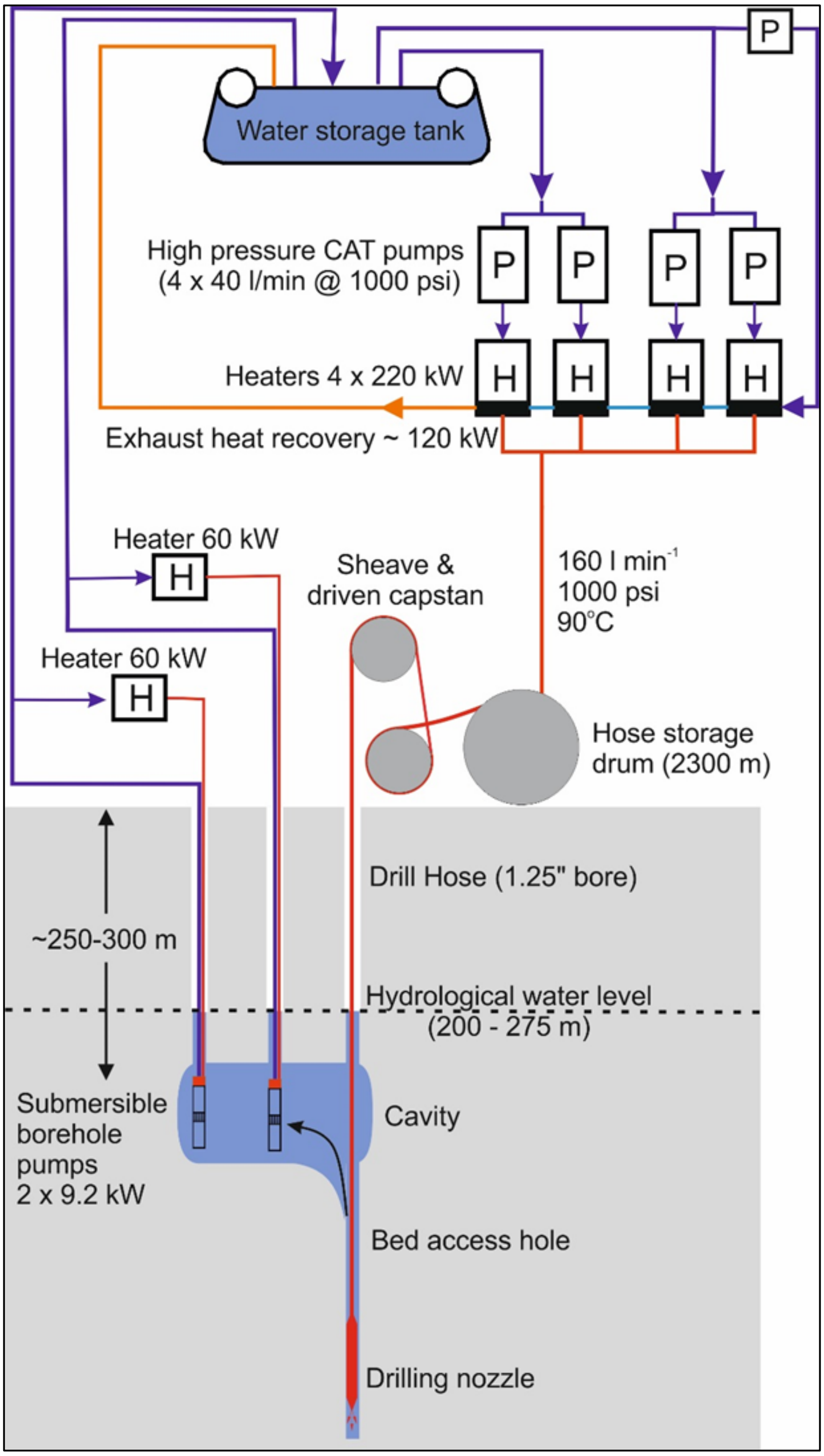


Figure 3. Schematic of the BEAMISH hot water drill system

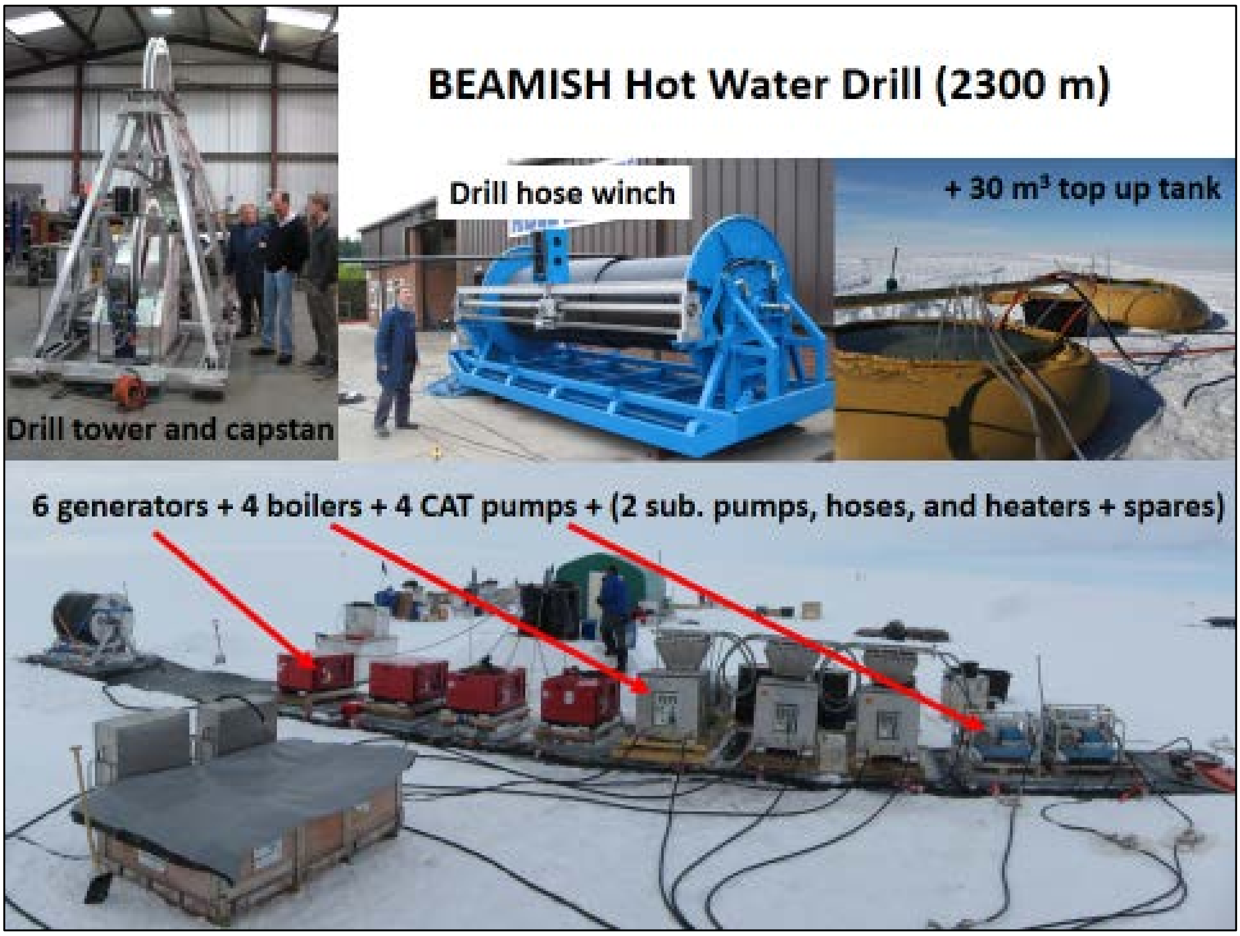


Figure 4. Photos of the BEAMISH drill tower and 2300 m hose winch with level wind. The remaining photos show the equipment units used in the smaller BAS ice shelf hot water drill which are identical to the unit to be used in the BEAMISH hot water drill.

From two of the holes, four sediment core sections up to 6cm in diameter and 3m in length will be recovered from the glacier bed. If time and logistics allow the project team would like to collect more sediment cores up to an estimated maximum volume of $0.1m^3$. Collecting sediment samples to which dating techniques can be applied, is a fundamental part of the BEAMISH Project.

A section 12 permit from the Foreign and Commonwealth Office (FCO) will be applied for prior to the 2017-2018 season when the sediment cores will be collected, as per the requirements of the Environmental Protocol.

Ice cores will be retrieved from specific depths within the ice column, where ice of particular interest is expected (e.g. specific crystallography or included material). Sections of ice up to 3m long will be recovered, each up to a maximum of 10 cm diameter. It is anticipated that a maximum of 6 ice cores will be acquired, a total volume of less than 0.2 cubic metres. Core length, diameter and weight will be measured on site. The cores will be kept frozen and returned to the UK for further analysis.

During the drilling process, samples of the drilling water will be taken to determine any biological content in the melted snow and the drilling system. To complement these, samples of uncontaminated surface snow will also be collected in sterile sample bottles upwind of the BEAMISH site, early in the project. These will be similarly analysed to determine any natural contaminant of the snow. This information can be compared with samples recovered from the ice stream bed to assess the possible impact from the drilling and bed sampling activities themselves. Total water and snow sample quantities are expected to be less than 50 litres, which will be returned to the UK for analysis.

Once the sediment samples have been collected a number of instruments will be deployed into each borehole. See Section 2.3.2 below for details. After the drilling is completed the holes will be left to refreeze naturally.

2.3.2. Bore hole Instruments

Once each of the four boreholes has been drilled a number of instruments and equipment will be deployed inside the holes to measure various elements of the ice stream. Some of these instruments will be transient i.e. deployed and recovered immediately, whilst others will be permanent installations and will not be retrieved.

The full suite of instruments planned for the boreholes is outlined below. The schedule of instrument deployment is expected to be different for the different holes and the details of this are still being determined.

2.3.2.1. Transient deployments

The deployment of each transient instrument will take up to approximately 12 hours. They include:

- Percussion corer
  This is the equipment used to retrieve the sediment samples once the borehole has been drilled. It will be deployed approximately 10 times in order to collect four good quality sediment cores. It is 5m in length, has a diameter of 20cm and consists of both steel and plastic components. It is deployed and retrieved using a winch-mounted, 2.5km long Kevlar rope.

- Camera
  A GoPro camera (or similar brand) will be used to record any visible imagery within the borehole. The intention is to record the nature of the ice, the glacier bed and the water system. It is also proposed to capture images showing how much sediment is frozen into the bottom of the ice stream. Each camera will be cased in a steel housing and will carry an on-board lithium battery, camera optics and electronics. It will be deployed concurrently with other equipment (mounted on the drilling hose, for example), but possibly also independently ~4 times in total, using a steel cable, 3mm in diameter and 2.5km long.

- Sonic Log
  A sonic logger will be deployed to determine the ice fabric (crystal size and orientation) by measuring the time taken for a sound pulse to travel through the ice from one end of the logger to the other. This is a single instrument comprising electronics and components in a sealed, pressure-tight housing and will be deployed using a dedicated umbilical cable of steel, copper & plastic. The logging tool is approximately 1m long and 20cm diameter and has a winch-mounted umbilical cable 2.5 km long. The deployment scheduled for the sonic logger is still to be determined but it is expected to be deployed once, in the second borehole and once in the fourth borehole.

2.3.2.2. Permanent deployments

A number of instruments will be installed into the ice column inside the boreholes and in the glacier bed. These will freeze in place within the ice and will not be retrieved. They will remain permanently in place, until they eventually melt out of the bottom of the ice and ultimately fall to the sea bed. These instruments will detect a number of different aspects with the boreholes.

A. Instrument strings.
These will comprise of approximately twenty individual sensor packages (each ~20cm long, 6cm diameter) distributed along a 2.2 km-long cable. Throughout the ice column these will measure the ice column temperature and its deformation. At the ice-bed interface, the water pressure will be measured. Pressure sensors will also be placed in the ice column, but once the hole freezes, the output from these will be meaningless.

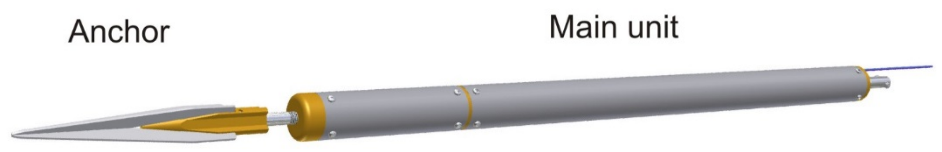
Some of the instrument strings are still being designed, but one set is already available and is shown in the photographs below

Existing instrument strings. Sections of each cable on individual reels are shown in the left-hand image, with a sensor package visible on top of each reel. Right-hand image shows one complete instrument string; the metal pressure-housings of the sensor packages can be seen at different locations along the cable.

Figure 5. Photos of Instrument Strings

B. Fibre-optic cables.
These will each comprise two 2.2km-long strands of fibre-optic cable that will be installed in the boreholes. Once frozen in place, measurements taken at the surface cable-ends will give the ice column temperature profile and vertical deformation.

C. Tethered stake.
At the glacier bed, the rate of slip of the ice across the bed will be detected by the relative displacement between an anchor installed into the bed sediment, and a monitoring unit still fixed within the ice. The design for this tethered stake is almost complete and is shown below.



Engineering sketch of a tethered stake instrument. The main unit stays within the ice near the bottom of the borehole. The anchor detaches on insertion into the sediment bed but remains attached to the main unit by thread, which unreels as the two parts separate. This unreeling is detected within the main unit, thus measuring the motion of the ice over the bed.

Figure 6. Tethered Stake

D. Subglacial plough

The strength of the bed sediments will be detected using a steel rod (3-4m long) installed into the bed, with its upper end still fixed within the ice above. As the ice moves, the rod will be dragged through the sediment. Any deformation experienced by the rod will be detected by strain sensors mounted at different positions along the rod's length. This instrument is still being designed.

Overall, there should be ten installations of permanent instruments. At each of the two locations there will be one of each type given above, except for the fibre-optic cables, for which there will be two. The details of which instruments will be installed in which of the two holes is still being determined.

All of these installations will be connected to data loggers at the surface by wires or fibre-optic cables. None of these instruments will be retrieved but all the surface data loggers will be removed over the following 1-2 years. Loggers will be contained within plastic or aluminium boxes (up to ~$0.2m^3$), powered by two 100 Ah sealed-gel lead acid batteries with a solar panel and wind generator.

These permanently-installed instruments will comprise the following materials:

- Steel and copper cables & fittings; plastic coatings
- Fibre-optic cables (glass with plastic sheath)
- Plastic (kevlar) rope and string
- Small (a few centimetres in size) circuit boards, strain gauges and sensors
- Steel, aluminium and brass components and weights

All the permanent deployments will be installed during the main field season in 2017/19. In the following field season of the project (2019/20) they instruments will be revisited to download data from the surface loggers. Following the final visit anticipated to be in 2019, data loggers and all other accessories will be removed. For instruments that could be re-measured in later years opportunistically, markers will be left in place until instruments are finally permanently abandoned and completely buried by snow.

2.3.3. Long Term Installations (Up to 3 years)

On the surface of the glacier a number of geophysical experiments will be undertaken. These are designed to study the flow and deformation of the ice, any basal melting and any natural seismicity caused by the ice sliding over the bed.

Up to six instruments (two each of passive seismic, GPS and radar as described below) will be installed for a period of up to three years in the areas close to the drill hole locations.

Each of these instruments will be retrieved at the end of the project which is scheduled for the 2018/19 Antarctic summer. Bamboo and aluminium marker poles will be installed to identify instrument locations and to mark hazards for future operations and field parties to be aware of. Detailed site maps will be kept and lodged with BAS Operations at the end of each summer season. All instruments, accessories and aluminium markers will be retrieved at the end of the 3 years.

All these stations (passive seismic, GPS and radar) will be based on the power systems developed by BAS over a number of years and deployed regularly at many locations, including the recent iSTAR overwinter GPS Stations on Pine Island Glacier, for example (see photograph, below). Batteries (100Ah, sealed gel, led-acid) will be housed in standard ~0.5 m^3 insulated wooden boxes (2 batteries per box), buried ~0.5 m below the snow surface to protect them from the worst of the winter temperatures. Data loggers and other electronics will be housed inside small aluminium Zarges boxes or plastic Peli cases, also buried just below the surface. The rest of the power system, those components which remain at the surface, will be anchored, guyed and marked as normal for these installations.

Example of recent iSTAR overwinter GPS deployment.
The BEAMISH overwinter, long term GPS deployments will be similar to these, although they will have fewer components (only one wind generator, for example). Battery boxes, logging equipment and other electronics are buried beneath the surface.

Figure 7. GPS Deployment

2.3.3.1. Passive seismic monitoring stations

Two passive seismic monitoring stations, which detect the natural seismicity from the ice stream bed as the glacier moves over it, will be deployed. Each long term passive seismic station will comprise:

- Sensor
- Data logger
- Batteries (4, sealed- gel lead-acid, 100 Ah)
- Solar panel

- Wind turbine
- Cables components, enclosures & mounting poles

The sensor will be buried ~1m below the snow surface, and ~10m away from the rest of the installation, to eliminate wind and other surface-environmental noise. A long cable will connect the sensor to the logger.

2.3.3.2. GPS stations

Two GPS stations will record the motion of the ice stream and any variations on daily, seasonal and annual time-scales. Each long term GPS station will comprise:

- Receiver & antenna
- Batteries (4, sealed- gel lead-acid, 100 Ah)
- Solar panel
- Wind turbine
- Cables components, enclosures & mounting poles

The GPS antenna will be mounted on a pole ~2m above the snow surface.

2.3.3.3. Radar stations

Two radar stations will be deployed which will show where water beneath the glacier is concentrated or distributed.

Each long term radar station will comprise:

- Antennas
- Radar
- Batteries (1, sealed- gel lead-acid, 100 Ah)
- Cables components, enclosures & mounting poles

The radar antennae will be buried just beneath the snow surface.

2.3.4. Temporary installations (Up to 3 months)

During each of the three field seasons, a number of geophysical instruments will be deployed for up to 3 months at a time. These will all be uplifted and removed at the end of each summer. Most of these temporary installations will be within 10km of the main study location S78° 08.383’ W083° 54.901’.

Twenty GPS stations are expected to be deployed to measure both spatial and temporal variability in movement of the ice. Each station will comprise a GPS receiver and antenna, battery and solar panel. The location of these stations is still to be determined; some will be co-located with passive seismic instruments (see below), others will be located to relative to specific ice flow characteristics.

Up to 100 passive seismic monitoring stations will be deployed to measure spatial and temporal variability of seismic events at the ice-bed interface. Station locations are still being determined. These will be chosen to give information on different basal conditions and how the ice moves over the bed. Locations may also be changed during the main drilling periods to detect intra-ice and ice-bed seismic activity associated with the drilling and access to the bed.

Some passive seismic stations will comprise separate sensor, logger, battery and solar panel. Others will use integrated installations in which the sensor, logger and battery are contained in a single unit; these stations will require downloading and recharging every few days. All instruments installed during the BEAMISH Project will be well marked and re-locatable, however short or long their deployment period.

2.3.5. Seismic Surveys

Seismic surveys will be used to determine the nature of the ice stream bed (i.e. the kind of material the ice is resting on – sediment, rock or water) and mapping the subglacial topography. They involve detonating a small (normally 300g) charge of high explosive, buried ~20m below the snow surface, and recording the echoes that come back from the bed. Most of the work will be carried out within ~10km of the main drill locations but some work could be carried out as far away as the grounding line region, 50 km downstream and the onset region, 100 km upstream.

Seismic surveys will be carried out in the second and third BEAMISH field seasons (2017/18 and 2018/19). In total, between 50 and 10km of seismic line is expected to be acquired, requiring 2-4 people. A small hot-water drill is used to drill 20m-deep holes, in which the charges are buried. The seismic work also involves using skidoos for transport and sealed-gel lead acid batteries (100 AH and 20 Ah) to power the data acquisition instruments. Batteries will be re-charged each day using solar panels. Over the complete BEAMISH Project, around 500 seismic shots are expected, using a total of ~300kg of explosives.

The use of explosives will follow appropriate safe operating procedures of handling, storage, transport, use and disposal. These are given in the BAS Explosives Code of Practice and the associated risk assessments. At least one person, who is suitably trained and experienced with explosives, will always be available and will be responsible for activities. The small hot-water drill is used to make the holes in which the charges are buried. Refilling the holes once they are charged means that there is no surface disturbance when the charge is detonated. Detonation results in normal products of combustion and is contained within the snowpack.

At the end of the project, excess explosives and detonators will be either destroyed on site by controlled detonation, or transferred by BAS to subsequent projects elsewhere. Explosives packaging will be burned on site to comply with Health & Safety guidelines. This will be done in a small pit dug into the snow, which will be re-covered with fresh snow once completed.

2.3.6. Radar Surveys

Radar surveys will be used to map the ice stream bed topography and internal structure. Most of the work will involve towing a BAS-designed radar behind a skidoo along a grid of pre-planned lines. The radar is battery-powered and comprises a Nansen sledge on which most of the equipment is mounted and a line of antennas that are towed behind the skidoo and sledge. The batteries which power the radar are sealed gel lead acid (100Ah and 20Ah) and are recharged each day using solar panels and small generators.

Most of the radar work will comprise grids of parallel survey lines, crossing almost the full width of the ice stream, and spaced 500m apart. Each survey grid will be up to roughly 20km x 20km in area. Occasional single survey lines (i.e. not part of a regular grid) will be acquired for information on specific, individual bed targets (crossing the ice stream ground line, for example). Smaller, closerspaced grids might also be acquired (e.g. 3km x 2km at 20m spacing) when more spatial detail of a specific target is required.

The radar equipment and operations have been developed by BAS over the last decade and are standard procedures on a number of projects each season. Every line is driven by one or two people (depending on safety and weather conditions), each with a skidoo. Radar surveys will be carried out in the first and second BEAMISH field seasons (2016/17 and 2017/18). Around 1000-2000 km of radar data, in total is expected each season.

2.4. Description of Support Activities

2.4.1. Tractor Traverse

In order to provide BEAMISH with the necessary fuel to operate the hot water drill, a tractor traverse will depot supplies in the 2016-2017 season ready for the drilling to take place the following year. A proportion of the fuel and some science equipment has already been deposited on the edge of the Ronne Ice Shelf at the Three Ronnes Fuel Depot (S76 53.377 W53 04.350). Between January and February 2017, the RRS Ernest Shackleton will deliver additional fuel and vehicles to this location.

The tractor traverse team will be flown in by BAS twin otter planes and the first of two tractor traverses to support BEAMISH will start in November 2016 and run through until February 2017. The first traverse will travel as far as Depot 1, the exact location of which is yet to be decided, but it will be in the south west corner of the Ronne Ice Shelf. This depot will be a new site and will be established in accordance with the normal BAS fuel depot protocols. The location of Depot 1 will be dependent on a number of factors including weather, progress made during the traverse and confirmation of other logistical requirements for future science projects. Some equipment and fuel will be deposited and the vehicles will return to the coast to collect further quantities of fuel.

The second traverse will commence in February 2016 and will aim to reach the BEAMISH depot on the Rutford Ice Stream by March 2016, having collected the other equipment already at Depot 1 if time and weather conditions and time allow. Alternatively, if this option is not possible the fuel and equipment at Depot 1 will be collected early in the 2017-2108 season. By the end of the 2016 -2017 season it is the intention that the vehicles, equipment and fuel from the second traverse will be overwintered at the BEAMISH depot.

The traverse will be co-ordinated by Tim Gee, the Traverse Leader and supported by three other drivers. The following vehicles will be used;

- 3 x Kassbohrer Pistonbully PB300 Polar tractors;
- 6 x long poly sleds, carrying a total of 16 fuel bladders;
- 1 x short poly sledge;
- 3 x metal cargo sledges, one of which carries an accommodation caboose; and
- a number of small wooden or plastic utility sledges.

The tractors named Polar 2, Polar 3 and Polar 4 will tow the fuel and science equipment including the drill across the Ronne Ice Shelf to the Rutford Ice Stream. The tractors are able to tow large loads at reasonable speeds with good fuel efficiency. Fuel consumption of all three tractors will be approximately 36,000 litres in the 2016-2107 seasons.

The tested combined total weight towed by the three tractors (including their own weight) will be 120 tonnes. Each tractor alone can tow over 43 tonnes. The average speed of the tractors is anticipated to be 12km/h based on previous traverses.

The poly sleds are specifically designed for towing fuel. They consist of a 21metre long sheet of high molecular weight (HMW) polyethylene, with metal towing hitches on both ends. The plastic is light, wear-resistant and much more flexible than metal sledges. The sledges are designed to carry four fuel bladders each capable of holding 5,800 litres of AVCAT or AVTUR (approximately 20 tonnes in weight when full). In total 126,000 litres of fuel will be transported in this manner; 48,000l of AVTUR and

10,000l of petrol, which will be for the BEAMISH project and other future science projects; and 23,300l of AVTUR will be used for the FISS project (see separate IEE). The rest of the fuel will be used to power the piston bullies and includes some contingency. One spare bladder will be available on the spill kit sledge to facilitate fuel transfers and for emergency use.

An additional shorter poly sledge will be used to tow four skidoos behind the tractor train when these are not in use. The more traditional sledges in the tractor traverse are steel Lehmann cargo sledges. These are heavy solid sledges used to transport fuel drums, field and scientific equipment.

Skidoos and utility sledges (Nansen, komatik or pulks) will be carried on the traverse for use in the main drilling season of 2017-2018. These will be used for smaller groups working away from the main drilling site. The skidoos have four-stroke engines, giving better fuel economy, more torque and lower emissions than models previously used with two stroke engines. It is anticipated that 10,000 litres of petrol will be requires to fuel the skidoos and generators during the project.

During the main drilling season one of the Pistonbully tractors will be used to transport the hot water drill to the desired locations on the Rutford Ice Stream. It is anticipated that 5,000 litres of fuel will be used to achieve this.

A comprehensive fuel spill kit will be carried during the traverses and during the main drilling season. This will be stored on a single Komatik or Siglin sledge to ensure easy access and deployment. The spill kit includes the following:

- Spare fuel bladder – capacity 5,800 litres;
- Spare empty fuel drum;
- Spate pump and hoses;
- Emergency bladder repair kit; and
- Absorbent spill mats, pig putty and drum funnels.

An oil spill contingency plan has been produced, which will be carried at all times with the spill kit. All the team members including the support drivers will be fully briefed on the appropriate procedures to use in the event of a spill and be competent in deploying the spill equipment and repair kit.

2.4.2. Fuel Depot

The main fuel depot for BEAMISH is a site that has been used by BAS to store fuel for many years depot (S78° 07.430 W083° 57.218, elevation 1100'). The main fuel stocks for BEAMISH will be established in the 2016-2017 season when the tractor traverse arrives. Fuel will be transported from the current location at the Three Ronnes depot (S76° 53.377 W53° 04.350) across the Ronne Ice Shelf onto the Rutford Ice Stream

This will include:

- 116,000 litres AVTUR in 20 bladders (48,000 litres of which is specifically for the BEAMISH tractor traverse);
- 50 x 205l drums of petrol
- 115 x 205l drums of AVTUR (which are already on site)
- 2 x 205l drums of kerosene

It is anticipated that approximately 40,000 litres (20 drums) of this fuel will remain at the BEAMISH fuel depot beyond 2019, for other science projects anticipated in the vicinity of the Ronne Ice Shelf.

In addition to the fuel listed above 40,000 litres of AVTUR and 8,000l of drummed petrol will be cached at the BEAMISH drill site, ready for drilling activities in the 2017-2018 season.

2.4.3. Field Camps

During the initial tractor traverse an accommodation caboose will be transported intended as a shelter, work space and cooking area. It consists of a modified shipping container mounted on one of the Lehman sledges and is fitted with a kitchen, snow melting system, generators, batteries and communications equipment. Toilet and shower facilities are also included. Solid human waste and all other camp waste will be contained and returned either to the RRS Ernest Shackleton or airlifted back to Rothera for segregation and disposal. Waste management in the field will be organised as per the BAS Waste Management Handbook 2016 edition 9 and the Field Operations Manual. Liquid human waste and strained grey water will be disposed of on site.

The caboose will not be used during the science fieldwork. Instead tents will be used for accommodation and for additional working space if required. There will be a single main camp at the BEAMISH drill site established for up to 100 days. Power at the camp will be provided by batteries, solar panels and small generators (1-3kw). 88kg of propane gas and 400l of paraffin will be used for cooking, and AVTUR fuelled Webasto heaters will be used for heating.

2.4.4. Overwinter Depot

The three Pistonbully's along with approximately 68,000 litres of AVTUR (drummed and in bladders), and 10,000 litres of petrol will be stored at the BEAMISH depot over the austral winter of 2017. The majority of the equipment; tractors, caboose, science equipment, sledges and fuel, will be placed on 2m high snow berms. (Berms are platforms of snow created at a height above the anticipated snow accumulation level.) This is a long established and effective technique which greatly reduces the burial of equipment by snow overwinter.

During the 2017-2018 season only one Pistonbully will be deployed on the BEAMISH project and this will be overwintered again in 2018. The other two vehicles will have been deployed elsewhere on other science projects

Batteries will not be stored on berms but will instead be buried 1m below the snow surface to protect them from the coldest air temperatures. These will be located away from the berms, marked sufficiently well that successful relocation can be guaranteed after two winters (i.e. one more than expected) and an absolute position determined by GPS receiver.

Explosives and detonators will be stored at the overwinter depot in accordance with appropriate safety guidelines. This may be on berms, or elsewhere, depending on circumstances and other activities at the time the depot is being established. Explosives and detonators will not be stored together, nor will they be stored in direct proximity to other hazardous items. All explosives and detonators will be appropriately marked with poles and flags, and clearly marked on the depot plan.

2.4.5. Removal of Science Equipment and Traverse Vehicles

Completion and demobilisation of the third science season in 2018-2019 will mark the end of the BEAMISH project. Personnel and some scientific equipment will be uplifted by BAS twin otter from the BEAMISH depot. It is planned that a final demobilisation traverse for BEAMISH will occur between January and February 2019. The three Pistonbully tractors, fuel bladders, all the larger BEAMISH science equipment, field camp equipment and waste will be transported to the Abbott Ice Shelf, using approximately 12,000 litres of fuel to get there. The intention is that the RRS Ernest Shackleton will meet the traverse and uplift all equipment not being deployed for other science programmes. All waste materials will be removed at this time.

3. DESCRIPTION OF THE ENVIRONMENT

3.1. Rutford Ice Stream

Rutford Ice Stream is a typical fast-flowing, dynamic WAIS ice stream. It is approximately 180 miles long and over 15 miles wide and drains south easterly between the Sentinel Range of the Ellsworth Mountains and Fletcher Promontory, into the southwest part of Ronne Ice Shelf.

The ice stream extends to over 2000m below sea level and is located in a deep trough between the Ellsworth Mountains and Fletcher Promontory. It is understood that the trough is a tectonic feature which may have ensured the stable position of the ice stream for millions of years. The flow speed of the ice stream reaches a maximum of 400 metres a year approximately 40km inland from where it meets the Ronne Ice Shelf and starts to float on the sea. Tidal changes are known to have a significant impact on the speed of Rutford Ice Stream.

Within the ice stream there is no ice-free ground. There is no known habitat for any flora or fauna and there are no protected areas in the local vicinity. The area has been visited many times by BAS over the past 30 years, and since 2000 has been the location of a fuel depot which was previously known as RABID.

3.2. Subglacial lakes

There are no known subglacial lakes in the immediate vicinity of the study area. The closest known lake is Subglacial Lake CECs (SLC) more than 150km away, on the other side of the Ellsworth Mountains. The shortest flow-line distance to the nearest subglacial lake is many hundreds of kilometres.

There is one report of ice surface elevation changes measured by satellite in 2003-2008 at a location approximately 10km to the SW (i.e. across the flow, rather than along it) of the BEAMISH project site. However, repeated, comprehensive coverage by radar surveys (the most reliable method normally used to identify lakes beneath the ice) of the ice stream bed and surface in this area show no evidence for a subglacial lake, and no further surface elevation changes have been reported.

3.3. Nunataks

Nunataks are rare exposures of the Earth's crust not covered with ice or snow within (or at the edge of) an ice field or glacier. One nunatak will be visited as part of the project, at the north east edge of the Ellsworth Mountains.

Whilst there are low levels of biological material recorded for these nunataks some lichens are known to be present. Most life is microbial in nature and micro invertebrates have been recorded such as tardigrades, nematodes and rotifers, but not micro arthropods as yet. Higher plant life is absent and mosses are extremely rare.

3.4. Protected Areas

There are no protected areas within the vicinity of the BEAMISH drill sites, survey areas or proposed tractor traverse routes. This includes Antarctic Specially Protected Areas, Antarctic Specially Managed Areas or Heritage Sites and Monuments. In addition none of the project activities are in proximity to any International Bird Areas.

4. ALTERNATIVES

4.1. Do nothing

BEAMISH aims to improve the understanding of the uncertainty in predicting future sea level rise associated with the melting of the Antarctic and the Greenland ice sheets. When completed, the BEAMISH project will provide information on:

- An age for the most recent collapse of the ice sheet in this region;
- The water system beneath the ice;
- The thermal regime of the ice and bed; and
- The partition of ice motion between the three different flow mechanisms – sliding, ice deformation and bed deformation.

The timing of the last ice sheet collapse will be extremely valuable because no other information yet exists in this region. It will help scientists to understand the way the ice sheet has changed as climate has warmed and cooled in the past.

Beneficiaries of this work include:

- Scientists involved in understanding cryospheric response to climate change, long-term climate modelling, ice sheet modelling, eustatic component of sea level change
- The glaciological community concerned with establishing subglacial conditions, particularly those beneath the West Antarctic Ice Sheet
- Cryospheric modellers requiring field observations to improve model parameterisations

The 'do nothing' alternative has been considered and rejected on the grounds of the important scientific benefit that will be gained from carrying out the project.

4.2. Do the activity elsewhere

The biggest uncertainty in predicting future sea level comes from the Antarctic and the Greenland ice sheets where the contribution to sea level rise is increasing much faster than anticipated. The melting on both continents has the potential to trigger irreversible changes to sea levels that could continue for many centuries. Reducing this uncertainty is currently one of the biggest challenges in glaciology. Rutford Ice Stream is typical of the fast-flowing glaciers that drain much of WAIS. It was chosen as the location for the BEAMISH Project for a number of reasons. Firstly, considerable data on surface flow and general basal conditions are already available from previous research; no other location anywhere in Antarctica has such comprehensive supporting data. Secondly, no date of the most recent ice sheet collapse is available for this region of West Antarctica. Thirdly, it is within the area of regular BAS operations, logistically feasible and a safe working location.

The option of using an alternative location has been rejected on the grounds that the proposed studies will enable more accurate predictions to be made with regard to climate change and sea level rise.

4.3. Do the activity with alternative science

Characterising ice stream dynamics and how ice, water and the sedimentary bed interact will help us to understand the processes by which ice streams move, and how we should include these processes into models. The results will help to clarify previous work from ice streams elsewhere in Antarctica, which in some cases have been contradictory or inconclusive. Overall, these results will be big steps forward in our ability to understand the way ice sheets behaved in the past, what controls them today, and how they might evolve in the future.

Hot water drilling has been identified as the most effective means of obtaining rapid access to the bed of Rutford Ice Stream. The technique has been used routinely by the British Antarctic Survey (BAS) for over 20 years to reliably provide access holes through ice shelves up to a 1000m thick.

An array of different scientific methods and techniques are proposed during the project in order to gain as much data as possible about the complex interactions of the processes taking place. These are considered to be the most appropriate techniques currently available which are suitable for deployment in Antarctica.

4.4. Do the activity with alternative logistics

BAS is always looking to use logistics which provide a long term legacy of improved capability. Over the past five years BAS has gained a huge amount of experience in operating tractor traverses. This technique has now become the preferred technique to support large-scale science activities in remote deep field locations in Antarctica. For the BEAMISH Project, combining tractor traverse capability with traditional methods of field activity is the most efficient logistics approach. The heavy equipment and bulk supplies will be delivered to the project site on Rutford Ice Stream by tractor traverse. One Pistenbully tractor will also be used during the fieldwork for depot work, moving equipment and other camp activities, whilst most of the scientific work (instrument installations, seismic surveys, radar surveys etc) will be done with skidoos. The proposed logistics are considered to be the most efficient use of resources in order to achieve the proposed science.

5. IMPACT IDENTIFICATION & MITIGATION MEASURES

Environmental impacts associated with BEAMISH have been identified in this chapter. Mitigation measures to minimise or avoid these impacts have been suggested beneath each impact. Table 2 provides a summary of those impacts and provides a qualitative measure of the probability of the impact occurring and the severity of the impact if it were to occur.

A staff briefing will be provided to members of the BEAMISH team prior to deployment in the 2017-2018 season. This will provide an overview of this IEE and specific guidance on compliance with the mitigation measures committed to within this document.

5.1. Hot Water Drilling

(i) **Potential Impact:** Seven generators will be used to power the hot water drill. Each unit uses up to 7 l hr-1, with a total petrol consumption per hole of approximately 1800 l. In additional four water heaters will be used to melt snow. In total approximately 7500 l of AVTUR will be used per hole for heating drill water. The risk associated with this activity is of a fuel spill during refuelling or operation of the drill which could contaminate the snow and ice in the vicinity.

Mitigation: All equipment will be well maintained prior to use and will be checked and serviced regularly during the time in the field. Equipment will be shut down when not in use to minimise fuel use.

A heat recovery system has been incorporated into the heat exchangers to maximise fuel efficiency.

Experienced staff will operate the equipment and will be briefed on spill response procedures outlined in the BAS Traverse Operations Manual and the Tractor Traverse Oil Spill Contingency Plan. Spill trays, funnels and absorbent pads will be used during any refuelling activities. A spill kit will be kept on site throughout drilling activities. Any spills will be reported on the BAS incident database AINME, and any spills greater than 1000l will be reported the FCO. Any contaminated oil spill absorbents will be removed from Antarctica via Rothera as hazardous waste and packed according to the BAS Waste Management Handbook.

(vi) **Potential Impact:** Major failure of equipment resulting in the drilling equipment becoming irretrievable.

Mitigation: Only experienced and appropriately trained staff will operate the equipment. Operating procedures will be carefully followed each time the drill is deployed and only established drilling techniques will be used.

(vii) **Potential Impact:** Drilling into subglacial environment could result in contamination of sediments and water.

Mitigation: The proposed drilling location is on the periphery of the grounded ice sheet, 40km upstream of the grounding line. It is known from geophysical observations that the ice flow and basal conditions are modulated by the ocean tides. The bed is mostly re-worked, deforming sediments, saturated with high-pressure pore water. The hydraulic gradients for the trunk of the ice stream where drilling will take place, are strongly downstream towards the ocean. If any drilling water entered the basal hydrological system it would be driven in the same direction and will enter the ocean at the grounding line.

These factors all suggest that the proposed drilling site is a marginal location and is not considered to be a pristine, isolated subglacial environment. Drilling for the BEAMISH Project will use hot water, derived by melting local snow, so any potential contamination will be minimal.

(i) **Potential Impact:** Air pollution will result from the operation of the hot water drill. This includes the combustion of AVTUR for the heat exchange process and through the use of petrol generators to power the drill.

40,000 litres of AVTUR will be used and 10,000 litres of petrol. Emissions will be the standard products of combustion of these fuels, including carbon monoxide, carbon dioxide, nitrous oxides, sulphur dioxide, heavy metals and particulates. The greenhouse gas emissions associated with the use of all the equipment on the project will be calculated for inclusion in the BAS carbon report.

Mitigation: Daily visual checks will be made of exhausts. Engines will be serviced at the required intervals and any maintenance to reduce atmospheric emissions carried out as required. Equipment will be shut down when not needed.

5.2. Sediment Coring

(i) **Potential Impact:** There is a risk that the sediment corer could become disengaged during operation and be irretrievable from inside the borehole. This could result in unnecessary waste being generated in the field which could never be recovered.

Mitigation: Only experienced and appropriately trained staff will operate the equipment. Operating procedures will be carefully monitored each time the corer is deployed. Any lost equipment will be reported to the BAS Environment Office.

5.3. Deployment of Camera

(i) **Potential Impact:** There is a low risk that the camera could become disengaged during operation and be irretrievable from inside the borehole. This could result in unnecessary waste being generated in the field which could never be recovered.

Mitigation: Only experienced and appropriately trained staff will operate the equipment. Operating procedures will be carefully monitored each time the corer is deployed. Any lost equipment will be reported to the BAS Environment Office.

5.4. Deployment of Ice Column Instruments

(i) **Potential Impact:** Deployment of equipment in the ice column will result in a permanent introduction of manmade items including hazards materials.

Mitigation: This is an unavoidable output of this type of equipment deployment. For practical as well as environmental reasons, all this equipment will be as small, simple and low-power as possible. A record of equipment which is deployed and left in the field temporarily or permanently will also be made by the PI and submitted to the BAS Environment Office.

5.5. Radar, GPS and Seismic Monitoring Station deployment – Ice Stream

(ii) **Potential Impact:** Possible non-recovery of temporary radar, GPS and seismic monitoring stations from ice stream. Total number to be deployed is two of each.

Mitigation: The intention is that each of these instruments will be retrieved at the end of the project which is scheduled for the 2018/19 Antarctic summer. Each installation has been designed to be sufficiently robust to endure the deployment period and anticipated conditions.

Bamboo and aluminium marker poles will be installed to identify instrument locations and to mark hazards for future operations and field parties to be aware of. Detailed site maps will be kept and lodged with BAS Operations at the end of each summer season. All instruments, accessories and aluminium markers will be checked each year of the project and will be retrieved at the end of the 3 years.

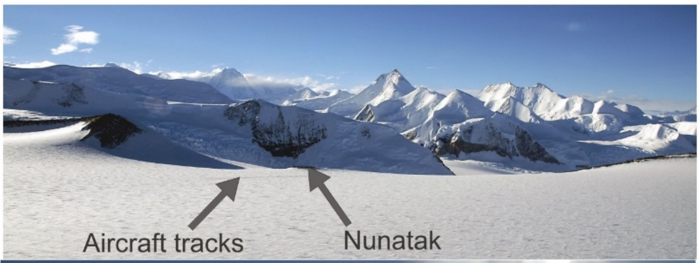
5.6. Temporary GPS Deployment – Ice stream, Ice Sheet and Nunatak

(i) **Potential Impact:** Possible non-recovery of temporary GPS systems from ice stream and adjacent locations. Total number to be deployed is up to 20 systems (actual number varies each field season).

Mitigation: The intention is to leave the GPS systems in the field for up to 3 months maximum before revisiting, retrieving the data and removing them. All equipment will be tested prior to deployment. The GPS systems will be removed at the end of each summer season. If equipment cannot be recovered this will be reported to the BAS Environment Office for input into the lost equipment log.

(ii) **Potential Impact:** The intention is to leave one GPS installed on at the edge of the Ellsworth Mountains, on a nuntak for up to 3 months. After the GPS is removed a small cairn of local rocks will be replaced at the site to mark where the occupation was made and enable future comparative research. The impact of this is that site will lose some its wilderness value.

(iii) **Mitigation:** The proposed site has been used for this purpose before and was chosen for its lack of prominence and accessibility, to minimise impact, as well as for satisfying the necessary science criteria. No permanent markers will be installed or fixed to the rock. A small rock cairn already exists at the site but no other evidence of the occupation will remain once the GPS is removed. Marking and logging the sites will provide an accurate record of where science has been undertaken and will aid future comparative research. All other sites will be on snow and no trace of the occupations will remain once they are removed.



Nunatak which may be used for a temporary GPS deployment.
Upper left image is taken from the air during approach to the site. Lower left image, taken from the adjacent icefield, shows a previous temporary GPS occupation. Image below shows the site and existing cairn.

5.7. Temporary Seismic Monitoring Stations

(i) **Potential Impact:** Possible non-recovery of temporary seismic systems from ice stream during 2016-2017 season. Total number to be deployed is ~100 systems.

Mitigation: The intention is to leave the stations in the field for up to three months maximum before revisiting, retrieving the data and removing them. All equipment will be tested prior to deployment. Way points will be taken at each deployment and bamboo and aluminium marker poles will be installed to identify the specific spot. The stations will be removed at the end of each summer season. All sites will be on snow and no trace of the occupations will remain once they are removed. If equipment cannot be recovered this will be reported to the BAS Environment Office for input into the lost equipment log.

5.8. Radar and Seismic Surveys

(i) **Potential impact:** Equipment is powered by battery, petrol engine or AVCAT. Batteries could leak and fuel could be spilled when refuelling.

Mitigation: All equipment is designed for remote field use. Only sealed, gel batteries are used. All equipment will be well maintained prior to use and during the time in the field. Experienced staff will operate the equipment and will be briefed on spill response procedures.

(ii) **Potential impact:** The use of explosives could result in noise associated with the detonation.

Mitigation: The charges will be buried at approximately 20m depth beneath the ice surface. This will result in the explosions being contained underground which results in a low audible effect and no disturbance on the surface.

(iii) **Potential impact:** Excess explosives remaining after the seismic surveys have been completed. Explosives packaging (mostly cardboard) must be burned to comply with health & safety guidelines.

Mitigation: Excess explosives will be either removed from the area by the departing tractors at the end of the fieldwork for deployment elsewhere, or destroyed on site by controlled detonation. Impact of burning the packaging is minimised by using a small pit dug in the snow. Only small quantities are burned at a time and the fire is continuously monitored. Once completed, the pit is re-covered with fresh snow.

5.9. Tractor Traverse & Field Camps

(i) **Potential Impact:** Aesthetic damage and reduction of wilderness value may occur as a result of the tractor traverse travelling in areas which have not been visited previously.

Mitigation: The location of the new fuel Depot 1 will be recorded and all camps and traverse routes will be logged on the BAS Operations GIS database. Rutford Ice Stream is an area which has been visited many times over the past 30 years by BAS.

(ii) **Potential Impact:** Snow drifts will occur during windy conditions where camps and depots have been positioned. These will temporarily change the local topography. In addition explosives will be used to make the traverse route safe by infilling crevasses, again changing the local topography.

Mitigation: Small snow drifts and the evidence of the traverse route will dissipate through natural processes once the infrastructure is removed. The traverse itself is merely a temporary safe route identified and not a permanent track. Evidence of the route taken will quickly be covered by snowfall. Berms and larger drifts, particularly at the overwinter depots, will be levelled when no longer required. If this proves impractical they will clearly marked with flagged bamboos leaving their positions identifiable for as long as they vary significantly from the surrounding topography.

(iii) **Potential Impact**: Human waste, general rubbish and hazardous waste will be generated during the tractor traverse, at the field camps (all seasons) and by the science activities. Based upon an average adult producing 1.8 litres of urine and faeces per day the field camps will generate approximately 7,300 litres of human waste.

Mitigation: All staff will comply with the BAS waste management policy and will follow the procedures outlined in the BAS Waste Management Handbook (BAS, 2016) and summarised below.

- All wastes (except for urine, grey water and explosives packaging) will be packed in appropriate containers and returned to Rothera. All field parties to be supplied colour coded waste sacks for the separation and disposal of wastes.
- Solid human waste and waste food will be collected in UN approved containers and returned to Rothera for incineration.
- Urine and grey water from domestic use will be disposed of on-site at each location along the traverse.
- Excess explosives will be destroyed by controlled detonation.
- Explosives packaging will be destroyed by supervised open burning, as required by Health and Safety protocols. All other open burning is prohibited.
- Wastes will be stored appropriately to ensure that wind blow does not occur.

5.10. Fuel transfer and storage depots

(i) **Potential Impact:** The large volumes of fuel that will be transported in bladders during BEAMISH present the risk of a fuel or oil spill. In the event of this happening localised pollution and contamination of snow and ice could occur. Up to 126,000 litres of fuel will be transported on the traverse, in 20 independent bladders. Up to 40,000 litres of that fuel will be used to power the drill.

Mitigation: The primary focus will be on spill avoidance. Methods will concentrate on techniques developed and previously used by BAS during other tractor traverses and drilling projects, for identical operations with fuel bladders. An Oil Spill Contingency Plan has been prepared for the project.

The fuel sledge assemblies comprise a double-thickness polyethylene layer for enhanced protection. Gate valves on all bladder fittings will ensure a backup system to the dry-break couplings. Repair kits for bladders and sledges will be carried on sledge specifically for fuel spill equipment. This will be the responsibility of the tractor train team who will undertake regular visual inspections throughout each day to ensure that the bladders are intact. Should a leak occur which cannot be sealed, fuel will be transferred to a spare bladder using spate pumps and hoses with dry-break couplings. Minor drips and spills will be contained by absorbent pads.

(ii) **Potential Impact**: Once a depot is left unattended for the winter, any subsequent fuel leak could potentially result in near-complete emptying of a bladder and the loss of more than 5,800 litres of fuel into the adjacent snowpack. Failure to secure bladder vents correctly would result in fuel loss during the winter driven by the weight of snow accumulation. Careless digging to remove snow around the bladders could also cause a tear.

Mitigation: The main risks to the fuel bladders which could result in a leak are associated with movement and transport- related operations; once a fuel sledge assembly is in-place and properly prepared, the chances of disturbance are negligible and any resulting leak is highly unlikely. Each fuel sledge assembly will be placed on a snow berm, followed by a period of regular checking for any disturbances and leaks. It is anticipated that this will involve checks every few hours over a continuous period of at least 2 days. The full period will be dictated by the length of time required for the other over-winter preparations and the schedule for uplift of personnel by BAS aircraft. Any leaks identified during this period will be addressed, either by repairs or by transfer to a spare bladder. A further checking period of at least two days will follow any repair or fuel transfer. Only plastic-bladed shovels will be used for any digging in the vicinity of the fuel bladders.

Critical to the over-winter integrity of the fuel sledges will be correct close-down procedures, especially the secure closing and locking of bladder vents. Dry-break couplings on the bladders will be backed up by gate valves on all fittings. A written procedure will be followed by trained and experienced personnel for the complete close-down sequence. Any waste absorbents or contaminated fuels must be removed from the field as hazardous waste and returned to Rothera before being disposed of. Procedures are outlined in the BAS Waste Management Handbook.

(iii) **Potential Impact:** Fuel leak from drummed fuel at depots.

Mitigation: Spare drums will be carried with the spill kit and can be used to decant fuel into from damaged drums. Absorbents are stored on the oil spill sledge which will travel with the main tractor train. A log of any fuel spills is to be kept for reporting on the AINME system. A separate spill kit will be deployed with personnel who are involved in restocking or raising any drum depots.

(iv) **Potential Impact:** Minor spills and fuel leaks could occur during daily vehicle or generator refuelling. Spilled fuel would pass quickly through the surface layer of snow, and be absorbed by it. A small quantity may also evaporate. There would be no direct biological effect of a minor fuel spill or leak on the ice sheet or shelf.

Mitigation: The tractors are fitted with a plumbed-in hose reel fuelling system, so minor fuel spills and drips should be limited to refuelling skidoos and generators. BAS minimises the risk of accidental fuel spills through careful attention to fuel management, at its stations and in the field. All reasonable precautions will be taken to ensure that minor fuel leaks and spills do not occur. Any minor fuel spills will be stopped as quickly as possible. A drum funnel and smaller fuel funnels will be provided to prevent spills. Absorbent mats and pads will be provided for immediate response to minor fuel spills and will be in place during any fuel transfers. Used absorbents will be treated as hazardous waste and returned to Rothera. Further information is provided in the Oil Spill Contingency Plan. A log of any fuel spills is to be kept for reporting on the AINME system.

(v) **Potential Impact**: Failure to re-locate buried batteries and explosives at the depot after the winter; permanent loss of these items (undamaged) to the environment. These items will not be placed on top of berms, but buried ~1m beneath the snow surface to protect them from the coldest of the winter air temperatures, so they could become buried more deeply than the other parts of the depot.

Mitigation: Depot components (batteries and explosives) to be buried will be placed well away from berms to avoid any snowdrift enhancing burial. Each will be well-marked and both absolute and relative positions determined by GPS. Markers will be of sufficient height (e.g. 4m) that successful re-location can be guaranteed after two winters, i.e. one more than is expected.

5.11. Ship, aircraft and tractor train operations

(i) **Potential Impact:** Air pollution will result from ship operations, deployment and uplift of the traverse parties (personnel and equipment) by BAS aircraft, traverse vehicle exhaust emissions (tractors and skidoos), and the use of petrol generators for electrical power.

Fuel consumption of the tractors during the project will be approximately 38,000 litres of aviation fuel (AVCAT). Fuel consumed by skidoos and generators is expected to be up to 10,000 litres of unleaded petrol. Fuel consumed for domestic use will be relatively small quantities of propane gas and paraffin. Emissions will be the standard products of combustion of these fuels, including carbon monoxide, carbon dioxide, nitrous oxides, sulphur dioxide, heavy metals and particulates.

The greenhouse gas emissions associated with the use of the AVCAT / AVTUR and petrol during the tractor train, and all other logistics (ship time and flights) will be calculated for inclusion in the BAS carbon report.

Meteorological data indicate that emissions will generally be rapidly and thoroughly dispersed by the strong and regular winds. The main polluting activities will be the tractor traverse where emissions will be distributed in small quantities along the route rather than in one concentrated area. Due to the mobile nature of the activity it is unlikely that background levels will be significantly exceeded.

Mitigation: Daily visual checks will be made of exhausts. Engines will be serviced at the required intervals and any maintenance to reduce atmospheric emissions carried out as required. Vehicles and generators will be shut down when not needed.

5.12. Import of Cargo

(i) **Potential Impact:** Through the unintentional importation of non-native species carried on equipment and general cargo, the local ecosystems (particularly in ice free areas) within Antarctica could be impacted if any non-native species become established. Whilst there is a very low probability of this occurring even on the ice free nunataks, if the impact were realised the severity could be significant.

Mitigation: All equipment and materials required for the proposed activity will be thoroughly cleaned before dispatch to Antarctica. Practices in the BAS Bio-security Handbook and SCAR's Environmental Code of Conduct for terrestrial scientific field research in Antarctica will also be followed.

5.13. Cumulative Impacts

A cumulative impact is the combined impact of past, present and future activities over time or space.

Over the past 30 years a number of scientific expeditions (including deployment of fuel and equipment) have been carried out on the Ronne Ice Shelf and Rutford Ice Stream. The proposed area of study and the associated access routes for BEAMISH are considered to be well within the existing operational footprint of BAS.

Within the past five years the improved capability of tractor traverses has provided improved access and support to deep field science locations within Antarctica. This is due to a number of reasons; firstly the tractor traverses provide greater fuel efficiency, in comparison to the twin otter flights needed to depot similar quantities of fuel. Secondly the ability to carry large quantities of fuel in one operation enables projects requiring significant power (such as the BEAMISH hot water drill) to be supported. The tractor traverses are also capable of supplying better infrastructure to field parties thereby reducing risks associated with remote camps. Subsequently the potential operational footprint of BAS operations deep field has expanded and should be considered as a cumulative impact for future assessments.

All routes, depots and equipment associated with this project will be logged on the BAS GIS database to enable a record of the operational footprint of BEAMISH to be recorded.

Should BEAMISH be extended for longer than described in this document or operate in different locations, further consideration of the impacts will be made and an update to the IEE provided.

Table 2. Predicted Probability and Severity of Impacts					
Activity	**Effect**	**Possible Impact**	**Probability of impact occurring**	**Severity of impact**	**Preventative or mitigating measures**
1. Hot water drilling	• Fuel use in generators and water heaters	• Fuel spill • Contamination of snow and ice	Medium	Low	• Experienced staff to use equipment • Equipment to be well maintained • Staff to be briefed on spill response procedures • Oil spill equipment with drill during operation • Oil spill contingency plan to accompany spill kit
	• Failure of equipment leading to non retrieval of drill or other items	• Equipment left inside the borehole. • Unplanned waste in the environment	Low	Low	• Only experienced, trained staff to use equipment • Equipment to be well maintained • Established drilling techniques to be used
	• Drilling into sub glacial environment	• Contamination of pristine environment	Low	High	• Drilling in a location where there are no known sub glacial lakes • Drilling sites are dynamic reworked sediments considered to be modulated by ocean tides • Drilling water will enter ocean at grounding line of the Ronne Ice Shelf due to localised hydraulic gradient of sediment. • Drilling sites not considered to be isolated pristine environment.
2. Sediment and ice coring	• Failure of equipment leading to loss or non retrieval	• Equipment left inside the borehole. • Unplanned waste in the environment	Low	Low	• Only experienced, trained staff to use equipment • Equipment to be well maintained • Established techniques to be used
3. Deployment of camera	• Failure of equipment leading to loss or non retrieval	• Equipment left inside the borehole. • Unplanned waste in the environment	Low	Low	• Only experienced, trained staff to use equipment • Equipment to be well maintained • Established techniques to be used
4. Deployment of ice column instruments	• Equipment permanently deployed in ice column	• Waste left in the ice column	High	Low/Med	• Equipment designed to be as small, simple and low-power, as possible. • Only essential items deployed

5. Deployment of GPS on nunatak	• Installation of solar panel, battery	• Damaged batteries could leak acid	Low	Medium	• All acid in sealed gel batteries
	• Equipment installed on nunatak for 3 months	• Loss of wilderness	High	Low	• Careful selection of sites to avoid sensitive areas (e.g. avoid summit) • SCAR Code of Conduct to be followed
	• Cairn left in place	• Loss of wilderness	High	Low	• Small cairn to be used rather than manmade markers
6. Seismic, GPS & radar monitoring stations	• Possible non-recovery of temporary radar and seismic monitoring stations from ice stream	• Possible non recovery of systems resulting in waste left in the field	Low	Low	• All deployments will be logged with a GPS • Additional visual markers will be used including bamboo and aluminium markers • Designed to be robust for the duration of deployment in Antarctic conditions • 2 x radar and 2 x seismic station will be recovered at end of season 3.
7. Deployment of GPS & seismic Systems on ice sheet	• Equipment installed on ice sheet for 3 months	• Possible non recovery of systems resulting in waste left in the field	Low	Medium	• Systems designed to provide an accurate location • All equipment will be tested prior to deployment • Only equipment with a proven track record and long battery life will be used. • Risk assessments completed for equipment deployment
8. Radar surveys; seismic surveys	• Battery- and generator-powered equipment • (transportation covered below in Science Traverse) • Use of small generators • Use of explosives	• Damaged batteries may leak • Fuel spill • Local snow contamination. • Noise from explosives • Excess explosives remaining once fieldwork completed	Low Low High	Low Low Low	• All batteries sealed gel. • Staff briefed on spill response • Explosives and detonators buried ~20m deep • Excess explosives removed from area or destroyed by controlled detonation • Packing burned to comply with Health & Safety requirements. Minimise impact using small pit dug in the snow and covered with fresh snow afterwards.
9. Tractor traverse	• Increased footprint of BAS operations	• Aesthetic Damage • Reduction of wilderness and pristine nature of localities	High	Low	• Some locations have previously been visited. • Log of depots, camps and traverse routes to be kept at BAS for future reference • Log to be kept of all equipment deployed and any equipment which is not retrieved

		• Impact on future science			
10. Fuel transfer and storage depots	• Fuel spills and leaks • Failure to re-locate after winter storage	• Contamination of snow • Loss (undamaged) to the environment	Low	Medium	• All staff will be trained in documented fuel handling and spill response procedures. • Only robust, reliable fuel storage and transfer equipment will be used. • Spill equipment to be carried on specially allocated sledge travelling with tractor train. • Fuel spills to be logged on AINME. • Separate items well-marked and positions determined by GPS • Markers of sufficient height for re-location to be guaranteed after two winters, although only one is scheduled.
11. Operating field camps	• Waste generated	• Contamination of ice. • Visual impact if scattered by wind.	Low	Low	• All staff to be briefed on environmental protection including waste handling. • All waste (except urine and grey water) to be removed from the field in accordance with the BAS Waste Management Handbook.
	• Snow drifts around camp structures.	• Change to local topography	Low	Low	• Camps to be cleared each day to prevent wind scatter. • Berms will be levelled when no longer required. • Drifts that may accumulate especially around depots will naturally dissipate.
12. Ship, aircraft and tractor train operations.	• Atmospheric emissions	• Minor but cumulative contribution to regional and global atmospheric pollution inc. greenhouse gas emissions	High	Low	• Most efficient logistics planned to reduce fuel burn (and cost). • Use of well maintained and regularly serviced equipment. • Daily checks of exhausts. • Shut down vehicles and generators when not in use.
13. Importation of cargo	• Possible importation of non-native species	• Potential ecosystem alteration.	Very low	Medium (High if species	• BAS Vehicle Cleaning Guidelines, SCAR / COMNAP Guidelines, CEP & BAS Bio security Handbook will be followed where appropriate.

		• Impact on future science.		become established)	• All procedures include measures to ensure that soils, seeds and propagules are not transported to Antarctica. • Vehicles, cargo and personal clothing must be cleaned prior to importation. • If soil, seeds or propagules are accidentally imported they must be carefully collected and removed. Disposal may include incinerated at Rothera or removed from Antarctica.

6. CONCLUSIONS

The polar ice sheets play a major role in controlling the Earth's sea level and climate. Concentrating field work on the Rutford Ice Stream, BEAMISH aims to reduce the uncertainty of predicting future sea level rises. BEAMISH brings together a number of different tried and tested scientific techniques to gather data on the variables in surface ice and bed sediments of the Rutford Ice Stream.

Each of the scientific techniques and operational procedures has been assessed within this document for possible negative impacts. Mitigation measures have been provided where impacts have been identified. Some of the mitigation measures have already been included into the design of the equipment or activities, whilst others will be implemented in the field during the field seasons.

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

7. REFERENCES

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8. AUTHORS OF THE IEE

This Initial Environmental Evaluation was prepared by Dr Andy Smith and Clare Fothergill of the British Antarctic Survey.

Further information or copies of this IEE can be obtained from:

Clare Fothergill
Environmental Manager
British Antarctic Survey
High Cross, Madingley Rd
Cambridge, CB3 0ET
United Kingdom