ARCTIC
RESPONSE
TECHNOLOGY
OIL SPILL PREPAREDNESS

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FIELD RESEARCH ON HELICOPTER APPLICATION OF CHEMICAL HERDERS TO ADVANCE IN-SITU BURNING

ARCTIC OIL SPILL RESPONSE TECHNOLOGY – JOINT INDUSTRY PROGRAMME

The oil and gas industry has made significant advances in the ability to detect, contain, and cleanup oil spills in arctic environments (Potter et al., 2012). Ongoing research continues to build upon more than fifty years of examining all aspects of oil spill preparedness, oil spill behaviour, and available options for oil spill response in the Arctic marine environment. This research has included hundreds of studies, laboratory and basin experiments, and field trials, conducted in the United States, Canada, and Scandinavia. To build on existing research and improve technologies and methodologies for arctic oil spill response, members from the IPIECA-Oil Spill Working Group, Industry Technical Advisory Committee (ITAC) and the American Petroleum Institute-Emergency Preparedness and Response Programme Group formed a joint committee in 2009. The committee's task was to review the oil and gas industry's prior and future work scope on prevention and response to oil spills in ice in order to identify and prioritise technology advances and research needs. One outcome was the recommendation to establish the Arctic Oil Spill Response Technology Joint Industry Programme (JIP) that would undertake targeted research projects identified to improve industry capabilities and coordination in the area of arctic oil spill response.

The JIP was launched in January 2012 and over the course of the programme is carrying out a series of advanced research projects in six key areas: dispersants, environmental effects, trajectory modelling, remote sensing, mechanical recovery, and in situ burning (ISB).

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GLOSSARY OF KEY TERMS

Acute Toxicity is a measure of the potential of a material (e.g., oil, chemicals) to cause adverse effects in an organism after only a short period of exposure (generally less than 4 days) relative to its life cycle.

Ambient Conditions are those in the surrounding environment, such as temperature, humidity, etc. For example, an oil slick at or above the temperature of its flash point will ignite rapidly and easily. If the ambient temperature is below the flash point for the spilled oil, the slick may be difficult to ignite.

API Gravity (API) is a scale for measuring fluid specific gravities based on an inverse relationship with specific gravity (SG). This scale was primarily developed to expand the scale for specific gravity so that larger values are used. An oil with a low specific gravity (e.g., gasoline; SG = 0.73) will have a high API gravity (API = 62).

$$\text{API gravity} = (141.5/\text{SG at } 15.5°\text{C}) - 131.5$$

Aromatic Hydrocarbons are composed solely of carbon and hydrogen atoms in various arrangements that typically include at least one benzene ring. Aromatic hydrocarbons give oil its smell.

Barrel (bbl) is equal to 42 United States gallons at 15.5°C.

Benzene, toluene, ethyl benzene and xylene (BTEX) compounds are volatile organic compounds that are present in light refined products and crude oils. Their presence after a burn would indicate incomplete combustion.

Biodegradation is the process in which naturally occurring bacteria and other micro-organisms consume hydrocarbons as a food source.

Booms are floating barriers used for the collection, diversion, deflection, and containment of spreading liquids.

Brackish is an intermediate salinity range for water bodies where the salt content is greater than in fresh (e.g., 0.50 to 17.00 parts per thousand).

Brash Ice is defined as accumulations of floating ice fragments not more than 2 m across. Brash ice is common between colliding floes or in areas where pressure ridges have collapsed.

Broken Ice is a deprecated term for an ice sheet that is not continuous. It has been replaced by the more descriptive terms pack ice, drift ice, etc.

Burn Efficiency is the proportion of oil removed from the water by burning and is usually expressed as the percent reduction by weight. It is a function of three main factors: initial slick thickness; thickness of residue at the extinction of the burn; and the aerial coverage of the flame.

Burn Residue is the unburned oil or incomplete combustion products remaining after a fire extinguishes. Residues can range from brittle stiff, taffy-like material, to a liquid similar to the original oil.

Centipoise (cP) a unit of measurement for dynamic viscosity.

Centistoke (cSt) a unit of measurement for kinematic viscosity.

Chemical Treating Agents are products used in treating oil spills, including dispersants, bioremediation agents (e.g., nutrient additions), herding agents, emulsion treating agents, solidifiers, elasticity modifiers, and surface washing agents.

Combustion By-Products include the smoke plume constituents and any incomplete burn combustion products remaining after a burn is extinguished (residue).

Containment is the use of boom, herding agents, natural barriers on land, or ice, to constrain and/concentrate the oil slick.

Controlled Burn is combustion that is started and stopped by human intervention.

Convective Motion is flow of a fluid induced by temperature differences.

Density of the oil is a measure of the weight of a specific volume of a solid, liquid, or gas in comparison with water. The greater the density of a resultant burn residue the more likely it is to sink.

Effectiveness / Efficacy is the ability to produce the desired outcome

Emulsification is the process of mixing water droplets into spilled oil. Emulsions are highly viscous mixtures that weather more slowly than the original oil and are usually more difficult to burn, disperse, and mechanically recover.

Emulsion, for spill response purposes, is the suspension of water in an oil slick, which alters its appearance, behaviour, fate, and affects recovery and treatment options. Water-in-oil emulsions may contain 20 to 80% water and may be temporary or permanent.

Encounter Rate refers to the amount of oil that comes into contact with a containment and recovery device (e.g., boom, skimmer, sorbents) or is treated (i.e., burned, dispersed) over a given period of time.

Evaporation is the transfer of light- and medium-weight components of oil from the liquid phase to the vapour phase. Evaporation is typically the most dominant weathering process and varies with oil type and ambient conditions at the spill location.

Fire Diameter is the horizontal distance from one side of a fire to the opposite side, through the centre of the fire.

Fire Point is the temperature of a fuel at which it will continue to burn for at least 5 seconds after ignition by an open flame.

Flammability limit is the range of concentration of flammable vapours in air that will ignite.

Flash Point is the lowest temperature at which the vapour of a flammable liquid will ignite in air. The flash point is generally lower than the temperature needed for the liquid itself to ignite. A substance may ignite briefly, but vapour may not be produced at a rate to sustain a fire. An oil’s fire points is generally about 10ºC higher than its flash point.

Fresh / Freshwater is water that has low salinity, less than 0.5 parts per thousand (ppt).

Heat Flux is the total amount of heat radiated, convected, and conducted away from a fire per unit time.

Herding Agent is a product that contracts a liquid (in this case an oil slick) on a water surface by exerting a higher spreading pressure than the oil slick.

Ice-affected waters are those that have ice in some form on their surface.

Ignition Sources/Igniters are devices designed to provide heat a material to its Fire Point and provide an ignition source. Commonly used ignition devices include propane or butane torches, gelled fuel with or without an attached flare, diesel-soaked rags or sorbents, helicopter-slung gelled fuel (e.g., Heli-torch), road flares, and solid-fuel pyrotechnic devices.

Ignitable Thickness is the thickness of oil necessary to generate sufficient vapours to enable ignition.

Immiscible Liquids do not mix with each other.

In-situ Burning (ISB) is the controlled combustion/burning of spilled oil in place such that the petroleum hydrocarbons are predominantly converted to CO_2 and water, which are released to the atmosphere. See *Controlled Burn*.

Interfacial Tension is the tendency of a liquid surface, in contact with an immiscible liquid, to contract. The imbalance of forces at the liquid-liquid interface is due to the difference in molecular forces in the two immiscible liquids.

LC_{50} or LC50 is the concentration of a product that causes 50 percent mortality to the test organism over a stated period of time. Length of exposure is typically 24 to 96 hours.

Marine or Saltwater is sometimes used synonymously with ocean, but reflects a broader salinity range, specifically water with a salinity of 17 parts per thousand and greater.

Microbial Degradation is a naturally occurring process in which micro-organisms consume or break down petroleum hydrocarbons as a food source. See *Biodegradation*.

Miscible is the ability of one liquid to be mixed at any ratio, into a second liquid without separation of the two liquids.

Natural Dispersion is the process of breaking waves forcing oil droplets into the water column, which can result in at least a portion of the droplets remaining in the water.

NEBA is an acronym for Net Environmental Benefit Analysis***.*** It is the comparison of environmental and socio-economic outcomes of selected spill scenarios using various response options against a baseline. The results are used in contingency planning and during a response to inform decision-making as to those options with the least negative effects. In this context, the baseline for comparison is slick monitoring and observation only, while response options can include mechanical only, mechanical and dispersants, dispersants only, ISB, etc. The Net Environmental Benefit Analysis method provides a framework to carefully consider and select available response options based on their effectiveness and associated environmental effects.

Oil means any kind of petroleum hydrocarbon, particularly those in liquid form that could be spilled.

Particulates are very small pieces of solid materials (e.g., dusts, soot, fumes) or liquid material (e.g., mists, fogs, sprays) that remain suspended in the air long enough to be inhaled.

Particulate Matter refers to particulates with a size range to are judged to be more easily inhaled and can enter lungs at 10 micrometres in diameter or smaller. Particulate matter is often grouped into two categories:

1. PM10 is a mixture of solid and liquid droplets up to 10 microns in diameter.
2. PM2.5 are particles less than 2.5 micrometres in diameter. These particles are so small they can be detected only with an electron microscope. Sources of fine particles include all types of combustion, including motor vehicles, power plants, residential wood burning, forest fires, agricultural burning, and some industrial processes.

Parts per billion (ppb) is a unit of concentration. One ppb is roughly equivalent to one teaspoon in 1,300,000 gallons.

Parts per million (ppm) is a unit of concentration. One ppm is roughly equivalent to one teaspoon in 1,300 gallons.

Parts per thousand (ppt) is a unit of concentration. One ppt is roughly equivalent to one teaspoon in 1.3 gallons.

Persistence refers to how long oil may remain in the environment. Persistent oils may not be completely removed from an affected environment as a result of weathering processes or clean-up operations.

Photo-Oxidation is the process by which components in an oil are chemically transformed through a photo-chemical reaction (in the presence of atmospheric oxygen) to produce compounds that tend to be both more water soluble and acutely toxic (in the near term) than the parent compounds.

Polycyclic (or Polynuclear) Aromatic Hydrocarbons (PAHs) are a group of hydrocarbons compounds characterized by multiple benzene rings, very low vapour pressures, and relatively low flammability (compared to other compounds found in crude oils). PAHs are found in unburned oil as well as in smoke plumes.

Pour Point is the temperature below which oil will cease to flow in a specified test apparatus and, from a spill response perspective, when oil transitions from a liquid to a solid.

Salinity is a measure of the relative concentration of salt in seawater and is typically measured as parts per thousand (ppt). Arctic ocean water is typically 28 to 34 ppt.

Sheen is a very thin layer of floating oil, i.e., less than 0.003 mm in thickness. Sheens range in colour from dull brown for the thickest sheens to greys (0.001 mm), rainbow (0.00015 mm), silver (0.00007 mm), and near-transparency in the case of the thinnest sheens.

Slick is a thin layer of spilled oil.

Soluble / Solubility is the relative ability of one material to dissolve in another. A product is considered “quite soluble” in water if its solubility is greater than 1 ppt. A product is considered “sparingly soluble” in water if its solubility is between 1 ppt and 1 ppm. A product is considered “very sparingly soluble” in water if its solubility is between 1 ppm and 1 ppb. A product is considered “essentially insoluble” in water if its solubility is 1 ppb or less.

Sorbent is any oleophilic material used to take up oil through absorption or adsorption. Essentially made from inert and insoluble materials, sorbents are used to remove oil and hazardous substances from water through: adsorption, in which the spill product is attracted to the sorbent surface and then adheres to it; or by absorption, in which the spill product penetrates the pores of the sorbent material; or a combination of the two.

Specific Gravity (SG) is the ratio of the mass of a material (e.g., oil) to the mass of freshwater, for the same volume and at the same temperature. Most crude oils and refined products have specific gravity values between 0.78 and 1.00. If the SG of an oil is less than the SG for a surface water (freshwater (SG) is = 1.0 at 4°C; seawater (SG) is = 1.03 at 4°C), the oil will float on the water surface.

Spreading is the dominant initial transport process for most oil spills, whether on water, on land, or in ice/snow. Spreading occurs due to surface tension and/ gravity.

Spreading Pressure is the force exerted against a fixed barrier as a liquid is compressed into a smaller surface area.

Surface Collecting Agents are chemical agents that form a surface film to control the layer thickness of oil. See *Herding Agent*.

Surface Tension is the tendency of a liquid surface, in contact with air, to contract due to an imbalance of forces on the molecules in the bulk liquid versus those at the surface in contact with air.

Surfactant, also referred to as surface-active agent, is a chemical that contains both oil-soluble and water-soluble components, such as soaps.

Toxicity is the inherent potential or capacity of a material (e.g., oil, chemicals) to cause adverse effects in a living organism.

Viscosity is the resistance to flow and may be reported in one of two ways for oil spills. Dynamic viscosity (µ) refers to internal friction of a substance (e.g., oil) that is a function of the oil type and temperature and is measured in Centipoise units (cP). The lower the viscosity, the thinner the fluid (e.g., water = 1 cP, molasses = 100,000 cP). Kinematic viscosity (ν) is a given fluids dynamic viscosity divided by its density, is measured in Stoke (St) units and is often reported in centistoke (cSt). Since the density of oil and water are similar, the dynamic and kinematic viscosities of oil are roughly equivalent.

Volatility is the tendency for the components in a liquid to vapourise.

Volatile organic compounds (VOCs) are a mixture of the lighter, Low Molecular Weight (LMW) hydrocarbons, including benzene. During any spill, the lighter, more volatile components evaporate more quickly, and much slick volume can be lost from within the first 24 to 48 hours.

Water Column is an imaginary cylinder or box from the surface of the water to the bottom.

Weathering is the process of alteration of physical and chemical properties of a material through natural processes, including spreading, evaporation, dissolution, photo-oxidation, emulsification, sedimentation, and biodegradation.

Window of Opportunity is an interval of time during which conditions are favourable and an opportunity exists for a spill response option to be implemented effectively.

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EXECUTIVE SUMMARY

During late April of 2015, in a custom-built test basin located 50 km northeast of Fairbanks AK, five tests were conducted to determine if a helicopter could be used to first apply herding agents to Alaska North Slope crude oil slicks in simulated drift ice conditions and then ignite the herded oil slicks using a Heli-torch. After some initial attempts failed to accomplish ignition within the time limits of the test conditions, two successful in-situ burns were accomplished using only aerial herder application and ignition. One burn was accomplished with OP-40 herder and one with ThickSlick 6535 herder. The burning of the free-floating slicks resulted in the removal of approximately 70 to 85% of the oil on the water surface.

In-situ burning (ISB) offers an effective spill response tool in a variety of ice concentrations. One key factor to ensure effective ISB is thick oil slicks, which retain heat and sustain combustion. In low ice concentrations, oil on water can rapidly spread to become too thin to ignite. The focus of herder research for Arctic oil spill response has therefore been on their application in drift ice conditions (1 to 6 tenths ice cover) in which slicks can spread fairly rapidly. The application of herders can reverse this process. Another advantage of using herders in drift ice conditions is the possibility that the entire operation could be carried out using a rapidly deployable platform such as helicopters, or possibly even remote control aircraft, to spray herders on the water around slicks and then ignite the thickened oil with aerially deployed igniters. This type of totally aerial response could be much faster, more effective, safer and less complicated than conventional icebreaker-based countermeasures in Arctic waters.

Two herding agents, ThickSlick 6535 and OP-40 have been listed on the U.S. EPA National Contingency Plan (NCP) Product Schedule for consideration for use on spills in U.S. waters. This report describes field research to advance the operational use of aerially applied herders and igniters for ISB in open water (<10% ice cover) and drift ice conditions (10 to 60% ice cover).

The primary objective of the field research was to validate the use of herders in combination with ISB, when both are applied by helicopter. The aim was to develop a rapid response aerial system that enhances responders’ ability to use offshore ISB in drift ice conditions. Specifically, the research involved five releases of 75 or 150 litres each (approximately 20 or 40 gallons) of Alaska North Slope (ANS) crude oil in a large, shallow test basin constructed on land.

The University of Alaska Fairbanks (UAF) had primary responsibility for: providing technical support, acquiring all permits required for the experiment including site approval, test basin construction, conduct of the tests, and disposal of any test materials. The test basin was located at the Poker Flat Research Range (PFRR), an extensive land area managed by UAF and situated approximately 50 km (30 miles) northeast of Fairbanks, Alaska.

The test basin (Figure ES-1) was a square lined pool 90 metres (300 feet) on a side, contained by a 1 metre (3 ft.) high berm. The basin was constructed in the fall of 2014; “ice floe” forms were placed within the basin in early winter 2015 and filled with water by a water truck. In the days prior to the start of the test, the pool was filled with approximately 15 cm (6 in) of water by pumping from a nearby pond.

Figure ES-1: Aerial view of basin and test site

Figure ES-2 shows the Herder Application System mounted in the Bell 407 helicopter used for the tests and shows the system spraying herder onto the basin. Figure ES-3 shows the Heli-torch, slung under the helicopter, being used to ignite the slick herded with ThickSlick 6535 during Test 5.

The successful application of OP-40 herder followed by ignition of the slick with the Heli-torch in Test 3 resulted in the removal of approximately 70to 80% of the free-floating ANS crude oil slick (Figure ES-4). During Test 5 (Figure ES-5) approximately 75 to 85% of the free-floating slick herded with TS 6535 was consumed by the ensuing fire.

The use of a robotic helicopter UAV to spray herder and deploy a modified-flare igniter was also demonstrated during the test programme (Figure ES-6).

Following the tests, the water in the basin was cleaned of visible oil and allowed to remain until August 2015. At that time the remaining water was tested, confirmed to be free of oil, and a *letter of no objection* for water disposal was acquired from Alaska Department of Environmental Conservation (ADEC).

Figure ES-2: Herder application system mounted in Bell 407 and operating over basin

Figure ES-3: Heli-torch operation

Figure ES-4: Successful burn of free-floating ANS crude oil slick herded with OP-40 in Test 3

Figure ES-5: Successful burn of free-floating ANS crude oil slick herded with TS 6535 in Test 5

Figure ES-6: Responder UAV spraying simulated herder and carrying ignited flare

A number of conclusions and recommendations were drawn from the testing programme including:

1. The application of two herders and subsequent ignition of free-floating oil slicks from a helicopter was successfully demonstrated.
2. The work was completed without any health, environmental, or safety incidents.
3. Both OP-40 and ThickSlick 6535 were effective in controlling the thickness of the floating oil spill.
4. Laboratory tests documented that the herders were equally effective in fresh water and salt water, allowing the full-scale tests to be performed in fresh water without loss of technical integrity.
5. The UAV herder application system and flare ignition system were successfully demonstrated, but additional work is needed to refine, and perhaps combine these technologies for commercial use.
6. A combined herder / igniter concept would be useful for both helicopters and UAVs to allow for a combined “herd and ignite” operation in a single flight.
7. Water should not be used to rinse the herder application system as it risks gelling the herder. Isopropyl alcohol has been demonstrated to work well, and diesel has been tested at a bench-scale.
8. Helicopter and a UAV were successfully and safely operated in the same airspace during the experiments by adhering to the test plan, maintaining spatial and temporal separation, and having the pilots maintain radio contact with one another. Operations were planned well in advance and discussed at length with both pilots (helicopter and UAV) prior to each test. Operations were conducted with the Bell 407 having absolute priority with an additional spotter on the ground directing the UAV away from the test tank area when the helicopter approached.
9. Further field trials of the concept of aerial application of herders and ignition in actual drift ice conditions offshore are necessary in order to allow extra time for herders to act on the slick. This will allow better estimates of likely oil burn efficiencies achievable with this countermeasure and the weather windows for its effective use.
10. The interaction of presently available gelling agents with gasoline should be studied, particularly gasoline containing significant fractions of ethanol.
11. Further work on UAVs is warranted as a platform to collect fire area data. This information may be used to generate more accurate estimates of burn rates and volumes of oil consumed, and would help monitor the progression of a burn.
12. More research is needed on the application of ThickSlick 6535 herder in cold weather conditions, specifically around its gelling point of (-3°C).

1. INTRODUCTION

In-situ burning (ISB) has been considered a viable, primary spill response option for oil spills in Arctic waters since offshore drilling began in the Beaufort Sea in the 1970s. Field trials at that time demonstrated that on-ice burning of spilled oil offered the potential to remove almost all of the oil present on an ice surface, leaving only minimal residue. Since then, numerous studies and trials have been undertaken to investigate and document the burning of crude oil slicks (both fresh and emulsified) in cold open water, slush ice, drift ice, pack ice and on solid ice. Laboratory and field experiments spanning the past 40+ years have led to a good understanding of the science of burning under a variety of ice conditions. These experiments also highlighted the importance of such factors as minimum ignitable slick thickness for various oil types and states of weathering; wind and wave limits for successful burning; and, the maximum water, ice and snow contents that can be tolerated for a successful burn (Buist *et al.* 2014).

The behaviour of oil spilled in ice-covered waters largely dictates whether ISB is possible for a given spill; and in the case of drift or pack ice conditions, is governed principally by the ice concentration.

The key to effective ISB is thick oil slicks. Solid ice and concentrated pack ice can enable ISB by slowing the spreading of a spill and keeping slicks thick. In high ice concentrations slicks that are initially thin can also be herded against ice edges by the wind and thickened enough to ignite and burn efficiently. In loose drift ice conditions oil on the water can rapidly spread to become too thin to ignite. Fire-resistant booms can collect and contain thick slicks in open water and low to moderate ice concentrations but would be ineffective in concentrations of 5/10ths or greater. Laboratory and mid-scale tank tests found that if slicks were in the 2 to 5 mm thick range, as could occur naturally in pack ice greater than 6 to 7 tenths coverage, even with no possibility of physical booming, effective burns could be carried out (Buist et al. 2003).

Herding agents were initially developed in the 1970's as a method of thickening oil slicks prior to mechanical recovery. Unfortunately, it was discovered during field tests that herded slicks resumed spreading within tens of minutes in all but relatively calm seas. They were never applied during an actual offshore spill because mechanical recovery requires longer periods to implement.

A research programme initiated in 2003[1] by SL Ross Environmental Research and funded by ExxonMobil, the U.S. Minerals Management Service (now the Bureau of Safety and Environmental Enforcement) and others to advance oil spill response in ice found that herding agents persisted long enough to enable ISB of relatively fresh, fluid oils in broken or drift ice – conditions in which slicks would otherwise be too thin to burn. This multi-year, multi-partner program (SL Ross and DCE 2015; Buist et al. *in press*) involved:

- A small-scale (1 m^2) preliminary assessment of a shoreline-cleaning agent with oil herding properties in 2003 to assess its ability to herd different oils on cold water and among ice.
- Small-scale (1 m^2) experiments subsequently carried out in 2005 to explore the relative effectiveness of three oil hydrocarbon-based herding agents in simulated ice conditions; followed by larger-scale (10 m^2) quiescent pan experiments to explore scaling effects; small-scale (2 to 6 m^2) wind/wave tank tests to investigate wind and wave effects on herding efficiency; and finally, small ignition and burn tests. These tests identified ThickSlick 6535 as an effective herding agent on cold water and in ice conditions.
- Experiments with ThickSlick 6535 herder at the scale of 100 m^2 in the indoor Ice Engineering Research Facility Test Basin at the US Army Cold Regions Research and Engineering Laboratory (CRREL) in November 2005.

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[1] A detailed summary of this programme may be found on the Arctic Response Technology JIP Web site at http://www.arcticresponsetechnology.org/wp-content/uploads/2015/05/Herder-Research-Summary.pdf

- Experiments with ThickSlick 6535 herder at the scale of 1000 m^2 at Ohmsett in artificial pack ice in February 2006.
- A series of 20 burn experiments in 2007 with ThickSlick 6535 herder at the scale of 30 m^2 in a specially prepared test basin containing broken sea ice in November 2006 at the Fire Training Grounds in Prudhoe Bay, AK with fresh crude oil.
- Field tests in pack ice in the Barents Sea 2008. One experiment involved the release of 630 litres of fresh Heidrun crude in a large lead. The free-drifting oil was allowed to spread for 15 minutes until it was far too thin to ignite (0.4 mm), and then ThickSlick 6535 herder was applied around the slick periphery. The slick contracted and thickened for approximately 10 minutes at which time the upwind end was ignited using a gelled gasoline igniter. A 9-minute long burn ensued that consumed an estimated 90% of the oil.
- Studies on alternative herding surfactants completed between 2008 and 2010. It was during this testing that the OP-40 silicone-based herder was identified as being more effective in certain situations.
- Development of techniques for applying herding agents to slicks in ice-affected water starting in 2010.

The focus of herder research for Arctic oil spill response has been on their application in drift ice conditions (1 to 6 tenths ice cover) in which slicks can spread fairly rapidly. Another potential advantage of using herders in drift ice conditions is the possibility that the entire operation could be carried out using helicopters, or possibly remote control aircraft, to spray herders on the water around slicks and then ignite the thickened oil with aerially deployed igniters. This type of totally aerial response could be much faster, more effective, safer and less complicated than conventional ship-based countermeasures in Arctic waters.

DESMI-AFTI worked in conjunction with SL Ross Environmental Research to gain approval for herders in North American waters. Test data from an accredited laboratory on three candidate-herding agents (also called surface-collecting agents) was submitted to the U.S. EPA for approval to list them on the National Contingency Plan (NCP) Product Schedule. As a result, two herders are now on the list and are commercially available. These two can be used, with the Federal On-Scene Coordinator’s concurrence, for spill response operations in U.S. waters. Samples of all three herders have been sent to Environment Canada, along with all the EPA test data, for their consideration. Quantities (200 L) of the two herders listed on the NCP Product Schedule have been produced and are stockpiled at DESMI-AFTI in Buffalo, NY.

An application system has been designed to be placed inside an appropriate helicopter. It incorporates a reel-able hose that is used to lower the application nozzle to the correct distance below the helicopter, minimizing downwash impacts during herder application. Land based static trials were conducted in September 2013, while helicopter flight trials and modifications to the original design were part of the present project. A backpack sprayer system for herder application from a small vessel is available off-the-shelf, with only minor modifications required for cold-temperature use.

A multi-project research program has been funded by the IOGP Arctic Oil Spill Response Technology Joint Industry Programme (JIP) to continue the R&D on the use of herding agents. This report describes field research to advance the operational use of herders for ISB in drift ice conditions.

2. OBJECTIVE

The project's overall objective was to prove the operational feasibility of an aerial herder/burn response strategy using manned and/or remote-controlled helicopters.

Specifically, the field research sought to validate the use of herders in combination with ISB, when both are applied by helicopter. The aim was to develop a rapid response aerial system that enhances responders' ability to use offshore ISB in drift ice conditions ranging from limited ice cover (1/10 to 3/10) to ice-free waters. The research involved five releases of 100 or 200 litres each (approximately 25 or 50 gallons) of Alaska North Slope (ANS) crude oil in a large, shallow test basin constructed on land.

3. GOALS

More specifically the research project goals were to:

- Construct an above-ground lined test basin (approximately 90 m x 90 m x 1 m deep).
- Conduct laboratory testing with a selected crude oil to determine its spill-related physical properties and determine the effectiveness of two commercially available herders in thickening the crude oil slick on fresh water.
- Conduct helicopter testing to confirm the suitability of the prototype aerial herder delivery system and its spray pattern.
- Evaluate the feasibility of robotic helicopter technology to apply herders and igniters.
- Prove the overall feasibility and effectiveness of using herders and ISB as an integrated, fully aerial response option.
- Prepare a project technical report.
- Present the research findings at a scientific/technical conference.
- Publish the research findings in a peer-reviewed scientific journal.

4. WORK PLAN

The goals were met by undertaking seven tasks:

1. **Obtain Necessary Permits:** University of Alaska Fairbanks (UAF) had primary responsibility, with SL Ross providing technical support where necessary, for acquiring all permits required for the experiment including site approval, test basin construction, conducting the burns, and disposal of any test materials.
2. **Construction of Test Pond:** UAF managed the construction of an above-ground lined test pond at a previously cleared site at the Poker Flat Research Range (PFRR). This is an extensive land area (thousands of hectares) managed by UAF approximately 50 km (31 miles) outside of Fairbanks, Alaska.
3. **Develop an overall project management plan, test plans, and HSE plans for the experimental releases:** An overall project management plan was developed by the research team based on a phase-gate model. The model included clear decision points along a timeline to approve moving to the next phase. A key component of the overall project management was the HSE plan that covered all identified hazards and their mitigation. This plan went through several stages of internal review and approval before testing began (more details are available in Section 7).
4. **Preliminary lab-scale testing of herders prior to the experimental release:** Prior to the experimental release, SL Ross performed laboratory scale experiments to verify that the test oil was amenable to herding and burning when fresh, and after weathering for a specified time. Tests also documented that the herders were equally effective in fresh water and salt water, allowing the full-scale tests to be performed in fresh water without loss of technical integrity.
5. **Operational readiness of aerial herder application and slick ignition systems:** Helicopter-based herding/ISB required both a herder delivery system and an ignition source on the helicopter(s). DESMI AFTI, the vendor for two herder formulations listed on U.S. EPA National Contingency Plan (NCP) Product Schedule, built a prototype herder delivery system for use in a manned helicopter. A previous project funded by ExxonMobil culminated with successful static tests from a crane. The next steps involved testing from an actual helicopter platform to verify that the spray pattern and airborne operation met requirements for the field test in Alaska. The project team ensured the necessary verification tests were completed to permit the aerial delivery system to be used on helicopters.
6. **Field Experiments:** Conducting field experiments to prove the operational feasibility and effectiveness of an aerial herder/burn response strategy using both manned and robotic helicopters.
7. **Write technical report, peer-reviewed scientific paper and technical presentation.**

5. PERMITTING

The University of Alaska Fairbanks (UAF) had primary responsibility, with SL Ross providing technical support for acquiring all permits required for the experiment including site approval, test basin construction, conduct of the burns, and disposal of any test materials. Copies of all permits are contained in Appendix A. Permitting for the tests involved four areas plus a Certificate of Authorisation, which are identified below.

5.1 Open-Burning Approval Application (Burn permit)

An application was made to Alaska Department of Environmental Conservation (ADEC) for a Black Smoke Permit (AQ1018OBR04) to conduct the ISB experiments at the PFRR test basin. ADEC granted a permit, valid until May 31, 2015, with a number of stipulations that were in alignment with the test and HSE plans. In particular, there was a requirement for public notifications prior to the tests. The public notice for the burning activities was published in the legal section of the Fairbanks Daily Newsminer, and posted at the Chatanika Lodge, a local establishment near PFRR. A point of contact was established for receiving and documenting any complaints about the black smoke, though no complaints were recorded by UAF or the ADEC. In addition, 24-hours before each burn the ADEC, FAA, airport and local fire departments needed additional notification of burning activities. A copy of the permit is available in Appendix A.

5.2 Storm Water Pollution Prevention Plan (SWPPP)

A Storm Water Pollution Prevention Plan was required to allow for earthmoving and berm construction at the basin site. The SWPP was filed and maintained by the berm construction contractors.

5.3 Temporary water use permit (Water withdraw permit)

A water use permit was required for filling the test basin, a volume of approximately 1,215 m^3 (320,000 gallons) for a depth of 6 inches. The Alaska Department of Natural Resources (AKDNR) granted a Temporary Water Use Authorization (TWUA 2015-001) to remove water from a pond adjacent to the basin. The permit is valid until November 30, 2019, and allows for 500,000 gallons of water to be pulled from the adjacent pond annually. A copy of the permit is available in Appendix A.

5.4 Scientific discharge permit

The ADEC recommended that the experimental activities at PFRR would be covered by a permit for scientific discharges according to Article 8 of 18 AAC 75, and that a wastewater discharge permit (land application) would not be required. UAF supplied ADEC with all land and water analyses for potential pollutants at the site before and after testing, and was instead granted a letter of No Objection for discharge of the water. The ADEC stipulated that the landowner (UAF) notify ADEC that the project has permission to discharge on its land, a restoration plan is prepared, and that the basin water be analysed by a third-party and the results filed with ADEC in case future concerns are identified. All of these stipulations have been met, and the informational package is supplied in Appendix A.

5.5 Certificate of Authorization

The Alaska Center for Unmanned Aircraft Systems Integration (ACUASI) was established by the University of Alaska Board of Regents in 2012 and is Alaska's premier operational Unmanned Aircraft Systems (UAS) entity. ACUASI manages the Federal Aviation Administration's (FAA) Pan Pacific UAS Test Range Complex (one of six nationwide), inclusive of six FAA approved test ranges within

Alaska. One of these Alaskan test ranges is centred at Poker Flat Research Range, where Certificates of Authorization are maintained for all aerial vehicles in the ACUASI fleet. An addendum to the ACUASI CoA for operations at Poker Flat to include the Responder aircraft was approved in writing by the FAA for this experiment. Extensive flight acceptance testing was required before the Responder was certified to fly over the test basin. Additional protocols associated with UAS missions were also employed, such as the Notice to Airmen that was published each time any of the UASs in the experiment flew. Comprehensive flight communications were maintained prior to, during and after each experiment with the helicopter pilot, allowing for safe operations of both manned and unmanned aircraft with temporal and/or spacial separation being maintained during the flight operations over the test basin.

6. CONSTRUCTION OF TEST BASIN AND PREPARATIONS FOR TESTS

6.1 Overview

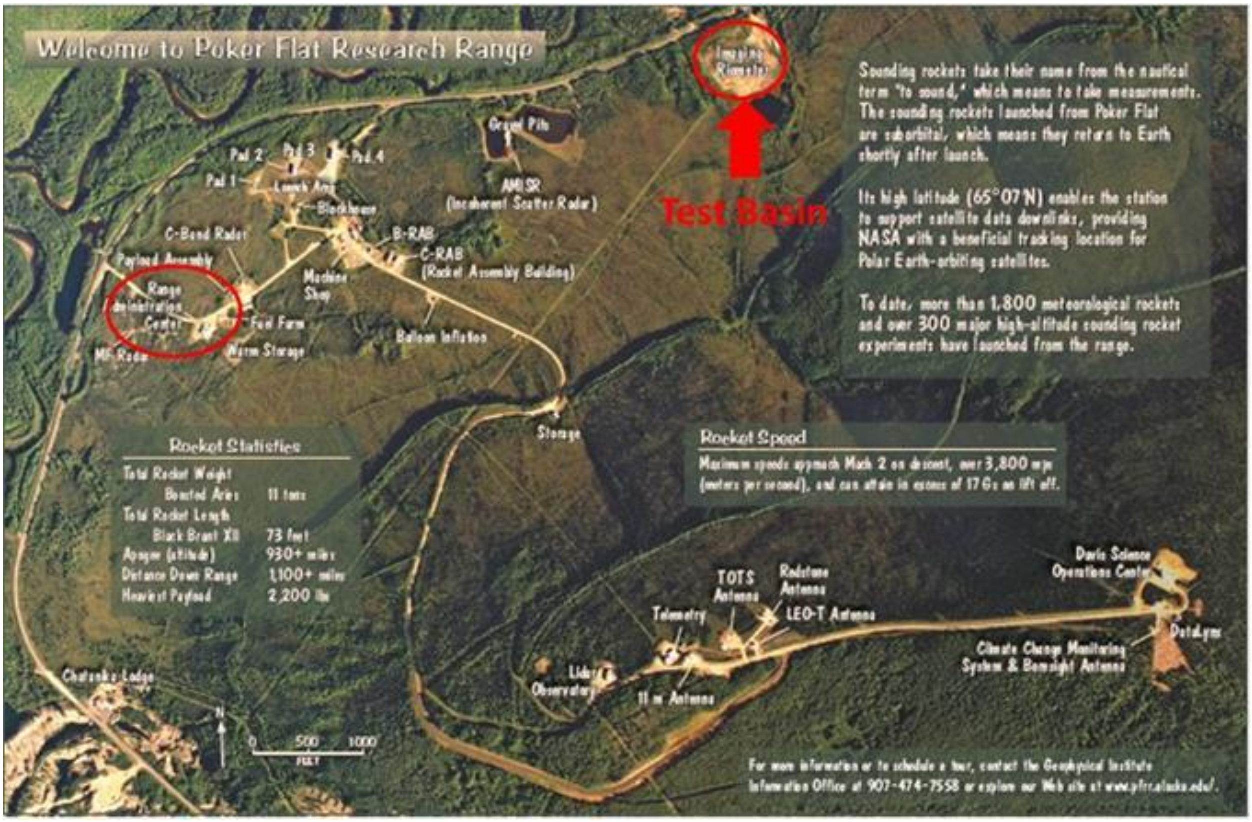
The test basin was sited and constructed at the Poker Flat Research Range (PFRR), an extensive land area managed by the University of Alaska Fairbanks (UAF) and situated approximately 50 km (30 miles) northeast of Fairbanks, Alaska. **Figure 1** shows the site location and **Figure 2** the highway access.

The test basin was a square pool 90 m (300 ft.) on a side, contained by a 1 m (3 ft.) high lined berm. The interior of the berm was lined with armoured rock; inclusive of a 10 cm (4 in) wide strip of metal flashing embedded into the rocks approximately 15 cm (6 in) above the basin bottom. Both the rock and the flashing were installed to prevent scorching and contamination of the liner itself. The basin was constructed in the fall of 2014; “ice floe” forms were placed with the basin in early winter 2015 and filled with water from a water truck. In the days prior to the start of the test, the pool was filled with approximately 15 cm (6 in) of water by pumping from a nearby pond. Additional “faux bergs” were constructed part of the way through the testing period to simulate the icebergs that had already melted.

Following the tests, the water in the basin was cleaned of visible oil subsequently subjected to third-party laboratory testing. Test results indicated that the basin water was free of petroleum-related compounds, and the water was left to evaporate over the course of the summer. After more than 90% of the original water had evaporated over the ensuring summer, the basin began filling up again during August 2015 due to autumn rains. Although UAF obtained a letter of no objection from the ADEC to dispose of the water on the ground surface outside the basin, the decision was made to leave the remaining water in the basin for the time being.

The location at the PFRR provided operational amenities and flight operations clearances, as well as distance from the Fairbanks air shed. The site has electric power available, a small building for gathering and storage of supplies, and some small storage buildings on the east side of the site. The site has had multiple uses including as an asphalt plant and processed materials site. The pond to the south is an old material pit and is approximately 3.3 m (11 ft.) deep on average. The site is almost flat and is kept free from vegetation by periodic mowing. The Chatanika River lies to the north of the highway.

One of the main features related to a previous use of the site is an antenna array, known as an “imaging riometer.” The riometer had been damaged by lightning and is inoperable. The original intention was to remove the riometer array prior to the test programme. However, due to ownership issues and the short time available for construction before winter freeze-up, demolition was stalled and the removal of the riometer array did not occur.



Sounding rockets take their name from the nautical term "to sound," which means to take measurements. The sounding rockets launched from Poker Flat are suborbital, which means they return to Earth shortly after launch.

Its high latitude (65°07'N) enables the station to support satellite data downlinks, providing NASA with a beneficial tracking location for Polar Earth-orbiting satellites.

To date, more than 1,800 meteorological rockets and over 300 major high-altitude sounding rocket experiments have launched from the range.

Rocket Statistics

Total Rocket Weight	
Boosted Aries	11 tons
Total Rocket Length	
Black Brant XII	73 feet
Apogee (altitude)	930+ miles
Distance Down Range	1,100+ miles
Heaviest Payload	2,200 lbs

Rocket Speed

Maximum speeds approach Mach 2 on descent, over 3,800 mps (meters per second), and can attain in excess of 17 Gs on lift off.

For more information or to schedule a tour, contact the Geophysical Institute Information Office at 907-474-7558 or explore our Web site at www.pfrr.alaska.edu/.

Figure 1: Aerial view of the lower Poker Flat Research Range

(IMAGE COURTESY OF THE GEOPHYSICAL INSTITUTE, UNIVERSITY OF ALASKA FAIRBANKS)

Figure 2: Close-up of test site

6.2 Basin construction

The basin is a 90-metre (300-ft) square as shown in **Figure 3** and **Figure 4**. A detailed construction report is given in Appendix B. A 4-metre (12 ft.) wide access route was built around the perimeter using compacted crushed material to allow light truck traffic and construction vehicles. One large ramp (vehicle-ready) was built into the berm wall for liner placement access. Two small ramps were built and installed after construction to allow access into the pool by workers during placement of the “ice floe” forms and cleaning of the water surface between experiments. The ramps allowed access without degrading the berm or damaging the liner. As a precaution against over flooding of the basin, a 15 cm (6 inch) diameter overflow pipe was installed perpendicular to the walkway and over the liner. Although overfill was quite unlikely, if it were to occur without the overflow pipe, the runoff would quickly cut through the berm and compromise the integrity of the basin. A 3 m by 3m (10’ by 10’) low area was created in one corner of the basin to facilitate pumping.

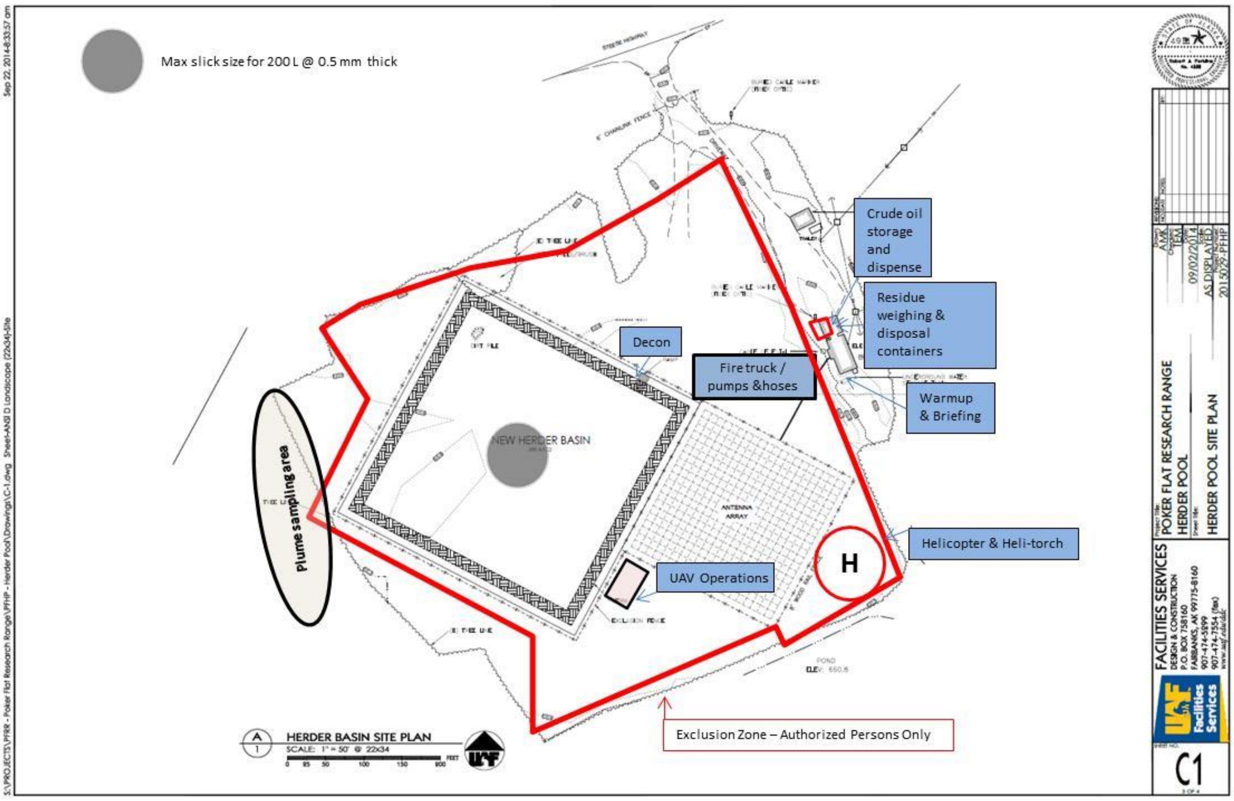


Figure 3: Herder test basin design and site layout

Figure 4: Aerial view of finished basin and site equipment locations

6.3 Berm Design

The berm was constructed with a trapezoidal profile (Figure 5) with an approximate 2:1 horizontal to vertical slope, which is typical for ungraded fill in highway construction. The top of the trapezoid was a 1-m (3-ft) walkway to allow observations around the perimeter of the basin by test personnel during the experiments. The fill was installed in 6-inch lifts of soil interspersed with passes with the tread of a bulldozer for compaction.

Material for the berm construction was collected by bulldozing the site after grubbing the area of vegetation. The soils are silty and well drained, with no deposits of organics rich soils such as tundra or peat were found. It was important to remove all shrubs and vegetation from the substrate to avoid punctures of the liner. The basin floor was levelled to plus or minus approximately 4 cm (1.5 inches) before the liner was installed.

Baseline soil samples were collected from the test basin area by a third-party analytical laboratory using state approved sampling and storage protocols. All third-party collected samples were analysed for DRO, RRO, GRO and BTEX; the results are available in Appendix A

6.4 Perimeter Berm and Liner

Figure 5 illustrates the section of the prism and details of the liner. The two features shown are the liner keyway and liner protection. During construction of the berm, the liner contractor began to lay down the geotextile and install the liner. The liner was anchored by placing it in a keyway and placing sandbags on it. After the liner was completely installed, the keyway was backfilled. Following this, crushed stone (i.e., thermal armour) was placed on the face of the berm where the liner was exposed. This was intended to provide radiant heat protection for the liner during the experimental burns. Finally, a 46 cm (18-inch) vertical shield of metal flashing material was installed near the base, extending below the water level, which served to keep oil or burning oil from impacting the thermal armour and liners. Although the burns were not expected to last more than a few minutes and were intended to be initiated away from the berm, any incidents that compromised the liner could significantly delay the completion of the testing. Prior to the tests, sorbent material was placed between the flashing and the thermal armour. Its purpose was to prevent oil migrating past the flashing and coating the rocks. Although there was only a slight chance of this occurring, cleaning oil from large areas of the rocks could be difficult and time-consuming.

The liner material selected was 8218 LTA (see Appendix B for specification sheet). This material is not recommended for storage of oil as a free product, but is standard in Alaska for containing waters contaminated with petroleum or other waste products, which most accurately reflects the conditions expected in this study. As recommended by the supplier, the liner was sandwiched between two layers of geo-textile fabric (GeoTex 801) to provide puncture and abrasion resistance from above and below.

After the conclusion of construction, a plastic exclusion snow fence was installed to warn snow machines and other possible intruders to stay off the liner.

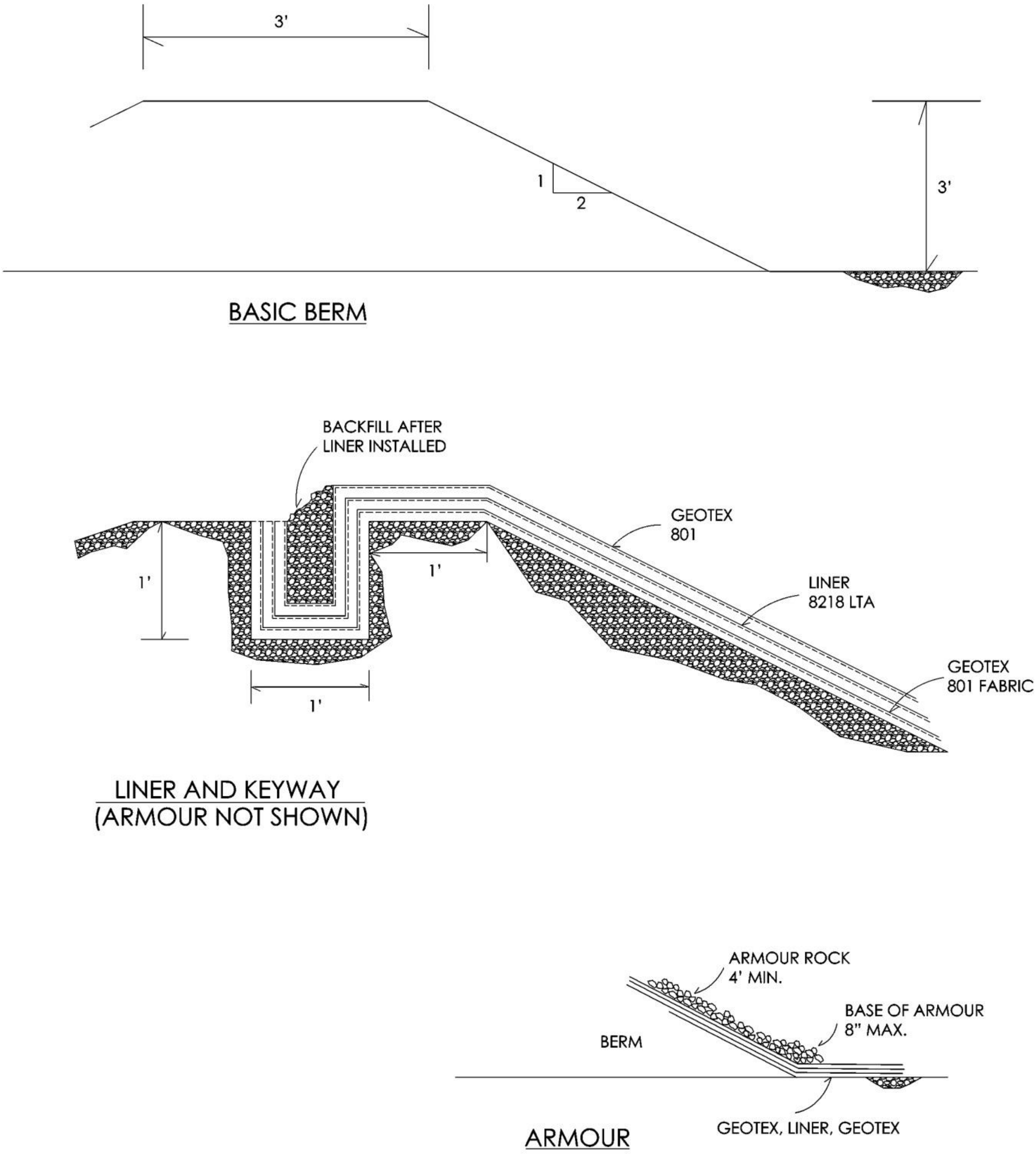


Figure 5: Berm and Liner Design (Cross-Section)

6.5 Ice Floes

The experimental plan called for 10% ice coverage through the central part of the basin. The planned layout of the ice floes is shown in **Figure 6**; it shows 10% areal coverage of the basin, leaving a 10-metre perimeter clear to allow easier clean-up of any oil and residual herder remaining after each test.

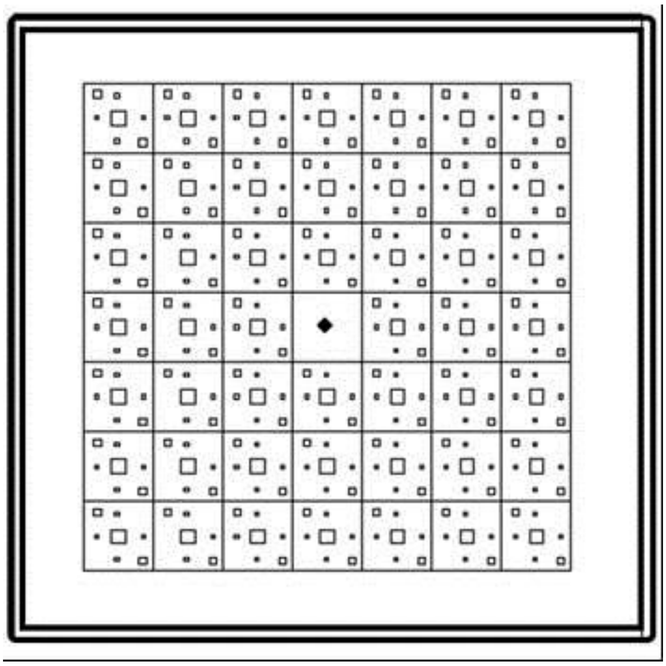


Figure 6: Planned layout of small, medium and large ice forms in test basin

Ice floes were of three dimensions: 60 cm and 120 cm square and 2.4 m diameter by 60 cm in height (2- and 4-foot square and 8-ft diameter by 2-feet in height). The 2.4 m (8-foot) ice floes were formed using plastic inflatable children's pools; the two smaller sizes were formed using heavy-duty cardboard boxes lined with plastic. The forms were placed in the empty basin in January 2015, and subsequently filled with water from a water truck (**Figure 7**). Freezing required several weeks, after which the forms were removed during the week of March 16 to 20. **Figure 8** shows the floes just prior to filling the basin with 15 cm (6 in) of water. Record warm conditions over the subsequent two weeks caused significant melting of the ice floes prior to the test program.

It rapidly became evident that the ice floes would deteriorate to such an extent as to be inadequate by the start of the tests, so alternative "faux" ice floes were created. Inasmuch as the main purpose of the ice floes was as a mechanical barrier to oil spreading, metal rings of various sizes were constructed to act as ice floe surrogates. Galvanized metal flashing in 2.4 m (8 foot) lengths were formed into rings using one, two, or three lengths to form circles with approximately 1 m, 2 m, and 3 m (8-, 16-, and 24-foot) circumference (**Figure 9**). Large pieces of white sorbent were placed inside the sheet metal rings to provide contrast for the aerial photography. The rings were placed within the central portion of the tank providing "ice" coverage of approximately 6% (**Figure 10**).

Figure 7: Cardboard boxes and children's pools used as forms to freeze water for ice floes

Figure 8: Ice floes in basin just before addition of water

Figure 9: Sheet metal "faux" floes constructed to replace melting ice

Figure 10: "Faux" floes in basin

6.6 Spill Release Frame

The test plan called for an instantaneous release of oil in the central portion of the basin. To achieve this, a spill release frame was constructed using 7.6 cm (3-inch) angle iron to form a 2.4 m (8-foot) square (**Figure 11**). The square was elevated by placing it on concrete paver blocks such that it had approximately 2.5 cm (1 inch) of freeboard. The selected volume of oil for each test, nominally either 100 or 200 litres, was then carefully poured into the ring (**Figure 12**). Stainless steel aircraft cable was attached to the frame and run to a position outside the basin at the upwind direction. When each test was initiated, workers pulled the cables to move the frame off its supports, dropping it below the water surface and causing the oil to be released (**Figure 13**).

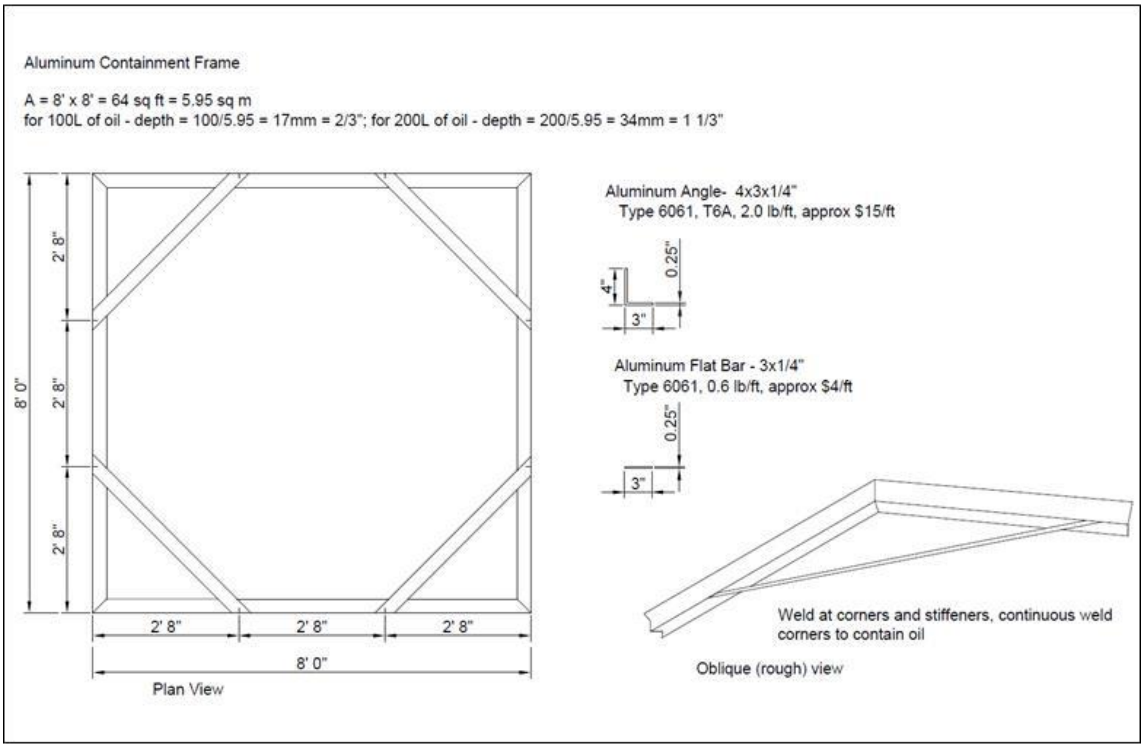


Figure 11: Aluminium angle release frame design sketch

Figure 12: Pouring pre-weighed buckets of ANS crude into release frame in centre of "faux" floe field

Figure 13: Release frame pulled off supports to release oil

6.7 Meteorology Station and Air Samplers

Figure 14 shows the portable meteorology station situated near the basin to record the weather conditions during the tests. The wind sensor was positioned 3 metres above the ground. **Figure 15**

shows the wind sock used for visual wind direction indication and flight operations attached to the corner of a storage container near the basin. The meteorological data collected during the tests is given in Appendix C. **Figure 16** and **Figure 17** show the air pollution samplers provided by the ADEC and used to measure the air before, during and after each test. These three samplers were positioned along a line perpendicular to the estimated drift direction of the combustion gases for each burn. The trailer-mounted samplers could be repositioned easily after the crude oil was ignited to increase the chance of collecting data from the plume. This data may be found in Appendix D.

Figure 14: Portable meteorology station

Figure 15: Wind sock on site

Figure 16: Trailer-mounted air samplers

Figure 17: Stationary air sampler

6.8 Measurement of Oil and Burn Residue

To estimate the amounts of crude oil released for each test, the oil that had been delivered to the site in steel drums was pumped into numbered plastic buckets that were then weighed using a digital hanging scale (**Figure 18**). These buckets were subsequently carried out to the release frame and carefully poured into the frame using a spill plate to ensure that it did not splash or contact and stick to the basin liner (**Figure 12** above). Once a burn had extinguished, the burn residue and any unburned oil was carefully collected with pre-weighed sorbent, placed in a pre-weighed plastic bag and reweighed on a digital hanging scale (**Figure 19**). The losses of oil to evaporation were not measured.

Figure 18: Digital Hanging Weigh Scale

Figure 19: Scale Weighing Fresh Crude in Pails

7. PROJECT MANAGEMENT PLAN, TEST PLANS, AND HSE PLANS

7.1 Project Management Plan

The project team developed an overall project management plan based on a phase-gate model (see **Figure 20**). The objective was to incorporate clear decision points along a timeline to approve moving to the next phase. A key component of the overall project management was the HSE plan that covered all identified hazards and their mitigation. All plans went through several stages of internal review and approval before testing began.

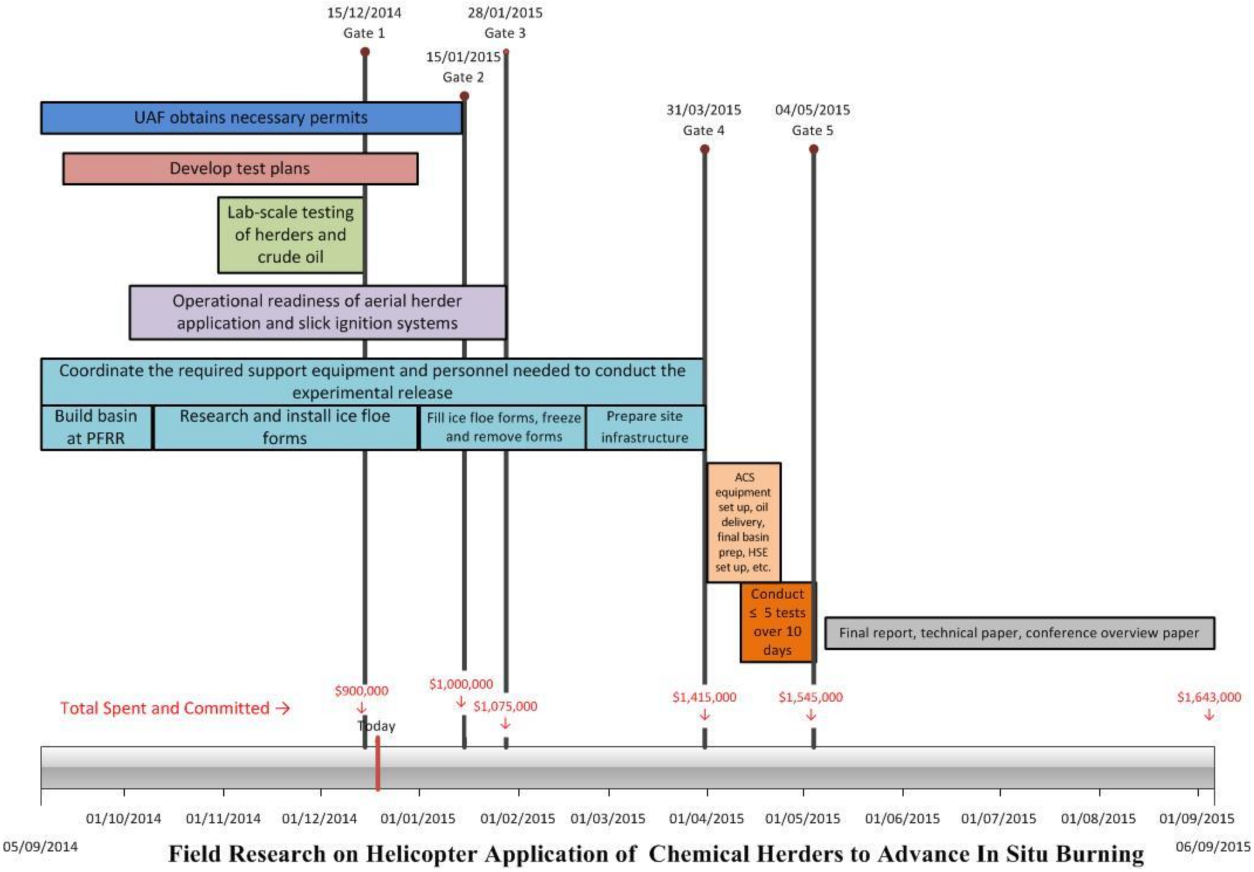


Figure 20: Phase Gate Management Plan

7.2 Experimental Plan

A detailed test plan is available in Appendix E. A much abbreviated version of the test procedure follows:

1. The oil release frame was positioned in the central part of the basin, set it on its supports, and a measured amount of oil carefully poured into it.
2. The helicopter and crew, with herder application system filled with the appropriate herder and pressurized (but with hose reeled inside the cabin), takes off and hovered nearby but not directly over the basin, avoiding rotor wash effects on the basin water surface.
3. A UAV with video camera was launched and hovered a safe distance off to the side of the basin, above the imaging riometer. All aircraft pilots maintained full communication throughout testing with aerial vehicles and ground support.
4. When it was confirmed by radio that all test personnel were ready, the release frame was pulled off its supports allowing the oil to release the oil to spread among the ice pieces.

5. The helicopter and UAV immediately started videotaping and photographing the spread of the oil (with GPS and altitude-encoded cameras and the radio altimeter of the helicopter).
6. The herder applicator hose was deployed from the helicopter. A small camera was mounted to the helicopter to capture oil movement and spray efficiency of the herder deployment system.
7. Once the spreading had essentially stopped the helicopter moved to the downwind edge of the basin and started applying herder onto the water surface in a circle around the oil slick. (Note: in practice, there was insufficient time for complete spreading of the oil, and herder was applied starting within 30 seconds of the oil release.)
8. The helicopter then flew to the landing area to pick up the Heli-torch.
9. All personnel exited the basin perimeter and relocated to a safe zone outside and upwind of the anticipated burn.
10. When the helicopter returned with the loaded Heli-torch, the video operator in the cockpit recorded the slick with the GPS and altitude encoded cameras (Note: in practice, regulations required that only the pilot be in the helicopter when carrying the Heli-torch).
11. The helicopter, on instruction from the Principal Investigator, applied gelled fuel igniters along the upwind edge of the herded slick (depending on the success of this application, additional gelled gas or hand-held igniters were applied elsewhere in the slick).
12. The UAV continued to record the ignition attempts and burn and the helicopter, and once ignition was achieved, moved off to a safe crosswind side of the basin and recorded the burn with the GPS and altitude-encoded cameras.
13. Once the burn had completely extinguished, the remaining oil and burn residue was recovered with pre-weighed sorbent, decanted to remove as much water as possible, and the pads placed in pre-weighed garbage bags for subsequent reweighing to determine burn efficiencies and rates. The pads were allowed to drain for 24 hours to remove water, and then reweighed. Any liquid water in the bottom of the garbage bags was returned to the basin.
14. Used sorbent was placed in an oily waste container for disposal.
15. Before the next test was started, the water surface was agitated with water from fire hoses to disperse remaining herder into the water column. This was done to minimize the influence of remaining herder on subsequent tests and to enhance its biodegradation.

7.3 Safety and Environmental Plan

A separate detailed HSE Plan was written and vetted that covers all aspects of the field tests. This HSE Plan was submitted as a separate document and is not included in this report. Safety of personnel was paramount during the tests at PFRR. The objective was to achieve zero accidents or lost-time incidents, and this was accomplished.

The HSE plan went through several iterations of review by the project team and IOGP’s safety committee and was modified and improved accordingly. Key areas of concern that were addressed in the HSE plan included:

- Safe storage and handling of unweathered crude oil and igniter fuel.
- Safe operations within the test basin with numerous tripping hazards.
- Safe helicopter operations when discharging herder and during operation of the Heli-torch.
- Safe operation of UAV’s in conjunction with helicopter operations.
- Safety of experimental staff and observers during ISB with attendant smoke concerns.

8. PRELIMINARY LAB-SCALE TESTING OF HERDERS

Prior to the field experiments, SL Ross performed laboratory-scale experiments to verify that the test oil was amenable to herding and burning when fresh, and after weathering for a specified time. Tests were also performed to document that the selected herders are equally effective in fresh water and salt water, allowing the full-scale tests to be performed in fresh water without loss of technical integrity. The laboratory work also included a full documentation of the spill-related properties of ANS crude oil, the oil that was to be used in the field experiments. The protocol and results for these tests are shown in Appendix F and Appendix G. Table 1 gives the measured properties of the ANS crude oil sample supplied by IOGP for the laboratory tests. Note that this sample was obtained from a refinery in California in 2013, and was not identical to the sample used in the basin in Fairbanks, which was obtained from Alyeska Pipeline Services Co. just prior to the April 2015 experiments.

The lab-scale herding experiments were performed in the SL Ross laboratory in November/December 2014. The results with the fresh and evaporated ANS crude at 0°C are shown in **Figure 21**. Briefly, the experiments showed that:

1. Both herding agents, ThickSlick 6535 and Siltech OP-40, were effective at herding fresh and moderately weathered oil.
2. Both herding agents, ThickSlick 6535 and Siltech OP-40, were similarly effective at herding oil on fresh and saline water. The large differences in herding effectiveness with the 31% evaporated crude are related to the oil's Pour Point (3°C) and not water salinity: the 31% evaporated oil gelled on the 0°C water.
3. Compared with previous herding studies with ANS crude, the herders were slightly less effective with the current blend of ANS, presumably due to slight changes in ANS composition.

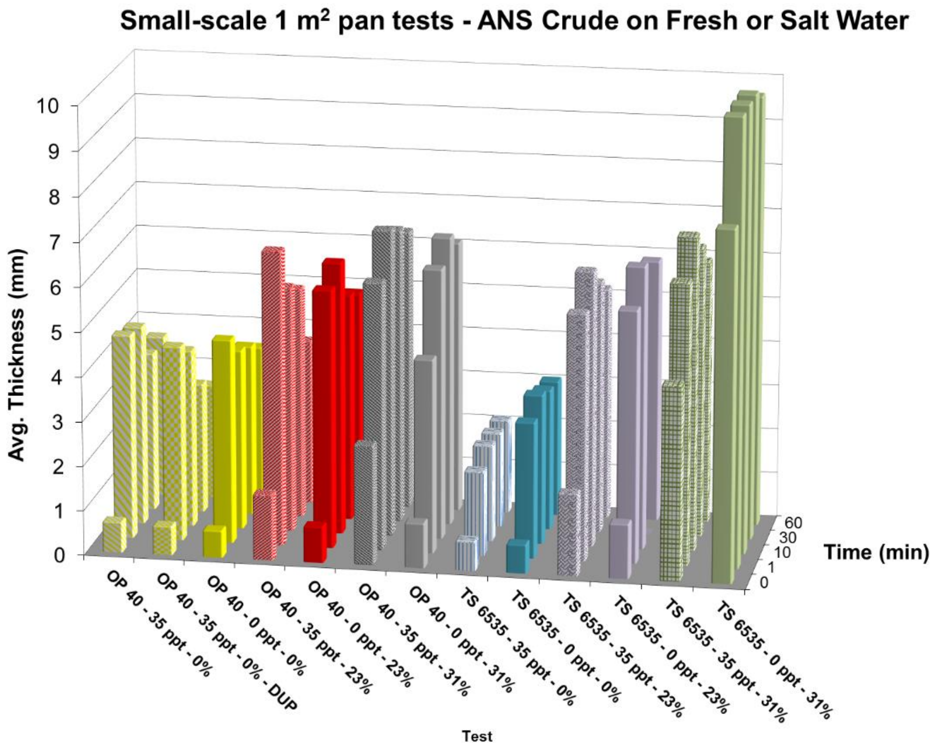
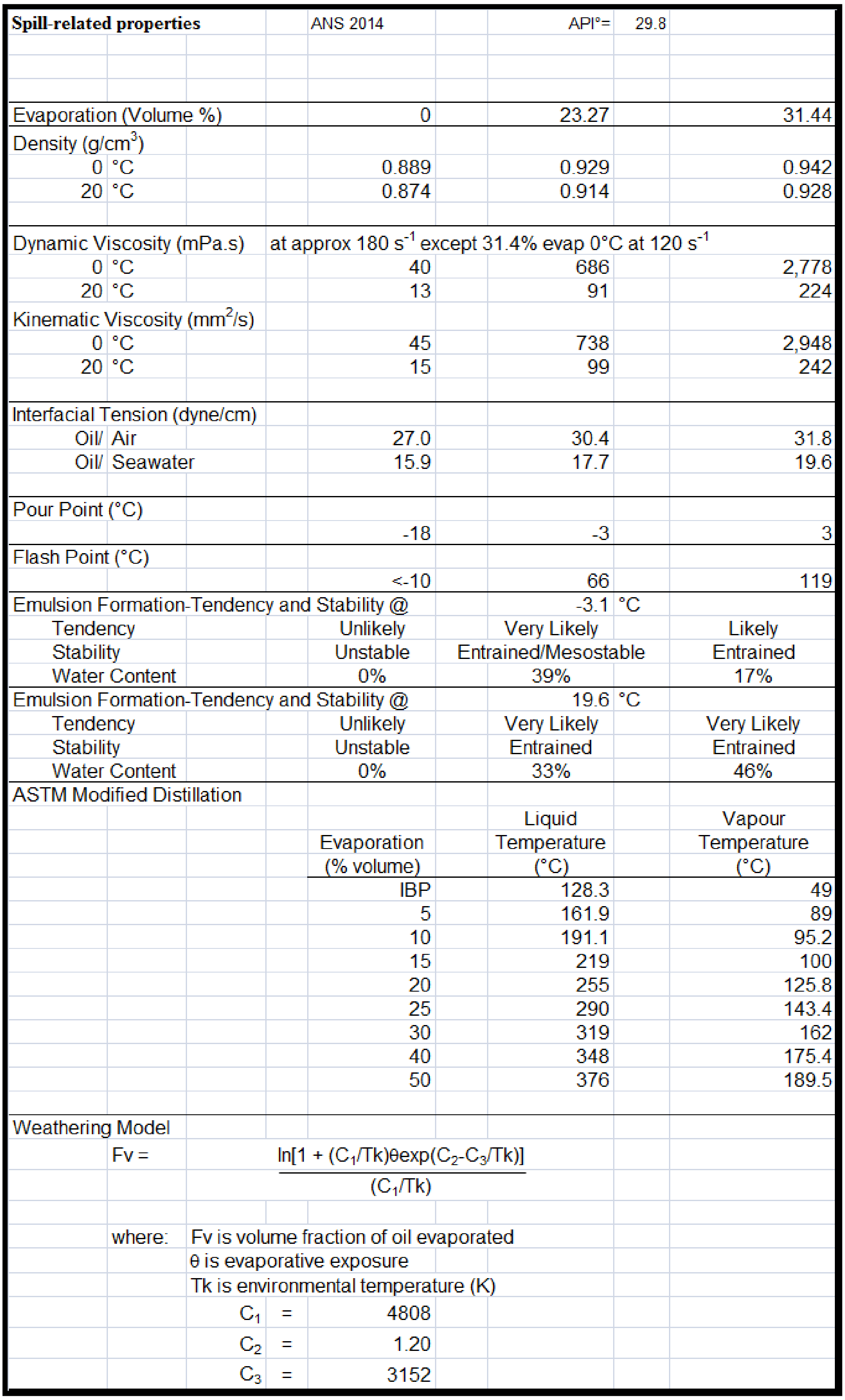


Figure 21: Laboratory Herder Test Results With Fresh ANS Crude

Table 1: Spill-related physical properties of ANS Crude Sample



Spill-related properties		ANS 2014	API°= 29.8	
Evaporation (Volume %)		0	23.27	31.44
Density (g/cm^3)				
0	°C	0.889	0.929	0.942
20	°C	0.874	0.914	0.928
Dynamic Viscosity (mPa.s)	at approx 180 s^{-1} except 31.4% evap 0°C at 120 s^{-1}			
0	°C	40	686	2,778
20	°C	13	91	224
Kinematic Viscosity (mm^2/s)				
0	°C	45	738	2,948
20	°C	15	99	242
Interfacial Tension (dyne/cm)				
Oil/	Air	27.0	30.4	31.8
Oil/	Seawater	15.9	17.7	19.6
Pour Point (°C)				
		-18	-3	3
Flash Point (°C)				
		<-10	66	119
Emulsion Formation-Tendency and Stability @			-3.1 °C	
Tendency		Unlikely	Very Likely	Likely
Stability		Unstable	Entrained/Mesostable	Entrained
Water Content		0%	39%	17%
Emulsion Formation-Tendency and Stability @			19.6 °C	
Tendency		Unlikely	Very Likely	Very Likely
Stability		Unstable	Entrained	Entrained
Water Content		0%	33%	46%
ASTM Modified Distillation				
		Evaporation (% volume)	Liquid Temperature (°C)	Vapour Temperature (°C)
		IBP	128.3	49
		5	161.9	89
		10	191.1	95.2
		15	219	100
		20	255	125.8
		25	290	143.4
		30	319	162
		40	348	175.4
		50	376	189.5
Weathering Model				
Fv =		$\frac{\ln[1 + (C_1/Tk)\theta\exp(C_2-C_3/Tk)]}{(C_1/Tk)}$		
where:	Fv is volume fraction of oil evaporated			
	θ is evaporative exposure			
	Tk is environmental temperature (K)			
C_1	=	4808		
C_2	=	1.20		
C_3	=	3152		

9. OPERATIONAL READINESS OF AERIAL HERDER APPLICATION AND SLICK IGNITION SYSTEMS

Helicopter-based herding/ISB requires both a herder delivery system and an ignition source to be deployed and controlled by either a dedicated operator, or the pilot. Equipment weight will affect ultimate payload of herder and ignition fuel that can be carried, thus a light, robust unit is ultimately the design target. DESMI-AFTI, the vendor for two herder formulations, built an initial prototype herder delivery system for use in a manned helicopter. A previous project, funded by ExxonMobil, culminated with successful static tests from a crane. The next step in the system development involved testing on an actual helicopter to verify that the spray pattern, dosage, and airborne operation met requirements for the field test in Alaska. To that end, three series of tests were performed to ensure that the operation and performance of the aerial delivery system were verified prior to the field tests.

9.1 Initial Prototype DESMI AFTI Herder Application System

The DESMI AFTI herder application system was designed to transport and apply either OP-40 or ThickSlick 6535 from the open rear door of a commercial helicopter. The storage tank is insulated and carries up to 75 litres (20 US gallons) of herder. The system runs on 28V using aircraft quality components. It comprises two modules mounted on aluminium frames that are easily handled by two persons. The first module contains an extensible reel housing approximately 30 m (100 feet) of Stratoflex stainless steel hose with a Teflon liner. The second module houses an air-powered pump and air compressor capable of purging lines at the end of an application pass. It also contains a self-contained 28V battery array plus a 28V accessory cord for attachment to aircraft power systems, if available. Complete electrical circuit protection is provided with integrated circuit breakers, while multiple nozzles are enabled to adjust flow rate. The reel module with approximately 30 metres (100 feet) of hose has overall dimensions of 1.22m x 0.81m x 0.74m (48”L x 32”W x 29”H) and weighs approximately 91 kg (200 lbs.) when the hose is full of herder. The pump and tank module (see **Figure 22** and **Figure 23**) has overall dimensions of 1.22 x 0.61 x 0.61m (48”L x 24”W x 24”H), and weighs 84 kg (185 lbs.), plus up to 73 kg (160 lbs.) of herder.

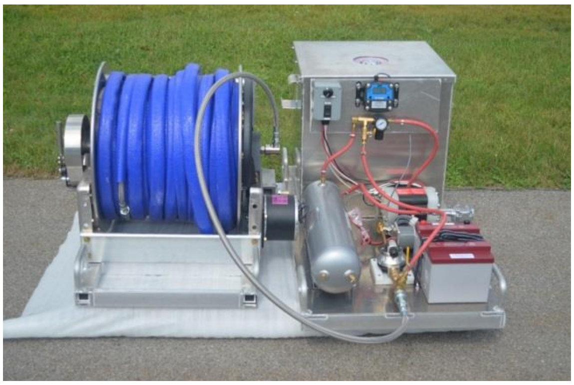


Figure 22: Initial Prototype Herder Application System Front

Figure 23: Initial Prototype Herder Application System Back

9.2 Initial wind tunnel testing of herder spray system

Initial testing of the herder spray system occurred in College Station, TX at the United States Department of Agriculture’s Aerial Application Technology Research Unit of the Agricultural Research Service. The Aerial Application Technology Research Unit has ample expertise in the development and implementation of new and improved aerial application technologies usually related to crop production and protection. Two of their primary areas of research focus on: optimizing aerial spray technologies for on-target deposition and droplet drift mitigation; and, characterizing the effects of spray systems and formulations on droplet size (see **Figure 24**).

Figure 24: Wind Tunnel for Nozzle Testing

A variety of testing parameters were selected to mimic the application of the herders from an airborne platform. The two main parameters, velocity of wind blowing past the nozzle representing the forward flight of a helicopter in the field and the operating pressure of the herder fluid being pumped through the herder application system, were mimicked in one of the Aerial Application Technology Research Unit's wind tunnels to determine the impact on the atomization and subsequent droplet size and distribution using a range of nozzles (see **Figure 25** through **Figure 28**).

Airspeed of approximately 60 knots (110 km/h, or 70 mph) was used as an upper limit for the helicopter housing the herder application system, while operating pressures up to 50 psi representing a value slightly over the approximate pressure drop through 100 vertical feet of hose were selected for the test matrix. Fluid properties were expected to impact the droplet formation and water was included in the test matrix to identify differences in flow dynamics.

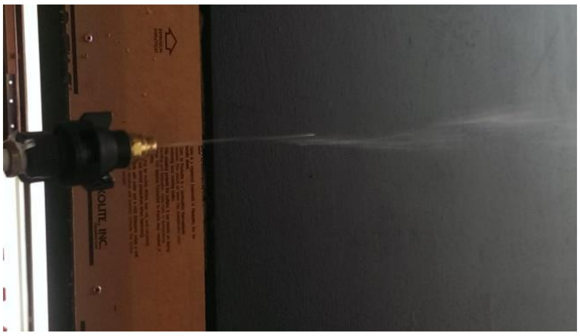


Figure 25: Baseline SS 0002 Nozzle Test with Water


Figure 26: Baseline Test Tunnel View


Figure 27: Flat Fan 8008 Nozzle with ThickSlick


Figure 28: CP Products 2008 Nozzle with ThickSlick 6535

The results of the testing showed that the best results were obtained using nozzles with an angled spray. Volume mean diameters in the 500 to 1000 **μm range were targeted so that the produced droplets would be large enough to land near where they were released (i.e., not carried away by wind or blown aside by rotor wash from the helicopter) yet small enough to minimise penetration upon impact on the water surface. Table 2 summarizes the results of the nozzle testing. VMD (DV0.5) refers to the midpoint droplet size where half of the volume of spray is in droplets smaller, and half of the volume is in droplets larger than the mean. DV0.9 indicates that 90% of the volume of spray is in droplets smaller (or 10% larger) than the stated value; DV0.1 value indicates that 10% of the volume of spray is in droplets smaller than the stated value.**

Table 2: Atomization Testing Results

Solution	**Nozzle**[2]	**Airspeed (mph)**	**Pressure (psi)**	**DV0.1 (μm)**	**DV0.5 (μm)**	**DV0.9 (μm)**
Water	SS 0002	40	40	1341	1581	2085
Water	SS 0002	40	50	1338	1635	2166
Water	SS 0002	70	40	1279	1545	1878
Water	SS 0002	70	50	1254	1507	1815
Siltec OP-40	SS 0002	70	40	886	1310	1481
Thick Slick 6535	SS 0002	70	40	560	1259	1592
Water	Flat Fan 8008	40	40	231	423	697
Water	Flat Fan 8008	40	45	214	382	641

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[2] The first two digits of the nozzle number specify the angle of the cone-shaped spray (00 means a straight stream) and the second two digits specify the nominal nozzle flowrate in gpm at a standard pressure – 02 is 0.02 gpm)

Solution	Nozzle[2]	Airspeed (mph)	Pressure (psi)	DV0.1 (µm)	DV0.5 (µm)	DV0.9 (µm)
Water	Flat Fan 8008	40	50	197	346	552
Water	Flat Fan 8008	70	50	197	354	573
Water	Flat Fan 8008	70	45	201	380	658
Water	Flat Fan 8008	70	40	203	394	680
Water	CP 2008	70	40	545	868	1268
Water	CP 2008	70	45	522	859	1270
Water	CP 2008	70	50	494	840	1269
Water	CP 2008	40	50	428	780	1213
Water	CP 2008	40	40	479	857	1287
Water	CP 2008	40	45	448	780	1160
Siltech OP-40	CP 2008	40	45	278	647	1203
Siltech OP-40	CP 2008	70	45	185	450	796
Siltech OP-40	FF8008	70	45	114	278	561
Siltech OP-40	FF8008	40	45	167	383	974
ThickSlick 6535	FF8008	40	45	297	630	994
ThickSlick 6535	FF8008	70	45	157	399	737
ThickSlick 6535	CP 2008	70	45	218	659	1266
ThickSlick 6535	CP 2008	40	45	992	1259	1427

The CP 2008 nozzle, which has a 20-degree nozzle (slightly fan pattern) and a 08 orifice, provided the best results under the test conditions.

9.3 Initial Helicopter testing of the Prototype Herder Application System

The test platform was an MD-600 NOTAR turbine powered helicopter (**Figure 29**). This is typically a six to seven passenger aircraft depending upon the configuration of the seats. This aircraft was configured for the pilot to be seated on the right-hand side. With the herder system, operator, plus pilot, there was sufficient gross weight capacity for the aircraft to operate with a fuel endurance of approximately two hours flight time.

Figure 29: MD-600 NOTAR Helicopter

The herder application system was fitted crossways to the aircraft with the rewind guide roller extending from the right side behind the pilot (**Figure 30**). The controls of the system were accessible to the system operator located in the left front seat of the aircraft, but the hose and roller were too far from the operator to be able to exert any control over the hose (**Figure 31**). Removing the left side controls made access to the system easier as the operator had to sit sideways in the aircraft to reach and engage switches on the application system during flight.

Figure 30: Herder Application System: Nozzle Assembly

Figure 31: Herder Application System: Controls and Reel

Most general aviation aircraft of this size are also 28v. It was possible to connect the battery of the herder application system to the electrical system of the aircraft with a direct wire that was initially designed to power a spray system permanently mounted to the aircraft below the skids. This connection provided sufficient energy to power the herder application system indefinitely. A 10- to 14-gauge wire from the accessory bus on the aircraft powered through a breaker would be suitable to "assist" the built-in herder application system electrical power.

The physical size of the herder application system, while tight, would be adequate for this model aircraft or larger, such as a Bell Long Ranger or 212/412/414, Eurocopter MBB109 or equivalent. Most twin-engine helicopters would have more than adequate floor space to accommodate the system.

A number of difficulties were encountered during the initial test flight and possible solutions were identified:

1. Extension of the hose was difficult due to the hose wrap insulation catching on the edge of the guide roller flange. The insulation wrapping is a stock aircraft *fire sleeve* material that was ultimately found to be too large for this application. Smaller fire sleeve could have been used but that material adds significant weight. One possible solution would be using a foam pipe wrap that clings directly to the hose, while providing the needed insulation value for cold weather operations, and has a minimal weight penalty. A foam wrap would also make the hose much smaller in diameter, making it easier to wind on the spool
2. The hose did not have adequate weight on the end to keep it sufficiently vertical during flight. It was envisioned that a 5.5-kg (12-lb) torpedo weight under the nozzle would help to put more load on the hose to make it unreel easier and keep it from sailing further from vertical while in motion (**Figure 32**). This solution was tested successfully at PFRR.
3. The control valves needed to be electrified so that the operator could run the system while facing forward in the helicopter. This could be done using simple solenoid valves. Three valves were required. In this fashion a simple on/off and purge system could duplicate the existing manual valves (**Figure 33**).
4. The pump compressor on/off needs a remote switch as well. A simple interrupter switch could be added to the remote control panel to control this function.
5. The spool control can be moved from the front of the system to the remote control panel to enable the operator to spool the hose in and out.

6. A similar solenoid needed to be fitted to the brake control so that the hose can be stopped mid-way in or out.
7. The hose reel needed to be mounted on the extensible frame so that it is parallel to the direction of flight and so that the hose does not have any bends or angles to negotiate when being deployed or retrieved. The spool needed to be narrowed significantly. By reducing the hose diameter it is believed that the spool can be made about 12 to 14" wide instead of the current 24".
8. The liquid storage tank needed to have a sight gauge and a drain valve fitted so that any excess liquid can easily be removed from the tank (**Figure 34**).

Figure 32: Helicopter Test Flight

Figure 33: System Control Valves

Figure 34: Filling Storage Tank

9.4 Second Helicopter testing of the Prototype Herder Application System

This evaluation of the modified Prototype Herder Application System was used to confirm that the system would be compatible with, and fit in, a Bell 407 helicopter, which was the selected platform for the field tests. This second helicopter testing was conducted at JBI Helicopters in Concord, New Hampshire on March 16, 2015 (see **Figure 35**).

Modifications of the framework of the two herder application modules were required to clear some of the space constraints, and this was performed in one day (see **Figure 36**). A deck section was constructed that could fit into any Bell 407 helicopters using the seat-belt attach points to secure it to the aircraft (see **Figure 37**). Some additional reinforcements to strengthen the deck plate and minimize any potential for flexing were also installed (see **Figure 38**). A power lead, Canon plug and diode were installed to take advantage of the accessory plug in the aircraft.

A test flight was performed to ensure that the system operated and flew properly. Several extensions and retrievals using the remote control system and remote brake handle were conducted. Several flights with the hose partially and fully extended were conducted to demonstrate that the system was controllable with an additional weight of approximately 5.5 kg at the end of the hose (see **Figure 39**). Forward speeds were in the 30- to 40-knot range.

An additional modification to the hose guide assembly was necessary to extend downward from the spool assembly to provide more control over the hose. A fairlead with brackets extending from the frame to the fairlead should ensure that the hose does not rub or have potential to become entangled with the skids on the helicopter. This may be especially important if pop-out emergency floats are fitted to the helicopter. Some chafing foam and tape had been installed on both the skid cross member, and the side of the fuselage to prevent any potential for paint abrasion.

Figure 35: System installed in Bell 407 helicopter


Figure 36: Hose reel extended out from helicopter


Figure 37: Rear seat belt attachment brackets


Figure 38: Forward seat belt attach points with machined stiffener bracket

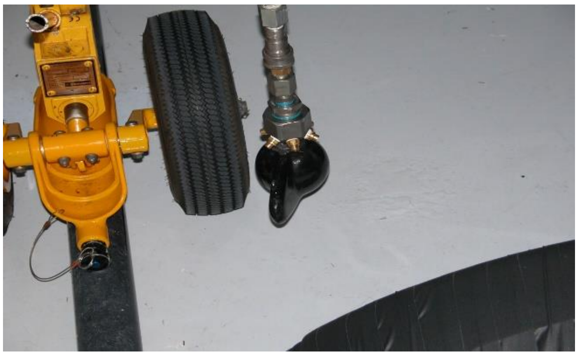
Figure 39: 5.5kg weight on end of nozzle

Some additional improvement possibilities were noted during the second series of helicopter testing:

1. The operator seat on the left side leaves very little room for the operator to turn and see what is going on behind: a mirror attached to the door frame for the operator would be useful.

2. The pilot needs to be able to see the bottom of the hose or a second operator is required to run the herder application system. One obvious option is to fly with the pilot side door removed. The pilot used in the second helicopter testing series was very experienced in operating underslung loads and was quite comfortable flying this system. There were no anomalies noted in the flying characteristics of this aircraft with the system installed.

3. The ground crew needs to remember to turn on the reel master and other switches on the control panel on the unit before the aircraft takes off.

4. The amperage draw of the compressor and spool motor together are at the limits of the aircraft accessory breaker. It might be necessary to install a switch on the remote control to turn off the compressor to avert any potential overload on the aircraft accessory breaker. The pilot did not see any issue with it when it was operating and the battery installed on the aircraft had enough energy to retract the hose while the compressor was running as long as the battery was fully charged. The use of the accessory lead to constantly charge the battery will ensure this.

5. Installing a GoPro camera on the nozzle and remotely connecting it to a tablet would enable the operator can see what is happening at the nozzle. The nozzle is too far from the pilot to see precisely what is coming out of it.

6. Developing more sophisticated remote controls with fault tolerant programming to automate the application of the herder and retrieval of the hose would simplify the tasks burdening the operator. The 407 is very small and does not permit the operator to sit in the rear or to have any access to the unit in flight.

10. FIELD EXPERIMENTS

10.1 Test Chronology

Dry runs with the helicopter and an empty Heli-torch were conducted on April 18th (the day the basin was filled) and 19th, 2015. Shipping delays of the herder application system meant it did not arrive at the helicopter hangar in Fairbanks until April 21st: a dry run with the herder application system mounted in the helicopter was conducted on the evening of April 21st. On April 20th, the field crew removed the upper Geotextile layer that had become a significant tripping hazard.

10.1.1 Test 1 – April 22, 2015

This initial test involved 70 litres (18 gallons) of fresh ANS crude oil. The planned release volume was reduced to eliminate spillage from the weighing buckets as they were hand-carried to the release frame in the basin. Winds were 1 to 1.5 m/s (measured at a height of approximately 3 m above the ground). The air temperature was between 6° and 7°C and the water temperature was 5.5°C. The sky was clear and sunny. The rind of ice that formed overnight on the basin had melted and open water conditions prevailed between the real and artificial floes.

The helicopter herder application system was loaded with approximately 15 litres (4 gallons) of OP-40. Based on the results of dry runs, additional hose had been added to the system reel and all 60 metres (200 feet) of hose was deployed beneath the helicopter. To minimize rotor wash the pilot was instructed to maintain an altitude of at least 70 m (220 feet), keep forward motion at all times, and not hover over the basin.

The Heli-torch was loaded with 19 litres (5 gallons) of a mixture of 60% diesel / 40% gasoline gelled using a new ACS supplied two part liquid-based gelling agent, Flash 21A and Flash 21B. The test data sheets may be found in Appendix H, with additional details in the run timing and comment sheets located in Appendix I.

The oil was released from the aluminium square in the middle of the test basin when the helicopter was positioned off to the side of the basin with the herder application hose deployed and charged with herder. It was noted that the added length of application hose caused the column of herder to open the 60 psi check valve at the end, and herder dribbled from the nozzle body even when the pump was not activated. The oil was allowed to spread for a short time (10 to 20 seconds) then the pilot was instructed to apply the herder. The helicopter was used to apply two lines of herder down each side of the basin (**Figure 40**) by making one upwind (inside the southeast edge of the basin) and one downwind pass (inside the northwest edge of the basin). Refer to **Figure 3** for the orientation of the basin. The pilot had difficulty controlling the swing of the 200-foot hose. A total of approximately 11 litres (3 gallons) of herder was applied by the helicopter (**Figure 41**). During this test, the nozzle of the herder application system became detached, and was subsequently modified to have a safety tie-off from the nozzle to the application system.

A small amount of additional herder (1.4 litres = 0.4 gallons) was manually applied from garden sprayers to the water along the sides of the basin not sprayed by the helicopter to ensure that the test slick was entirely surrounded by herder. This was felt to be necessary because of the size of the test basin and the resultant constraints on test times. If the body of water were infinitely large, the helicopter could fly in a circle or make multiple spray runs and the herder would have ample time to spread from the helicopter spray swath to surround the slick and contract it from all sides. The relatively small size of the test basin limited the amount of time that the oil had available to drift freely before contacting an edge. Once the oil had contacted an edge, the experimental data collection part of the test was over.

As the slick approached the edge of the basin, it was visually confirmed that the herder was acting on the slick edge: the edges were distinct and rounded with no sheen bleeding out, typical of herded slicks.

Figure 40: Helicopter applying herder (Test 1)

Figure 41: View from helicopter of herder spraying from nozzles (Test 1)

Approximately six minutes after the application of the herder had ended, the helicopter returned with the loaded and activated Heli-torch. Despite several attempts, the 60% diesel/40% gasoline fuel mixture would not ignite as it passed by the propane ignition system of the Heli-torch (**Figure 42**). The helicopter landed, and the Heli-torch was reloaded, but again the fuel mixture would not ignite. By this time the slick had drifted into the north corner of the basin and was manually ignited (**Figure 43**). The fire did a small amount of damage to portions of the liner that were not entirely shielded by the armoured rock, all of which was well above the water line.

After the crude oil slick had burned off, the Heli-torch was loaded with straight gelled gasoline: this ignited successfully in a brief test of the ignition system that did not involve a crude oil release.

Figure 42: Diesel / gasoline mix failing to ignite from Heli-torch

Figure 43: Crude burning in NW corner of basin (Test 1)

10.1.2 Test 2 – April 23, 2015

This test was essentially a repeat of Test 1 with a different mix of gelled fuel for ignition. It involved 75 litres (20 gallons) of fresh ANS crude oil. Winds were 1.5 to 2.1 m/s. The air temperature was approximately 10°C. The sky was clear and sunny. The skim of ice that formed overnight on the basin had melted and open water conditions prevailed between the artificial and few remaining real floes.

The helicopter herder application system was loaded with approximately 19 litres (5 gallons) of OP-40. Based on the results of Test 1, only 37 metres (120 feet) of hose was deployed beneath the helicopter (**Figure 44**). To minimize rotor wash, the pilot was instructed to maintain an altitude of at least 46 to 52 metres (150 to 170 feet), keep forward motion at all times, and not hover over the basin. The six model #0002 nozzles in the nozzle body for Test 1[3] were replaced with model #2504 nozzles to provide better atomization of the herder.

The Heli-torch was loaded with 19 litres (5 gallons) of recently-gelled gasoline.

The oil was released from the aluminium square in the middle of the test basin when the helicopter was positioned off to the side of the basin with the herder application hose deployed and charged with herder. The oil was allowed to spread for a short time (10 to 20 seconds) then the pilot was instructed to apply the herder. The helicopter applied one line of herder upwind inside the southeast edge of the basin and then circled around over the woods to make a second upwind pass inside the northwest edge. A total of approximately 4 litres of OP-40 was applied by the helicopter. The pilot had good control of the 120-foot hose in flight. The hose was then reeled in and the helicopter returned to pick up the Heli-torch. Again, a small amount of additional herder (0.5 litres = 0.14 gallons) was manually applied from garden sprayers to the water along the two remaining sides of the basin not sprayed by the helicopter to ensure that the test slick was entirely surrounded by herder.

Approximately six minutes later, the helicopter returned with the Heli-torch loaded with a pure gasoline gel. Although this fuel ignited as it passed the propane flame at the end of the Heli-torch, the gasoline was not gelled enough to produce large blobs of burning fuel (**Figure 45**). By the time the small droplets of burning gasoline reached the water surface they had either already extinguished, or did not have enough flame left to ignite the herded crude. The helicopter landed, the Heli-torch was reloaded with another 19 litres (5 gallons) of recently-gelled gasoline, and returned. This second ignition attempt also failed to ignite the crude oil slick. By this time the slick had drifted into the snow along the southwest edge and into the west corner of the basin and was manually ignited (**Figure 46**). It was apparent as the slick approached the edge that the herder was acting on the slick.

After Test 2, in an attempt to produce a more effective Heli-torch fuel, the gelled fuel was switched to an 85% / 15% blend of gasoline and diesel and additional gelling time was provided prior to torch ignition. In order to test the Heli-torch, eight gallons of ANS crude were placed within the oil release square. The pilot flew the Heli-torch over the oil contained in the square and ignition was successful (**Figure 47**), with large blobs of burning fuel reaching the surface and easily igniting the contained crude. The pilot flew in a slow upwind path, which allowed for accuracy with no rotor wash. Additional testing to ascertain the ideal fuel and gelling agent for Heli-torch use in colder climates is recommended. The presence of ethanol in modern gasolines may affect gelling.

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[3] The #0002 nozzles initially selected, were not the “fan” type that the research in College Station suggested, and produced droplets slightly above the target range which would be less affected by rotor wash.

Figure 44: Helicopter with herder spray nozzle in position for Test 2

Figure 45: Heli-torch ignition attempt (Test 2)

Figure 46: Test 2 burn in corner of basin

Figure 47: Successful Heli-torch test with 85:15 mixture of gasoline and diesel and longer gelling time

10.1.3 Test 3 – April 24, 2015

For this test, the oil volume was increased to 151 litres (40 gallons) of fresh ANS crude oil and the release square was moved upwind from the centre of the basin to allow more time before the slick would reach the edge after release. Winds were 1.5 m/s. The air temperature was approximately

13°C. The sky was clear and sunny. The skin of ice that formed overnight on the basin had melted and open water conditions prevailed between the artificial floes.

The helicopter herder application system was loaded with 19 litres (5 gallons) of OP-40. Based on the successful herder application in Test 2, 37 m (120) feet of hose was deployed beneath the helicopter, and the pilot was instructed to maintain an altitude of at least 46 to 52 m (150 to 170 feet) and keep forward motion at all times. The nozzle body was fitted with model #2504 nozzles.

The Heli-torch was loaded with 38 litres (10 gallons) of fully gelled 80% gasoline / 20% diesel mixture.

The oil was released from the aluminium square in the middle of the test basin when the helicopter was positioned off to the side of the basin with the herder application hose deployed and charged with herder. The oil was allowed to spread for a short time (10 to 20 seconds) then the pilot was instructed to apply the herder. The helicopter applied one line of herder upwind inside the southeast edge of the basin then circled around over the woods to make a second upwind pass inside the northwest edge, in the same way as the herder was applied in Test 2. **Figure 48** shows the herder spraying from the nozzles in flight. A total of approximately 4 litres of OP-40 was applied by the helicopter. A small amount of additional herder (0.6 litres = 0.16 gallons) was applied from garden sprayers to the sides of the slick not sprayed by the helicopter to surround the slick. The hose was then reeled in and the helicopter returned to pick up the Heli-torch.

Approximately six minutes later, the helicopter returned with the Heli-torch loaded with a fully gelled 80:20 gasoline - diesel mixture and made a pass from south to north over the slick. The burning gelled fuel fell onto the slick (**Figure 49**) and ignited the herded oil (**Figure 50**). A robust burn proceeded (**Figure 51**), in the middle of the basin, away from all the basin walls. Once the initial burn had died down the pilot made a second pass over the slick and ignited another portion of the slick. Only a weak burn was initiated. About three minutes after the second ignition, the leading edge of the ignited slick reached the edge of the basin, and the fire intensity increased. The remainder of the burning slick drifted to the west corner of the basin and continued to burn intensely in a small area (**Figure 52**) until the remaining oil extinguished. It was apparent as the slick remnants approached the edge of the basin that the herder was acting on the slick, even after burning. The following link plays a video clip of the burn, from ignition to extinction, compiled from video taken from various locations: RUN 3 VIDEO

Figure 48: OP-40 spraying from nozzles in flight (Test 3)

Figure 49: Burning gelled fuel hitting slick

Figure 50: Test 3 Burn after first pass with Heli-torch

Figure 51: Slick burning in middle of basin (Test 3)

Figure 52: Oil burning in west corner of basin at end of Test 3

10.1.4 Test 4 – April 25, 2015

For this test, the oil volume was 155 litres (41 gallons) of fresh ANS crude oil and the release square was placed close to the centre of the basin due to rapidly changing wind direction. Winds were 2.0 m/s just prior to the oil release, but quickly dropped to 1 m/s just after the oil was released. The air temperature was approximately 12°C. The sky was clear and sunny. No ice had formed on the water in the basin the previous night and open water conditions prevailed between the artificial floes.

The helicopter herder application system had been emptied of OP-40, flushed with fresh water and refilled with 5 gallons of ThickSlick 6535. Based on the results of Test 2, 37 metres (120 feet) of hose was deployed beneath the helicopter, and the pilot was instructed to maintain an altitude of at least 46 m to 52 metres (150 to 170 feet) and keep forward motion at all times. The nozzle body was fitted with model #2504 nozzles.

The Heli-torch was loaded with 10 gallons of fully gelled 80% gasoline / 20% diesel mixture.

The oil was released from the aluminium square in the middle of the test basin when the helicopter was positioned off to the side of the basin with the herder application hose deployed and charged with herder. The oil was allowed to spread for a short time (10 to 20 seconds) then the pilot was instructed to apply the herder. At this point the herder pump was started, but no herder came out of the nozzles. The helicopter hovered for several minutes until some amount of herder could be seen exiting the nozzles, as slow, viscous fluid dripping. **Figure 53** shows some of this herder lying on the water. It did not appear to be spreading rapidly as herder usually does. The helicopter applied one line of ThickSlick in an east to west pass, with a slight arc at the end of the pass to get herder coverage of the basin as much as possible from the air. The helicopter pilot did this first on the north side of the basin, then the south starting at the east side of the basin and moving westward to have the aircraft’s nose into the wind for both passes. Only at the very end of the second pass could significant amounts of herder be seen exiting the nozzles (**Figure 54**). It was learned later that this was the point at which the herder application system operator had engaged the air pressure purge system in an attempt to improve flow. Overall, very little viable TS6535 was applied by the helicopter due to the clogging of the system with gelled herder. The hose was then reeled in and the helicopter returned to pick up the Heli-torch. Additional herder (1 litre = 0.25 gallons) was applied from garden sprayers from the basin edge to surround the slick.

Figure 53: Herder laying on water surface after first application by helicopter (Test 4)

Shortly after the herder application was complete, the oil slick began to contact the base of the entrance ramp to the basin, on the northeast side. It was apparent as the slick approached the edge of the basin that the herder applied manually near the ramp was acting on the slick; however, it was not possible to confirm if sufficient herder had been applied to all sides of the slick.

Approximately six minutes later, the helicopter returned with the Heli-torch loaded with a fully gelled 80% gasoline / 20% diesel mixture and made a pass from north to south over the slick. The burning gelled fuel fell onto the slick against the ramp and northeast side of the basin (**Figure 55**). The pilot made a second pass over the slick after circling around and ignited another area. A robust burn proceeded (**Figure 56**) against the vehicle-access ramp and sidewall of the basin.

After Test 4 was complete, a set of bench-scale experiments with the herding agents were undertaken to determine the possible causes of incomplete herder deployment during Test 4. Based on these tests, it was discovered that when a small amount of water was added to OP-40, it almost instantly became a viscous gel. The same, but less dramatic, behaviour was noted when a small amount of water was added to ThickSlick 6535. Additional bench-scale tests indicated that diesel fuel mixed with the herders did not cause gelling later tests indicated that iso-propyl alcohol mixed with the herders did not cause gelling either.

Figure 54: Herder streaming from nozzle when air pressure used to purge system at end of Run 4

Figure 55: Aerial ignition of oil against ramp and northeast sidewall of basin

Figure 56: Burn against ramp and northeast sidewall of basin (Test 4)

10.1.5 Test 5 – April 27, 2015

Visitor’s day was safely and successfully conducted on Monday, April 27, 2015 with 28 invitees in attendance. Following the welcome, introductions and safety briefing, visitors saw two PowerPoint presentations, one on the JIP and one on herders. Visitors then moved to the test site 1.5 miles away, where they received another safety briefing, toured the test tank, observed the herder burn experiments, and then saw demonstrations of the remote-controlled helicopter in operation (but not testing). The visitors returned to the conference room for a question and answer and debrief session where they were given press packs on the JIP. Attendees included Alaska Department of Environmental Conservation (ADEC), Alaska Response Company, Bureau of Safety and Environmental Enforcement (BSEE), ExxonMobil, Marine Spill Response Corporation (MSRC), National Oceanic and Atmospheric Administration (NOAA), Oil Spill Response Limited (OSRL), Statoil, and U.S. Fish and Wildlife Service.

This test was essentially a repeat of Test 4. The oil volume was again 155 litres (41 gallons) of fresh ANS crude oil and the release square was placed toward the upwind side of the basin to maximize the time the slick would drift before contacting the edge. Winds averaged 1.6 m/s, gusting to 3.3 m/s. The air temperature was approximately 15°C. The sky was clear and sunny. No ice had formed on the water in the basin the previous night and open water conditions prevailed between the artificial floes.

The helicopter herder application system had been emptied of the gelled herder the previous day (the cause of the inconsistent herder application during Test 4), rinsed with isopropyl alcohol, dried with compressed air, and refilled with 5 gallons of fresh ThickSlick 6535. Based on the results of Test 2, 36.6 m (120 feet) of hose was deployed beneath the helicopter, and the pilot was instructed to maintain an altitude of at least 46 m to 52 metres (150 to 170 feet) and keep forward motion at all times. The nozzle body was fitted with model #2504 nozzles. Good atomization was achieved (**Figure 57**).

The Heli-torch was loaded with 10 gallons of fully gelled 80% gasoline / 20% diesel mixture.

The oil was released from the aluminium square in the middle of the test basin when the helicopter was positioned off to the side of the basin with the herder application hose deployed and charged with herder. The oil was allowed to spread for a short time (10 to 20 seconds) then the pilot was instructed to apply the herder. Given the periodic wind gust conditions and wanting to surround the entire slick, the helicopter pilot lifted to 52 metres (170 ft.) and flew in a west to east pattern, with a slight arc at the start and end of the pass. The helicopter pilot flew first on the south side of the basin, and then the north starting both runs at the west side of the basin and moving eastward to have the helicopter nose into the wind. The nozzle was observed to be spraying herder at all times during these passes: approximately 4 litres (1 gallon) was applied by the helicopter. The hose was then reeled in and the helicopter returned to pick up the Heli-torch. A very small amount of additional herder (0.4 litres = 0.1 gallons - less than previous tests due to the better coverage by the helicopter) was applied from garden sprayers from the basin edge to ensure encirclement of the slick.

It was apparent as the slick approached the edge of the basin that the herder was acting on the slick.

Approximately six minutes later, the helicopter returned with the Heli-torch loaded with a fully gelled 80% gasoline / 20% diesel mixture and made a pass from south to north over the slick. The burning gelled fuel fell onto the slick (**Figure 58**) and ignited it. A robust burn proceeded (**Figure 59**) away from all sidewalls. After the first burn subsided, the pilot made a second pass over the slick after circling around and ignited another area. A second robust burn was initiated (**Figure 60**). It was observed that when the pilot hovered over the northeast side of the basin to empty the Heli-torch of gelled fuel, the rotor wash affected the flames of the adjacent burning slick. Initially, burning occurred away from all sidewalls, but eventually after the second ignition, the burning slick drifted to the west corner under the influence of the wind, where some burning continued as the slick collected against the sidewall. The following link plays a video clip of the burn, from ignition to extinction, compiled from video taken from various locations: RUN 5 VIDEO

Figure 57: Good atomization of TS 6535 during Test 5 application

Figure 58: Gelled fuel igniters falling on herded slick (Test 5)

Figure 59: First burn of Test 5

Figure 60: Second burn of Test 5

10.2 UAV Tests

The team from ING Robotic Aviation arrived in Fairbanks late Wednesday, April 15, 2015 with two UAV's each named Responder, and reassembled the payload and flight components. On Thursday April 16 they headed to Poker Flat to meet with ACUASI (University of Alaska Fairbanks, Alaska Center for Unmanned Aircraft Systems Integration) and begin flight testing of the two UAV's modified for the project (as per FAA Certificate of Authorization). Late on Friday April 17, the UAV with the Herder Application System payload crashed, and both systems were grounded until the root cause of the problem could be identified.

During the April 17 flight testing with the herder application payload the pilot would sporadically lose full control of the Responder, and the unit crashed as the pilot attempted to land it, damaging multiple components. Because this type of failure had never occurred before, the other UAV was grounded for safety reasons while an investigation into the cause of the malfunction was performed. Three obvious possibilities presented themselves early in the investigation: failure of a gyro, failure of the auto-pilot, and possible interference from a nearby antenna array. Telemetry from the crashed UAV was extracted and sent to the ING Robotic Aviation head office in Ottawa as part of the investigation. The team in Fairbanks continued to rebuild as well as troubleshoot the damaged unit while the Ottawa staff analysed the telemetry systems.

One of the significant roles that the UAV was to play was in video documentation of the tests. As it became clear that it not be able to fly over the test basin during the experiments with the helicopter, ACUASI offered to collect the imagery using their UAV, the Ptarmigan. The Ptarmigan is a hexacopter developed and built at ACUASI and was outfitted with a GoPro camera to capture slick area, slick movement, burn efficiency and additional small observations for each test. The same pilot and co-pilot that were to operate the ING UAV were able to easily transition to collecting video footage with the Ptarmigan. The Ptarmigan was already approved for flight and added to the ACUASI CoA at PFRR prior to the tests in April, so was an easy and convenient substitution. In an effort to utilize the higher resolution digital camera that was to be the payload on the Responder for video recording, a platform was erected on the northwest side of the test basin where the Responder was mounted to collect footage of the burns that were within its field of view. The Ptarmigan successfully collected video footage throughout the test period, which proved invaluable to result analysis and interpretation.

On Monday April 20 it was confirmed that a third UAV that had been brought as back-up would not be allowed to fly, due to FCC regulations that differ from those in Canada, and would have to go through an approval process that would take weeks or months. Parts from this third unit were used to repair the crashed device but the loss of control issue remained – leading the ING engineers to conclude that a dedicated control board was damaged and would have to be replaced with a remanufactured one. By Thursday April 23 ING Robotic Aviation confirmed that the circuit board would be completed and someone from the company would fly to Fairbanks with the part so that the unit could be repaired, qualified, and readied to participate in the basin tests before Sunday, April 26.

On the morning of Sunday April 26 the circuit board was installed and qualification flights were conducted from late-morning through 4:00pm at the “Balloon Inflation Area” of PFRR. The repaired UAV was transferred to the test basin and conducted a test run involving simulated herder application, followed by activating, then dropping a modified marine flare igniter. The herder application spray system worked well, when spraying water to simulate herder (**Figure 61**).

Figure 61: Responder UAV spraying water to simulate herder application

The Responder did not have an operational Point-of-View camera system and manual “spotters” were used to direct the pilot to the ignition target. This approach was not systematically accurate and the flares missed their target during these first test deployments of the UAV ignition system.

The ING Responder flew a demonstration flight for the Visitor’s Day on Monday April 27 (see **Figure 62** and **Figure 63**). A short test was planned later in the afternoon on Monday, but higher than expected winds and a sticky release mechanism for the flare forced the pilot to “shake” the UAV, which unfortunately lobbed the flare just outside the target zone. Two additional attempts at releasing the flare over the target were also unsuccessful.

Figure 62: Responder UAV with Remote Igniter

Figure 63: Responder UAV with Remote Igniter spraying simulated herder

A final UAV test, without oil, was conducted on Tuesday April 28. The targeting camera was reprogrammed overnight and made operational for the flight. The Responder was able to successfully fly with the herder application payload, then ignite and drop a marine flare within the target area (see **Figure 64** through **Figure 66**).

Figure 64: UAV Responder with active modified flare

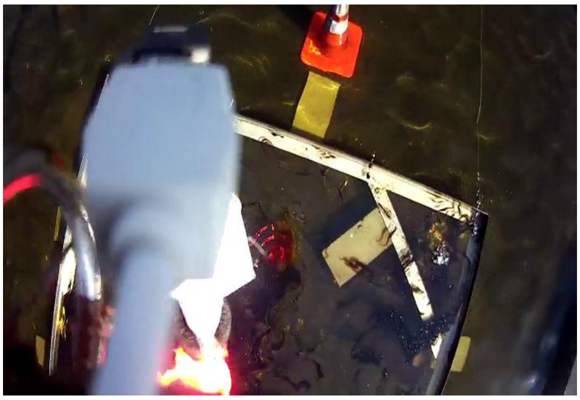

Figure 65: UAV Responder on-board view of active modified flare

Figure 66: UAV Responder on-board view of successful flare release

10.3 Supplementary UAV Testing

Following the reliability issues that surfaced at the recent testing in Fairbanks, AK. ING Robotics was tasked with improving the suitability of the ING Robotics Responder as a platform to apply herder to a simulated spill of oil, then ignite a contained patch of oil. Three areas of improvement were identified in the original prototype that warranted additional consideration: increasing the capability of the herder application system to accommodate higher working pressures and a purge mode to clear fluid from the system following its use with a herder; redesign of the igniter trigger to a simpler design; and, redesign of the retaining claw that holds the igniter to ensure smooth operation while retaining and releasing the igniter.

10.3.1 Bench Scale Testing

Herder Application System

The Herder Application System was upgraded to a new pump and motor combination (ShurFlo 8000-443-236, with a bypassed limit switch to temporarily operate in the 60 to 100 psi range that allows for more control of the operating pressure, enabling adjustment of pressure up to 100 psi to be triggered (as opposed to a single pressure of approximately 40 psi from the original prototype). Additional testing with ten off the shelf nozzles was performed (see **Table 3** below) to determine the best combination for applying fluid with properties similar to Siltech OP-40 and ThickSlick 6535. The target flow rate was approximately 1 lpm when operating between 40 to 60 psi, while producing most drops near the 1 mm diameter size. Nozzle model BETE WL-1/4 60 was selected for use during the subsequent field testing phase.

Table 3: Nozzle Flow Rates at Operating Pressures

Nozzle	Flow range with water	Flow range with canola oil
Bex 18 S3.5	1.0 – 2.3 lpm at 11 – 35 psi (too high)	(too high)
Bex GS 3007	1.0 – 2.2 lpm at 10 – 35 psi (too high)	2.1 lpm at 90 psi (too high)
Hago M4 LODA	0.2 lpm at 100 psi (too low)	0.3 – 0.4 lpm at 105 psi (too low)
Hago M15 TOJM	0.6 – 0.7 lpm at 45 – 60 psi (too low)	0.6 – 0.9 lpm at 90 – 100 psi (slightly low)
Hago M10 TOJO	**0.4 – 0.5 lpm at 7.5 – 15 psi (possible)**	**0.6 – 0.9 lpm at 62 – 100 psi (possible)**
Hago M5 KOJ	0.2 – 0.2 lpm at 20 – 25 psi (too low)	0.3 – 0.4 lpm at 82 – 105 psi (too low)
BETE WL-14 60	**0.4 – 1.2 lpm at 10 – 55 psi (possible)**	**1.2 - 1.6 lpm at 60 – 100 psi (possible)**
Hago M3 TOGF	0.1 lpm at 53 psi (too low)	Flow too low at 100 psi (too low)
Bex GS 6.5	1.1 – 4.4 lpm at 5 – 30 psi (too high)	2.0 – 4.9 lpm at 10 – 42 psi (too high)
Bex GS 3009	(too high)	1.8 – 3.4 lpm at 22 – 57 psi (too high)

Igniter Initiator

The marine flare based igniter system was further modified to update the original design which incorporated a small model rocket engine as an initiator to trigger the marine flare with electronic matches as the trigger. One of the problems with the original design of using a model rocket engine is that the burns last for many seconds, and the rocket engine provides localized propulsion (moving the modified flare around) which makes it difficult for a UAV to hover at a specific location while it prepares to drop the flare. Electronic matches used to trigger fireworks, while lasting only a few seconds, do not have this characteristic and are strong enough to trigger the flare. Some redundancy was incorporated into the final design of the flare igniter initiator as two matches were wired in parallel so that the failure of a single electronic match could be accommodated in the triggering sequence.

The fully assembled marine flare system with electronic match initiator, foam floatation, gelled gasoline, and counterweight embedded in the white cap in Figure 67.

Figure 67: Marine Flare based Igniter System

Retaining Claw

ING Robotics redesigned the igniter retention system (Figure 68) and initiated testing of loads well in excess of the expected igniter weight to ensure the servo controlling the system would not overheat. Roughly 100 tests have been completed with a range of weights between 0.2 lb and 2.2 lb without failure.

Figure 68: Retaining claw with redesigned retention bars

10.3.2 Field Testing/Demonstration

Herder Application System

The herder application system was demonstrated by having the ING Robotics Responder fly past a target area while dispensing herder. The target area had a strip of coated cards (Kromekote) to detect any herder spray landing in the vicinity. A small quantity of dye (red) was added to the herder, Siltech OP-40, to allow for better tracking of the fluid through the dispensing system onboard the UAV and to allow better detection of any residue impacting the coated cards. Additionally, two small trays of oil were placed along the strip of cards to determine if the herder sprayed from the Responder would impact the oil and cause it to contract. Multiple cameras, both still and video, were used to record the results.

Figure 69 shows the ING Responder with the Herder Application System and Marine Flare Igniter retention claw. The target area is shown in **Figure 70**, while Figures 71 and 72 show the two target trays of oil in advance of the application of herder.

Herder application testing was performed on November 3, 2015 under sunny conditions with temperatures ranging from 10 to 12 °C during the testing. Wind was from the northwest at approximately 15 km/h but did not pose much of a challenge for the UAV. Herder application passes were performed at altitudes in the 2 to 3 metre range, at speeds around 3 to 5 m/s. Figure 73 shows the UAV beginning one of the herder application passes, while Figure 74 shows the herder being sprayed from the application nozzle, with the Marine Flare Igniter System in the foreground. Figure 75 and Figure 76 show the results of the herder application on the oil trays.

Figure 69: Responder with Herder Application System

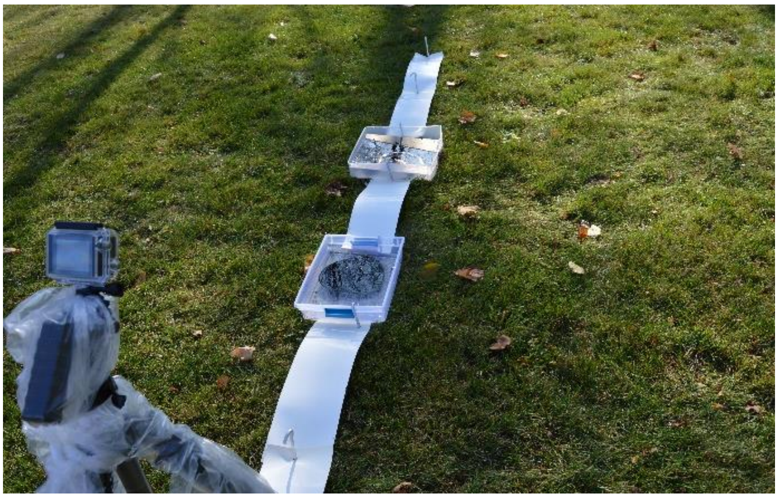

Figure 70: Target Area With Coated Cards and Oil Trays

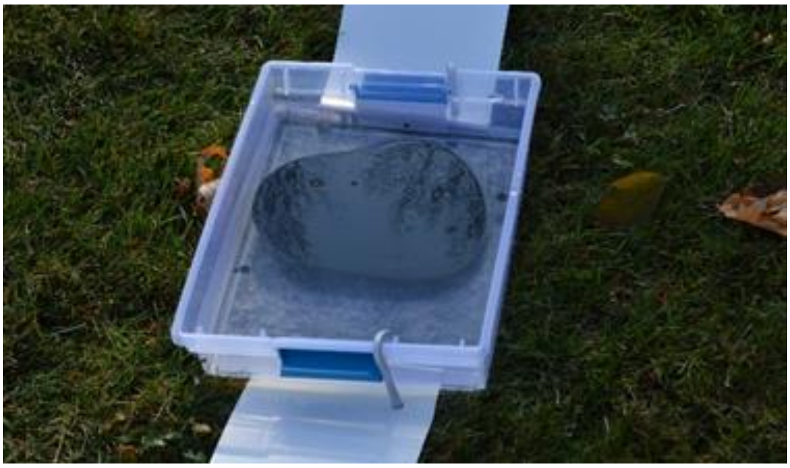

Figure 71: Tray 1 prior to herder application

Figure 72: Tray 2 prior to herder application

Figure 73: Responder during herder application

Figure 74: Herder being dispensed (igniter flare in foreground)

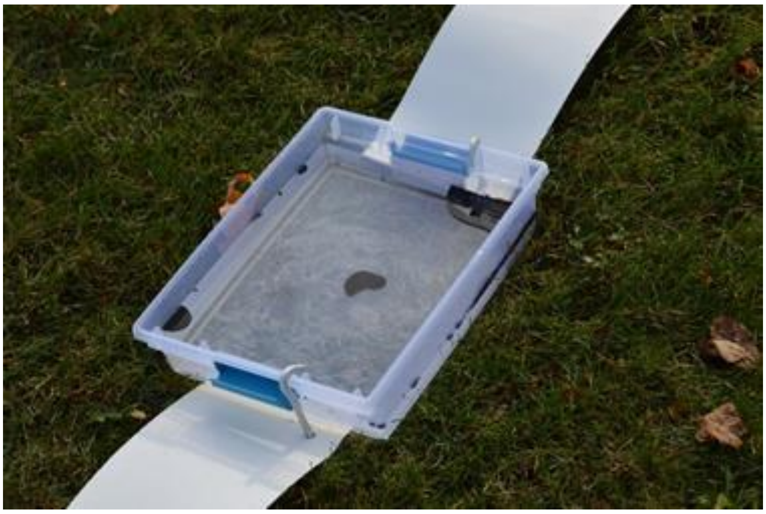

Figure 75: Tray 1 after herder application

Figure 76: Tray 2 after herder application

Igniter System

The marine flare igniter system was demonstrated by having the ING Robotics Responder fly over an oil slick, then ignite and drop the modified flare to trigger combustion of the slick. Mechanical containment was used to hold the oil in place due to the prevailing winds (SSE at 9 km/h), otherwise the slick would have blown to the side of the larger pool area within a short period of time and contacted the sides, creating a long, thin slick at this small scale. The target area was a steel ring with a diameter of 67 cm (26 inches) located in a pool of water with a diameter of approximately 2 m (6 feet). Approximately 1 L of crude oil was added to the middle ring to create a small slick of 3 mm thickness.

After a few test drops of a deactivated flare to gauge the accuracy of the pilot, the Responder was loaded with a functional marine flare igniter system and took off, approaching the slick area at an altitude of approximately 3 m. The pilot was able to use one of the onboard cameras that was pointing down to get into position above the slick, then hover for approximately 10 seconds while adjusting for small gusts of wind. The modified marine flare igniter was triggered, then released (Figure 77). Within 5 seconds the gelled gasoline portion of the igniter started burning, then the oil ignited and quickly engulfed the entire surface of the slick (Figure 78). As the fire continued to burn the Responder remained hovering in the area, photographing the burn from altitude.

While the herder application and ignition systems were successfully demonstrated over the two days of testing, some technical issues remain and should be addressed before this can be considered a fully operational system. The marine flare igniter system was very “prototype” in nature, and additional development is suggested to commercialize the concept, because issues as simple as shipping can be problematic for the current design. One general problem with any battery-powered UAV, given the currently available technologies, is flight duration. The ING Responder has a large payload and relatively long battery life, but it is still limited to approximately 25 minutes flight time. Increasing the flight time/endurance and payload would be needed in order to compete with larger, full size helicopter systems. Finally, the regulatory arena needs to better address the use of UAVs. There are currently severe restrictions on the operation of UAVs for commercial purposes in a variety of jurisdictions. Things are slowly progressing on this front but the technology seems to be evolving quite fast and applications for their use will continue to grow. Demonstrating an application such as the one we are helping to develop here to combat oil spills will hopefully support progress on all fronts.

Figure 77: Responder triggering modified flare ignition

Figure 78: Complete combustion coverage

10.4 Herder Effectiveness

The effectiveness of the herders on the experimental slicks was determined by analysing aerial photographs and video of each test to measure the area of the slick over the time frame of the test. Using Adobe Photoshop®, the known dimensions and spacing of the "faux" floes and the edges of the basin were employed as relative control points to correct the perspective of the photographs of the slicks taken from the helicopters (various cameras on the Bell 407 and the ACUASI "Ptarmigan" UAV). Next, the oil slick was manually traced and colorized black. Then, the rest of the image was masked out defined as white. **Figure 79** illustrates the transformation of the aerial pictures for subsequent analyses. Finally, image analysis software called Scion Image© was used to count the number of black pixels in each image. The pixel count was converted to area using scaling factors obtained from images of the basin and "faux floes" with known dimensions. Average slick thickness was calculated from the determined area and the initial spill volume. The error in slick thickness determined using this method is likely on the order of ±10%.

Figure 80 shows the area of the 70-L slick in Test 1 over time and **Figure 85** shows the calculated average thickness of the slick. Raw and processed data may be found in Appendix J. The coloured vertical lines indicate when various events occurred:

1. The light blue line indicates when the first dose of herder was applied by the Bell 407.
2. The light grey line shows when the second dose of herder was applied by the Bell 407 on the opposite side of the slick.
3. The yellow dashed line shows the first ignition attempt with the Heli-torch, the dashed orange line shows the second, and the dashed purple line the third (this usually occurred manually from ground level when the slick reached the side of the basin).
4. The solid black line shows when the slick touched a side of the basin, signifying the end of run.
5. The dashed red line shows the start of burning.

Unfortunately, due to the limited time available before the wind drove the slick to the side of the basin, there was insufficient time to allow the slick to spread to its maximum area, apply herder, and then allow it to contract the slick for ignition. Based on previous field trials, the spreading phase can take up to 15 minutes, and the contraction of the slick after the herder is applied can take an additional 15 or more minutes (Buist and Potter 2010). This test series was predicated on slowing or stopping the spreading of the slick after it was released, and then igniting it, so it is not surprising that none of the graphs show a shrinking of the slick area or thickening of the slick after release The slick in Test 1 touched the basin wall approximately 20 minutes after it was released.

Figure 81 shows the area of the 75-L slick in Test 2 over time and **Figure 86** shows the calculated average thickness of the slick. This slick spread more than the similar slick in Test 1 and touched the side of the basin sooner than in Test 1 as well. Both of these observations could be due to the higher wind speed in Test 2 and the smaller volume of herder applied.

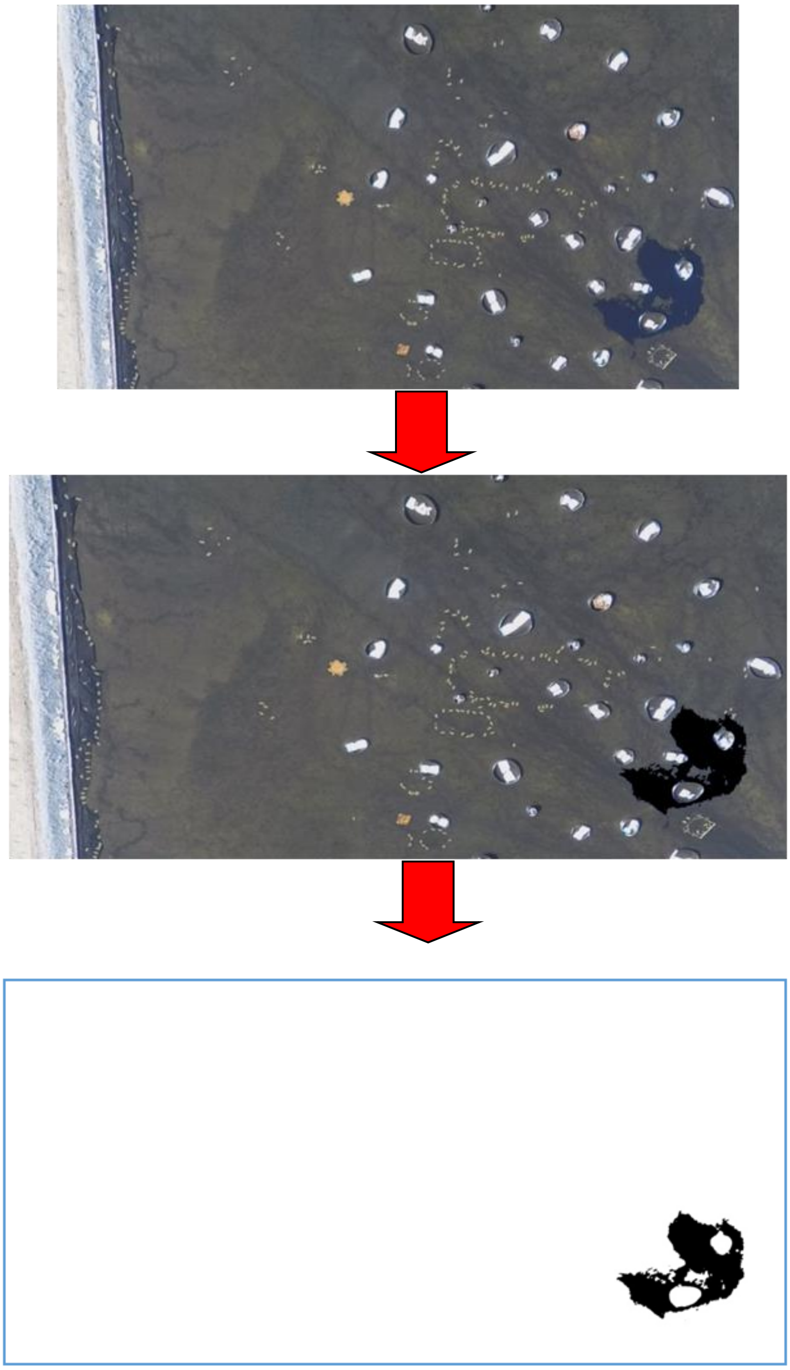

Figure 79: Digital transformation of aerial photographs to determine slick area

Area plots

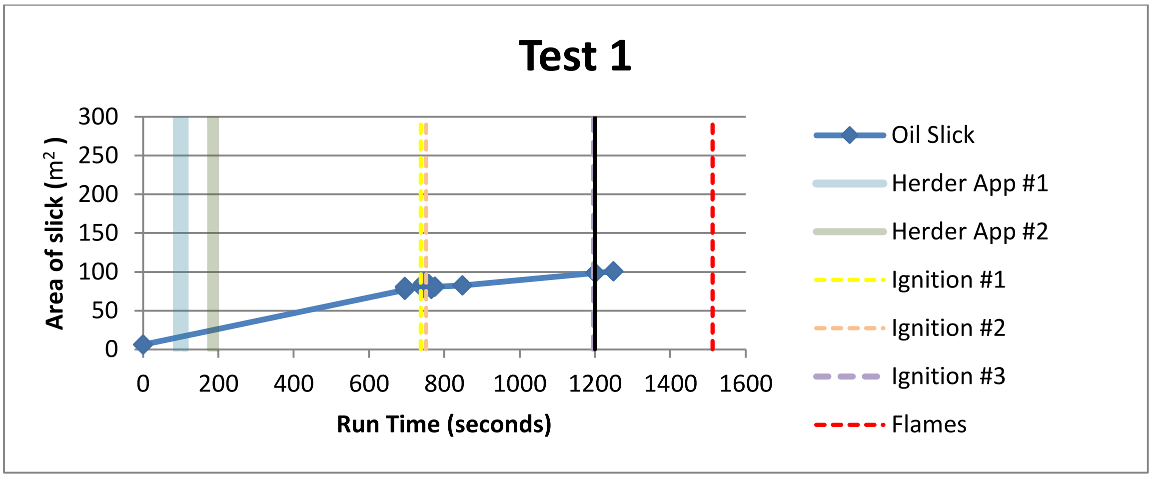

Figure 80: Area of Test 1 Oil Slick vs. Time

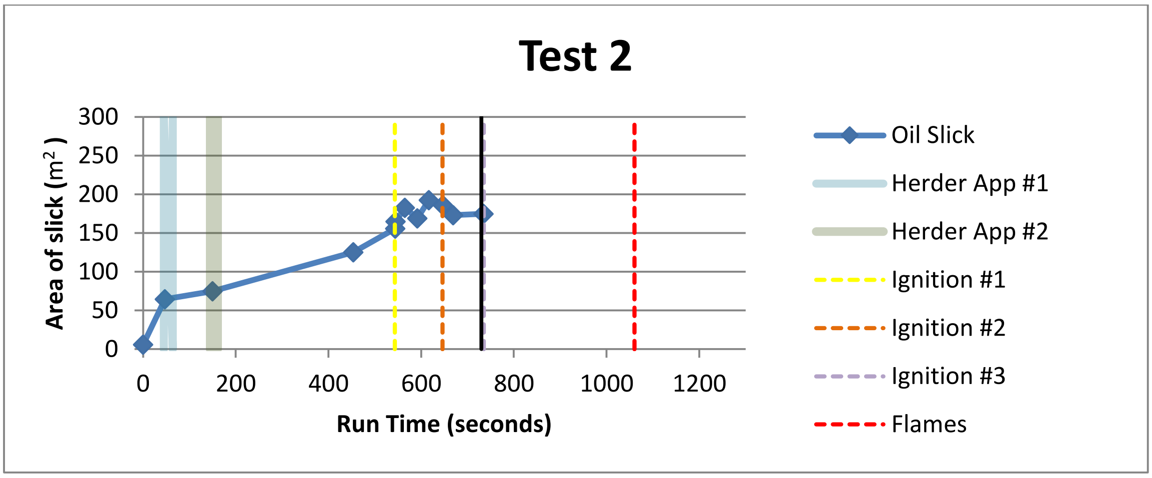

Figure 81: Area of Test 2 Oil Slick vs. Time

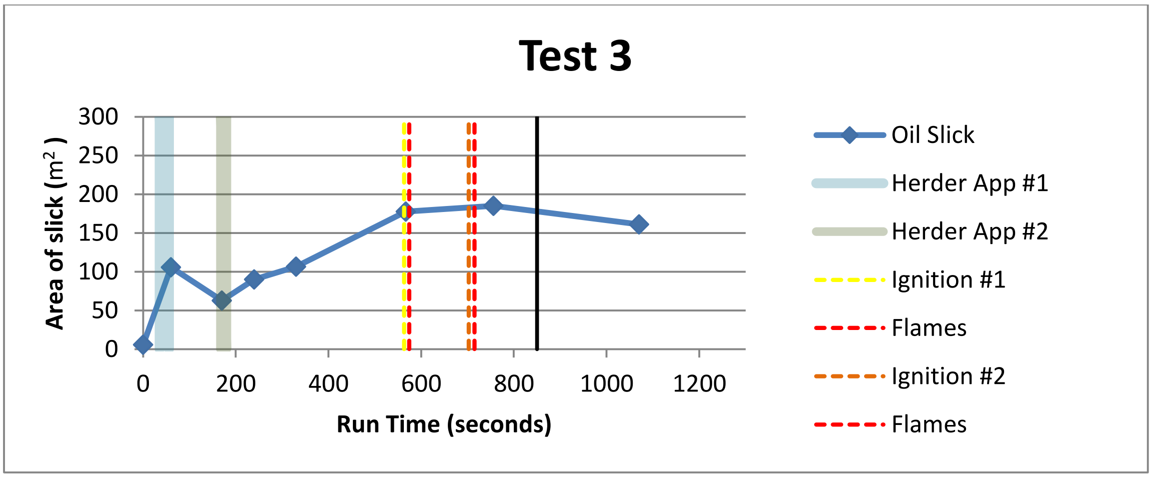

Figure 82: Area of Test 3 Oil Slick vs. Time

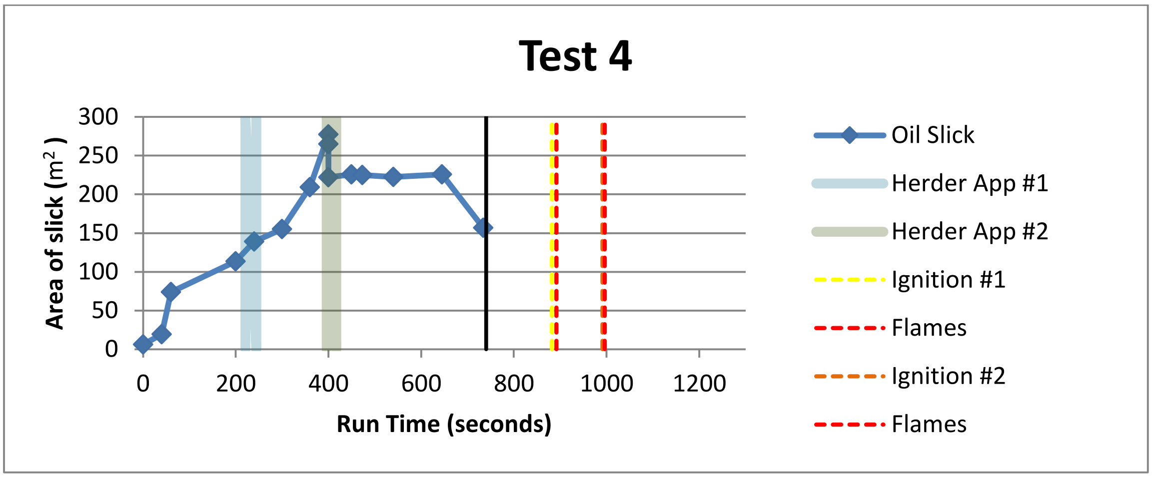

Figure 83: Area of Test 4 Oil Slick vs. Time

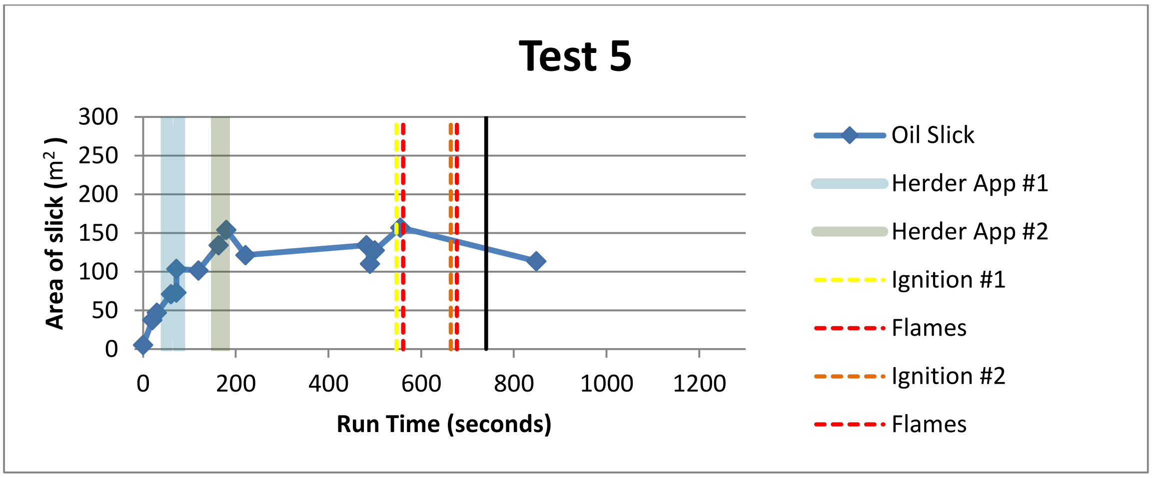

Figure 84: Area of Test 5 Oil Slick vs. Time

Thickness plots

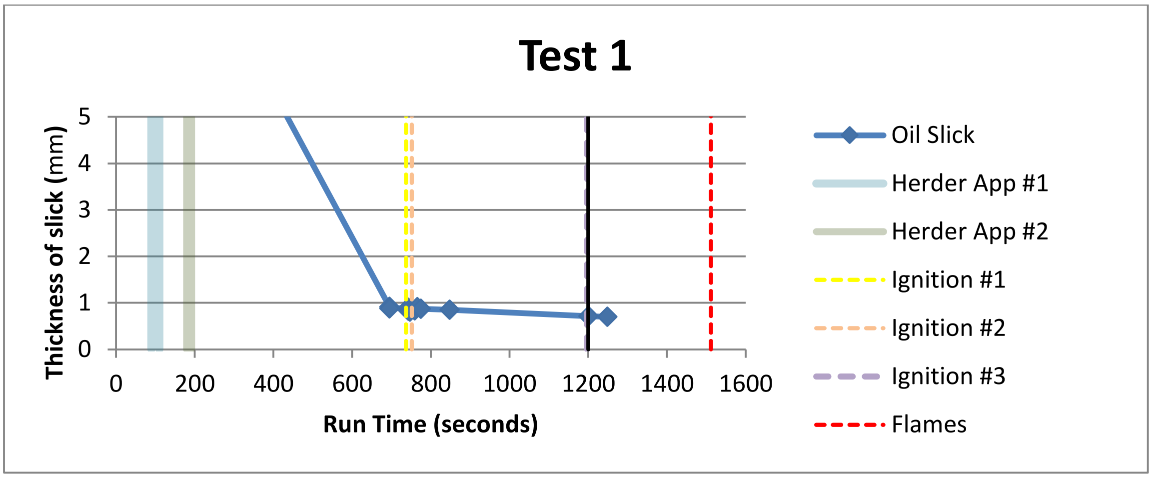

Figure 85: Thickness of Test 1 Oil Slick vs. Time

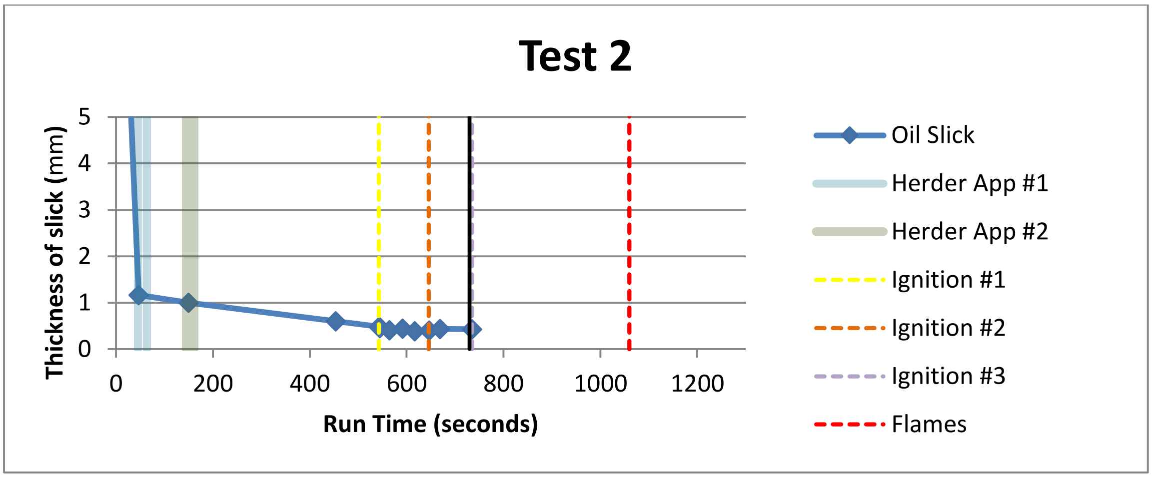

Figure 86: Thickness of Test 2 Oil Slick vs. Time

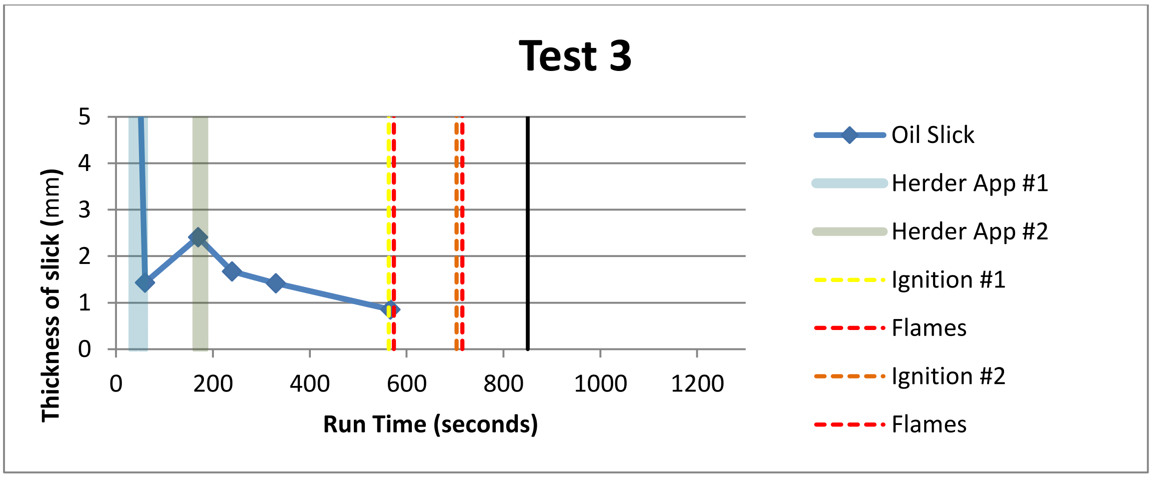

Figure 87: Thickness of Test 3 Oil Slick vs. Time

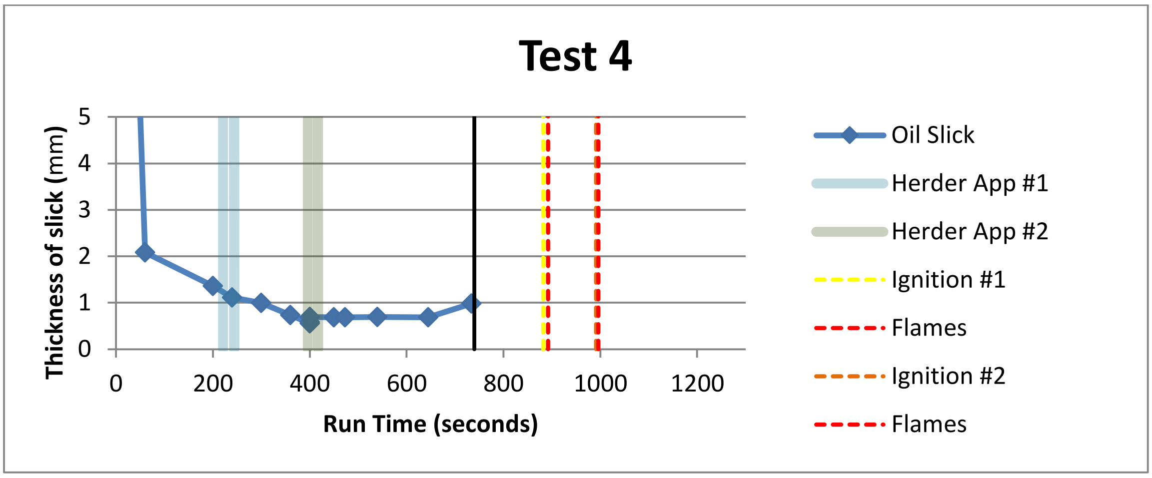

Figure 88: Thickness of Test 4 Oil Slick vs. Time

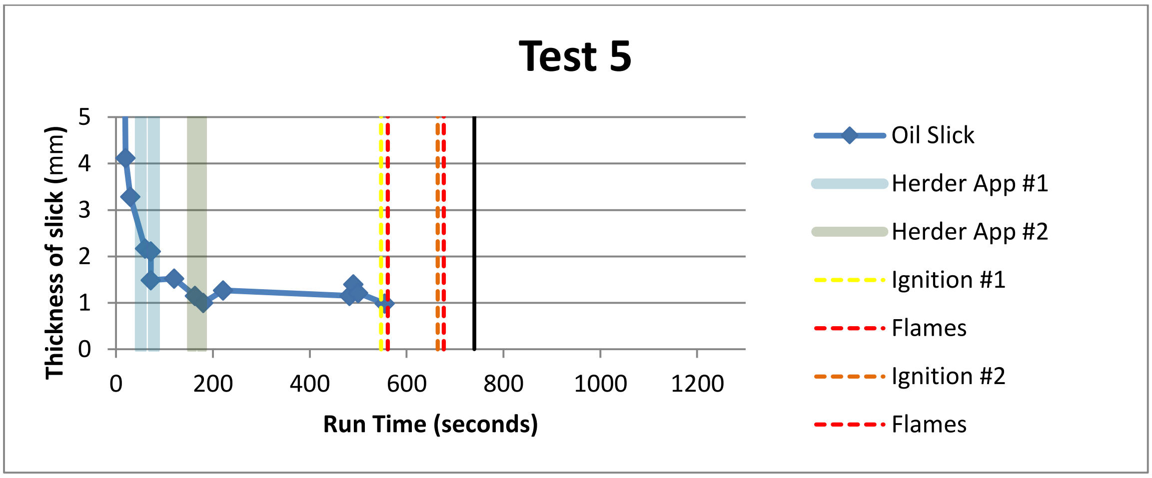

Figure 89: Thickness of Test 5 Oil Slick vs. Time

Figure 82 shows the area of the 151-L slick treated with OP-40 in Test 3 over time and **Figure 87** shows the calculated average thickness of the slick. This slick spread more than the similar slick in Tests 1 and 2 due to its larger volume. The slick was successfully ignited by the Heli-torch 600 seconds (10 minutes) after its release. At the time of its ignition it was estimated to be approximately 1 mm thick. After the first burn, the slick area did not increase appreciably. Thickness data is not shown on Figure 87 after the burn commenced because the volume of oil remaining in the slick can only be estimated.

Figure 83 shows the area of the 154-L slick in Test 4 over time and **Figure 88** shows the calculated average thickness of the slick. This slick spread much more than the similar slick in Test 3, probably due to the problems applying the TS6535 herder: unbeknownst to the project team, in flushing the spray system, the wash water caused the herder to gel and plug the spray nozzles. It is quite likely that very little herder was applied on the basin until the end of the second pass by the helicopter, when liquid was finally observed coming from the spray nozzles and the land-based herder spraying commenced. As such, for the first 400 seconds of Test 4 the data represent the unhindered spreading of the ANS crude on the test basin. In Test 3, in similar wind speeds to Test 4, 400 seconds after the oil was released and more than 200 seconds after the herder application was finished, the same volume of oil had only spread to approximately 100 m2 and its average thickness was more than 1 mm. In Test 4 the oil had spread to approximately 275 m2 and was approximately 0.5 mm thick. The application of herder from the garden sprayers after the 400 second mark of Test 4 appears to have stopped the oil spreading, and may have started to contract the slick.

Figure 84 shows the area of the 154-L slick in Test 5 over time **Figure 89** shows the calculated average thickness of the slick. In comparison with the Test 4 data it can be seen that, even in the much higher winds on the day of Test 5, the same volume of oil spread much less. After 400 seconds the Test 5 slick covered only approximately 125 m^2, half the size of the Test 4 slick at the same elapsed time. In Test 5 the TS6535 herder maintained the free-floating slick at a thickness greater than 1 mm for almost 500 seconds.

As noted earlier, the crude oil used in these tests was obtained from the Trans Alaska Pipeline System shortly before the tests, and was not the same as the 2013 sample used in the laboratory tests discussed in Chapter 8. The properties of ANS crude change both seasonally (due to property-enhancing additives based on ambient temperature) and over longer time frames (due to changes in the mix of crudes from different fields blended together at Pump Station 1in Prudhoe Bay). As such, the herder effectiveness measured in the laboratory tests with the 2013 ANS sample (i.e., 3 to 4 mm thick slicks with OP-40: 1 to 2 mm thick slicks with ThickSlick 6535) may not accurately predict the effectiveness of the herders on the 2015 batch of ANS crude used for the field tests.

10.5 Burn efficiency

Burn efficiency for Tests 3 and 5 was estimated using three independent approaches (gravimetric approach, integrated time area approach, and maximum burn area approach). Each approach required a different set of assumptions to complete the calculations (**Table 4**). The three approaches and the results are briefly discussed.

Gravimetric Method. Burn efficiency via the gravimetric method was calculated after the completion of each of the five burns burn, and is defined the ratio of the mass of oil burned to the initial oil mass. The following equation was used to calculate the overall burn efficiency for each experiment using the equation below.

$$\textit{Overall Burn Efficiency (mass \%)} = \frac{\textit{(Initial Oil Net Weight - Residue Net Weight) x 100\%}}{\textit{Initial Oil Net Weight}} \quad \textbf{(1)}$$

The residue was assumed to be water free. The individual oil and residue weight data can be found in Appendix K.

Table 4: Summary of field test parameters and results

Test and Date	Oil volume	Herding Agent	Heli Torch Fuel	Wind speed	Air Temperature	Max. Slick Area Prior to Contact with Wall	Burn Efficiency			Successful Aerial Herder Application?	Successful Aerial Ignition?
							Gravimetric*	Integrated Time-Area Method**	Max Burn Area Method**		
Test 1 April 22	70 L	11L OP-40	60% diesel / 40% gasoline	1 - 1.5 m/s	6° - 7°C	101 m^2	86%	--	--	Yes	No
Test 2 April 23	75 L	4L OP-40	100 % gasoline	1.5 - 2.1 m/s	10°C	193 m^2	59%	--	--	Yes	No
Test 3 April 24	151 L	5L OP-40	20% diesel / 80% gasoline	1.5 m/s	13°C	185 m^2	94%	73%	79%	Yes	Yes
Test 4 April 25	155 L	1L TS 6535	20% diesel / 80% gasoline	1 - 2 m/s	12°C	277 m^2	73%	--	--	No	Yes***
Test 5 April 27	155 L	4L TS 6535	20% diesel / 80% gasoline	1.6 - 3.3 m/s	15°C	157 m^2	86%	84%	74%	Yes	Yes

*Quantifies burn efficiency of free floating slick + sidewall-associated slick
**Quantifies burn efficiency of free floating slick only
***Test 4 slick was ignited from the air, but only after slick was herded by wind against the sidewall

As described previously, the mass of oil added to the basin was measured prior to each test, and the mass of residue and unburned oil was quantified after each test. Using this method, 6.0% of the original mass following the Test 3 burn was recovered, and 14% of the original mass following the Test 5 burn was recovered. Thus, the burn efficiency obtained via the gravimetric method was 94% and 86% for Tests 3 and 5, respectively.

Uncertainty associated with the gravimetric methods arises from its inherent assumptions. First, this method assumes that all mass was lost as a result of burning, and not due to other factors such as dissolution of soluble components of the oil or evaporation of the volatile components. Second, this method assumes that all remaining oil and residue following the burn was retrieved and weighed.

Both of these assumptions are reasonable, given the short time period between addition and collection of the oil, and the lack of visible oil remaining following clean up. Minor losses in that regard would likely be insignificant. However, the gravimetric method also assumes that no water was present in the pads following the overnight draining. While much of the water mass likely drained out, it is reasonable to assume that at least some amount of water remained entrained in the pads at the time of final weighing. Finally, the wind ultimately blew the oil and residue against the basin sidewalls in Tests 3 and 5 while the oil was still burning. As stated previously, the wind itself effectively acted as a herding force under those conditions. As a result, the gravimetric burn efficiency estimate quantifies the total efficiency of not just the added herding agents, but also the herding action of the wind. To overcome these inconsistencies, aerial imagery approaches were employed to estimate burn efficiencies of the free-floating slicks.

The aerial imagery approaches employed a similar image analysis technique as that used for determination of slick area, with the exception that in this instance, it was the enflamed surface area that was being quantified. However, due to the presence of smoke, more than one image taken from different perspectives was required to estimate flame area at any given time. The instantaneous flame/burn area estimates during the course of Test 3 and Test 5 are presented in Figures 90 and 91 respectively. These estimates of flame area obtained over the burn duration were then used to estimate burn efficiency of free-floating slicks using the two approaches described below. The error in estimating flame area using this technique is greater than when estimating slick area, and is likely in the ±20% range.

Integrated Time-Area (ITA) approach. In this approach, the flame area integrated over the duration of the burn is multiplied by an assumed burn rate. In this instance, the burn rate of fresh ANS crude was assumed to be 1.75 mm/min, based upon a 1 to 2 mm slick thickness (Buist et al, 2014). Thus,

$$ITA\ Burn\ Volume = Burn\ Rate\ \int_0^t Flame\ Area\ (dt) \qquad \textbf{(2)}$$

Maximum Burn Area (MBA) approach. In this approach, the maximum burn area is determined, then multiplied by the assumed burn rate and the duration of time over which more than 50% of the maximum burn area is aflame. This is mathematically described as below.

$$MBA\ Burn\ Volume = Burn\ Rate\ x\ Maximum\ Flame\ Area\ x\ (E_{50} - I_{50}) \qquad \textbf{(3)}$$

Where E_{50} represents the time at which the burn area diminishes to half its maximum area (extinction half-time), and I_{50} represents the time at which the spreading burn reaches half its maximum area (ignition half-time).

It is noted that the ITA and MBA approaches represent estimates only, due to uncertainties associated not only with interpretation of the aerial imagery, but also associated with the assumed burn rate of 1.75 mm/min. While a value of 3.5 mm/min is often assumed to be the burn rate for open water slicks, this study assumed a lower burn rate due to the relatively thin slicks. Previous results suggest that in the thinner slicks, a larger proportion of heat is lost to the water underlying the slick, thus diminishing the burn rate (Buist et al., 2014).

Figure 90 shows the burn area data collected for Test 3 (151 litres of ANS herded with OP-40). Using Equation 2 with an area-time integration of 3800 m^2s gives an oil volume burned estimate of 110 litres. Using the Maximum Burn Area approach results in an estimated burn volume of 120 litres. Based on this, the burn in Test 3 resulted in the removal of approximately 70 to 80% of the oil.

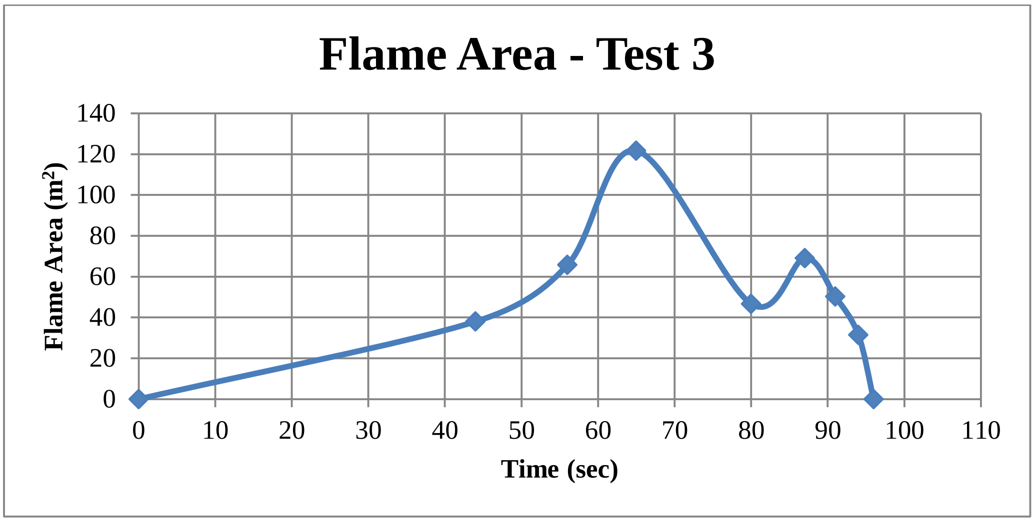

Figure 90: Flame area data for Test 3

Figure 91 shows the burn area data collected for Test 5 (154 litres of ANS herded with TS6535). Using the Integrated area-time approach with a value of 1500 m^2s for the first burn and 2900 m^2s for the second burn gives a total oil volume burned estimate of 130 L. Using Equation 3 results in an estimated burn volume of 40 litres for the first burn and 75 litres for the second for a total of 115L burned. Based on this, the burn in Test 5 resulted in the removal of 75 to 85% of the oil using herding and burning applied from a helicopter.

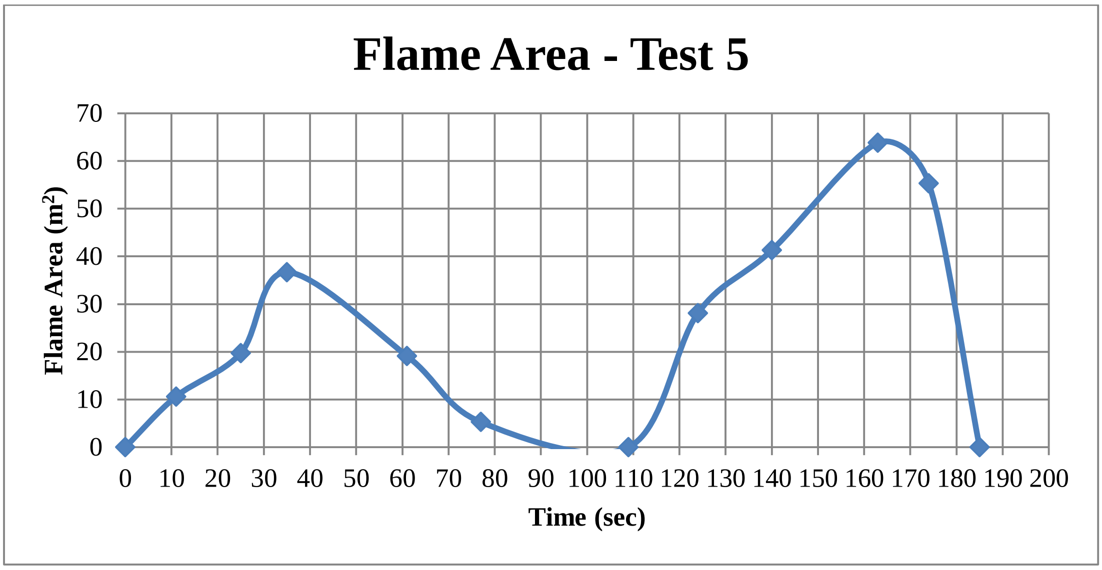

Figure 91: Flame area data for Test 5

11. CONCLUSIONS

A number of conclusions were drawn from the testing programme including:

1. The application of herders and subsequent ignition of a free-floating oil slick from a helicopter platform were successfully demonstrated.
2. A large above-ground lined test basin was constructed to provide an on-land location for the field tests. Although theoretically possible, it is not feasible at the present time to obtain the necessary approvals to conduct deliberate oil releases at sea in US waters. The need for such test opportunities was called out as priority issue by the National Research Council (2014) and the National Petroleum Council (2015). The tank at Poker Flat was a necessary compromise and it worked well for its intended purpose. No artificial basin, however, large enough, can substitute for tests in the open sea to accomplish all the objectives of the programme.
3. Laboratory testing completed in support of the testing demonstrated the suitability of herding operations for the selected oil and herders. In addition, the finding of similar herder performance in both fresh and salt-water greatly simplified the test design. It also simplified the regulatory approval for the tests and facilitated disposal of the basin water to the surrounding land following the tests.
4. The helicopter-based herder application system was effectively pre-tested, modified, and tested again in advance of the field trials where it was mounted in the back of a Bell 407. Additional modifications are required before deployment into an operational environment.
5. The UAV herder application system and ignition system were demonstrated, but additional work is needed to refine, and perhaps combine these technologies into a single payload.
6. Remote video feeds were limited (distance) and loss of signal occurred on a few occasions to three systems used during the testing, for different reasons (ING Robotics targeting camera, GoPRO mounted on UAF Ptarmigan, GoPRO mounted on hose reel). This reiterates the need for back-up planning and redundancies. UAV technology is rapidly evolving and can be considered still in its infancy.
7. Water should not be used to rinse the herder application system as it risks gelling the herder. Isopropyl alcohol has been demonstrated to work well, and diesel has been tested at a bench-scale.
8. In tests 3 and 5, both OP-40 and ThickSlick 6535 were successful in limiting slick spreading and maintained the thickness of the floating oil spill at close to or above 1 mm, approximately double the thickness required for ignition of the ANS test oil.
9. In tests 3 and 5 the herded slicks were successfully ignited with a Heli-torch slung under the helicopter and burned for a considerable time before contacting the edge of the test basin. In the range of 70 to 85% of the free-floating oil was consumed by the fire before the burning slicks contacted the basin edge.
10. The limited size of the test basin meant that there was insufficient time for the herders to have their full effect prior to ignition attempts, however it was visually confirmed that the herder was acting on the slick edge: the edges were distinct and rounded with no sheen bleeding out, typical of herded slicks.
11. The helicopter and UAVs were successfully and safely operated in the same airspace during the experiments by adhering to the test plan, maintaining spatial and temporal separation, and having the pilots maintain radio contact with one another. Operations were planned well in advance and discussed at length with both pilots (helicopter and UAV). Operations were conducted with the Bell 407 having absolute priority.
12. The work was completed without health, safety, or environmental or incidents occurring.

12. RECOMMENDATIONS

A number of recommendations have been derived, based upon the performance of equipment during the field tests. These recommendations include:

1. The basin at Poker Flat was a necessary compromise and worked well for its intended purpose; however it was not large enough to accomplish all the objectives of the programme. Further full-scale field trials of the concept of aerial application of herders and ignition in real drift ice conditions offshore are necessary in order to allow extra time for both spreading oil to reach equilibrium, and for herders to act on the slick. This will allow better field estimates of likely oil burn efficiencies achievable with this countermeasure and the weather windows for its effective use.
2. Further refinement of the herder application system is required to simplify operations and allow more control over its operation. Suggested refinements include: pumping, valving, flow control, reel control, nozzle tie-off, and cleaning aspects. Video capability at the nozzle end of the system would enable the operator or pilot to quickly determine if the application system is not operating properly and assist in trouble-shooting. A solenoid valve at the end of the hose to halt flow and prevent drain-down would be a benefit. A method of metering the herder being dispensed would be a valuable addition, as would a method of measuring or metering the deployed hose length.
3. UAV helicopters show promise as a herder application / igniter deployment vehicle, but require additional R&D and system redundancies to be operationally viable.
4. There is a need to study the interaction of presently available gelling agents with gasoline and other candidate Heli-torch fuels, particularly those containing significant fractions of ethanol in order to prevent the problems that occurred during the first few tests.
5. Further sensor development for UAVs is warranted to fully utilize this platform to collect fire area data. This information may be used to generate more accurate estimates of burn rates and volumes of oil consumed, and would help monitor the progression of a burn.
6. Additional work on the atomization of herders from the helicopter-based application system is needed, with an emphasis on working pressure, nozzle size, nozzle type, and resultant flow rate, droplet size, and droplet distribution.
7. More research is needed on the application of herders in cold weather conditions, specifically around the gelling point of ThickSlick 6535 (-3°C).
8. A combined herder / igniter concept would be useful for both helicopters and UAVs to allow for a one-flight herd and ignite operation. It is understood that a new ART JIP project launched in October 2015 is aimed at following up on this recommendation.

13. REFERENCES

Bronson, M., E. Thompson, F. McAdams and J. McHale. 2002. Ice Effects on a Barge-Based Oil Spill Response Systems in the Alaskan Beaufort Sea. Proceedings of the Twenty-fifth Arctic and Marine Oilspill Program Technical Seminar, Environment Canada, Ottawa, pp 1253-1269.

Buist, I., L. Majors, K. Linderman, D. Dickins, J. Mullin and C. Owens, 2003. Tests to Determine the Limits to In-situ Burning of Thin Oil Slicks in Brash and Frazil Ice. Proceedings of the Twenty-sixth Arctic and Marine Oilspill Program Technical Seminar, Environment Canada, Ottawa, pp 629-648.

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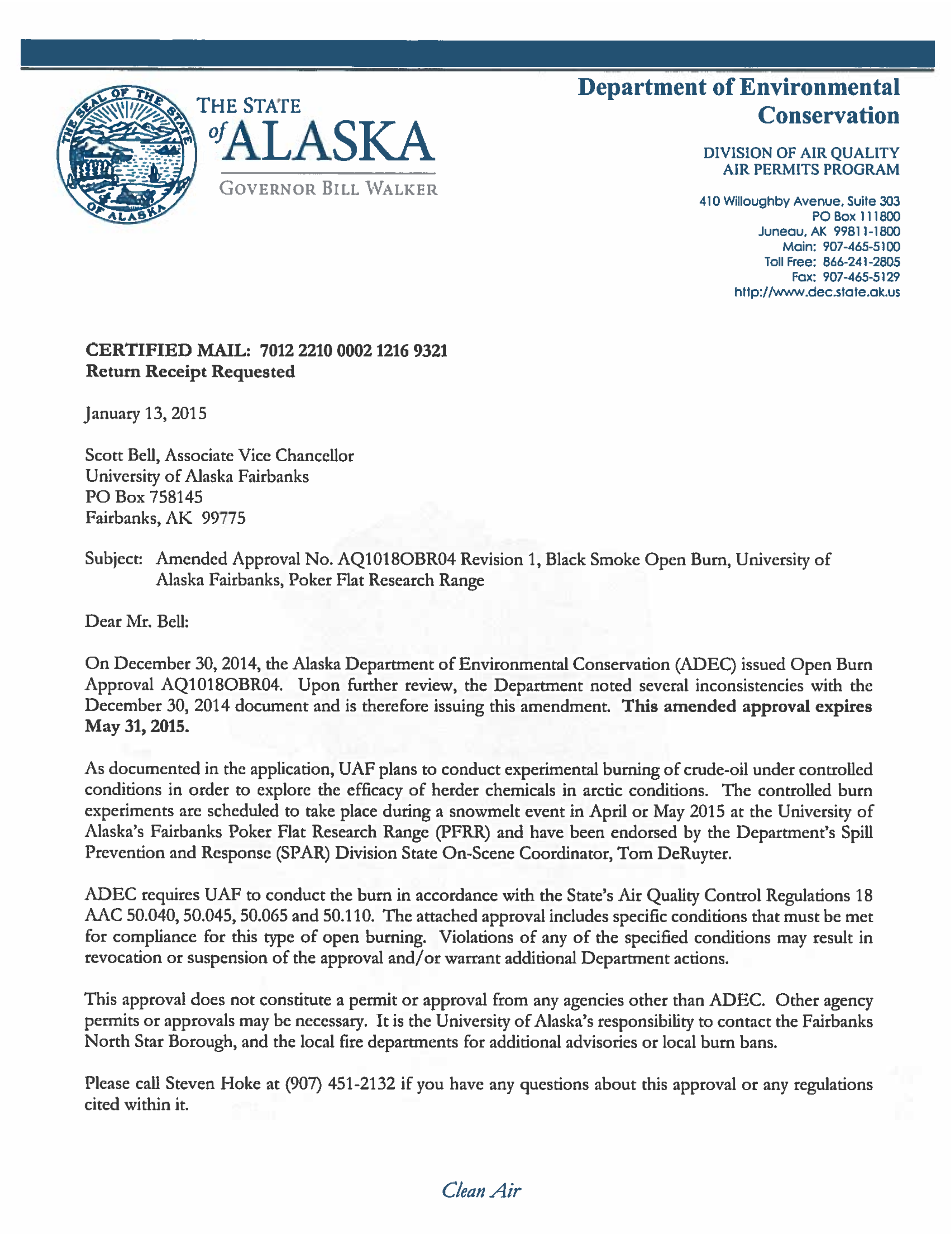
Buist, I. A, Potter, S.G., Trudel, B.K., Shelnutt, S.R., Walker, A.H., Scholz, D.K., Brandvik, P.J., Fritt-Rasmussen, J., Allen, A.A., Smith, P. 2013. In-situ Burning in Ice-Affected Waters: State of knowledge report. Final report 7.1.1. Report from Arctic Oil Spill Response Technology Joint Industry Programme (JIP). p. 1-294.

Potter, S. and I. Buist, 2010. In-situ Burning in Arctic and Ice-covered Waters: Tests of Fire-resistant Boom in Low Concentrations of Drift Ice. Proceedings of the Thirty-third AMOP Technical Seminar on Environmental Contamination and Response, Environment Canada, Ottawa, pp 743-754.

SL Ross Environmental Research and Danish Centre for Environment and Energy (DCE). 2015. Research Summary. Herding Surfactants to Contract and Thicken Oil Sills for In-Situ Burning in Arctic Waters, Report to IOGP, Arctic Response Technology Oil Spill Preparedness (http://www.arcticresponsetechnology.org/wp-content/uploads/2015/05/Herder-Research-Summary.pdf)

APPENDIX A – PERMITTING



THE STATE
of ALASKA
GOVERNOR BILL WALKER

Department of Environmental Conservation

DIVISION OF AIR QUALITY
AIR PERMITS PROGRAM

410 Willoughby Avenue, Suite 303
PO Box 111800
Juneau, AK 99811-1800
Main: 907-465-5100
Toll Free: 866-241-2805
Fax: 907-465-5129
http://www.dec.state.ak.us

CERTIFIED MAIL: 7012 2210 0002 1216 9321
Return Receipt Requested

January 13, 2015

Scott Bell, Associate Vice Chancellor
University of Alaska Fairbanks
PO Box 758145
Fairbanks, AK 99775

Subject: Amended Approval No. AQ1018OBR04 Revision 1, Black Smoke Open Burn, University of Alaska Fairbanks, Poker Flat Research Range

Dear Mr. Bell:

On December 30, 2014, the Alaska Department of Environmental Conservation (ADEC) issued Open Burn Approval AQ1018OBR04. Upon further review, the Department noted several inconsistencies with the December 30, 2014 document and is therefore issuing this amendment. **This amended approval expires May 31, 2015.**

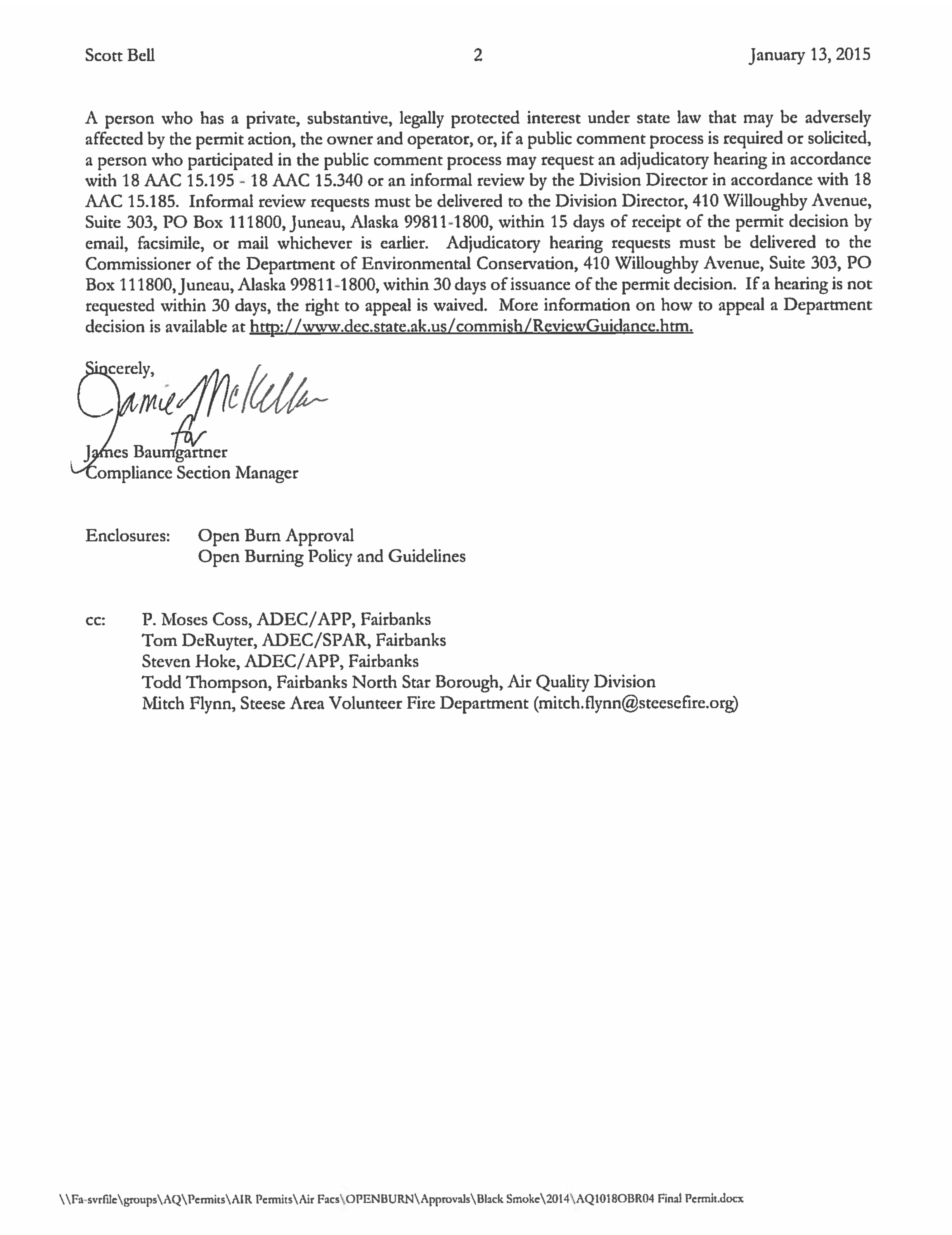
As documented in the application, UAF plans to conduct experimental burning of crude-oil under controlled conditions in order to explore the efficacy of herder chemicals in arctic conditions. The controlled burn experiments are scheduled to take place during a snowmelt event in April or May 2015 at the University of Alaska's Fairbanks Poker Flat Research Range (PFRR) and have been endorsed by the Department's Spill Prevention and Response (SPAR) Division State On-Scene Coordinator, Tom DeRuyter.

ADEC requires UAF to conduct the burn in accordance with the State's Air Quality Control Regulations 18 AAC 50.040, 50.045, 50.065 and 50.110. The attached approval includes specific conditions that must be met for compliance for this type of open burning. Violations of any of the specified conditions may result in revocation or suspension of the approval and/or warrant additional Department actions.

This approval does not constitute a permit or approval from any agencies other than ADEC. Other agency permits or approvals may be necessary. It is the University of Alaska's responsibility to contact the Fairbanks North Star Borough, and the local fire departments for additional advisories or local burn bans.

Please call Steven Hoke at (907) 451-2132 if you have any questions about this approval or any regulations cited within it.

Clean Air



Scott Bell 2 January 13, 2015

A person who has a private, substantive, legally protected interest under state law that may be adversely affected by the permit action, the owner and operator, or, if a public comment process is required or solicited, a person who participated in the public comment process may request an adjudicatory hearing in accordance with 18 AAC 15.195 - 18 AAC 15.340 or an informal review by the Division Director in accordance with 18 AAC 15.185. Informal review requests must be delivered to the Division Director, 410 Willoughby Avenue, Suite 303, PO Box 111800, Juneau, Alaska 99811-1800, within 15 days of receipt of the permit decision by email, facsimile, or mail whichever is earlier. Adjudicatory hearing requests must be delivered to the Commissioner of the Department of Environmental Conservation, 410 Willoughby Avenue, Suite 303, PO Box 111800, Juneau, Alaska 99811-1800, within 30 days of issuance of the permit decision. If a hearing is not requested within 30 days, the right to appeal is waived. More information on how to appeal a Department decision is available at http://www.dec.state.ak.us/commish/ReviewGuidance.htm.

Sincerely,

Jamie McKellar
for

James Baumgartner
Compliance Section Manager

Enclosures: Open Burn Approval
Open Burning Policy and Guidelines

cc: P. Moses Coss, ADEC/APP, Fairbanks
Tom DeRuyter, ADEC/SPAR, Fairbanks
Steven Hoke, ADEC/APP, Fairbanks
Todd Thompson, Fairbanks North Star Borough, Air Quality Division
Mitch Flynn, Steese Area Volunteer Fire Department (mitch.flynn@steesefire.org)

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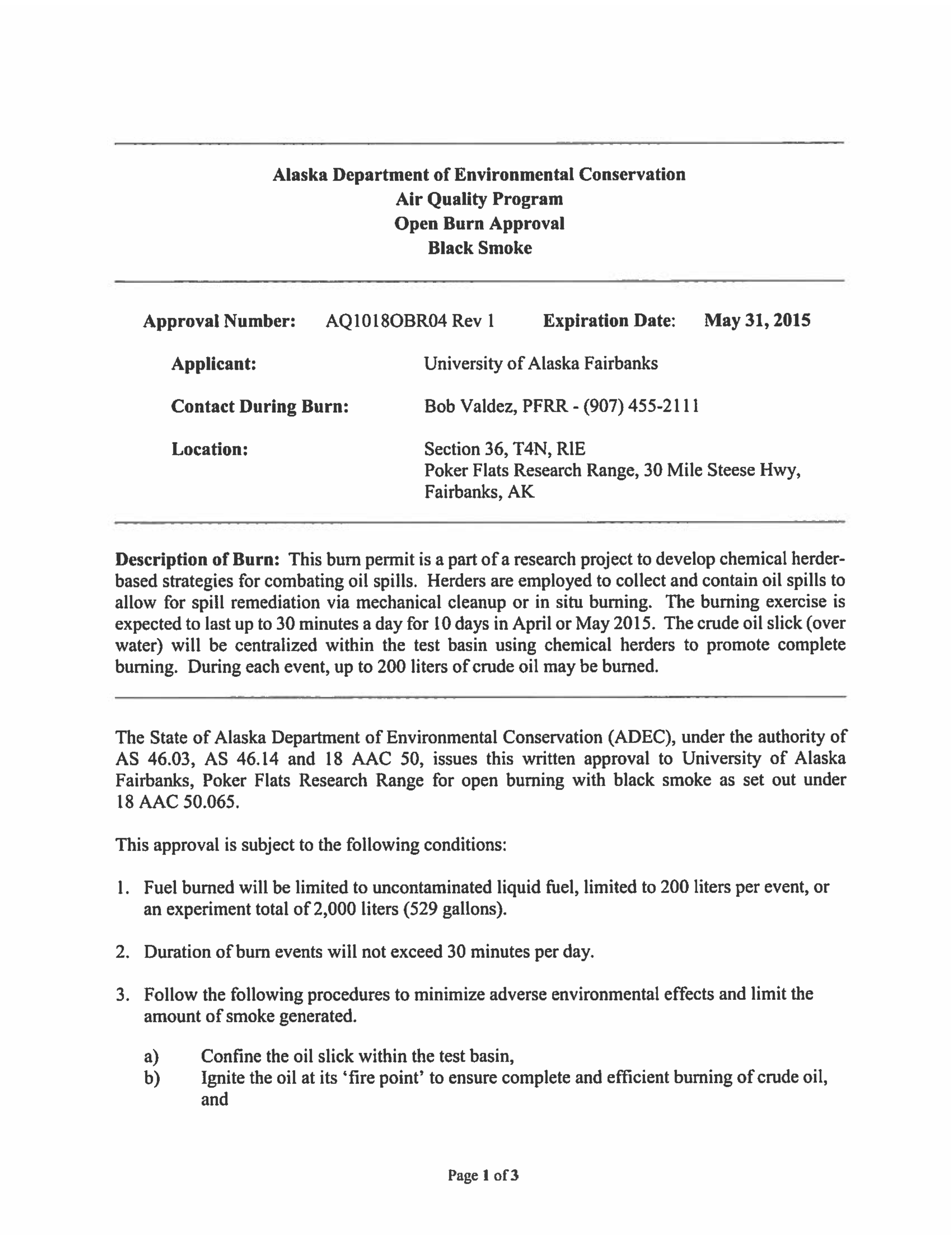


Alaska Department of Environmental Conservation
Air Quality Program
Open Burn Approval
Black Smoke

Approval Number: AQ1018OBR04 Rev 1 **Expiration Date:** **May 31, 2015**

Applicant: University of Alaska Fairbanks

Contact During Burn: Bob Valdez, PFRR - (907) 455-2111

Location: Section 36, T4N, RIE
Poker Flats Research Range, 30 Mile Steese Hwy,
Fairbanks, AK

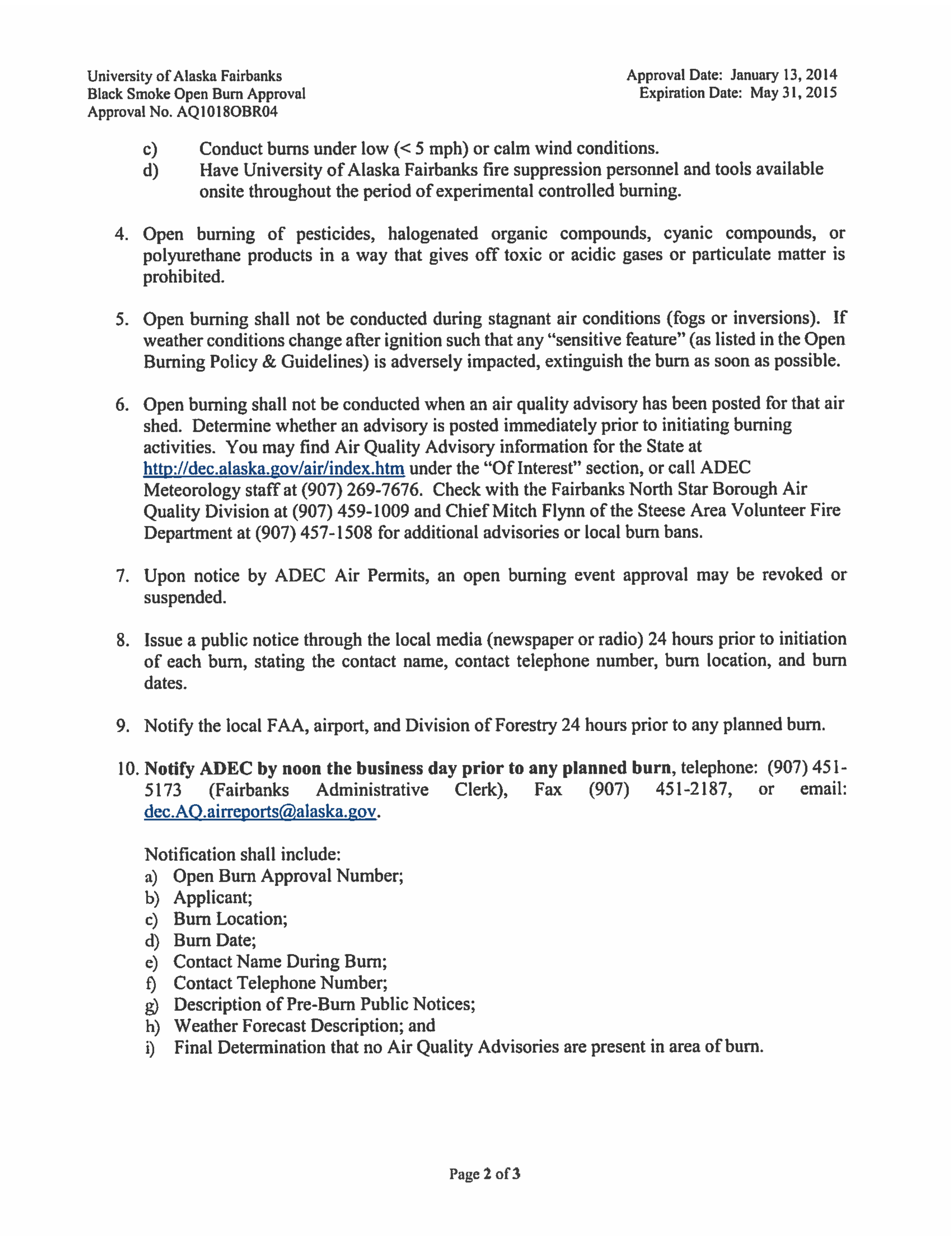
Description of Burn: This burn permit is a part of a research project to develop chemical herder-based strategies for combating oil spills. Herders are employed to collect and contain oil spills to allow for spill remediation via mechanical cleanup or in situ burning. The burning exercise is expected to last up to 30 minutes a day for 10 days in April or May 2015. The crude oil slick (over water) will be centralized within the test basin using chemical herders to promote complete burning. During each event, up to 200 liters of crude oil may be burned.

The State of Alaska Department of Environmental Conservation (ADEC), under the authority of AS 46.03, AS 46.14 and 18 AAC 50, issues this written approval to University of Alaska Fairbanks, Poker Flats Research Range for open burning with black smoke as set out under 18 AAC 50.065.

This approval is subject to the following conditions:

1. Fuel burned will be limited to uncontaminated liquid fuel, limited to 200 liters per event, or an experiment total of 2,000 liters (529 gallons).
2. Duration of burn events will not exceed 30 minutes per day.
3. Follow the following procedures to minimize adverse environmental effects and limit the amount of smoke generated.
   a) Confine the oil slick within the test basin,
   b) Ignite the oil at its 'fire point' to ensure complete and efficient burning of crude oil, and

Page 1 of 3



c) Conduct burns under low (< 5 mph) or calm wind conditions.
d) Have University of Alaska Fairbanks fire suppression personnel and tools available onsite throughout the period of experimental controlled burning.

4. Open burning of pesticides, halogenated organic compounds, cyanic compounds, or polyurethane products in a way that gives off toxic or acidic gases or particulate matter is prohibited.

5. Open burning shall not be conducted during stagnant air conditions (fogs or inversions). If weather conditions change after ignition such that any "sensitive feature" (as listed in the Open Burning Policy & Guidelines) is adversely impacted, extinguish the burn as soon as possible.

6. Open burning shall not be conducted when an air quality advisory has been posted for that air shed. Determine whether an advisory is posted immediately prior to initiating burning activities. You may find Air Quality Advisory information for the State at http://dec.alaska.gov/air/index.htm under the "Of Interest" section, or call ADEC Meteorology staff at (907) 269-7676. Check with the Fairbanks North Star Borough Air Quality Division at (907) 459-1009 and Chief Mitch Flynn of the Steese Area Volunteer Fire Department at (907) 457-1508 for additional advisories or local burn bans.

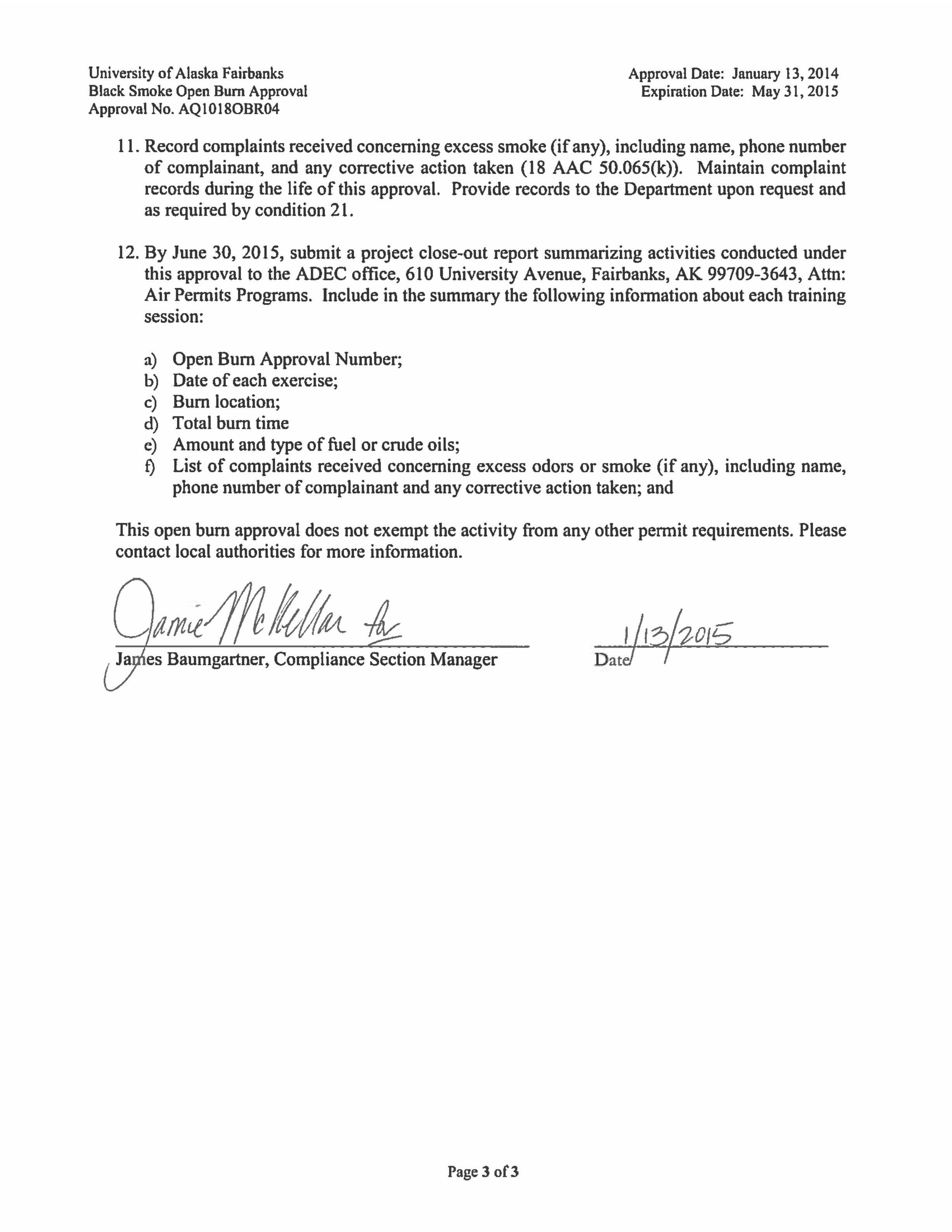
7. Upon notice by ADEC Air Permits, an open burning event approval may be revoked or suspended.

8. Issue a public notice through the local media (newspaper or radio) 24 hours prior to initiation of each burn, stating the contact name, contact telephone number, burn location, and burn dates.

9. Notify the local FAA, airport, and Division of Forestry 24 hours prior to any planned burn.

10. **Notify ADEC by noon the business day prior to any planned burn**, telephone: (907) 451-5173 (Fairbanks Administrative Clerk), Fax (907) 451-2187, or email: dec.AQ.airreports@alaska.gov.

    Notification shall include:
    a) Open Burn Approval Number;
    b) Applicant;
    c) Burn Location;
    d) Burn Date;
    e) Contact Name During Burn;
    f) Contact Telephone Number;
    g) Description of Pre-Burn Public Notices;
    h) Weather Forecast Description; and
    i) Final Determination that no Air Quality Advisories are present in area of burn.



11. Record complaints received concerning excess smoke (if any), including name, phone number of complainant, and any corrective action taken (18 AAC 50.065(k)). Maintain complaint records during the life of this approval. Provide records to the Department upon request and as required by condition 21.

12. By June 30, 2015, submit a project close-out report summarizing activities conducted under this approval to the ADEC office, 610 University Avenue, Fairbanks, AK 99709-3643, Attn: Air Permits Programs. Include in the summary the following information about each training session:

    a) Open Burn Approval Number;
    b) Date of each exercise;
    c) Burn location;
    d) Total burn time
    e) Amount and type of fuel or crude oils;
    f) List of complaints received concerning excess odors or smoke (if any), including name, phone number of complainant and any corrective action taken; and

This open burn approval does not exempt the activity from any other permit requirements. Please contact local authorities for more information.

Jamie McKellar for
James Baumgartner, Compliance Section Manager

1/13/2015
Date

THE STATE
of ALASKA
GovERNOR BILL \VALKER

Department of Environmental
Conservation

DIVISION OF SPILL PREVENTION & RESPONSE
Prevention, Preparedness, and Response Program

610 University Avenue
Fairbanks. Alaska 99709-3643
Main: 907.451.2145
Fax: 907.451.2362
dec.olosko.gov

File: 105.02.002

July 27, 2015

Frances Isgrigg, Director
UAF Environmental Health, Safety and Risk Management
1855 Marika Road
Fairbanks, AK 99709

Subject: University of Alaska Fairbanks PFRR Herder Basin Water Discharge No Objection Letter

Dear Ms. Isgrigg:

In response to the University of Alaska Fairbanks' (UAF) request to discharge water contained in a 300 x 300 foot burn basin within UAF's Poker Flats Research Range (PFRR) facility by milepost 31 of the Steese Hwy., the Alaska Department of Environmental Conservation (ADEC or Department) has reviewed documentation provided by UAF to determine if a permit is required before discharge occurs.

Background: It is the Department's understanding that the PFRR herder basin was used for research related to utilizing herding agents to concentrate crude oil to allow for its ignition (in-situ burn) to test the efficacy of the herding agents. Throughout the experiments, the basin was filled with approximately 400,000 gallons of water transferred from a nearby fresh water body, as well as approximately 5 L of the chemical herder plus 200 L of Alaska North Slope (ANS) Crude Oil applied during six separate tests between April22-26, 2015.

Response Actions & Analytical Data: Based on discussions with UAF personnel, as well as the closeout report provided by UAF on July 10, 2015, it is the Department's understanding that Alaska Clean Seas personnel removed as much of the remaining crude oil leaving little or no sheen on the water surface of the basin after each of the tests. The burn basin with the remaining water, containing residual herder and petroleum hydrocarbons, was then left to naturally attenuate (evaporation, photo oxidation and biodegradation). Given the hot, dry, summer, approximately 10% of the original volume of water remains in the burn basin. Analysis of this remaining water provided by UAF, comparing Gasoline Range Organics (GRO), Diesel Range Organics (DRO), and Residual Range Organics (RRO) concentrations pre- and post-test, show no increase in concentrations for those contaminants of concern (COC). It is the Department's understanding that the herding agent has been identified as another potential COC; UAF did provide ADEC with a report describing changes in water surface tension, caused by the varying concentrations of herder in the basin. That report shows that the water surface tension, measured in dynes per em, decreased from 72.7 to 44.0 between April22-26, 2015 (during the experiments), and has since increased to 66.2 indicating that the herder has undergone significant degradation. That information, along with the review of the material safety data sheets for the herder product, is sufficient for the Department to make a decision regarding discharge of the water in the burn basin.

Decision: Based on the information provided by UAF, the Department has determined that the remaining herder in the water docs not present an imminent and substantial danger to the public health or welfare or to any potential environmental receptors hence, it docs not meet the definition of a hazardous substance in AS 46.09.900 (4). The analysis of the oil fractions found in the water of the bum basin are all below the groundwater and surface water cleanup levels found in Table C, 18 AAC 75.345. The Department has no objection to UAF discharging the water from the bum basin on to lands owned by UAF and the discharge location being no closer than 100 feet from any moving or still water body or drainage ditch.

If additional areas or levels of contamination arc discovered in the future that are not included in the information submitted to the Department, you are required under 18/v\C 75 to contact this office at (907)451-2121. If you have questions or comments regarding this matter, please call me at (907)451-2145.

Sincerely,

State On-Scene Coordinator

cc: Ashley Adamczak, EPS N, ADEC/Fairbanks (via email)
Srijan Aggarwal, Assistant Professor, UAF/Fairbanks (via email)
Robert Perkins, Professor, UAF/Fairbanks (via email)
Jessica Garron, Senior Science Consultant, UAF/Fairbanks (via email)
David Barnes, Professor, UAF/Fairbanks (via email)
Robin Bullock, PhD Student, UAF/Fairbanks (via email)
William Schnabel, Associate Professor, UAF/Fairbanks (via email)

Enclosure: UAF Poker Flat Test Basin Water Closeout Report

Poker Flat Test Basin Water Closeout Report

7/10/15

To: Tom DeRuyter, State On-Scene Coordinator
ADEC Division of Spill Prevention and Response

From: Bill Schnabel, Interim Director
UAF Institute of Northern Engineering

Objective of the Report

We seek a letter of no objection from the Alaska Department of Environmental Conservation to discharge any water remaining in the Poker Flat test basin to the soil surface adjacent to the basin.

Summary

UAF constructed a test basin at Poker Flat Research Range in Fall 2014, filled it to approximately 15 - 20 inches of water from an adjacent lake in April 2015, then conducted five *in situ* burning tests using crude oil in April 2015. Approximately 200 L of crude oil was added to the basin for each test, then subsequently removed via *in situ* burning. Residual oil was removed from the basin following each test by Alaska Clean Seas using mechanical recovery methods, and a final cleanup was performed after all tests were completed. Approximately 1 L of the EPA-approved herding compounds Siltech OP-40 or Thickslick was added to the basin water prior to each burn. Aerially-applied gelled gasoline/diesel was used as an ignition source.

Basin water was analyzed before and after the tests by a third party, Pollen Environmental. Analytes consisted of gasoline range organics (GRO), diesel range organics (DRO), residual range organics (RRO), and benzene/ethylbenzene/toluene/xylene (BTEX). A summary of those results is provide in a subsequent section, and a copy of the official test results is included in the appendix.

In addition to the basin water, Pollen also analyzed the soils adjacent to the basin before and after the tests. These soils were analyzed in order to provide a baseline, in anticipation of discharging the basin water to the soils following cleanup. However, to date, no basin water has been discharged to the soils. As the basin is located at a site previously used as an asphalt plant for road construction, it was anticipated that the site soils would contain residual hydrocarbons not associated with tests conducted at the basin.

The University of Alaska submitted an Oil Discharge for Scientific Purposes permit application to ADEC in June 2015. At that time, we sought a permit to discharge the basin water to the ground adjacent the basin. Since that time, however, we have reviewed the third party sample analysis and determined that the level of petroleum hydrocarbons in the basin water following cleanup was equal to or lower than the basin water prior to the addition of any petroleum products. We have also measured the surface tension of the water over time as a proxy for the amount of herder remaining in the water, and witnessed the surface tension return to approximately pre-test levels. Finally, the hot, dry summer weather has evaporated most of the water in the basin. For these reasons, we believe that a discharge permit is no longer necessary.

We anticipate that the basin will begin accumulating rainwater in late summer/early fall 2015, and will accumulate substantial water following snowmelt in spring 2016. In order to ensure that this new water does not co-mingle with any residual water associated with the 2015 tests, we seek to discharge any residual water to the adjacent soils in the coming weeks. While the residual water is clean, we consider it an important step in the close-out of the current project to assure our funding partners that all water associated with the test has been removed. Moreover, as ADEC has provided guidance and oversight throughout all aspects of the project, we seek a letter of no objection from ADEC for discharging the clean water, in recognition of the notion that the permit is no longer required.

Petroleum Hydrocarbon Concentrations

Water samples were collected at three points in the basin prior to the tests (4/20/15), and approximately two weeks after the tests (5/10/15). The sample results are summarized in Table 1, and provided in their entirety in the Appendix. As demonstrated in the table, no light end compounds (GRO or BTEX) were detected in the basin water at any time. However, small levels of DRO and RRO were detected in the basin water before and after the tests. We note that the average concentrations after the tests were actually lower than the average concentrations before the test. That the basin water contained slight levels of DRO and RRO prior to the tests is not surprising, as these non-selective tests quantify ranges of hydrocarbons based upon carbon chain length, and are not strictly limited to hydrocarbons originating from petroleum.

Soil samples were also collected and analyzed to provide a baseline reading of the surface soils at the site. These results are presented in Table 2. In Table 2, the samples designated at North, Center, and West represent the approximate area surrounding the basin that would receive discharged water. The samples designated Opp West, Opp Center,, and Opp East represent opportunistic samples obtained from an area noted to contain a small amount of dark colored material, presumably originating from the site's original use as an asphalt plant. We note that no basin water had been discharged to these soils prior to the time of collection. Again, we do not find the existence of DRO or RRO in some of the samples surprising, given the site's previous use.

Table 1: Water sample summary

Sample Name	Collection Date	AK 101 GRO (ug/L) RL = 100	AK 102 DRO (mg/L) RL= 0.1	AK 103 RRO (mg/L) RL = 0.1	EPA 8260 Benzene (ug/L) RL = 1.0	EPA 8260 Ethylbenzene (ug/L) RL = 1.0	EPA 8260 Toluene (ug/L) RL = 1.0	EPA 8260 Xylene (ug/L) RL = 1.0
UAF Herder West (Control)	4/20/2015	ND	0.78	0.36	ND	ND	ND	ND
UAF Herder North (Control)	4/20/2015	ND	1.30	0.60	ND	ND	ND	ND
UAF Herder East (Control)	4/20/2015	ND	0.94	0.44	ND	ND	ND	ND
Average of Pre-Burn Samples			**1.01**	**0.47**				
Post Burn Water North	5/10/2015	ND	0.77	0.59	ND	ND	ND	ND
Post Burn Water Center	5/10/2015	ND	0.63	0.32	ND	ND	ND	ND
Post Burn Water South	5/10/2015	ND	0.63	0.32	ND	ND	ND	ND
Average of Post Burn Samples			**0.68**	**0.41**				

RL = Reportable limit of detection; ND = Analyte not detected

Table 2: Soil sample summary

Sample Name	Collection Date	AK 101 GRO (mg/kg)	AK 102 DRO (mg/kg)	AK 103 RRO (mg/kg)	EPA 8260 Benzene (ug/kg)	EPA 8260 Ethylbenzene (ug/kg)	EPA 8260 Toluene (ug/kg)	EPA 8260 Xylene (ug/kg)
North	4/15/2015	ND	ND	104	ND	ND	ND	ND
Center	4/15/2015	ND	ND	90.5	ND	ND	ND	ND
South	4/15/2015	ND	ND	88.6	ND	ND	ND	ND
North	5/15/2015	ND	ND	139	ND	ND	ND	ND
Center	5/15/2015	ND	ND	81.9	ND	ND	ND	ND
South	5/15/2015	ND	ND	121	ND	ND	ND	ND
Opp Center	5/10/15	ND	ND	137	ND	ND	ND	ND
Opp East	5/10/15	ND	41.9	190	ND	ND	ND	ND

ND = Analyte not detected

Herder Concentrations

Chemical herders reduce the surface tension, thus surface tension values act as a surrogate for herder concentration values in the water column. Lower surface tension values indicate higher herder concentrations. Surface tension values are routinely used in laboratory and field scale herding studies/operations to quantifiably estimate the herder concentrations. Thus, for the chemical herder mediated in-situ burning study, samples were systematically collected for surface tension measurements before the test commenced (to collect baseline data), during the tests and after the tests; to track herder concentrations and subsequent post-test degradation. The results of these measurements are presented in Figure 1.

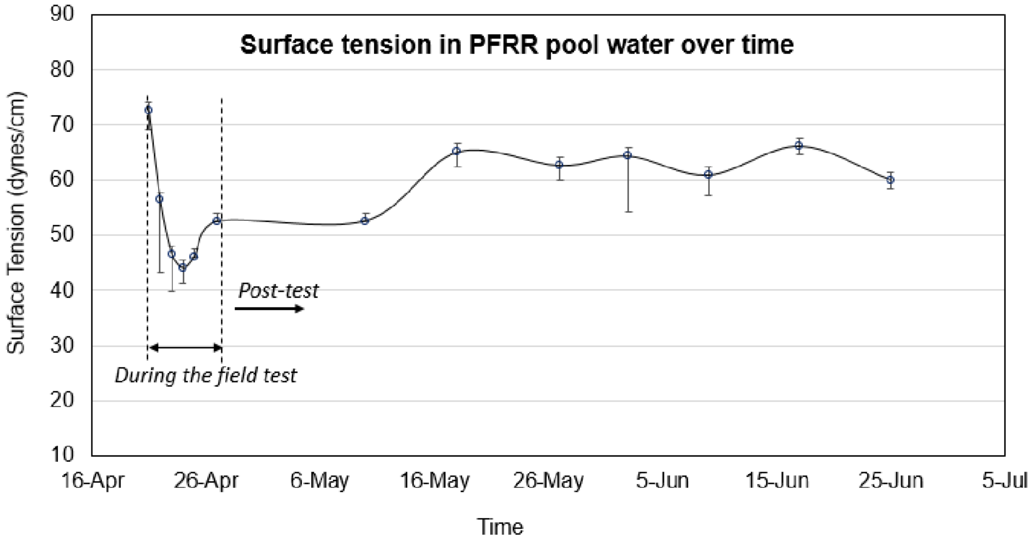


Figure 1: Surface tension results from Poker Flat test basin (2015)

As indicated in Figure 1 above, the baseline surface tension value was ~73 dynes/cm and reduced to a minimum of ~44 dynes/cm during the five day test period (4/23/15 -4/27/15) showing a nearly 40% reduction. Post-test measurements indicate that the surface tension values increased with time after the test. In less than three weeks (by 5/18/15), the surface tension was back up to ~65 dynes/cm, within 10% of the baseline values. The data trends are indicative of potential biodegradation or photodegradation of chemical herders.

Another point to note is that while collecting the post-test samples in May-June 2015, the water levels in the PFRR test pool showed marked reduction; due to high summer temperatures leading to evapotranspiration. The above plot does not account for the loss in water volume and thus the 'corrected' concentrations could well be nearer to the baseline values.

These results indicate that the herders are no longer impacting surface tension, and likely no longer measurably present in the basin water. Given the small quantity originally added along with the point that both Thickslick and OP-40 are EPA-approved compounds, we do not consider the basin water to be degraded by residual herders.

Current Disposition of the Basin Water

Our team has visited the basin weekly following the tests to collect samples and make observations. During those visits, we noted that there is no visible petroleum sheen, and also that the basin water level has dropped considerably due to evapotranspiration. On our 7/4/15 visit, we noted that approximately 40% of the basin area was dry, with the remaining water existing only in the low spots. Given that the basin bottom is relatively flat, the residual water likely accounts for much less than 10% of the approiximately 400,000 gallons present during the April field tests. A picture of the basin on that 7/4/15 visit is presented in Figure 2.

Figure 2: Basin condition on 7/4/15.

Conclusion

We intend to leave the basin intact during winter 2015 with the intention of identifying future projects for the site. However, we hope to close out the current project—the project that provided the funding to construct the basin—this summer. Consequently we seek a letter of no objection from ADEC to discharge any residual basin water on the soil surface outside the basin prior to the onset of the fall rains. This will allow us to inspect the condition of the entire basin in order to demonstrate that the current project poses no potential for future contamination.

Please feel free to contact me with any questions or concerns.

Regards,

William Schnabel, Ph.D., P.E.
Interim Director, UAF Institute of Northern Engineering
907-474-7790
weschnabel@alaska.edu

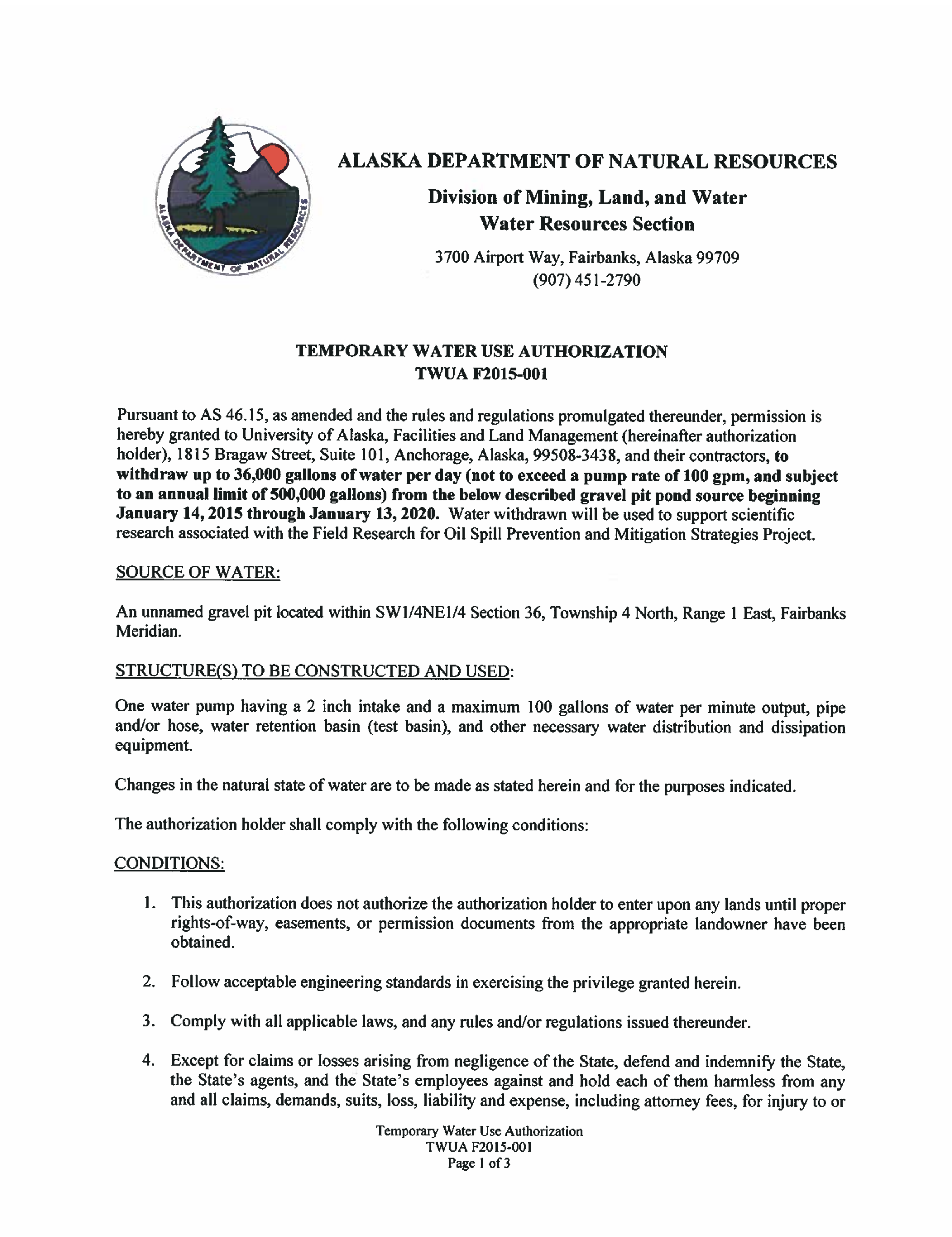
Please address the letter of no objection to:

Frances Isgrigg, Director
UAF Environmental, Health, Safety and Risk Management
1855 Marika Road
Fairbanks, AK 99709
fisgrigg@alaska.edu

Appendices

PEF19644-19646: Laboratory results of pre-test water samples
PEF19611-19616: Laboratory results of pre-test soil samples
PEF19993-20003: Laboratory test of water and soil samples following test

Note: Appendices PEF19644-19646, PEF19611-19616, and PEF19993-20003 are NOT attached.



ALASKA DEPARTMENT OF NATURAL RESOURCES

Division of Mining, Land, and Water
Water Resources Section

3700 Airport Way, Fairbanks, Alaska 99709
(907) 451-2790

TEMPORARY WATER USE AUTHORIZATION
TWUA F2015-001

Pursuant to AS 46.15, as amended and the rules and regulations promulgated thereunder, permission is hereby granted to University of Alaska, Facilities and Land Management (hereinafter authorization holder), 1815 Bragaw Street, Suite 101, Anchorage, Alaska, 99508-3438, and their contractors, **to withdraw up to 36,000 gallons of water per day (not to exceed a pump rate of 100 gpm, and subject to an annual limit of 500,000 gallons) from the below described gravel pit pond source beginning January 14, 2015 through January 13, 2020.** Water withdrawn will be used to support scientific research associated with the Field Research for Oil Spill Prevention and Mitigation Strategies Project.

SOURCE OF WATER:

An unnamed gravel pit located within SW1/4NE1/4 Section 36, Township 4 North, Range 1 East, Fairbanks Meridian.

STRUCTURE(S) TO BE CONSTRUCTED AND USED:

One water pump having a 2 inch intake and a maximum 100 gallons of water per minute output, pipe and/or hose, water retention basin (test basin), and other necessary water distribution and dissipation equipment.

Changes in the natural state of water are to be made as stated herein and for the purposes indicated.

The authorization holder shall comply with the following conditions:

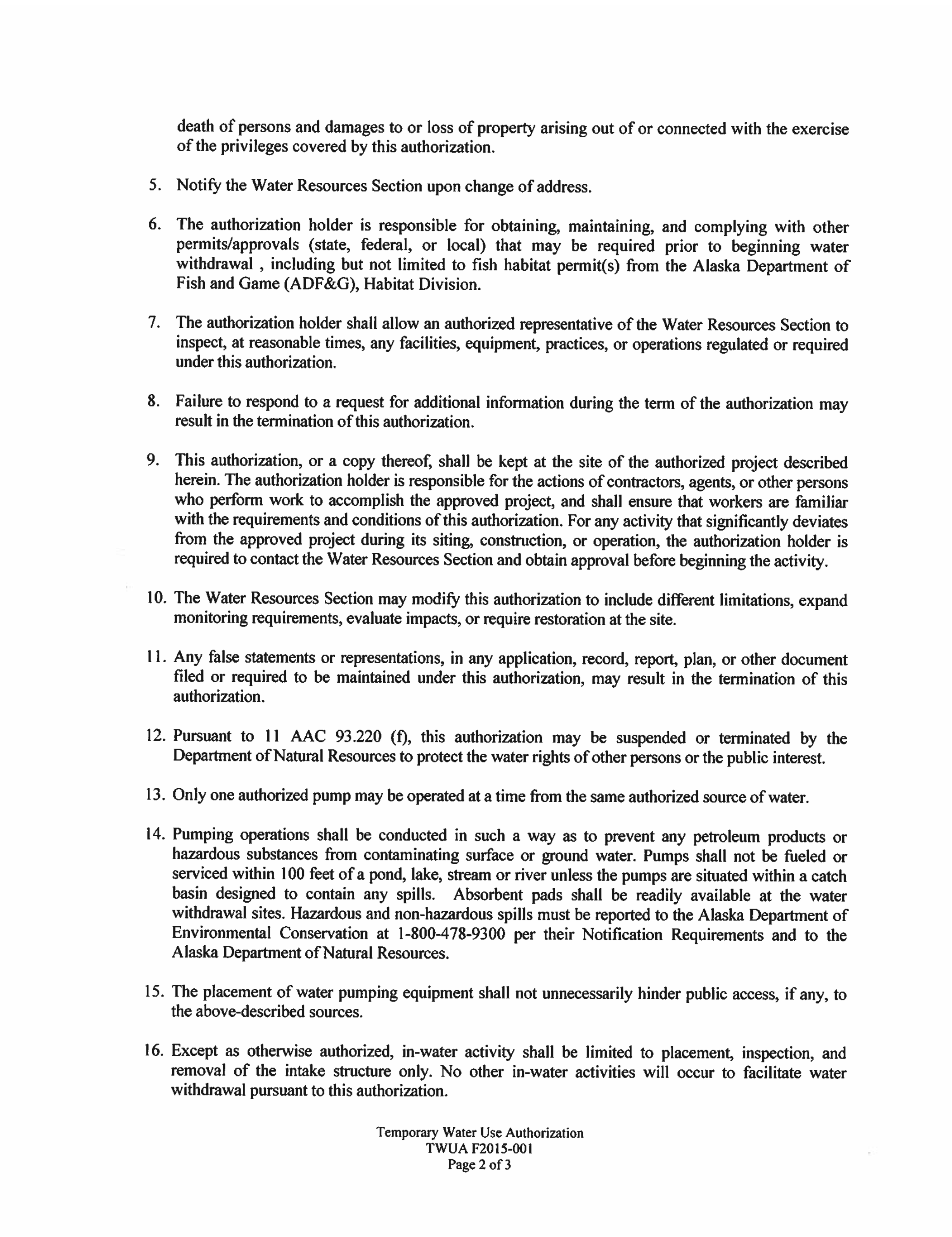
CONDITIONS:

1. This authorization does not authorize the authorization holder to enter upon any lands until proper rights-of-way, easements, or permission documents from the appropriate landowner have been obtained.

2. Follow acceptable engineering standards in exercising the privilege granted herein.

3. Comply with all applicable laws, and any rules and/or regulations issued thereunder.

4. Except for claims or losses arising from negligence of the State, defend and indemnify the State, the State's agents, and the State's employees against and hold each of them harmless from any and all claims, demands, suits, loss, liability and expense, including attorney fees, for injury to or



death of persons and damages to or loss of property arising out of or connected with the exercise of the privileges covered by this authorization.

5. Notify the Water Resources Section upon change of address.

6. The authorization holder is responsible for obtaining, maintaining, and complying with other permits/approvals (state, federal, or local) that may be required prior to beginning water withdrawal , including but not limited to fish habitat permit(s) from the Alaska Department of Fish and Game (ADF&G), Habitat Division.

7. The authorization holder shall allow an authorized representative of the Water Resources Section to inspect, at reasonable times, any facilities, equipment, practices, or operations regulated or required under this authorization.

8. Failure to respond to a request for additional information during the term of the authorization may result in the termination of this authorization.

9. This authorization, or a copy thereof, shall be kept at the site of the authorized project described herein. The authorization holder is responsible for the actions of contractors, agents, or other persons who perform work to accomplish the approved project, and shall ensure that workers are familiar with the requirements and conditions of this authorization. For any activity that significantly deviates from the approved project during its siting, construction, or operation, the authorization holder is required to contact the Water Resources Section and obtain approval before beginning the activity.

10. The Water Resources Section may modify this authorization to include different limitations, expand monitoring requirements, evaluate impacts, or require restoration at the site.

11. Any false statements or representations, in any application, record, report, plan, or other document filed or required to be maintained under this authorization, may result in the termination of this authorization.

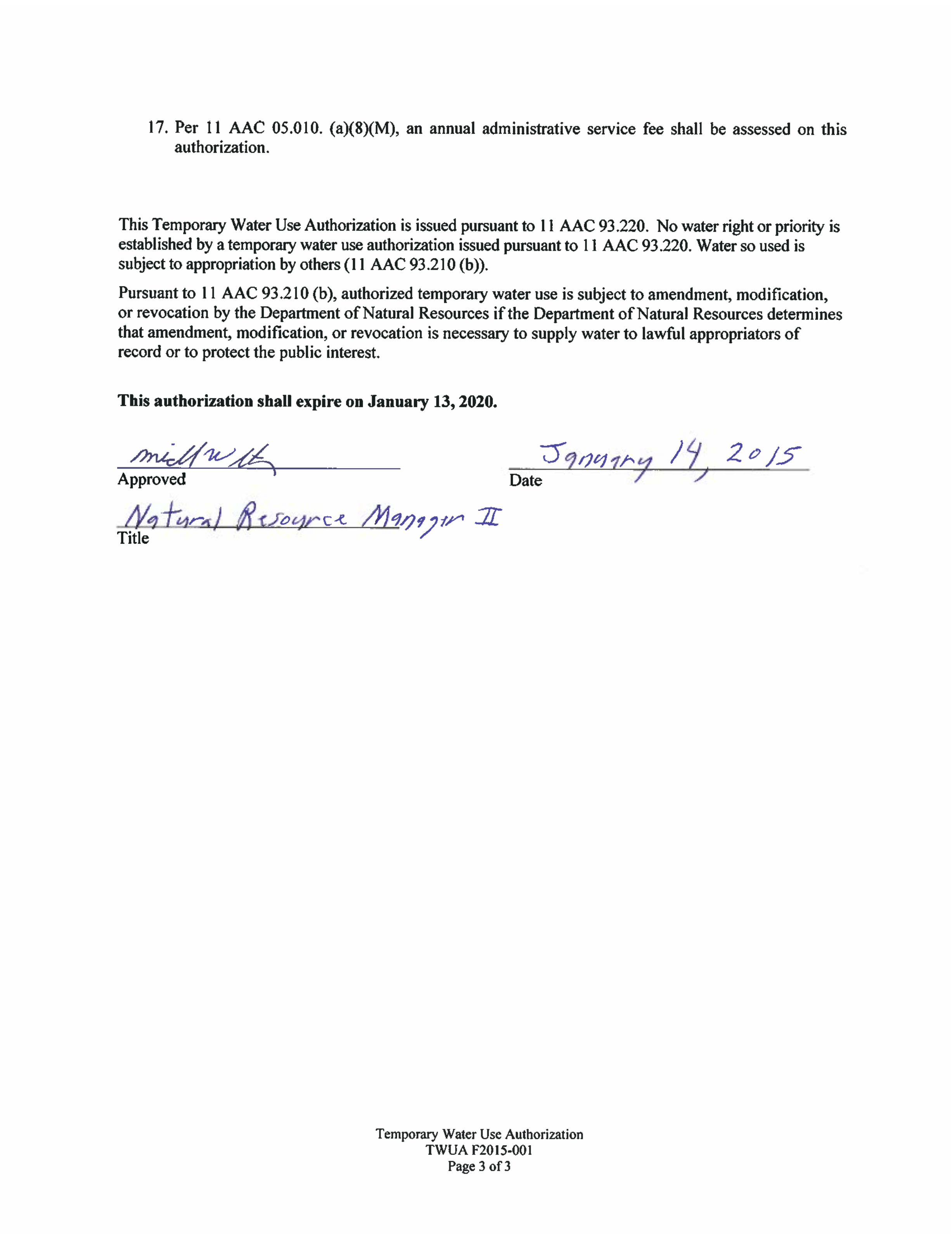
12. Pursuant to 11 AAC 93.220 (f), this authorization may be suspended or terminated by the Department of Natural Resources to protect the water rights of other persons or the public interest.

13. Only one authorized pump may be operated at a time from the same authorized source of water.

14. Pumping operations shall be conducted in such a way as to prevent any petroleum products or hazardous substances from contaminating surface or ground water. Pumps shall not be fueled or serviced within 100 feet of a pond, lake, stream or river unless the pumps are situated within a catch basin designed to contain any spills. Absorbent pads shall be readily available at the water withdrawal sites. Hazardous and non-hazardous spills must be reported to the Alaska Department of Environmental Conservation at 1-800-478-9300 per their Notification Requirements and to the Alaska Department of Natural Resources.

15. The placement of water pumping equipment shall not unnecessarily hinder public access, if any, to the above-described sources.

16. Except as otherwise authorized, in-water activity shall be limited to placement, inspection, and removal of the intake structure only. No other in-water activities will occur to facilitate water withdrawal pursuant to this authorization.



17. Per 11 AAC 05.010. (a)(8)(M), an annual administrative service fee shall be assessed on this authorization.

This Temporary Water Use Authorization is issued pursuant to 11 AAC 93.220. No water right or priority is established by a temporary water use authorization issued pursuant to 11 AAC 93.220. Water so used is subject to appropriation by others (11 AAC 93.210 (b)).

Pursuant to 11 AAC 93.210 (b), authorized temporary water use is subject to amendment, modification, or revocation by the Department of Natural Resources if the Department of Natural Resources determines that amendment, modification, or revocation is necessary to supply water to lawful appropriators of record or to protect the public interest.

This authorization shall expire on January 13, 2020.

Approved

January 14, 2015
Date

Natural Resource Manager II
Title

APPENDIX B – CONSTRUCTION REPORT

Helicopter Application of Herders and Igniters for In-Situ Burning of Oil in Drift Ice Project

Poker Flat Research Range
In-situ Burn Test Basin

University of Alaska at Fairbanks
Fairbanks, Alaska

Final Construction Completion Report

Project Construction Date:
September 2014 – April 21, 2015

Construction Report Table of Contents

List of Appendices

B1.0 Introduction

In situ burning, “ISB,” is an important oil spill response option for the Arctic. In ice infested waters, ice leads can provide natural containment, while cold temperatures inhibit loss of volatiles. Remote locations reduce objections to smoke and ISB requires much less support infrastructure than mechanical recovery. In broken ice conditions, however, oil may spread and become too thin to be ignited. Small quantities of chemical agents, “herders,” provide a method of thickening the oil. Herders likewise require little infrastructure for support.

The University of Alaska Fairbanks (UAF) is participating in the conduct of a research project to examine the effectiveness of chemical herders and in situ burning for oil spill clean-up actions in ice infested waters. The University was contracted by SL Ross, who is funded by the International Association of Oil and Gas Producers (IOGP, formerly OGP) Arctic Oil Spill Response Technology Joint Industry Programme, to construct a 300 x 300 ft. (90m x 90m) shallow test basin and help conduct field studies in late spring of 2015 to test the aerial application of herding agents and igniters to burn oil slicks in the presence of ice. The field research will be performed at Poker Flat Research Range (PFRR), a UAF asset approximately 30 miles NE of Fairbanks, AK.

The UAF project team for this work included:

Dr. Bill Schnabel Co-Principal Investigator
Dr. Bob Perkins Co-Principal Investigator
Jessica Garron Project Manager
Dr. Srijan Aggarwal Team member
Dr. David Barnes Team member
Bill Krause HSE site representative
Robin Bullock Graduate student
Patrik Sartz Graduate student

B1.1 Purpose and Objectives

The purpose of this preliminary Construction Completion Report is to document the construction status and outline remaining construction tasks in order to ensure open communications with the OGP and SL Ross and timely completion of all remaining construction items so as to meet contract and test objectives.

As a result of previous laboratory and field experiments (Buist, 2013), the primary objectives of the research project are twofold:

1) Prove the operational feasibility of an aerial herder application/burn response strategy using both manned and remote-controlled helicopters; and
2) Reaffirm the effectiveness of herders in open water and with ice present.

The specific objectives for the Test Basin construction include:

- Construction of a 300 foot X 300 foot lined impoundment;
- Installation of fixed monitoring equipment;
- Preparation and placement of an approximate 10% ice cover at a depth of 2 feet;
- Test Basin to contain a minimum of 6 inches of fresh water; and
- Construction of an oil release mechanism.

B2.0 Description of Construction Work

The experimental design includes utilization of a 300 ft. x 300 ft. shallow test basin (Test Basin) constructed at the PFRR. The Test Basin will be filled with 6 inches of freshwater, and will incorporate grounded, freshwater icebergs, composing approximately 10% of the Test Basin surface area. The test water is proposed to be pumped from the gravel pit adjacent to the Test Basin site. Construction completed through January 9, 2015 is described in the following sections.

B2.1 Site Preparation and Grading

The site had been used in the past to site a contractor's asphalt plant. The pond to the south is an old material/gravel site and is approximately 11 feet deep on average. The site is almost flat with low bushes, 1 to 2 feet tall. The Chatanika River lies to the north of the highway.

Prior to design finalization and bid, a soils sampling program was completed to assess the usability of on-site subgrade and soils for compaction and drainage. The soils were found to be variable, but no deposits of organics rich soils such as tundra or peat were found.

The selected contractor, Better Way Construction (Contractor), prepared the site by removing the shrubs and completing initial clear and grubbing work. The Contractor proceeded to excavate and push up the subgrade soils into the trapezoidal berm. Compaction of the berms was performed in 6-inch lifts as well as on the final floor of the Test Basin. Prior to compaction, the basin floor was levelled to plus or minus 1.5 inches, with the exception of a 10-foot by 10-foot low area, which was over-excavated and compacted in the northwest corner of the Test Basin.

This low area was developed to facilitate pumping and final cleanout. An overflow spillway was installed in the northern area of the Test Basin to enable discharge in the unlikely event of overfill. The Test Basin location is as shown in Appendix B-I and construction photos are provided in Appendix B-II.

An emergency access route was constructed to accommodate entry into the basin. The access route is 12 foot wide and has a gentler slope to allow ease of entry and egress. The access berm was constructed from imported D1 material as noted in the Material Specifications (Appendix B-IV). Two additional foot ramps were constructed to provide access to the basin for emergency access and for ease of operations. The two ramps were also constructed of D1 material, however, the material was not compacted on the interior due to placement over the flashing and the thermal rock layer.

B2.2 Liner Installation

Alaska Tent and Tarp was the contractor selected to procure and install both the geotextile as well as the liner material. The liner material selected was 8218 LTA and the geotextile was Geotex 801 (see Appendix B-IV for Material Specifications). The geotextile was placed on the compacted subgrade following a visual review of the subgrade by both the Contractor and Alaska Tent and Tarp to ensure that no sharp rocks, protrusions or other materials were at the surface of the Test Basin which could impact the liner performance. The liner was then rolled out and fused in place within the Test Basin and lies directly over the geofabric. An additional layer of geofabric was then placed on top of the fused liner material. Both geotextiles and the liner covered the base of the test basin, as well as the interior berm side slopes, access route and water overflow spillway. The top layer of 801 geotextile will be applied and panels stitched together to prevent folding and movement of the top layer. All field seams will be tested with the Air Lance method to ensure impermeability. The liners stopped at the key way for all areas except the spillway. For the spillway area, the liner was extended down the outside of the berm to reduce the potential for berm erosion and support water release as needed. Post liner and geotextile installation, the keyway was backfilled and compacted with site soils and residual keyway liner removed to reduce tripping hazards.

A maximum of 8 and minimum of 4 inch layer of thermal rock armor was placed over the interior berm side slopes (excluding the access route) and metal flashing was installed to a height of 14 inches vertical and 6 inches horizontal to assist in management of any oil or residue which may reach the side slopes. The horizontal portion of the flashing was also covered with a minimum of 4 inches of rock armor.

Due to the potential for the geotextile to float, concrete pavers were uniformly spaced to cover the base of the Test Basin. These pavers were anticipated to remain in the Test Basin until dismantlement of the Test Basin. (See Appendices B-II and B-III) However, once the basin was filled with water, the geotextile floated and was therefore cut and removed from the basin, along with the pavers prior to test initiation. It was also observed that during construction of the basin sump location, it appears that the excavated material was placed in a semi-circle around the sump, therefore during water filling, an additional volume of water was required to be placed in the basin in order to allow for the “beach area” around the sump to also be covered with approximately 2-3 inches of water. This will be a factor to be managed during basin water discharge.

B2.3 Iceberg Construction

Over 360 manmade ice blocks (“icebergs”) were formed and filled with procured freshwater and reside within the base of the Test Basin. Work to procure, erect and fill the forms was completed January 9, 2015. The forms were developed from 2 sources, 3 ply corrugated boxes lined with

2.5mil trash bags or 4x4 plastic liners, and 8-foot diameter vinyl children’s swimming pools. These two mediums, following a series of pilot tests, turned out to be the most cost effective and efficient method of making the icebergs for the Test Basin given the design parameters. The nominal height on all forms is 24 inches. The forms were placed in a 48 square grid pattern, with random form locations within each grid cell. Slight adjustments were made to iceberg placement to avoid iceberg installation over the pavers. Once the forms were placed, freshwater was pumped into the forms from a local water supply contractor, Water Wagon. Each water truck held approximately 3600 gallons, which was sufficient for the filling of approximately 2 grids per truck. Student labor was utilized to erect and fill each of the forms. Given projected winter temperatures, it is anticipated that the icebergs will be completely frozen by mid-February.

Iceberg forms were:

1) 66 Large: 8’diameter
2) 103 Medium: 4’x4’x2’
3) 206 Small: 2’x2’x2’

There were no icebergs installed within the 30-foot diameter centroid or a 30-foot boundary around the interior perimeter of the Test Basin. The Test Basin centroid location is reserved for the installation of the oil release mechanism. The interior perimeter along the base of the Test Basin is void of icebergs to assist in cleanup of residue between burns and acts as an extreme outer perimeter for herder application. Form dismantlement work was completed in mid-March 2015. Primary work included snow removal in order to get to the forms, and then form removal. The 2x2 boxes and pools were fairly easy to remove all side, and in case of the 2x2s- the bottom of the form as well. The 4x4s took additional effort given their size. All formwork was completed in 2 days. An additional day was spent cleaning up plastic and placing snow back on the icebergs- given the warming conditions.

Oil release mechanism was constructed to SL Ross specifications; with additions of eyebolts and metal pull cables. Oil release square was built locally in Fairbanks by Karolds Manufacturing. As temperature increased in late March and early April, Tyvek was draped over portions of the icebergs to reduce solar intensity on the ice with the intent to slow the melting of the icebergs. Water from the nearby gravel pit was pumped into the basin on April 17. A 10-inch ice auger was used to provide sufficient width for the suction hose. Approximately 3 to 4 ft. of ice overlain the pit water. A 4-inch trash pump was used along with 25ft of suction hose and 300 ft. of discharge line to fill the basin. Basin filling took 8 to 9 hours to complete.

Given warming conditions and that the herder application unit was not available until April 22, most of the icebergs had melted or were in the process of melting by the Day 1 burn. To continue to have the opportunity to simulate ice conditions, a series of sheet metal 22 gauge flashing material were used to construct 16 inch and 24 inch high, approximately 3 ft., 6 ft., and 10 ft. diameter “faux” bergs. The 6 ft. bergs required weight support [via pavers wired to the sides] to retain structure, however, the others retained their structure without additional support. In order to assist the pilot in seeing the “faux” bergs as he was applying the herder, white sorbent was placed in the interior of specified bergs.

B2.4 Monitoring Installations

A series of fixed and temporary monitoring stations have been installed through January 9, 2015. A meteorological station and data logger was installed in the southern portion of the site, in close

Proximity to the onsite buildings. All sensors are Campbell Scientific unless otherwise noted.

The meteorological (met) station includes the following devices:

- RM Young Wind speed and direction;
- HMP 45C air temperature and relative humidity;
- SR50A snow depth sensor;
- A Netcam XL webcam;
- 1 windsock for visual wind direction and speed;
- 2 staff gages for basin water monitoring;
- 3 EBAMs for air emission monitoring; and
- CR1000 data logger.

Close to the centroid of the basin, the following devices were installed:

- 1 thermocouple in each type of iceberg form (local fabrication);
- SR50A snow depth sensor; and
- CR1000 data logger.

B3.0 Permits

A temporary Storm water Pollution Prevention Plan and permit was developed and implemented by Better Way Construction for the completion of on-site Test Basin grading and liner installation activities. In addition, a temporary water use permit was obtained to allow for basin filling. No other permits were required for the construction of the Test Basin. Additional permits are required for Test implementation, however are not addressed in this construction completion report and instead addressed as part of the Test Plan.

B4.0 Material Quantities

The total quantities of materials listed below were calculated based on procurement documentation and calculations.

Rock Armor	120 cubic yards
D1 soil material	30 cubic yards
Liner	108,900 square feet
Geotextile	210,000 square feet
Flashing	1100 lineal feet
2X2 3 ply boxes	206 units
4X4 3 ply boxes	103 units
8 foot diameter pools	66 units
Concrete pavers	400 units
Iceberg Water	86,400 gallons
Sheet Metal Flashing	4ftx10ft sheets

B5.0 Modifications from Original Design

As part of the contract with SL Ross, UAF provided correspondence on all design modifications for input and authorization. In addition, during construction, small adjustments were made on the width of the berm and surrounding grade to assist in construction feasibility and berm stability. The design modifications included:

- The berm width was extended outward to allow for a six foot flat top of the berm. The contractor proposed this to accommodate his standard compaction equipment.
- Addition of flashing material on base of slope to reduce potential for oil and/or herder material from entering the rock armor; and
- Conversion of iceberg forms from wood construction to use of 3 ply cardboard boxes and 8-foot diameter vinyl swimming pools.
- Addition of sheet metal icebergs
- Addition of two dirt foot ramps
- Crude storage moved to UAF garage
- Decontamination structure was placed on basin ramp

B6.0 Health, Safety and Environment

UAF required all contractors, students and employees to complete the project in accordance with UAF policies and procedures, and Federal and State standards. Daily safety meetings were held every morning during conduct of on-site work activities. No first aids, recordable or lost time incidents were observed or recorded during conduct of this work.

Baseline soils and water samples were obtained prior to initiation of test implementation.

B7.0 Remaining Materials

Materials remaining post the test and their storage locations are as follows:

Poker Flats Test Basin

- 1 inflatable pool
- Trash bags and visqueen
- Safety glasses and vests
- Traffic cones
- Sheet metal for faux bergs- outside
- Oil release mechanism- outside

Duckering 106

- Siltech OP-40 and ThickSlick 6535 herder materials

UAF Hazardous Materials Facility- Cell H

- 4 barrels of Alaska North Slope Crude- under Bill Schnabel and Jessica Garron's names
- 1 oil dispensing pump [in visqueen]

B8.0 References

Buist, I, S.G. Potter, B.K. Trudel, S.R. Shelnutt, A.H. Walker, D.K. Scholz, P.J. Brandvik, J. Fritt-Rasmussen, A.A. Allen, P. Smith. In Situ Burning in Ice-Affected Waters: State of Knowledge Report, Report from Joint Industry Programme to present status of regulations related to in situ burning in Arctic and sub-Arctic countries, October 2013.

APPENDIX B-I

Construction Plan View

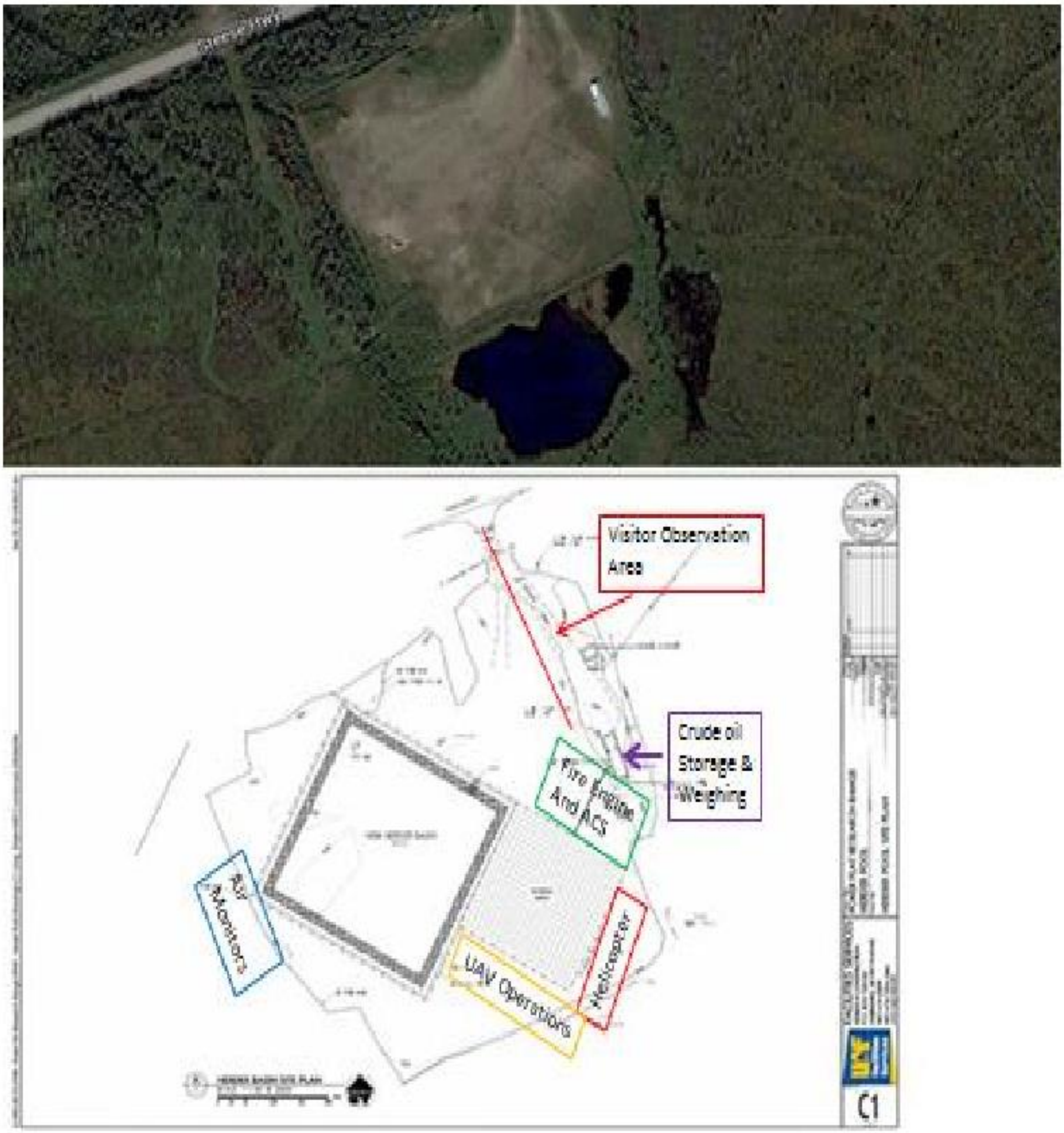


Figure B-1: Plan view of test site

APPENDIX B-II

Construction Photos

Figure B-2: PFRR Test Basin Site Grading

Figure B-3: PFRR Test Basin Berm Grading and Compaction

Figure B-4: Keyway Liner and Geofabric Installation

Figure B-5: Keyway with Liner and Geofabric and Rock Armor to Stabilize prior to backfill

Figure B-6: Concrete Paver placement over Liner/Geofabric

Figure B-7: Test Basin panoramic view

Figure B-8: Rock Armor and Flashing installation along southern side of Test Basin

Figure B-9: Rock Armor and flashing installation near the Access Route

Figure B-10: Filling of 8 foot diameter pool for iceberg development from water truck

Figure B-11: 8 Foot diameter 'iceberg' post form removal

igure B-12: Water source for Test Implementation- Adjacent gravel pit/water body

Figure B-13: Snow Sensor

Figure B-14: Thermocouples and Data Logger locations within the Test Basin Centroid

Figure B-15: Icebergs post form removal

Figure B-16: Staff Gage

Figure B-17: Basin with “faux” bergs, sorbent, and oil release mechanism – prepared for test initiation

APPENDIX B-III

Considerations for Future Tests in Basin

Health Safety Security Environment:

- Krause - great to have a dedicated HSE rep on site
- Air ADEC- air stations worked well, but pegged out
- Pollen Environmental timely and good reports
- Decontamination area- on the ramp, no need for decon trailer, but it was good to have to store the ACS materials to keep secure and covered
- No protesters, no complaints, limited need for security guards
- Good job in changing the HSE plan as risks were identified
- Good wildlife hazing, need to maintain some type of fencing to keep walking animals off the basin
- 4 wheeler and trailer helped to alleviate many loads and potential back concerns
- Outstanding permit tasks: burn permit close out, discharge permit
- Outstanding sampling tasks: post work for soils and water prior to and during discharge, and weekly basin water samples

Team:

- Poker provided good on-site support during the field test. Prior to the test is a potential area for improved alignment and communication
- Alignment between suppliers-UAF fire department, ACS and maritime did a great job. It would be good to see better alignment between delivery of the drones, herder and application unit- so as to have the ability to conduct work when weather allows vs. loosing time and ice
- Visitors' day- many invited, several OGP members attended. ADEC spill response person most likely the only regulatory decision maker in attendance. Limited community and UAF participation beyond team. May be an opportunity for future tests.

Building ice:

- Icebergs lasted approx. 3 days following flooding of the basin. Temps during that period were in the 50's during the day. Largest icebergs at time of flooding were approx. 6' diameter and 1.5' tall. Could have performed the experiment several weeks earlier (bergs would have lasted longer), but we would have had to break more ice in the mornings. Bergs inside boxes which did not have forms removed, retained as ice into May.
- May change to one or more options
    - Either go to all pools, and maybe large boxes [somewhat the bigger the better], with water wagon and students;
    - Corral icebergs into a smaller area, and replace bergs with ice cut from lake as needed
    - Use the sheet metal fauxberg forms to hold water. Place forms on the liner following the first significant snowfall (in very cold conditions). Add a small amount of water to the snow inside the forms, and allow a layer of slush to freeze a seal at the interface. Then come back a day later and fill to the top. Do not remove the forms until the basin has been filled and the water melts the ice at the interface; or
    - Look into contracting it out and doing ice cutting
- Either option(s)- still have coordination issue of being ready to implement plan in a timely fashion based on weather

Construction:

- If choose not to put a geotextile - anticipate that it may be a single use liner
- Generally well-constructed
- Flashing and rock extremely important for any burn tests
- Sump area- beach zone…need to factor in for water discharge pumping, potential claim and future use
- Add a 4th ramp to keep people off rocks [1/side] and compact all foot ramps
- If using geotextile in the future, consider using sand on top of the geotextile vs. pavers
- Construct a stable platform for viewing and AV people in a safe location
- 4-inch pump and lake/pit worked well to provide water. Basin filled at approximately 0.6 inches per hour at max capacity of 4" pump. Flow rate was observed to be 500 gallons/minute, and the pump ran for 8.5 hours. Total water withdrawn during fill (4/17/15) was 255,000 gallons.
- Note in future permit applications that test holes were drilled in the ice near the suction hole. The test holes showed no decline in water level at any point during the period of water withdrawal. This indicates that the lake was being replenished as fast as we could remove the water.
- If keeping the basin, should consider repairing the liner where melted and the beach/sump area
- Decision point on summer maintenance- either keep water in basin, decommission basin or reinstall geotextile or other.

APPENDIX B-IV

Material Specifications

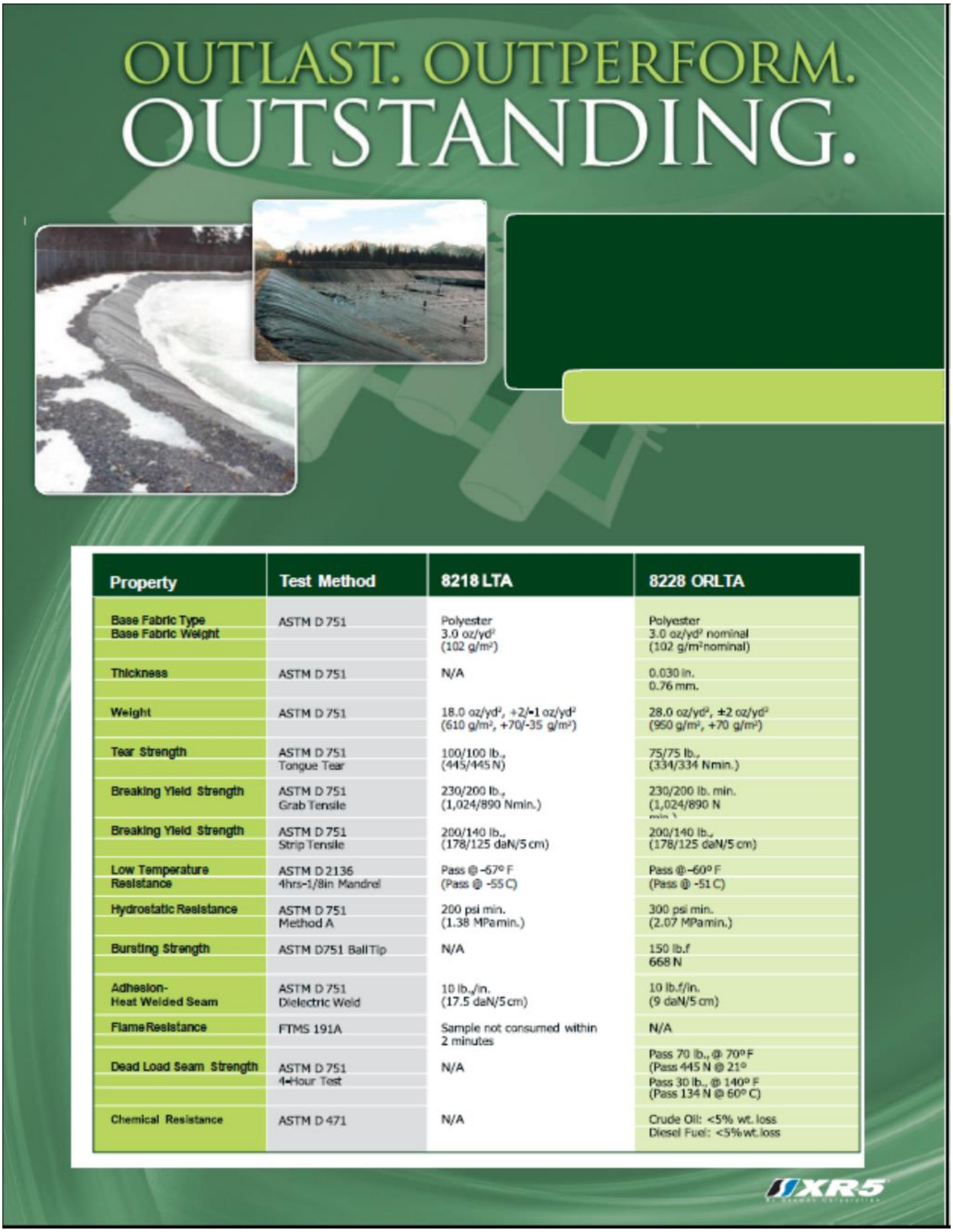
D1 Soils

State of Alaska standard specifications for highway construction

Sieve Designation	Percent Passing by Weight
1 inch	100
¾ inch	70-100
3/8 inch	50-80
No. 4	35-65
No. 8	20-50
No. 40	8-30
No. 200	0-6

Thermal Rock Armor

The thermal armor must be at least 4” thick and hold an angle of repose so that it does not slip off the liner material, and the bottom of the armor is not thicker than 8”. The armor must be washed material and free of silt and organics. The finished armor shall not have any gaps the permit air to communicate between the surface of the armor and the liner material.



Property	Test Method	8218 LTA	8228 ORLTA
Base Fabric Type Base Fabric Weight	ASTM D 751	Polyester 3.0 oz/yd^2 (102 g/m^2)	Polyester 3.0 oz/yd^2 nominal (102 g/m^{2}nominal)
Thickness	ASTM D 751	N/A	0.030 in. 0.76 mm.
Weight	ASTM D 751	18.0 oz/yd^2, +2/-1 oz/yd^2 (610 g/m^2, +70/-35 g/m^2)	28.0 oz/yd^2, ±2 oz/yd^2 (950 g/m^2, +70 g/m^2)
Tear Strength	ASTM D 751 Tongue Tear	100/100 lb., (445/445 N)	75/75 lb., (334/334 Nmin.)
Breaking Yield Strength	ASTM D 751 Grab Tensile	230/200 lb., (1,024/890 Nmin.)	230/200 lb. min. (1,024/890 N min.)
Breaking Yield Strength	ASTM D 751 Strip Tensile	200/140 lb., (178/125 daN/5 cm)	200/140 lb., (178/125 daN/5 cm)
Low Temperature Resistance	ASTM D 2136 4hrs-1/8in Mandrel	Pass @ -67° F (Pass @ -55 C)	Pass @ -60° F (Pass @ -51 C)
Hydrostatic Resistance	ASTM D 751 Method A	200 psi min. (1.38 MPamin.)	300 psi min. (2.07 MPamin.)
Bursting Strength	ASTM D751 Ball Tip	N/A	150 lb.f 668 N
Adhesion- Heat Welded Seam	ASTM D 751 Dielectric Weld	10 lb.,/in. (17.5 daN/5 cm)	10 lb.f/in. (9 daN/5 cm)
Flame Resistance	FTMS 191A	Sample not consumed within 2 minutes	N/A
Dead Load Seam Strength	ASTM D 751 4-Hour Test	N/A	Pass 70 lb., @ 70° F (Pass 445 N @ 21° Pass 30 lb., @ 140° F (Pass 134 N @ 60° C)
Chemical Resistance	ASTM D 471	N/A	Crude Oil: <5% wt. loss Diesel Fuel: <5% wt. loss

Figure B-18: Thermal Rock Armor Specifications

APPENDIX C – METEOROLOGICAL DATA

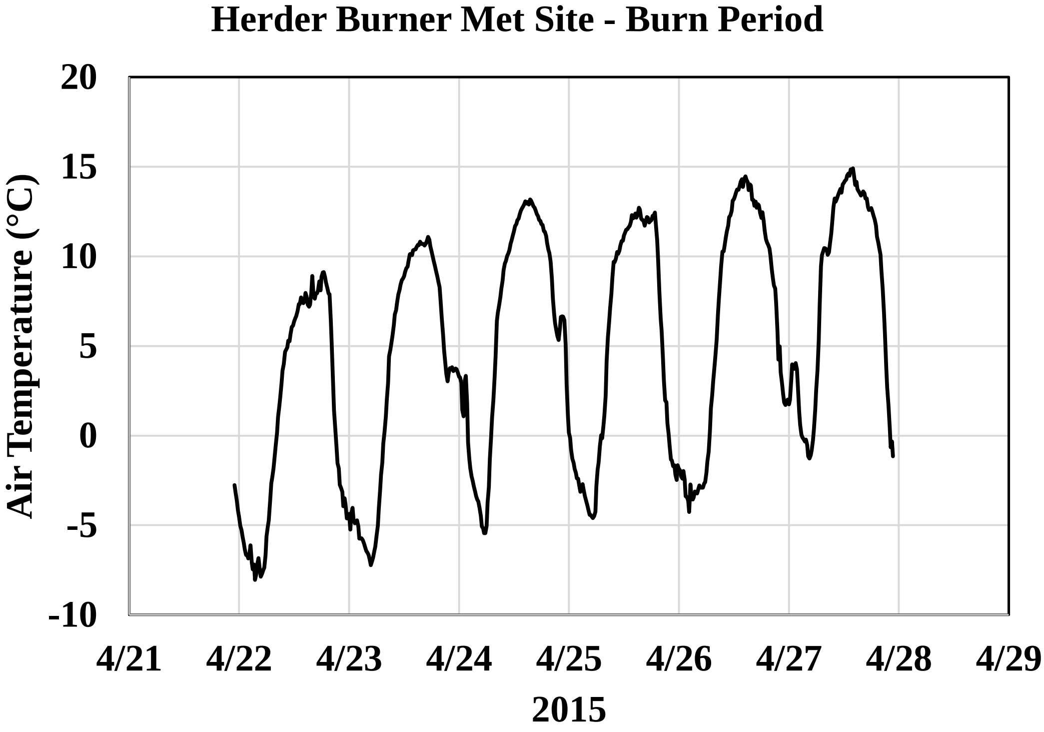


Figure C-1: Air Temperature During Testing

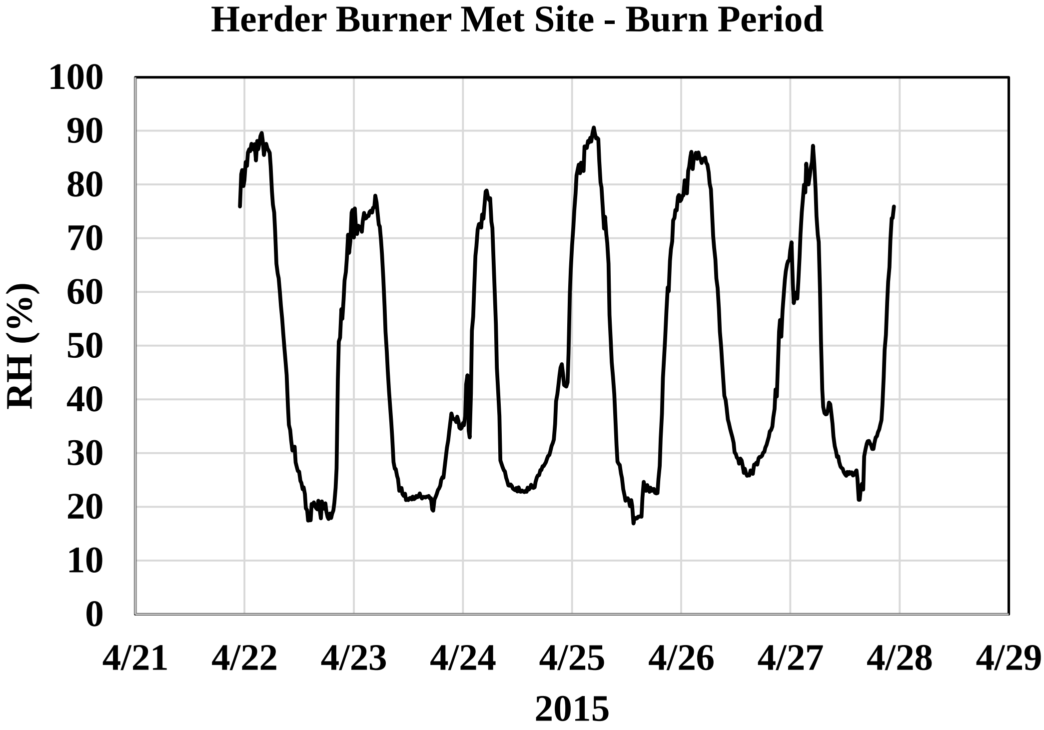


Figure C-2: Relative Humidity During Testing

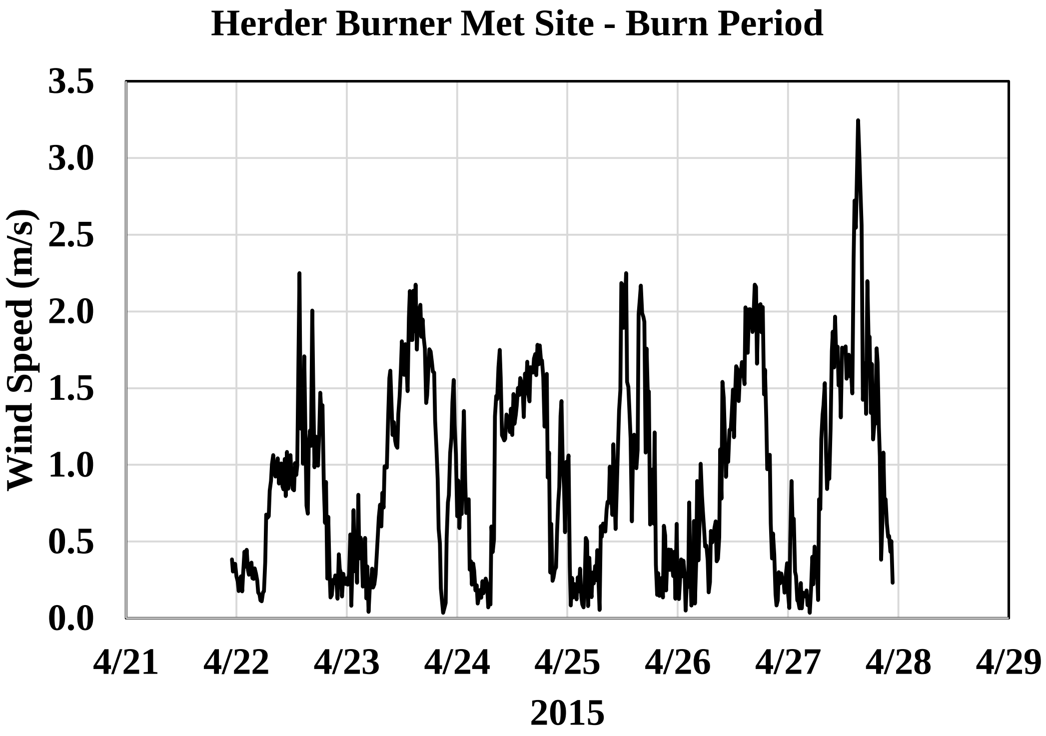


Figure C-3: Wind Speed During Tests

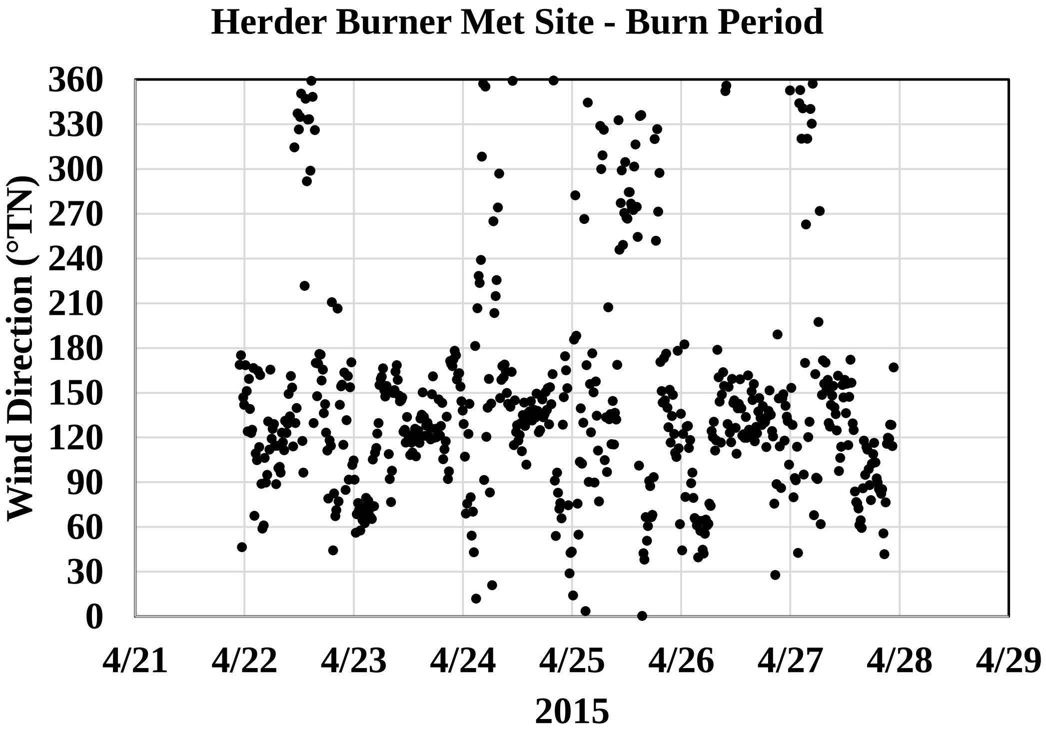


Figure C-4: Wind Direction During Tests

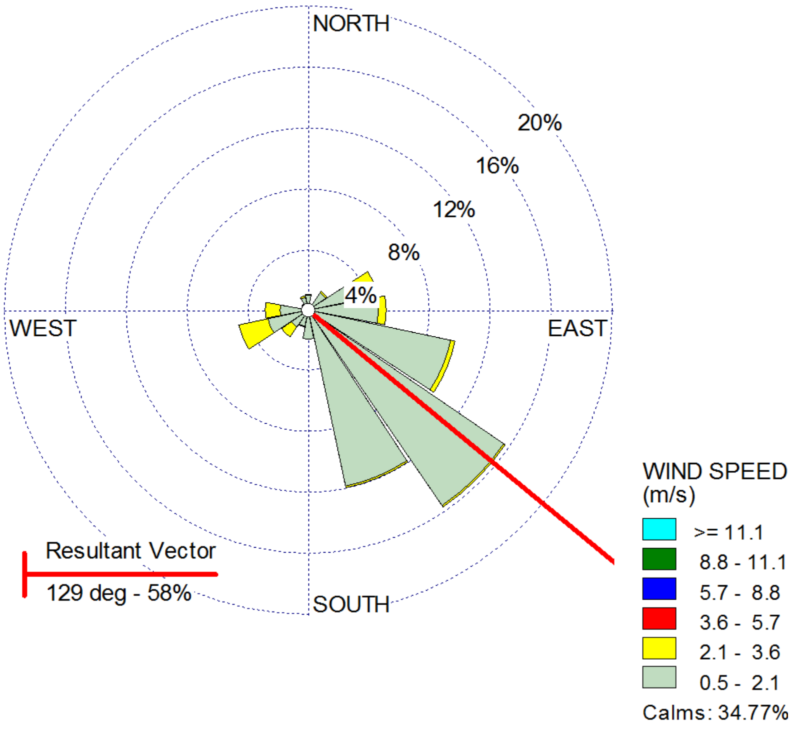


Figure C-5: Wind Rose for March 18 Through April 30, 2015

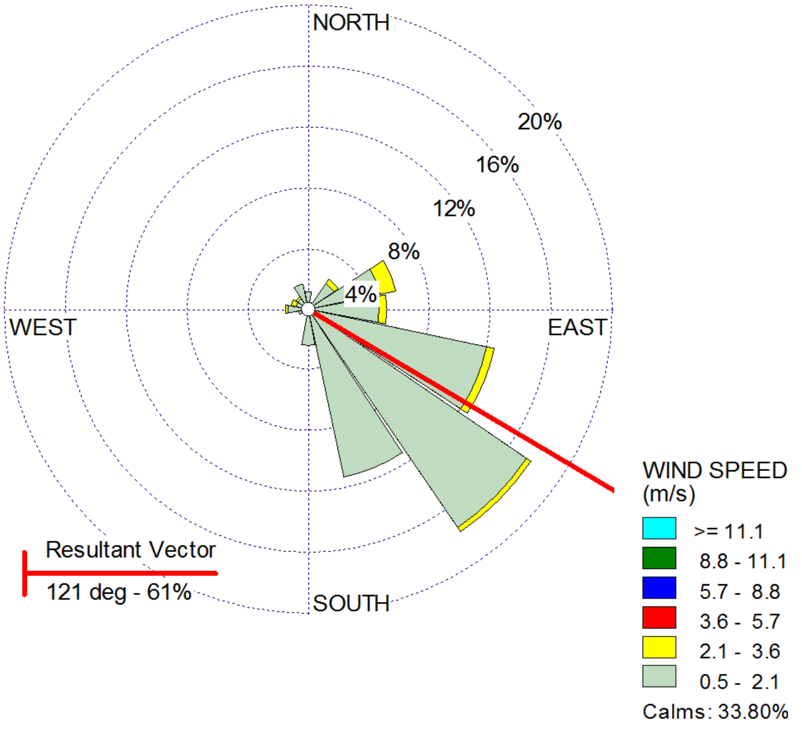


Figure C-6: Wind Rose during Field Tests, April 22 Through April 27, 2015

APPENDIX D – PLUME MONITORING DATA

Air Quality data

The data below shows ranges of air pollutants measured during the April 27th 2015 burn (Test-5). The data is presented in terms of box-plots showing the minimum, 25th percentile, 50th percentile (median), 75th percentile and maximum values; all measured during the burn duration.

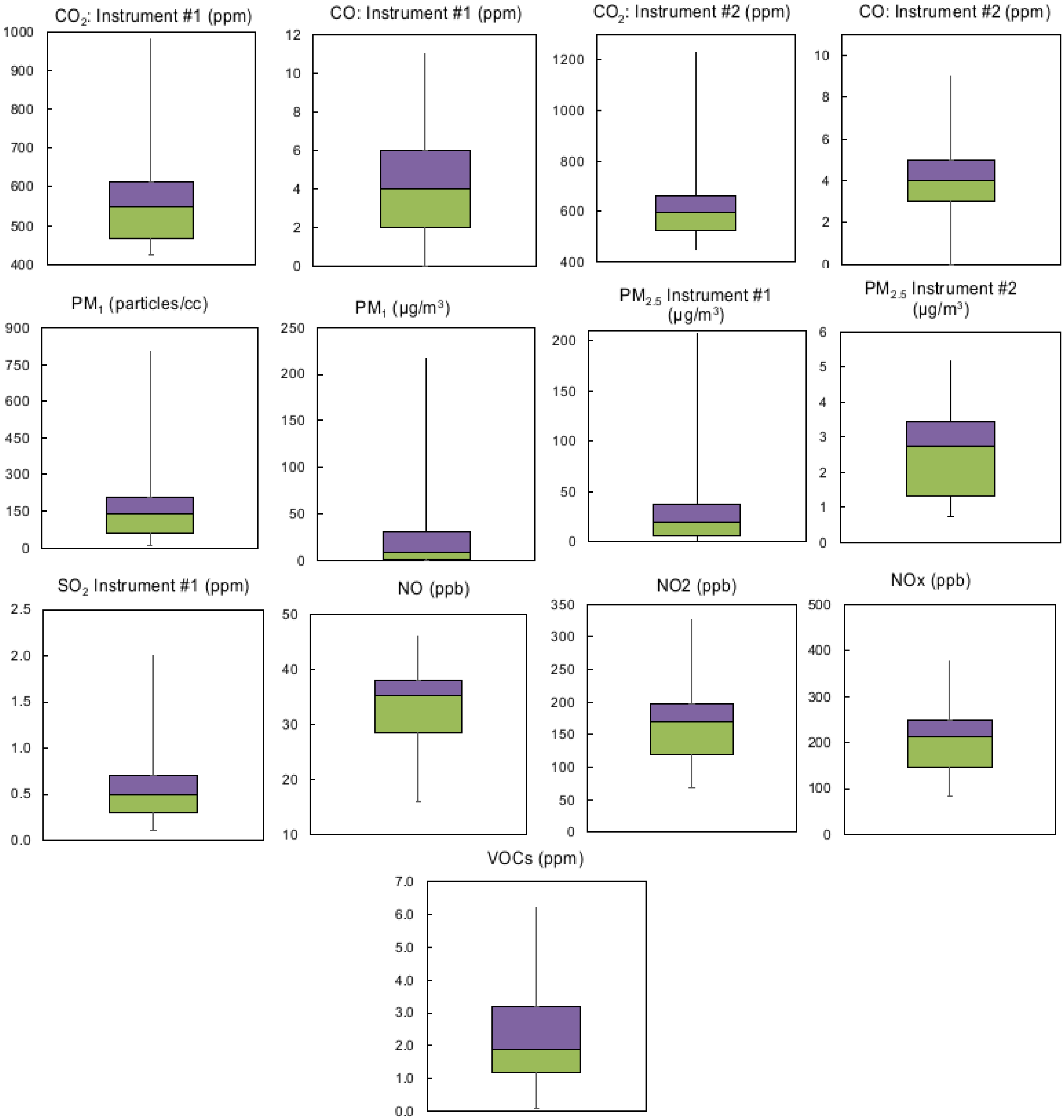


Figure D-1: Air Quality During Tests

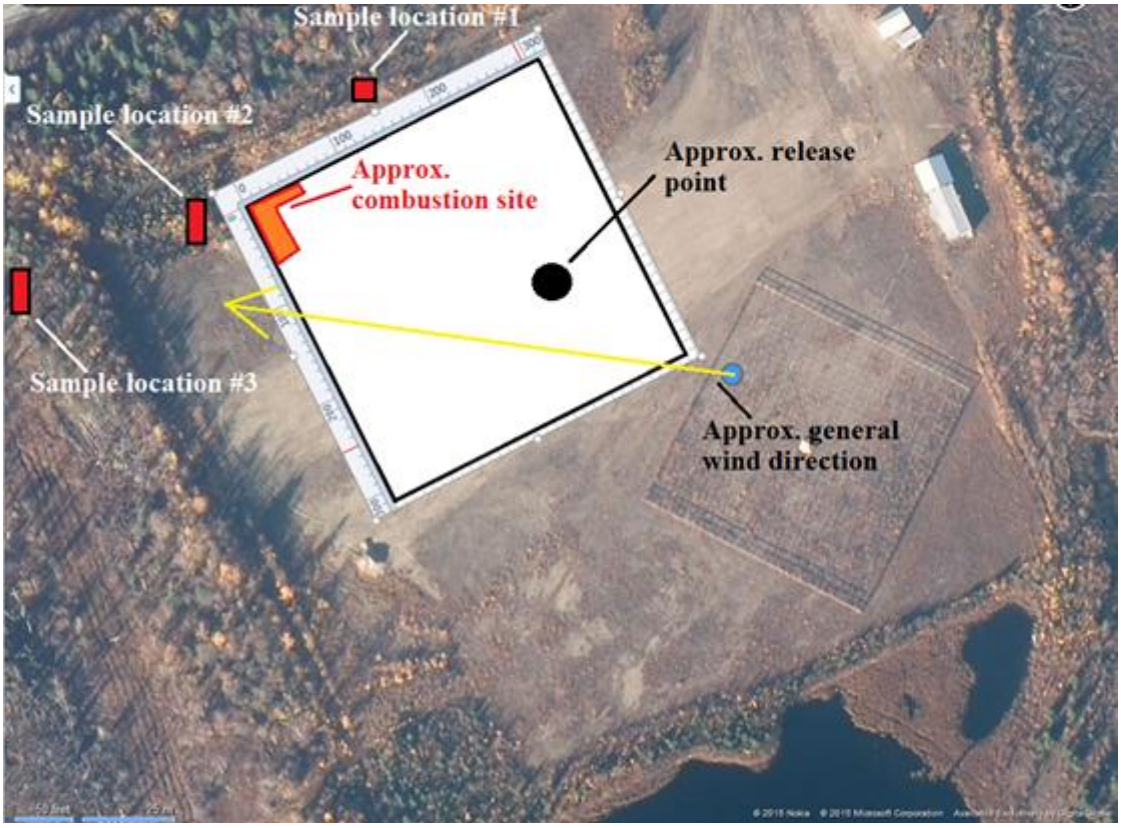


Figure D-2: Locations of Air Samplers

APPENDIX E – FIELD TEST PLAN

The primary goal of the field tests is to validate the use of herders in combination with in-situ burning (ISB), when both are applied by helicopter and thus prove the overall feasibility of using herders and ISB as an integrated, fully aerial response option in light drift ice conditions.

Organizations Participating in the Field Testing

The project team will facilitate the provision of logistics and other in-kind support such as: weather forecasting; environmental sensitivity data; test basin, helicopters; response crews and back-up response equipment. The team will also assemble the necessary data collection equipment (cameras, video cameras, weigh scales, etc.) to document the herder and burn efficiency in the field and backup herder application equipment and igniters for use manually. In addition, SL Ross will coordinate with UAF and monitor/manage the use of their scientific personnel in data collection and analysis as appropriate.

The International Association of Oil and Gas Producers - Arctic Response Technology JIP

- Funds and administers the participation of SL Ross, UAF and other subcontractors
- Reviews and approves the test plan, HSE Plan and draft and final reports and scientific/technical papers

SL Ross Environmental Research Ltd.

- Main contractor responsible for administering the various subcontractors
- Prepares the Test Plan and HSE Plan with UAF
- Arranges for the herding agents to be shipped from DESMI-AFTI to UAF
- Designs the oil release system
- Monitors the DESMI-AFTI Herder Application System tests and modifications
- Assists ING Robotic Aviation with design of herder release and igniter systems for Responder robotic helicopter
- Provides and operates the DuNuoy tensiometer
- Provides and operates weigh scales to determine residue weights
- Provides backpack herder sprayers as backup
- Directs each experiment
- Assists with the test equipment operation during the tests
- Collects data, including aerial digital photos and HD video
- Analyzes data
- Writes the final report

UAF

- Prepares the Test Plan with SL Ross
- Obtains the various environmental permits from regulatory agencies for the tests
- Applies for FAA approvals for UAV (Responder) operation at PFRR site
- Approves the HSE Plan
- Provides Site Safety Supervisor
- Provides warming facility (garage and office area)
- Provides safety orientations for all personnel
- Provides a fire truck and crew for each test day
- Constructs one 8 ft. x 8 ft. oil release frame of aluminum angle and flat
- Provides a lined Test Basin (90 m x 90 m x 1 m deep) at a selected site at PFRR
- Provides and operates required environmental data collection equipment on site (meteorological, water quality and air quality)
- Provides freshwater ice floe surrogates for the Test Basin
- Provides fresh water to fill the Test Basin to an average depth of 6” (15 cm)
- Collates environmental data and transmits it to SL Ross
- Level D PPE for UAF personnel
- Provides input to the final report
- Disposes of waste sorbent, oil residue, solid waste, and basin water

- Digital photography and video of the tests from the ground using OGP PR guidelines
- Portable rest room
- Decontamination area (extent of facility to be confirmed with SL Ross/ACS)

DESMI-AFTI

- Provides 5 gallons each of ThickSlick and Siltech OP-40 in cans or plastic containers
- Tests, modifies and retests Herder Application System for manned helicopter
- Operates Herder Application System

ING Robotic Aviation

- Provides two Responders to be used in concert with each other to minimize grounded time and efficiently carry out this testing task with optimal surveillance
- Create two new payload options (1: Herding canister remote activator; and 2: Ignition system grabber)
- Provide four pilots/ technicians for tests at PFRR. Technicians must operate in pairs (one for flying, the other for line of sight). One technician would fly Responder to dispense the herder and the igniter kits, while the other technician would fly Responder to film the testing at the same time
- Slightly modify their existing flight certificate to allow the towing/dropping of a payload
- Communicate with Maritime Helicopter personnel re UAV operations

Alaska Clean Seas (ACS)

- Obtain 1 m3 ANS in an IBC (aka a tote), placed inside a portable spill berm with minimum 1.1 m3 capacity, and on an elevated stand so Jerry cans can be easily filled with crude and hand-carried to release system.
- Simplex 55-gallon Heli-torch c/w helicopter remote control
- Gasoline and gelling agent
- Spare 55-gallon Heli-torch drum
- Mixing portable berm or 20’ Conex
- Portable gasoline fuel tank (100 gallons) with secondary containment
- Handheld tin can igniters (as back up)
- Sorbents
- Pads
- boom (1200’
- sweeps (1500’)
- walkways from basin to Decon Trailer
- Heavy duty garbage bags for oiled sorbent
- Skimmer (MI-11/24) c/w power pack, hoses, spares, etc.
- Portable tank for oil recovery/decanting with secondary containment
- Portable fire pumps and for post-test herding
- Four labourers + supervisor(s): oil pumping, residue recovery, Heli-torch, (persons to operate mixing/loading/heli-pickup and drop off site as per US Interagency Task Force Guidelines (or ACS procedures?)
- Review HSE plan
- Level D and some Level C PPE for ACS people (crude oil and gasoline handling, crude oil vapours from oil on water)
- Radios, some capable of aircraft frequencies

Maritime Helicopters

- Provide 30 hours of Bell 407 on-site flying time c/w OAS carded pilot
- Review HSE plan
- Provide completed SMS forms and/or computerized tools prior to commencing the tests at PFRR (one month prior to tests)
- Visit PFRR basin site and assist with selecting a landing and Heli-torch loading site
- Communicate with ING Robotic Aviation staff re UAV operations
- Operations shelter at staging location

Test Personnel

The test personnel assignments are listed in Table E-1.

Table E-1: Test Personnel Assignments

Affiliation	Name	Role
University of Alaska Fairbanks	Jessica Garron	UAF Project Manager
	Bill Schnabel	UAF Principal Investigator (PI)
	Bob Perkins	UAF Co-PI
	Srijan Aggarwal	UAF Co-PI
	Robin Bullock	UAF graduate student
	4-man fire/EMT crew	UAF fire department
	Bill Krause	UAF Site Safety Supervisor
	Marty Rogers	ACUASI UAV Airboss
	Kathe Rich	PFRR Range Manager
	Jason Avila	PFRR general labour
	Bob Valdez	PFRR Deputy Range Manager, site liaison
	Andy Cummins	UAF GI A/V team
	Azara Mohammadi	UAF GI A/V team
SL Ross Environmental Research	Ian Buist	Principal Investigator / Backup herder/igniter
	David Cooper	Helicopter Video/Photo
	Steve Potter	Project Manager/ Backup herder/igniter
DESMI-AFTI	Peter Lane	Herder Application/ Air Operations Technical Coordinator
Alaska Clean Seas	Supervisor	ACS Crew Boss, Heli-torch Manager
	4-person crew	Oil storage, transfer, release, residue cleanup, unburned oil cleanup, basin polishing, waste preparation for disposal
ING Robotic Aviation	2 x 2-person flight teams	Each includes Pilot / Operator & Safety Observer / Supervisor
Maritime Helicopters	Pilot	Fly helicopter with herder application system then operate Heli-torch

Test Design

Preparations

The preparations for the tests include:

- SL Ross provides and operates the DuNuoy Tensiometer
- SL Ross provides weigh scales to determine fresh oil and residue weights
- SL Ross provides backpack herder sprayers as backup
- UAF obtains all required environmental permits

- UAF provides/maintains site security
- UAF provides a lined Test Basin (90 m x 90 m x 1 m deep) at a selected site at PFRR
- UAF constructs one 8 ft. x 8 ft. oil release frame of aluminum angle and flat bar
- UAF provides a fire truck and crew for each test day
- UAF provides and operates required environmental data collection equipment on site
- UAF provides freshwater ice floe surrogates for the Test Basin
- UAF provides fresh water to fill the Test Basin to an average depth of 6” (15 cm)
- UAF provides containers for and disposal of waste sorbent and oil residue, and completes disposal of basin water
- UAF provides warming area (onsite building joined to garage)
- UAF provides warm staging area for weighing, small equipment, and materials (the garage)
- UAF provides decon area
- UAF and ACS provide respective personal monitoring as required in the HSE plan
- DESMI-AFTI provides 5 gallons each of ThickSlick and Siltech OP-40 in cans or plastic containers
- DESMI-AFTI provides modified and tested Herder Application System for manned helicopter
- ING provides two Responder robotic helicopters that can be fitted with herder canister and remote activator, ignition system grabber and video cameras.
- ACS provides secondary containment for each hydrocarbon storage area
- ACS provides 1 m^3 ANS in an IBC
- ACS provides Simplex 55 gallon Heli torch c/w helicopter remote control,
- ACS provides gasoline and gelling agent,
- ACS provides spare 55-gallon Heli-torch drum,
- ACS provides gelled fuel mixing portable berm or 20’ Conex,
- ACS provides portable gasoline fuel tank
- ACS provides handheld tin can igniters (back up)
- ACS provides sorbents (pads, boom, sweeps, walkways)
- ACS provides heavy duty garbage bags for oiled sorbent
- ACS provides skimmer (MI-11/24) c/w power pack, hoses, spares, etc.
- ACS provides portable tank for oil recovery/decanting
- ACS provides fire pumps and hoses for herding
- ACS provides Level D and some Level C PPE for ACS personnel
- Maritime Helicopters provides a Bell 407 and pilot

Test Set-up and Instrumentation

A bermed test basin lined with an impermeable cold weather membrane resistant to hydrocarbons and geotextile protection above and below the liner has been constructed at the PFRR site. The main dimensions of the basin are 90 m x 90 m x 1 m (300 ft. x 300 ft. x 3 ft.). The berm will be filled with water to a depth of 15 cm (6 inches) from the adjacent pond. This depth was selected to minimize water disposal and allow easy access to the oil and residue on foot. Figure E-1 shows the general location of the test basin. Range Control is in the lower left of the image outlined in red, and the test basin is located at the Imaging Riometer site in the top right corner, also circled in red. The distance between the two sites is 1.8 km (1.1 miles) as a straight line, or 2.6 km (1.6 miles) on the road system. Image care of the Geophysical Institute, University of Alaska Fairbanks. Figure E-2 shows a close-up view of the site before the basin construction. Figure E-3 shows the design used for construction of the basin and berms. Figure E-4 shows the finished basin.

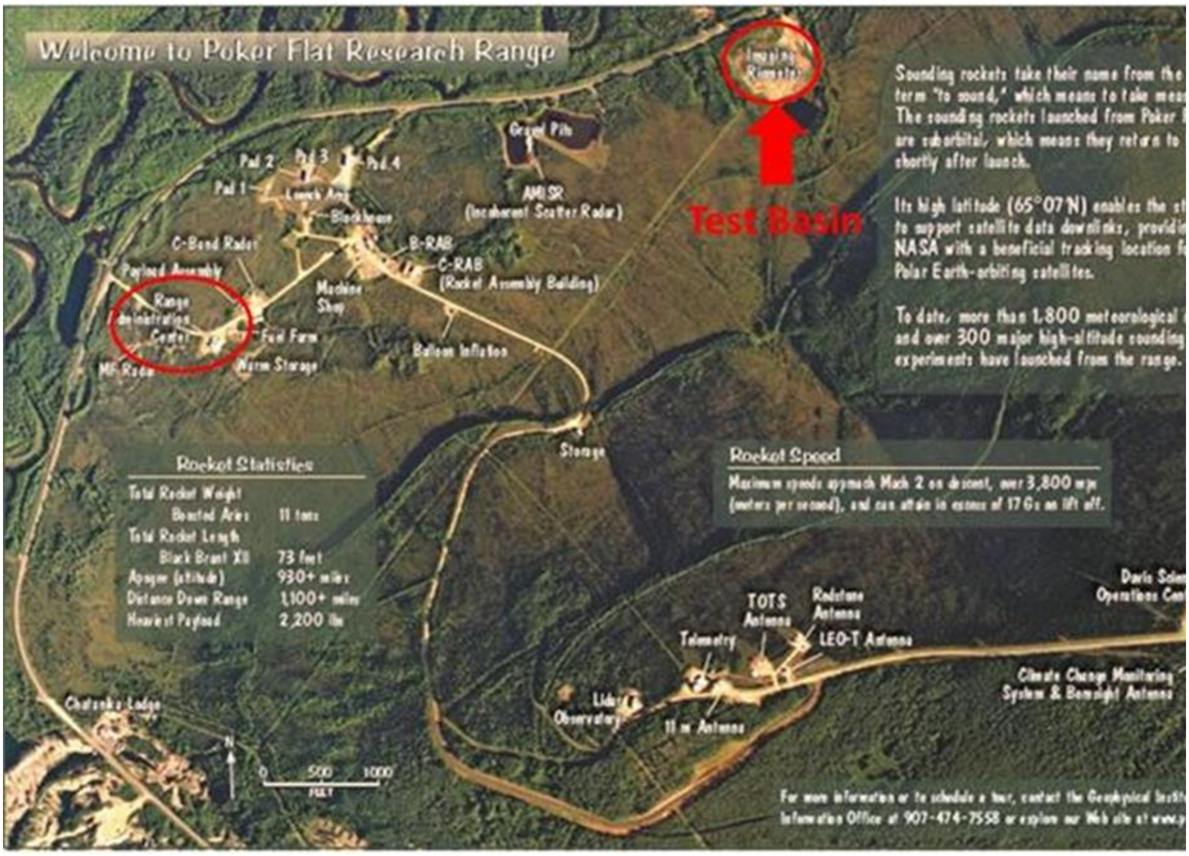


Figure E-1: Aerial View of the Lower Poker Flat Research Range

Figure E-2: Close-Up of Test Site

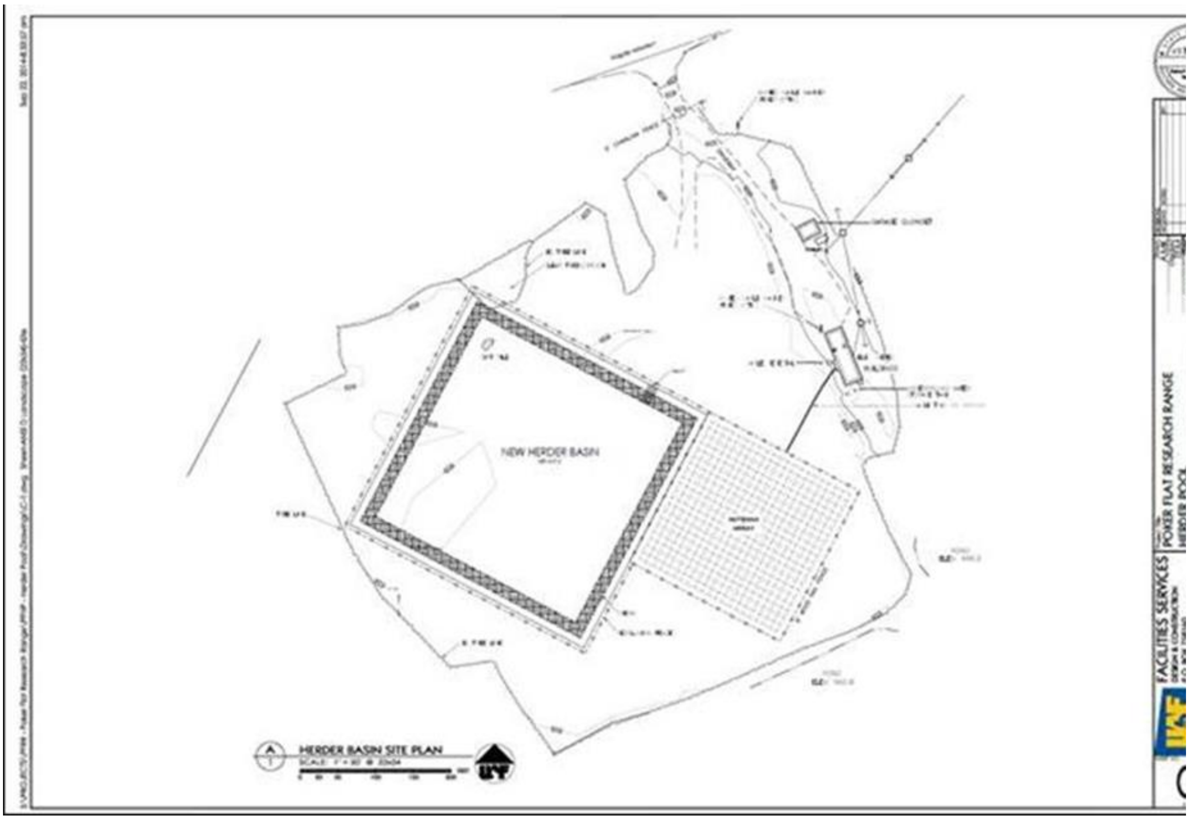


Figure E-3: Herder Test Basin Design and Site Layout

Figure E-4: Panoramic View of Finished Herder Test Basin with Liners and Geotextile Installed

Figure E-5 shows the completed basin from the northeast corner with the sheet metal fire shield around the inner edge and access ramp. Sorbent boom will be placed between the metal sheeting and the berm edge once the basin is filled. It will be necessary in the weeks before the field trials to select a location for the helicopter to land, board personnel, and prepare for the herder application and subsequently the Heli-torch ignition attempt with the herder oil. Figure E-6 shows two nearby sites that could suit these operations. The final choice will be made by the helicopter pilot based on reconnoitering the sites from the air and ground. Heli-torch mixing and loading equipment and shelters, to be provided by ACS, will be located at that site.

Figure E-5: View of Completed Basin from East Corner Facing West 10/9/14

Figure E-6: Potential Helicopter Landing, Herder Application System Loading and Heli-Torch Preparation Sites Near Test Basin (Shown in Light-Blue)

Over winter, ice forms were placed in the basin, filled with water, and allowed to freeze in order to simulate a 10% ice cover during the field tests in spring. The surrogate ice floes are 8’x 8’ x 2’ (Large); 4’x 4’ x 2’ (Medium); and, 2’x 2’ x 2’ (Small). The distribution of sizes is approximately: 49 Large; 103 Medium, and 206 Small, equivalent to an area distribution of 56% large, 29% medium, and 15% small. This is based on an earlier analysis of ice piece size distributions at offshore test sites (Dickins 2001) that resulted in area distributions of 55% large, 27% medium, and 18% small.

Preliminary research showed that high-strength cardboard boxes lined with plastic film could be used as forms for the small and medium surrogates, and inflatable children’s pools as forms for the large size (Figure E-7). The cardboard and plastic form material will require removal prior to burn tests. Figure E-8 shows the layout of the ice field. No ice forms will be placed in a 10-m (30`) wide band around the inside edge of the basin to simplify residue recovery and cleaning post test.

Figure E-7: Iceberg Form Tests Using Boxes and Inflatable Pool

Crude oil will be poured into Jerry cans and carried by hand from the storage IBC to a release square located in the centre of the test basin (see Figure E-8). The open-bottom release frame is to be constructed in Fairbanks from welded 4” x 3” x ¼” Type 6061 structural aluminum angle (4” side vertical) with 3” x ¼” aluminum flat bar welded across each corner for stiffening (Figure E-9). The frame is designed to be balanced on 3” supports (e.g. hinged and pinned legs, brick, concrete blocks, etc.) on the bottom of the basin, with 1” of freeboard during filling and test preparation. A 100 L volume of crude in the frame will be 17 mm thick (⅔”) with a freeboard of approximately 2 mm and a 200 L volume will be 34 mm thick (1⅓”) with a freeboard of approximately 4 mm. At the beginning of each test, the frame will be pulled off the supports using stainless steel wire rope attached to one side, causing the frame to sink to approximately 2” below the surface and instantly release the 100 or 200 L of oil to spread on the water.

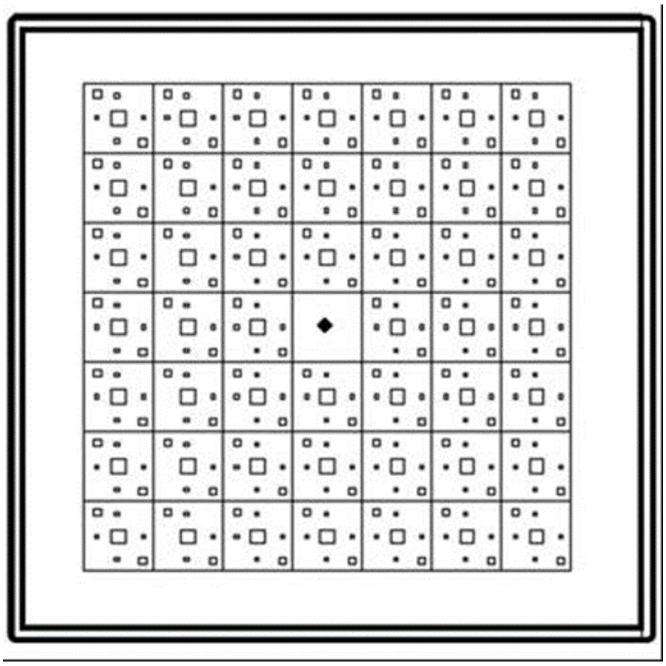


Figure E-8: Planned Layout of Small, Medium and Large Ice Forms in Test Basin

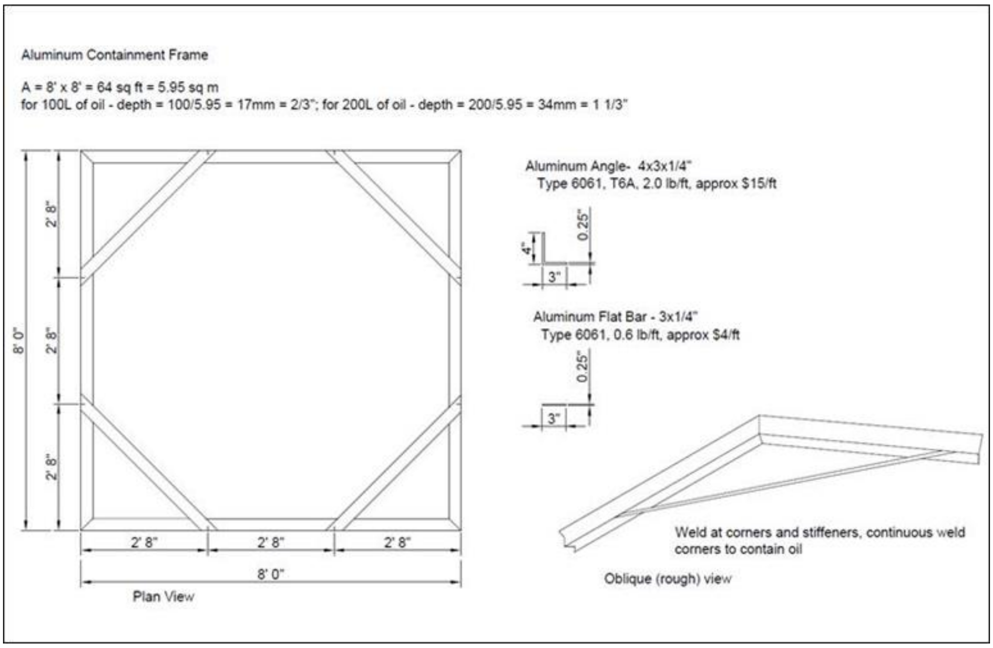


Figure E-9: Aluminium Angle Release Frame Design Sketch

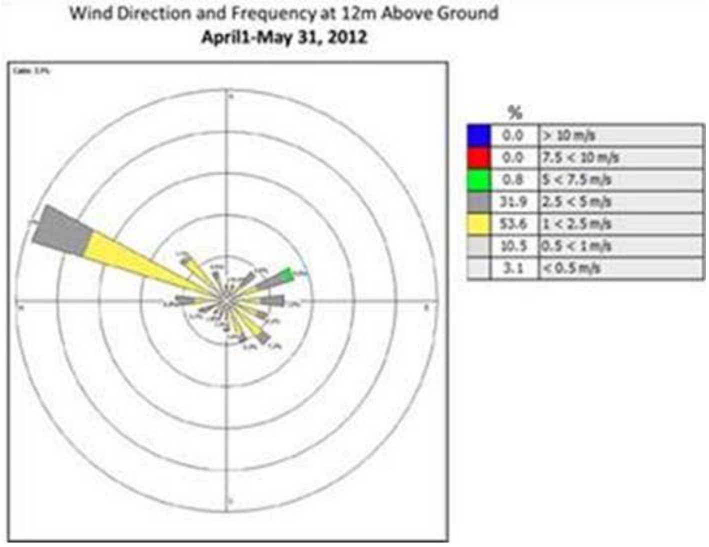
In planning the layout of the test site, wind data from a nearby meteorological station was analyzed. Figure E-10 shows the wind data for the last three springs (April 1 to May 31) presented as wind roses. The predominant winds are from the W and WNW and are less than 2.5 m/s (at a height of 12 m) more than 60% of the time.

Figure E-11 shows the proposed layout of the test site. Based on the predominant wind directions in spring, the UAV operating area will be located upwind (west) of the test basin, and the air sampling station will be located in an area downwind of the basin (east). The crude oil storage tank will be located crosswind from the basin (north), as will the residue weight measuring station and the containers for hazardous waste collection/disposal. Also north of the basin will be the warm-up and briefing shack and the decontamination trailer. The fire truck and/or fire pumps and hoses will be located to the south of the basin, adjacent to the pond (not shown: see Figure E-2).

A UAF portable weather station will be deployed and placed on the nearby building for the riometer electric power to collect wind and temperature data at a standard height above ground.

Also shown on Figure E-11 is a red line defining the approximate location of the Site Control Zone (SCZ) in which only authorized personnel are permitted in a well-defined Exclusion Zone (EZ). Details may be found in the accompanying HSE plan for the field tests. The approximate size of a 200-L slick spread out to 0.5 mm thick, the size of a 200-L slick herded to 3 mm thick (sufficient to support combustion) and the safe approach distance to the edge of the fire (four fire diameters from the edge of the burning oil).

Gelled gasoline will be used as the primary igniter for these tests; however, two types of igniters will be on hand: gelled gasoline and hand-held (Dome) igniters, as backup. The detailed procedures for mixing the gelled gasoline are given in the HSE Plan. Gelled fuel mixing will take place in a heated, ventilated mixing Conex or tent near the helicopter landing area. Only a few gallons of gelled gas will be mixed each time. The actual mixing of the gasoline and gelling agent (requiring 2 to 3 minutes) will take place just outside the tent/Conex to limit exposure to gasoline fumes. Once gelled, the volatility of the gasoline is greatly reduced. At the same site, the empty herder application system will be readied and filled with 2 gallons of one of the two herders to be tested: ThickSlick 6535 or OP-48. Theoretically only 1.2 L of herder are required to cover the entire surface of the basin at the recommended dose rate (150 μL/ m²).



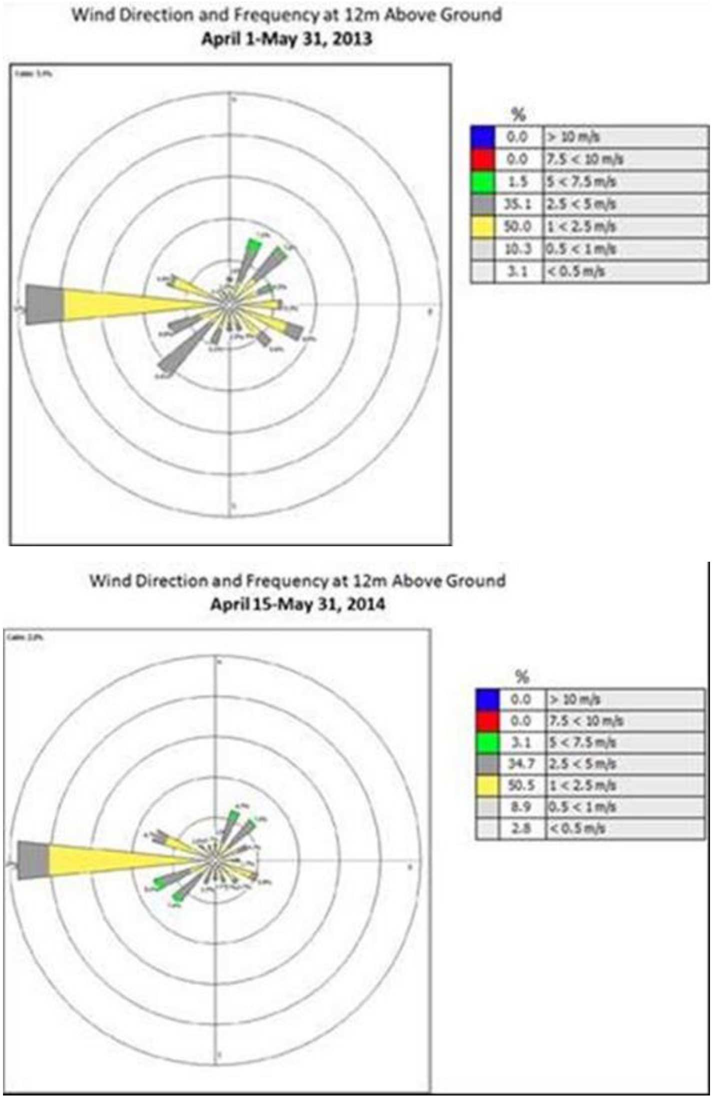


Figure E-10: Test Site Wind Roses for April and May for the Last Three Years

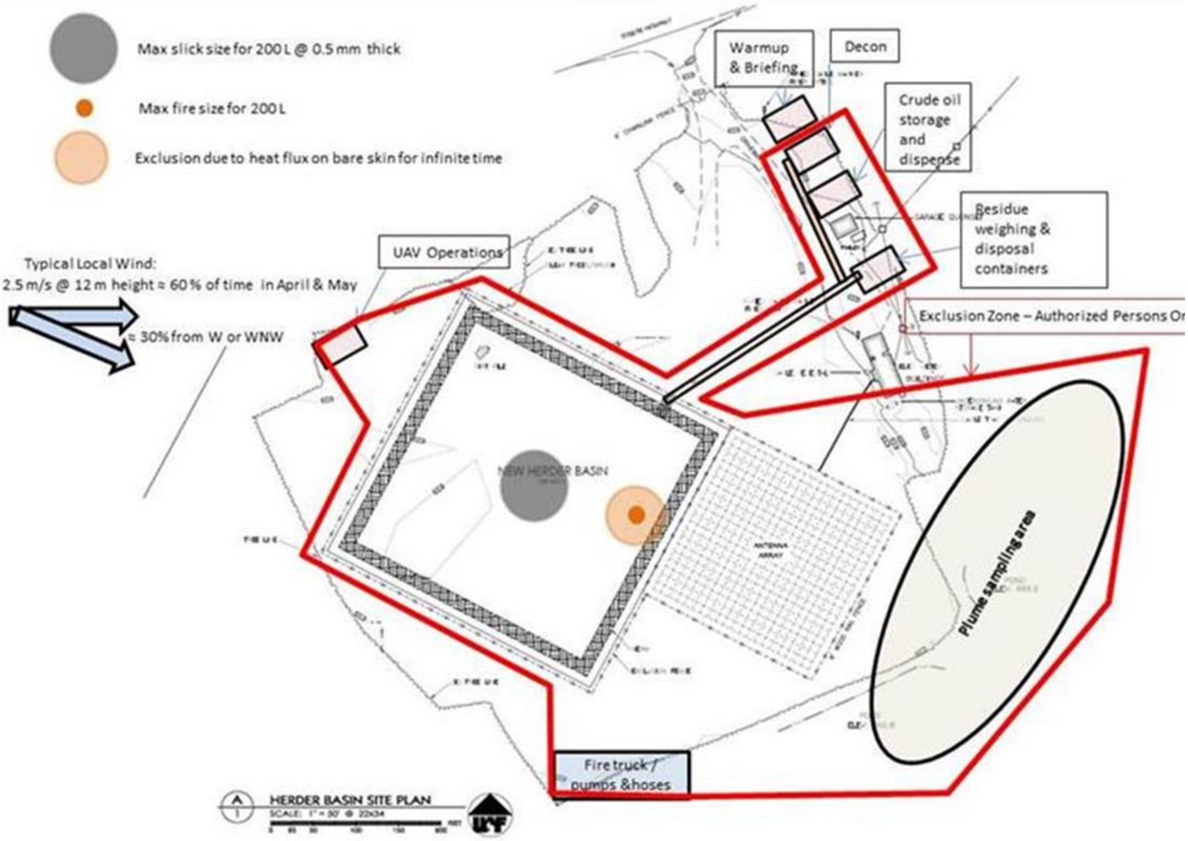


Figure E-11: Proposed Test Basin Layout

Test Procedures

Early in the morning, the site wind and weather conditions will be checked and the day's forecast weather reviewed. The primary criteria for a test to take place are daylight, air temperatures above 0°C., and winds < 2.5 m/s. The wind limit is to allow sufficient time after release of the oil for the herder and igniters to be deployed and for the slick to ignite and extinguish, before the ambient wind moves it to the edge of the basin. In a 2.5 m/s wind, the slick will move across the basin at approximately 4.5 m/min, or approximately 11 minutes to cover 50 metres. Suitable VFR flying conditions need to exist at the site and between the site and the Fairbanks Airport.

Prior to each test an operational and safety briefing will be held in the warm-up shack with all participants to go over the day's test plans in detail. Following each daily decision to proceed, UAF shall implement all required regulatory and media notifications.

In the day(s) before the first test with oil, all test procedures will be practiced in one or more dry runs. It is particularly important to visually determine the speed and altitude to be maintained so that the helicopter and UAV rotor wash do not unduly disturb the water surface in the basin.

The general procedure for a test basin experiment is:

1. Use sorbent sweeps hand-towed in the basin to remove as much of the visible sheen and herder monolayer as possible from around the periphery of the ice field and between ice pieces.
2. Use fire hoses to agitate the water surface in the basin to disperse any herder monolayer into the water.

3. Take a sample of the water from the surface using a Petri dish and measure and record the water-air interfacial tension (IFT) using a DuNuoy Ring Tensiometer.
4. Raise the release frame and set it on its supports and confirm that the pull cables are attached and untangled and lead to an upwind or cross wind side of the basin.
5. Fill the required number of Jerry cans with ANS crude and weigh each one. Record the gross weight of each individual Jerry can.
6. Place 100 or 200 L of fresh crude in the release frame at the centre of the basin by hand carrying the Jerry cans from the oil storage area and gently pouring the contents down a spill ramp located inside the release frame to minimize the amount of oil that enters the water column.
7. Reweigh the empty Jerry cans and record their tare weight.
8. Any air pollution monitoring equipment is activated and the personnel involved leave the sampling area.
9. Have the helicopter and crew, with herder application system filled with the appropriate herder and powered up (but with hose reeled inside the cabin) take off and hover nearby but not directly over the basin, due to rotor wash effects on the basin water surface.
10. Launch the Responder UAV with the video camera and have it hover a safe distance off to the side of the basin.
11. If the particular test involves a UAV applying herder or an igniter, launch that Responder and have it hover off to the side of the basin.
12. When it has been confirmed by radio that all test personnel are ready, pull the release frame off its supports to release the oil to spread among the ice pieces.
13. The helicopter and/or UAV immediately commence videotaping and photographing the spread of the oil (with GPS and altitude encoded cameras). Any ground-based videoing also starts.
14. While videotaping, the herder applicator hose is deployed from the helicopter.
15. If the slick approaches the downwind edge of the basin too quickly, herder will be applied from backpack sprayers along that edge just inside the sheet metal shield to prevent the oil from reaching it.
16. Once the Principal Investigator has determined that the spreading has essentially stopped the helicopter moves to the downwind edge of the basin and commences applying the herder onto the water surface in a circle around the oil slick.
17. The helicopter then flies to the landing area to pick up the Heli-torch.
18. All personnel exit the basin perimeter and are relocated to a 'safe zone' outside of the immediate burn area
19. The UAV and any ground-based video continue to record the contraction of the slick.
20. When the helicopter returns with the loaded Heli-torch, the video operator in the cockpit records the slick with the GPS and altitude encoded cameras.
21. The helicopter, on instruction from the Principal Investigator, applies gelled gas igniters along the upwind edge of the herded slick (depending on the success of this, additional gelled gas or hand-held igniters may be applied elsewhere in the slick).
22. The UAV continues to record the ignition attempts and burn and the helicopter, once ignition is achieved, moves off to a safe crosswind side of the basin and also records the burn with the GPS and altitude encoded cameras.
23. The Principal Investigator records burn times with a stopwatch.
24. When the burn extinguishes and the residue cools, and after water and residue samples have been taken, fire hoses are employed carefully to herd the residue into a downwind corner/side of the basin and to wash off the ice pieces.
25. The remaining oil and burn residue is recovered with pre-weighed sorbent, decanted to remove as much water as possible and the pads are placed in pre-weighed garbage bags for subsequent reweighing to determine burn efficiencies and rates. The pads may be left to drain for 24 hours to remove water, and then reweighed. Any liquid water in the bottom of the garbage bags will be poured into a container (plastic tub) and returned to the basin.
26. Used sorbent is to be placed in an oily waste container for disposal.
27. The water surface is agitated with water from fire hoses to disperse remaining herder into the water column for biodegradation.

Data Processing

Burn efficiency and burn rate will be calculated for each experiment using equations (1) and (2), respectively. Burn efficiency is the ratio of the mass of oil burned to the initial oil mass. Oil burn rate is a measure of the decrease in the oil thickness over the period of the burn, from the time when 50% of the slick area is aflame (ignition half-time) to the time when the flame area has decreased to 50% of the slick area (extinction half-time). If 100% flame coverage was not achieved, the rate is corrected by employing the maximum percent flame coverage observed.

$$\text{Burn Efficiency (mass \%)} = \frac{\text{(Initial Oil Mass - Residue Mass) x 100\%}}{\text{Initial Oil Mass}} \qquad (1)$$

$$\text{Oil Burn Rate (mm/min)} = \frac{\text{(\% Burn Efficiency) x (Initial Oil Volume)}}{\text{(Slick Area) x (Max. \% Flame Cover) x (Extinction Half-Time - Ignition Half-Time)}} \qquad (2)$$

Digital video and still photographs of the ignition and burn taken from the helicopter will be analysed in order to document burn times and areas. Once the slicks have extinguished, aerial photographs will be taken to document the residue area and samples of the residue and water collected for later analysis.

Using Adobe Photoshop®, the GPS positions and altitude of the cameras in the helicopter(s) and/or scaled items in the photos will be used to correct the vertical angle of the photos. Next, the oil slick will be colorized to make it stand out better from the background. Then, the coloured oil slick in the image will be defined as black and everything else as white. Figure E-12 illustrates the transformation of the images. Finally, image analysis software (either Image J or Scion Image©) will be used to count the number of black pixels in each image. The pixel count is converted to area using scaling factors obtained from images of objects in the field of view with known dimensions. The slick area is converted to average thickness using the initial spill volume.

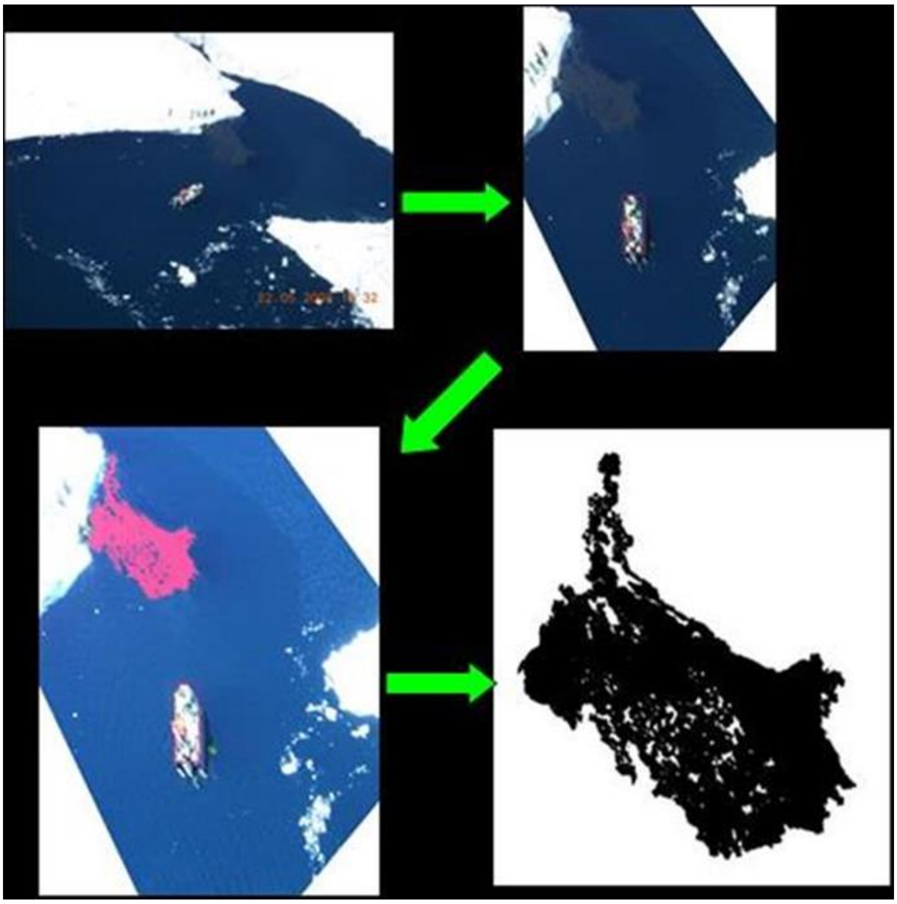


Figure E-12: Digital Transformation of Aerial Photographs to Determine Slick Area

Test Matrix and Schedule

The test variables will include:

- Ice concentration (0 to1 tenth)
- Oil volume (100 L and 200 L)
- Two herding agents (ThickSlick 6535 and OP-49)

This equates to four tests: adding one with UAV application of herder and igniters brings the total to five tests.

It should be possible to run one test per day consuming 5 days, leaving five for weather downtime (winds are less than 2.5 m/s [at a height of 12 m] more than 60% of the time). Should extended periods of higher winds prevail; the project team staff will remain in Fairbanks for up to a total of two weeks in order to finish the tests.

Ideally the average air temperatures will be slightly above 0°C to prevent the fresh water in the basin from freezing and to preserve the ice pieces in the basin for as long as possible. If the ice pieces do melt, the testing will continue. Figure E-13 shows the air temperatures in April and May over the last five years. Based on this data, testing is tentatively scheduled to take place from April 15, 2015 to April 29, 2015. Table E-2 gives the revised matrix for the tests.

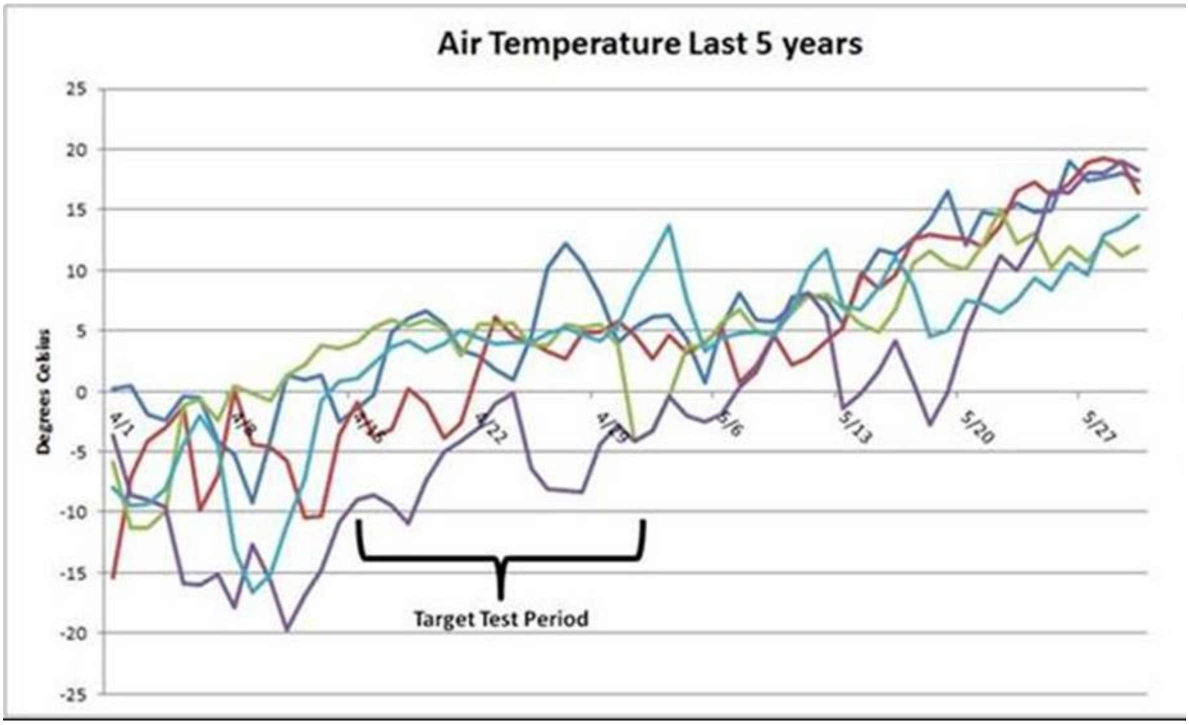


Figure E-13: Average daily temperature at test site over last five years – April 1 to May 31

Table E-2: Preliminary Matrix of Tests

Day	Test	Ice Conc	Herder	Helicopter	Oil Volume (L)
0	Setup, Dry run	10 %		Bell 407 & UAV	0
1	Setup, Dry run	10 %		Bell 407 & UAV	0
2	1	10 %	6535	Bell 407	100
3	2	10 %	OP-40	Bell 407	100
4	3	0 to 10 %	6535	Bell 407	200
5	4	0 to 10 %	OP-40	Bell 407	200
6	5	0 to 10 %	6535	UAV Responder	200
7	Demobilization				

Visitors Day

April XY is the tentative date for Visitors Day, with final approval for invitations, visitors, etc. to be responsibility of OGP, as prime funder, and UAF, as the host of the tests. PFRR is a UAF facility, and safety and security clearance will be required for all visitors (see the separate HSE Plan).

Quality Control Plan

The following quality control measures will be employed for these experiments.

Initial Calibration Data. A check is made to ensure that data is available to show the initial source of calibration data for each piece of instrumentation used in the project. This includes any calibration information necessary to assure that the calibration data is current for the project.

Pre- and Post-Daily Checks. These are checks that are performed on the instrumentation (i.e., DuNuoy tensiometer with pure water) each morning before testing starts and at the end of the day when testing stops. This is done on all days that testing occurs. Note is made of any unusual conditions that occur. These conditions must be evaluated before testing is started or if noted at the end of the day, the day's data is examined to determine its validity and whether the affected experiments need to be repeated.

Test Checks and Conditions. These checks ensure that the test plan's instructions on how the experiment is to be done are followed or require modification, and that the records that are to be made during the experiment are completed accurately.

Significant Occurrences/Variations. This part of the quality checks will be concerned with recording any significant occurrences/variations that might occur during the experiments. These will be immediately reported to I. Buist.

Data Reduction and Validation. All data reduction and validation will be performed in accordance with approved and accepted methods. When non-standard methods are utilized, they shall be included in the Draft Technical Report and sufficiently described so that they can be used by independent sources to duplicate the results. With respect to written material, all draft material will be reviewed by at least one other SL Ross senior staff Professional Engineer before submission to the OGP JIP TWG.

Safety and Environmental Plan

A separate detailed HSE Plan has been written and vetted that covers all aspects of the field tests.

Safety of personnel will be paramount during the tests at PFRR. The objective is to achieve zero accidents or lost-time incidents. The project team is committed to providing a work environment that protects the health and safety of our personnel. We will proactively pursue compliance with applicable health and safety regulatory requirements, seek to reduce injuries and illnesses, and incorporate leading health and safety practices into our daily work. In all situations, priority is given to protecting our employees and visitors from illness, injury, and risk, and preserving materials, assets, and the environment against the risk of fire, damage, and other losses. We will accomplish these high standards of performance through a strong Environment, Health and Safety Program and its related procedures integrated with regular inspections and periodic evaluations of this policy and the program itself. All personnel on site have the right to work in a safe environment and to refuse unsafe work until appropriate mitigative measures are put in place.

We all share the responsibility for workplace health and safety. All levels of management are accountable for their health and safety responsibilities that include, but are not limited to, maintaining a working environment as free as possible from actual and potential hazards, ensuring the security and safety of all employees, and ensuring that this policy is followed. Personnel on site are responsible for working in a safe and healthy manner, abiding by established safety rules, and for reporting all sub-standard and/or unhealthy conditions.

The project team is committed to complying with all applicable legislation and requirements and is an organization whose mission is to make an effective contribution to workplace health and safety. It is important for all of us to respect this policy and honour its commitment.

APPENDIX F – LABORATORY SCALE TEST PLAN

The laboratory testing will involve two types of experiments with a recent sample of ANS crude (the crude oil to be used for the field tests):

1. Spill-related physical properties of fresh and artificially-evaporated ANS crude; and,
2. Small-scale herding tests with the fresh and artificially evaporated ANS crude to determine the effectiveness of the ThickSlick 6535 and OP-40 herding agents on fresh and salt water.

Spill-related Properties of ANS crude

Simulated oil spill weathering experiments were performed on ANS crude oil to predict the behavior and properties of the ANS crude during the field experiments.

The laboratory testing described here involved a sample of ANS crude oil shipped to Ohmsett in 2014, and from there to CRREL. CRREL shipped a 40-L sample to SL Ross for these tests.

Four litres of the oil were divided into three aliquots. Two aliquots were weathered in a wind tunnel: one for two days and one for two weeks. Depending on the conditions at a spill site, this is typically equivalent to a few hours and a few days at sea. In addition, the fresh oil was subjected to a modified ASTM distillation (ASTM D86, modified in that both liquid and vapor temperature are measured) in order to obtain two oil-specific constants for evaporation prediction purposes.

Table F-1: Test Procedures for Spill-Related Analysis of 2014 ANS Crude Oil

Property	*Test Temperature(s)*	*Equipment*	*Procedure*
Evaporation	Ambient	Wind Tunnel & ASTM Distillation Apparatus	ASTM D86
Density	1 – 20°C	Anton Paar Densitometer	ASTM D4052
Viscosity	1 – 20°C	Brookfield DV III+ Digital Rheometer c/w Cone and Plate	Brookfield M/98-211
Interfacial Tension	Room Temperature	CSC DuNouy Ring Tensiometer	ASTM D971
Pour Point	N/A	ASTM Test Jars and Thermometers	ASTM D97
Flash Point	N/A	Pensky-Martens Closed Cup Flash Tester	ASTM D93
Emulsification Tendency/ **Stability**	1 to 20°C	Rotating Flask Apparatus	(Hokstad and Daling 1993)

The fresh and two weathered oil samples were subjected to the analyses outlined in Table 1. Test temperatures were chosen to cover the typical range of spring temperatures at the PFRR test site: 1°C to 15°C. The quantitative results of the tests (involving both fresh and weathered oil) can be used as input to most oil spill models that are used internationally to predict the fate and behavior of spills of specific oils.

1-m^2 Pan Tests

The goal of the 1-m^2 experiments was to determine the effectiveness of the two herders (ThickSlick 6535 and Siltech OP 40) in contracting slicks of ANS crude to ignitable thicknesses on fresh and salt water.

The 1-m^2 pan test matrix included:

- Two herding agents (ThickSlick 6535 and Siltech OP-40);
- One crude oil type (Alaska North Slope);
- Three extents of evaporation for each crude (fresh and two degrees of evaporation); and,
- Fresh and 35 ppt salt water at 0°C.

The general procedure for a 1-m^2 pan experiment is:

1. Place 20 L (a depth of 2 cm) of cold water in each 1-m^2 pan (Figure F-1) lined with freshly rinsed (with tap water) new plastic film.
2. Take a sample of the water from the surface using a Petri dish and measure the water-air interfacial tension (IFT) using the DuNuoy Ring Tensiometer. If the IFT reading is less than 60, replace the water and film and retry.
3. Carefully pour 500 mL of the crude on the water using a plastic paint scraper, as a spill plate making sure that it does not stick to the bottom of the tray while being poured.
4. Place a sign on the pan that will be visible in the photos denoting test number, conditions and photo time (0, 1 min, 10 min, etc.)
5. Allow the oil to spread to equilibrium and take a digital photograph from overhead for subsequent oil area analysis.
6. Apply prescribed amount (150 µL) of herding agent to open water area with micropipette.
7. Allow the oil to contract and take another digital photograph after one minute, 10 minutes, 30 minutes and 1 hour.
8. Collect herded oil with sorbent pad, empty water from pans, remove and dispose of plastic film, dry pans with paper towels.

Figure F-1: Lined 1-m^2 Steel Pans Used For Experiments

The slicks (including any oil sheen) in the photographs are corrected for perspective, converted into black and white images using Paint Shop Pro or Adobe Photoshop (Figure F-2), and then a computer program (Image J or Scion Image©) is used to count the number of black pixels. The area of the slick in the photograph is then calculated by dividing the total number of black pixels by the number of pixels per square inch in the original image. Average slick thickness is estimated by dividing the volume of oil added originally by the calculated area. The error in estimating area should be quite small, less than 5% taking into account parallax errors at the sides of the pans. Errors in average slick thickness would increase as time progressed, as evaporation losses are not taken into account, but in the quiescent laboratory environment over the period of one hour would not likely exceed 10%.

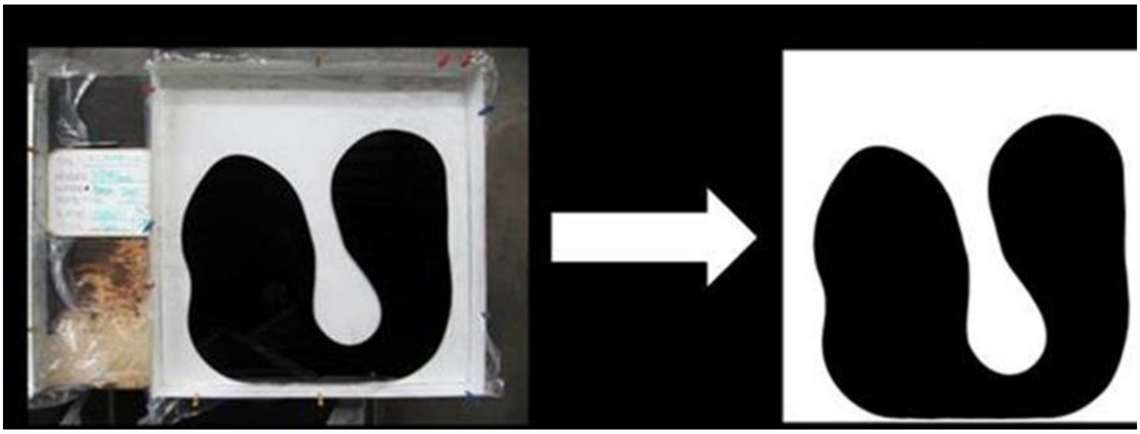


Figure F-2: Determining Slick Area Using Overhead Digital Photos

APPENDIX G – LABORATORY TEST RESULTS

Spill Related Properties of
ANS 2014

For

The International Association of Oil and Gas Producers

Arctic Response Technology JIP

Oil Spill Herder Field Release Project

By

SL Ross Environmental Research Ltd.

December 2014

G1.0 Introduction

When oil is spilled in the marine environment its physical and chemical properties will change over time through the processes of evaporation and emulsification. These changes will affect both the fate and behavior of the spill and the opportunities for using countermeasures effectively. For example, an oil may be relatively fluid and non-viscous when initially spilled, but may become viscous within a short time. It is important to know whether this will happen and how long it will take, defining the so-called Window of Opportunity for countermeasures.

The objective of this study was to conduct simulated oil spill weathering experiments with a sample of Alaska North Slope (ANS) crude collected for OGP in 2014. The quantitative results of the tests (involving both fresh and weathered oil) can be used as input to most oil spill models that are used internationally to predict the fate and behavior of spills of specific oils.

G2.0 Physical Property Tests: Methods and Results

The laboratory testing described here involved 2.7 L of the crude oil. The oil was subjected to the analyses outlined in Table G-1. Test temperatures were chosen to cover the typical range of seasonal variation for the open water season in the target region. For winter a temperature of 15^{o}C was chosen and for summer, 30^{o}C.

A discussion of the methodology of each of these tests is presented in Appendix G-I, along with an explanation of the effect that each oil property has on spill behavior.

The results of the weathering and analyses of the crude oil are presented separately in the following section.

Table G-1: Test Procedures for Spill-Related Analysis of ANS 2014 Crude Oil

Property	***Test Temperature(s)***	***Equipment***	***Procedure***
Evaporation	Ambient	Wind TunnelASTM Distillation Apparatus	ASTM D86
Density	0° and 20°C	Anton Paar Densitometer	ASTM D4052
Viscosity	0° and 20°C	Brookfield DV III+ Digital Rheometer c/w Cone and Plate	Brookfield M/98-211
Interfacial Tension	Room Temperature	CSC DuNouy Ring Tensiometer	ASTM D971
Pour Point	N/A	ASTM Test Jars and Thermometers	ASTM D97
Flash Point	N/A	Pensky-Martens Closed Cup Flash Tester	ASTM D93
Emulsification Tendency/Stability	0° and 20°C	Rotating Flask Apparatus	(Hokstad and Daling 1993)

G2.1 Results

The results of the property analysis of ANS 2014 are summarized in Table G-2. The two levels of evaporation noted in the table represent the amounts evaporated from a 2 cm-thick slick in the wind tunnel after two days and two weeks, respectively.

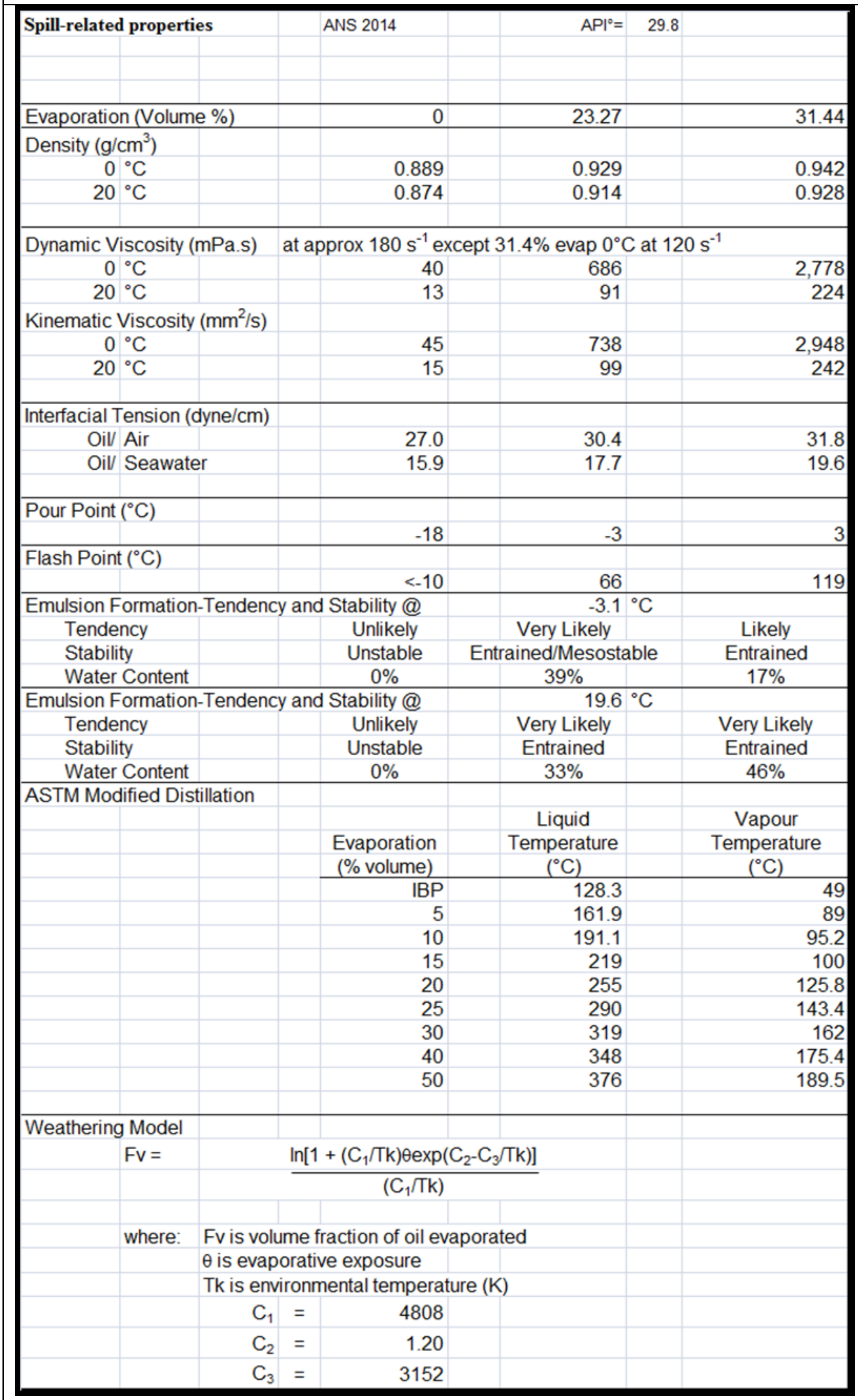
G2.1.1 Evaporation

ANS 2014 is a medium-gravity (29.8° API) crude oil. Approximately 23% of the oil evaporated after two days in the wind tunnel, and about 31% evaporated after two weeks of exposure.

Figure G-1 is a predicted evaporation curve for a spill involving a 1-mm thick slick in a 2.5 m/s (5 knot) wind at 0°C. Please note that the curve only applies at a water temperature of 0°C. If other temperatures (or slick thicknesses and wind speeds) are of interest, these curves can be generated using the equations in Appendix G-I and data in Table G-2. Computerized oil spill models automatically do these calculations.

Figures G-2, G-3 and G-4 show the effect of evaporation on the properties of oil viscosity, density and pour point.

Table G-2: Spill-Related Properties of ANS 2014 Crude Oil



Spill-related properties		ANS 2014	API°= 29.8	
Evaporation (Volume %)		0	23.27	31.44
Density (g/cm³)				
0	°C	0.889	0.929	0.942
20	°C	0.874	0.914	0.928
Dynamic Viscosity (mPa.s)	at approx 180 s^{-1} except 31.4% evap 0°C at 120 s^{-1}			
0	°C	40	686	2,778
20	°C	13	91	224
Kinematic Viscosity (mm^2/s)				
0	°C	45	738	2,948
20	°C	15	99	242
Interfacial Tension (dyne/cm)				
Oil/	Air	27.0	30.4	31.8
Oil/	Seawater	15.9	17.7	19.6
Pour Point (°C)		-18	-3	3
Flash Point (°C)		<-10	66	119
Emulsion Formation-Tendency and Stability @			-3.1 °C	
Tendency		Unlikely	Very Likely	Likely
Stability		Unstable	Entrained/Mesostable	Entrained
Water Content		0%	39%	17%
Emulsion Formation-Tendency and Stability @			19.6 °C	
Tendency		Unlikely	Very Likely	Very Likely
Stability		Unstable	Entrained	Entrained
Water Content		0%	33%	46%
ASTM Modified Distillation				
		Evaporation (% volume)	Liquid Temperature (°C)	Vapour Temperature (°C)
		IBP	128.3	49
		5	161.9	89
		10	191.1	95.2
		15	219	100
		20	255	125.8
		25	290	143.4
		30	319	162
		40	348	175.4
		50	376	189.5

Weathering Model

$$Fv = \frac{\ln[1 + (C_1/Tk)\theta\exp(C_2 - C_3/Tk)]}{(C_1/Tk)}$$

where: Fv is volume fraction of oil evaporated
θ is evaporative exposure
Tk is environmental temperature (K)
C_1 = 4808
C_2 = 1.20
C_3 = 3152

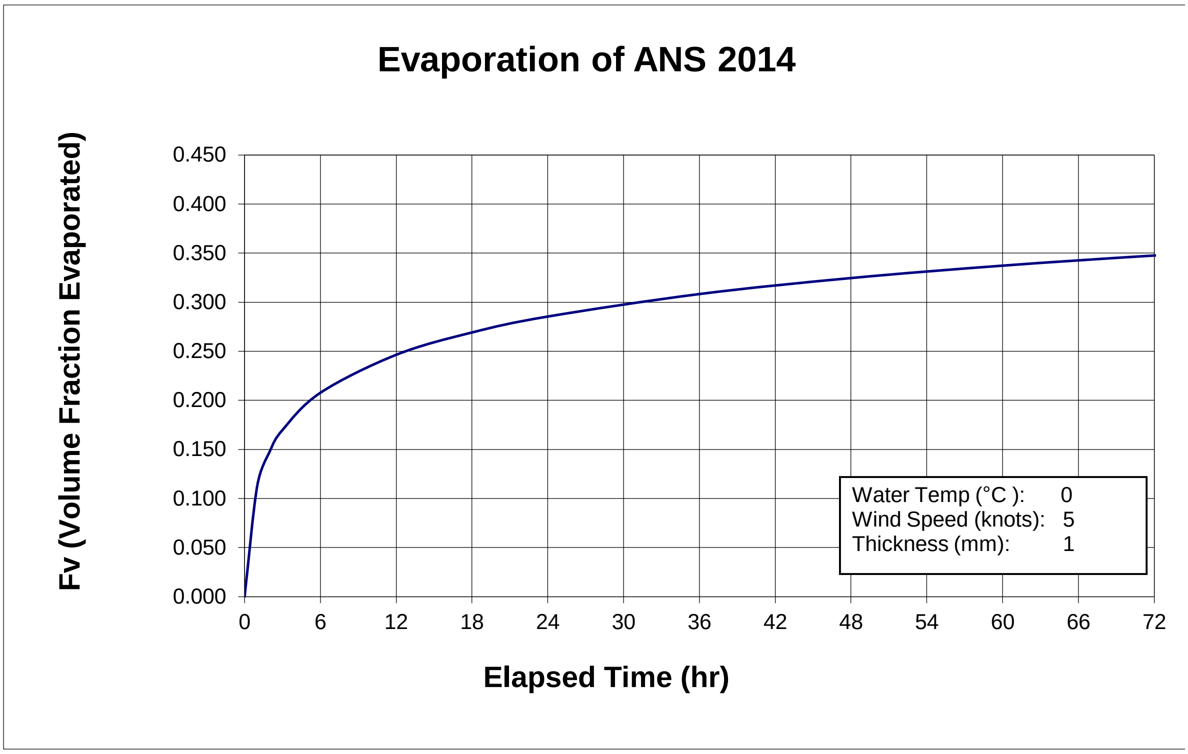


Figure G-1: Evaporation of ANS 2014

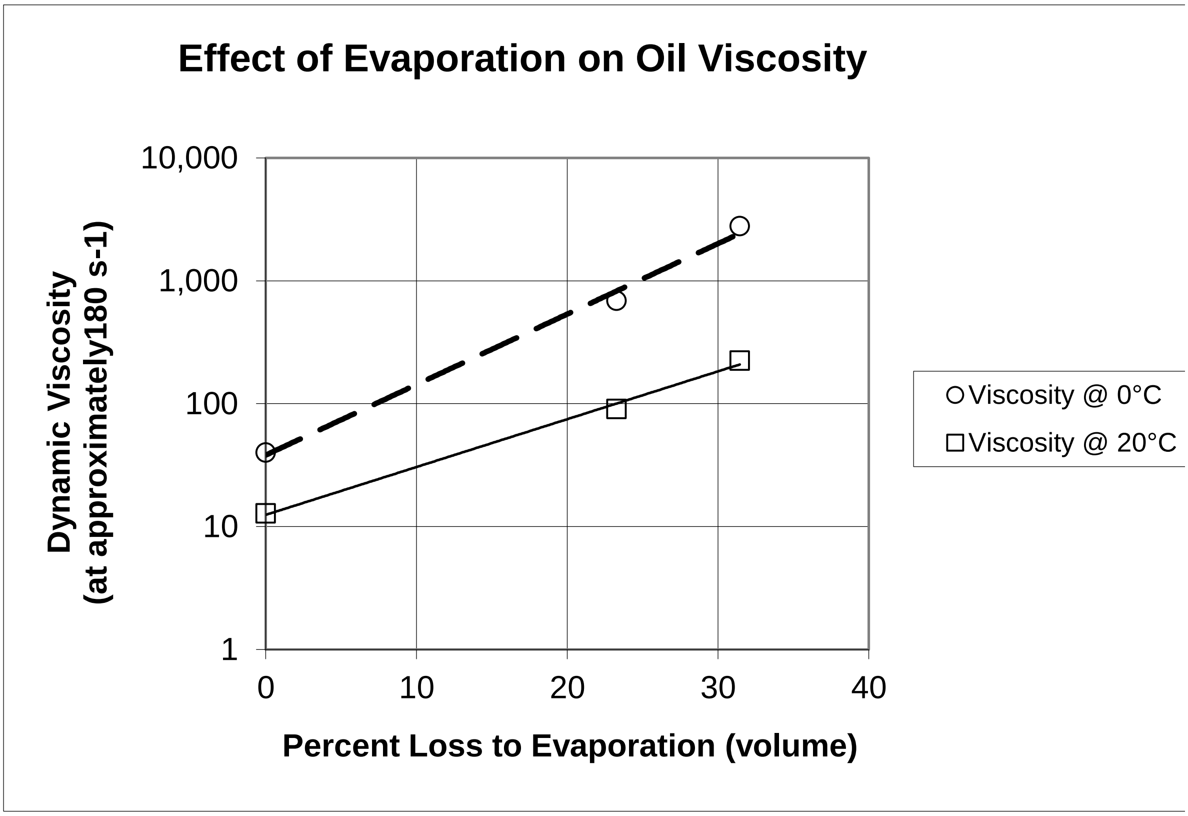


Figure G-2: Effect of Evaporation on Oil Viscosity

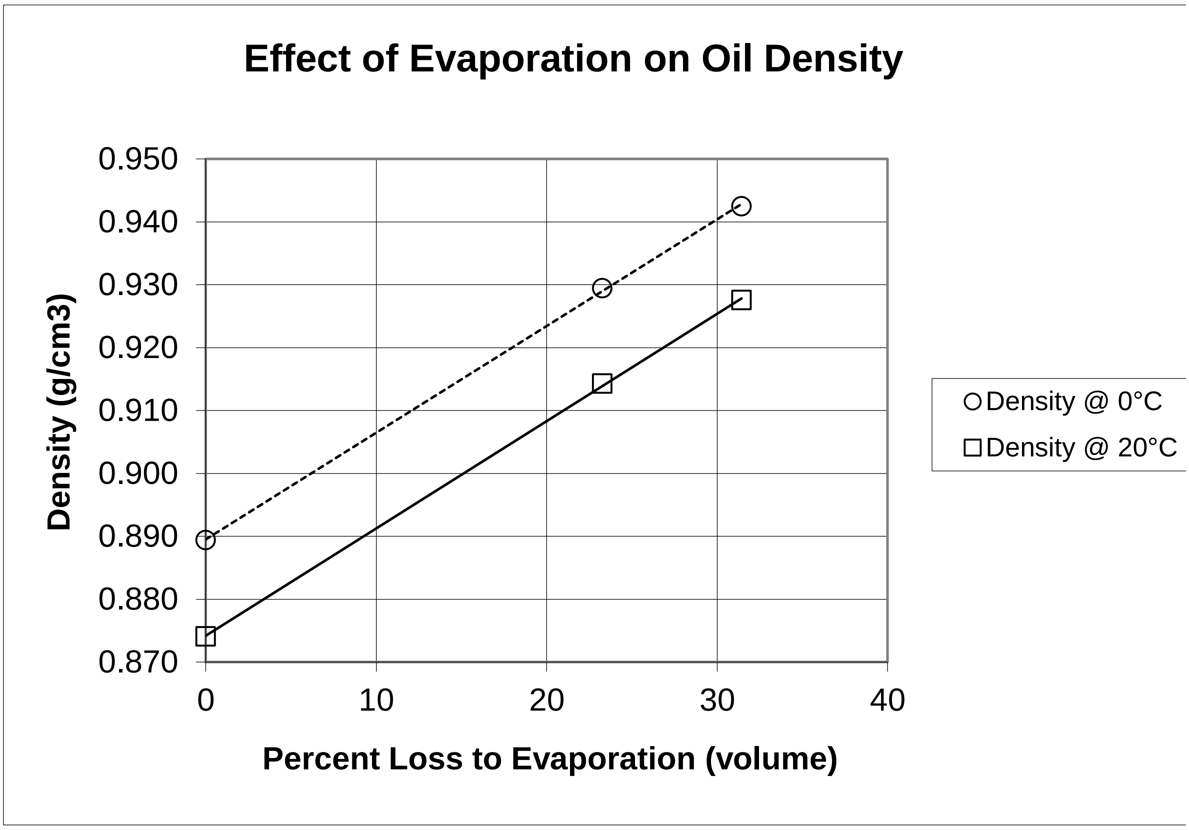


Figure G-3: Effect of Evaporation on Oil Density

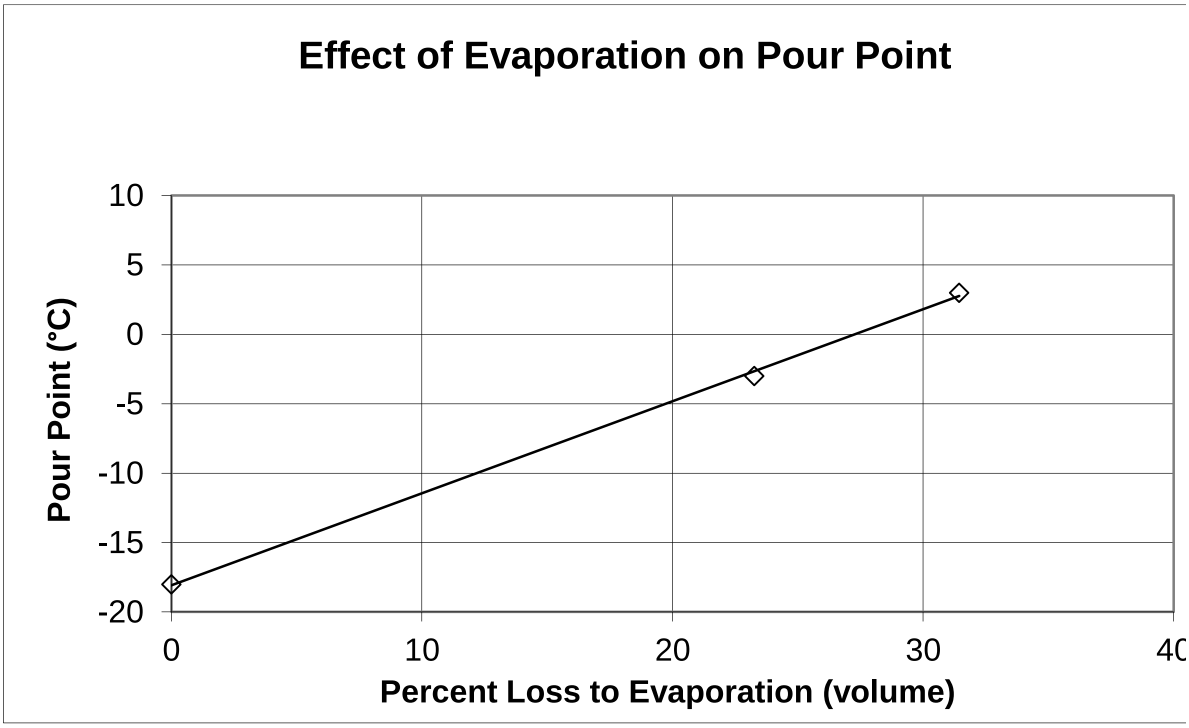


Figure G-4: Effect of Evaporation on Pour Point

G2.1.2 Density

ANS 2014 oil is a medium gravity crude oil, with a density of 0.877 g/cm^3 at 15.5°C (API gravity of 29.8^o). At 0° C the fresh oil has a density 0.889 g/cm^3.

G2.1.3 Viscosity

The oil has standard viscosity that is typical of a medium gravity crude oil. At 20^{o}C the viscosity of the fresh oil is about 13 cP (mPa.s). The viscosity increases to 91 cP after 23% evaporation and to 224 cP after 31% evaporation. At 0° C the fresh oil has a viscosity of 40 cP (mPas).

G2.1.4 Interfacial Tension

The oil/water interfacial tension of ANS 2014 was measured using standard laboratory water with 35 ppt of salt. The value measured was 15.9 dynes/cm, which is in the range of most crude oils.

G2.1.4 Pour Point

ANS 2014 is has a pour point of -18^{o}C when fresh, -3 ^{o}C after 23% evaporation and to 3 ^{o}C after 31% evaporation. As a result of the increasing pour point, 24% evaporated ANS crude at 0° C has a viscosity of 686 cP (mPas) and 31% evaporated ANS crude at 0° C has a viscosity of 2780 cP (mPas).

G2.1.5 Flash Point

ANS 2014 has a flash point below -10^{o}C when fresh. This rises after 31% evaporation to 119^{o}C.

G2.1.6 Emulsification Tendency and Stability

From the viewpoint of spill countermeasures and slick persistence, emulsification is a very negative process because strongly emulsified oils are highly viscous — they can have ten to 100 times the viscosity of the parent oil. It is general believed that oils that have relatively high concentrations of asphaltenes are the most likely to form stable water-in-oil emulsions. Some oil spills do not form emulsion immediately, but once evaporation occurs and the asphaltene concentration increases, the emulsification process begins and usually proceeds quickly thereafter.

One characteristic of ANS 2014 is that it has a high tendency to form “entrained” or “meso-stable” water-in oil emulsions at any degree of evaporation tested when mixed with seawater. The defining characteristics of these types of emulsion are (Fingas et al. 1998) are:

- Entrained Water – looks black, with large water droplets; water contents after 24 hours of 26% to 62% averaging 42%; emulsion viscosity 13 times greater than oil on average
- Meso-stable – brown viscous liquid; water contents after 24 hours of 35% to 83% averaging 62%; emulsion viscosity 45 times greater than oil on average

G3. References

Fingas, M., B. Fieldhouse and J. Mullin. 1998. Studies of Water-in-Oil Emulsions: Stability and Oil Properties. *Proceedings of the 21st Arctic and Marine Oilspill Technical Semina.* Environment Canada, Ottawa. pp 1-26

Hokstad, J. and P. Daling. 1993. Methodology for Testing Water-in-Oil Emulsions and Demulsifiers. Description of Laboratory Procedures. In *Formation and Breaking of Water-in-Oil Emulsions: Workshop Proceedings* Marine Spill Response Corporation, Washington DC, MSRC Technical Report Series 93-108, pp 239-254

Zagorski, W. and D. Mackay. 1982. Water in oil emulsions: a stability hypothesis, in Proceedings of the 5th Arctic and Marine Oilspill Program Technical Seminar, Environment Canada, Ottawa, ON, pp 61-74.

APPENDIX G-I. OIL PROPERTY TEST METHODOLOGY AND RELATIONSHIP TO SPILL BEHAVIOR

Evaporation

The oil was divided into three aliquots. Two aliquots were weathered in a wind tunnel: one for two days and one for two weeks. Depending on the conditions at a spill site, this is typically equivalent to a few hours and a few days at sea. In addition, the fresh oil was subjected to a modified ASTM distillation (ASTM D86-90, modified in that both liquid and vapor temperature are measured) in order to obtain two oil-specific constants for evaporation prediction purposes. Evaporation is correlated using Evaporative Exposure (θ), a dimensionless time unit calculated by:

$$\theta = kt/x$$

where:

k = a mass transfer coefficient [m/s] *(determined experimentally in the laboratory wind tunnel or by an equation related to wind speed for spills at sea)*

t = elapsed time [s]

x = oil thickness [m]

Physical properties

The oils were subjected to the analyses outlined in Table G-I1. Test temperatures are chosen to represent typical values for the region for those tests that are temperature-sensitive, such as density and viscosity.

Table G-I1: Test Procedures for oil analysis

Property	**Test Temperature(s)**	**Equipment**	**Procedure**
Evaporation	Ambient	Wind Tunnel ASTM Distillation Apparatus	ASTM D86
Density	1° and 15 °C	Anton Paar Densitometer	ASTM D4052
Viscosity	1° and 15 °C	Brookfield DV III+ Digital Rheometer c/w Cone and Plate	Brookfield M/98-211
Interfacial Tension	Room Temperature	CSC DuNouy Ring Tensiometer	ASTM D971
Pour Point	N/A	ASTM Test Jars and Thermometers	ASTM D97
Flash Point	N/A	Pensky-Martens Closed Cup Flash Tester	ASTM D93
Emulsification Tendency/Stability	1° and 15 °C	Rotating Flask Apparatus	(Hokstad and Daling 1993)

Density

Density, the mass per unit volume of the oil (or emulsion), determines how buoyant the oil is in water. The common unit of density is grams per millilitre or cubic centimetre (g/mL or g/cm^3); the SI unit is kg/m^3, which is numerically 1000 times the value in g/mL. The density of spilled crude oil increases with weathering and decreases with increasing temperature. Density affects the following spill processes:

- Sinking - if the density of the oil exceeds that of the water it will sink;

- Spreading - in the early stages of a spill, more dense oils spread faster;
- Natural dispersion - more dense oils stay dispersed more easily; and,
- Emulsification stability - dense oils form more stable emulsions.

Viscosity

Viscosity is a measure of the resistance of oil to flowing, once it is in motion. The common unit of dynamic viscosity is the centi-Poise (cP); the SI unit is the milli-Pascal second (mPas), which is numerically equivalent to the centi-Poise. The common unit of kinematic viscosity (calculated by multiplying the dynamic viscosity by the density) is the centi-Stoke (cSt) the SI unit is the square millimetre/second (mm^2/s), which is numerically equivalent to the centi-Stoke. The viscosity of spilled crude oil increases as weathering progresses and decreases with increasing temperature. Viscosity is one of the most important properties from the perspective of spill behavior and affects the following processes:

- Spreading - viscous oils spread more slowly;
- Natural and chemical dispersion - highly viscous oils are difficult to disperse;
- Emulsification tendency and stability - viscous oils form more stable emulsions; and,
- Recovery and transfer operations - more viscous oils are generally harder to skim and more difficult to pump.

Interfacial Tension

Interfacial tension is a measure of the surface forces that exist between the interfaces of the oil and water, and the oil and air. The common unit of interfacial tension is the dyne/cm; the SI unit is the milli-Newton/metre (mN/m), which is numerically equivalent to the dyne/cm. Chemical dispersants work by reducing the oil/water interfacial tension to allow a given mixing energy (i.e., sea state) to produce smaller oil droplets. Emulsion breakers also work by lowering the oil/water interfacial tension; this weakens the continuous layer of oil surrounding the suspended water droplets and allows them to coalesce and drop out of the emulsion. Interfacial tensions (oil/air and oil/water) are fairly insensitive to temperature, but are affected by evaporation. Interfacial tension affects the following processes:

- Spreading - interfacial tensions determine how fast an oil will spread and whether the oil will form a sheen;
- Natural and chemical dispersion - oils with high interfacial tensions are more difficult to disperse naturally, chemical dispersant work by temporarily reducing the oil/water interfacial tension;
- Emulsification rates and stability; and,
- Mechanical recovery - oleophilic skimmers (e.g., rope-mop and belt skimmers) work best on oils with moderate to high interfacial tensions.

Pour Point

The pour point is the lowest temperature (to the nearest multiple of 3 °C) at which crude oil will still flow in a small test jar tipped on its side. Near, and below this temperature, the oil develops a yield stress and, in essence, gels. The pour point of an oil increases with weathering. Pour point affects the following processes:

- Spreading - oils at temperatures below their pour points will not spread on water;
- Viscosity - an oil’s viscosity at low shear rates increases dramatically at temperatures below its pour point;
- Dispersion - an oil at a temperature below its pour point may be difficult to disperse; and,

- Recovery - crude oil below its pour point may not flow towards skimmers or down inclined surfaces in skimmers

Flash Point

The flash point of crude oil is the temperature at which the oil produces sufficient vapors to ignite when exposed to an open flame or other ignition source. Flash point increases with increasing evaporation. It is an important safety-related spill property.

Emulsification Tendency and Stability

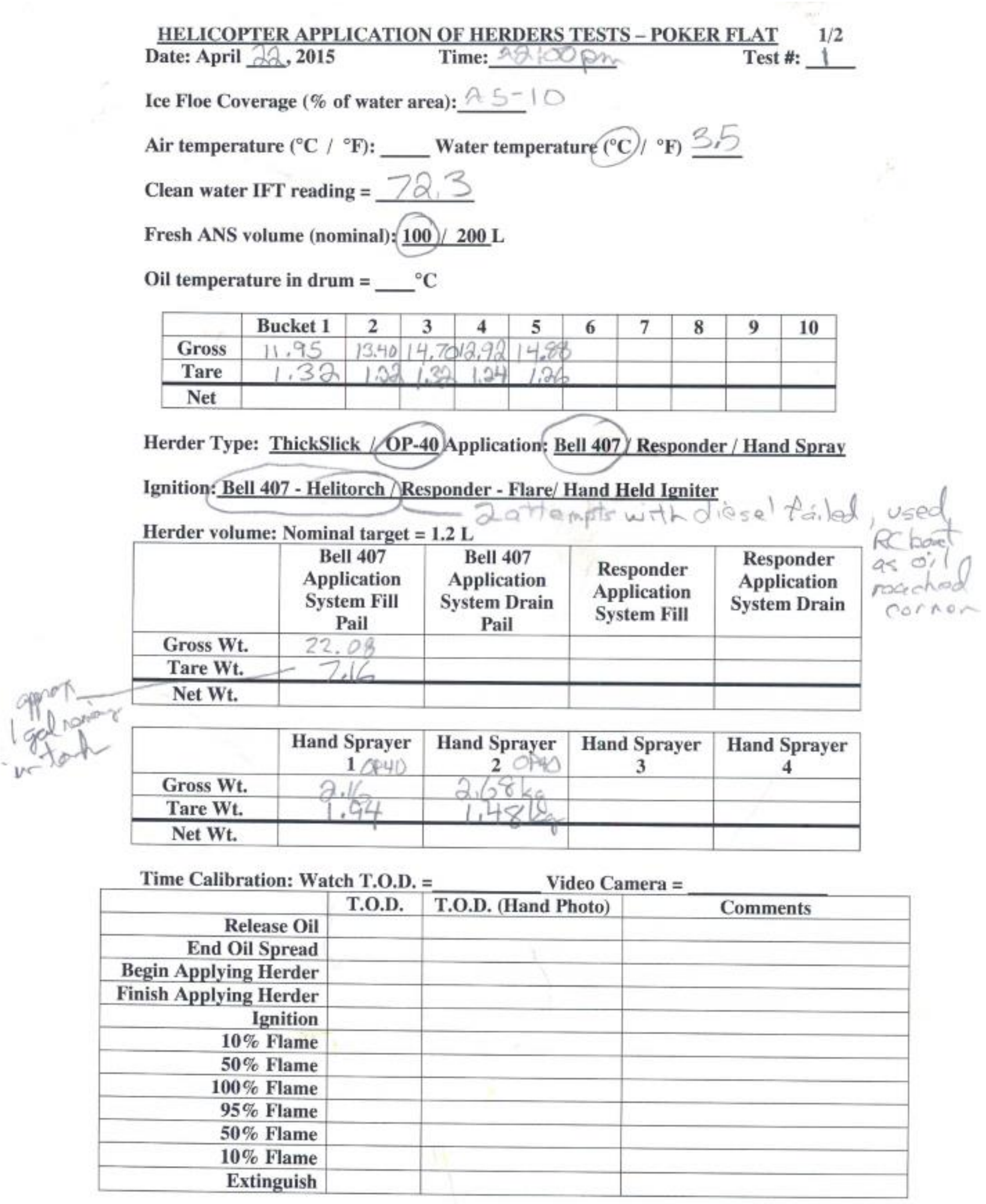
The tendency of crude oil to form water-in-oil emulsions (or “mousse”) and the stability of the emulsion formed are measured by two numbers: the Emulsification Tendency Index (Zagorski and Mackay 1982, Hokstad and Daling 1993) and the Emulsion Stability (adapted from Fingas *et al.* 1998). The Emulsification Tendency Index is a measure of the oil’s propensity to form an emulsion, quantified by extrapolating back to time = 0 the fraction of the parent oil that remains (i.e., does not cream out) in the emulsion formed in a rotating flask apparatus over several hours. If a crude oil has an Emulsification Tendency Index between 0 and 0.25 it is unlikely to form an emulsion; if it has a Tendency Index between 0.25 and 0.75 it has a moderate tendency to form emulsions. A value of 0.75 to 1.0 indicates a high tendency to form emulsions. Recently the Emulsion Stability assessment has been changed to reflect the four categories suggested by Fingas *et al.* 1998. Emulsion types are selected based on water content, emulsion rheology and the visual appearance of the emulsion after 24 hours settling. The four categories, and their defining characteristics, are:

- Unstable – looks like original oil; water contents after 24 hours of 1% to 23% averaging 5%; viscosity same as oil on average
- Entrained Water – looks black, with large water droplets; water contents after 24 hours of 26% to 62% averaging 42%; emulsion viscosity 13 times greater than oil on average
- Meso-stable – brown viscous liquid; water contents after 24 hours of 35% to 83% averaging 62%; emulsion viscosity 45 times greater than oil on average
- Stable – the classic “mousse”, a brown gel/solid; water contents after 24 hours of 65% to 93% averaging 80%; emulsion viscosity 1100 times greater than oil on average

Under the old emulsion stability assessment scheme, the stability was determined by the fraction of the original oil that remained in the emulsion after 24-hours settling (0 to 0.25 = unstable, 0.25 to 0.75 = fairly stable, 0.75 to 1 = very stable).

Both the Tendency Index and Stability generally increase with increased degree of evaporation. Colder temperatures generally increase both the Tendency Index and Stability (i.e., promote emulsification) unless the oil gels as the temperature drops below its pour point and it becomes too viscous to form an emulsion. Emulsion formation results in large increases in the spill's volume, enormous viscosity increases (which can reduce dispersant effectiveness), and increased water content (which can prevent ignition of the slicks and *in situ* burning).

APPENDIX H – TEST DATA SHEETS



HELICOPTER APPLICATION OF HERDERS TESTS – POKER FLAT 1/2

Date: April 22, 2015 **Time:** 22:00pm **Test #:** 1

Ice Floe Coverage (% of water area): 25-10

Air temperature (°C / °F): ____ **Water temperature** [✓ (°C)] / °F) 3.5

Clean water IFT reading = 72.3

Fresh ANS volume (nominal): [✓ 100] / 200 L

Oil temperature in drum = ____ °C

	Bucket 1	2	3	4	5	6	7	8	9	10
Gross	11.95	13.40	14.70	12.92	14.88					
Tare	1.32	1.22	1.32	1.24	1.26					
Net										

Herder Type: ThickSlick / [✓ OP-40] **Application:** [✓ Bell 407] / Responder / Hand Spray

Ignition: [✓ Bell 407 - Helitorch] / Responder - Flare/ Hand Held Igniter

2 attempts with diesel failed, used RC boat as oil reached corner

Herder volume: Nominal target = 1.2 L

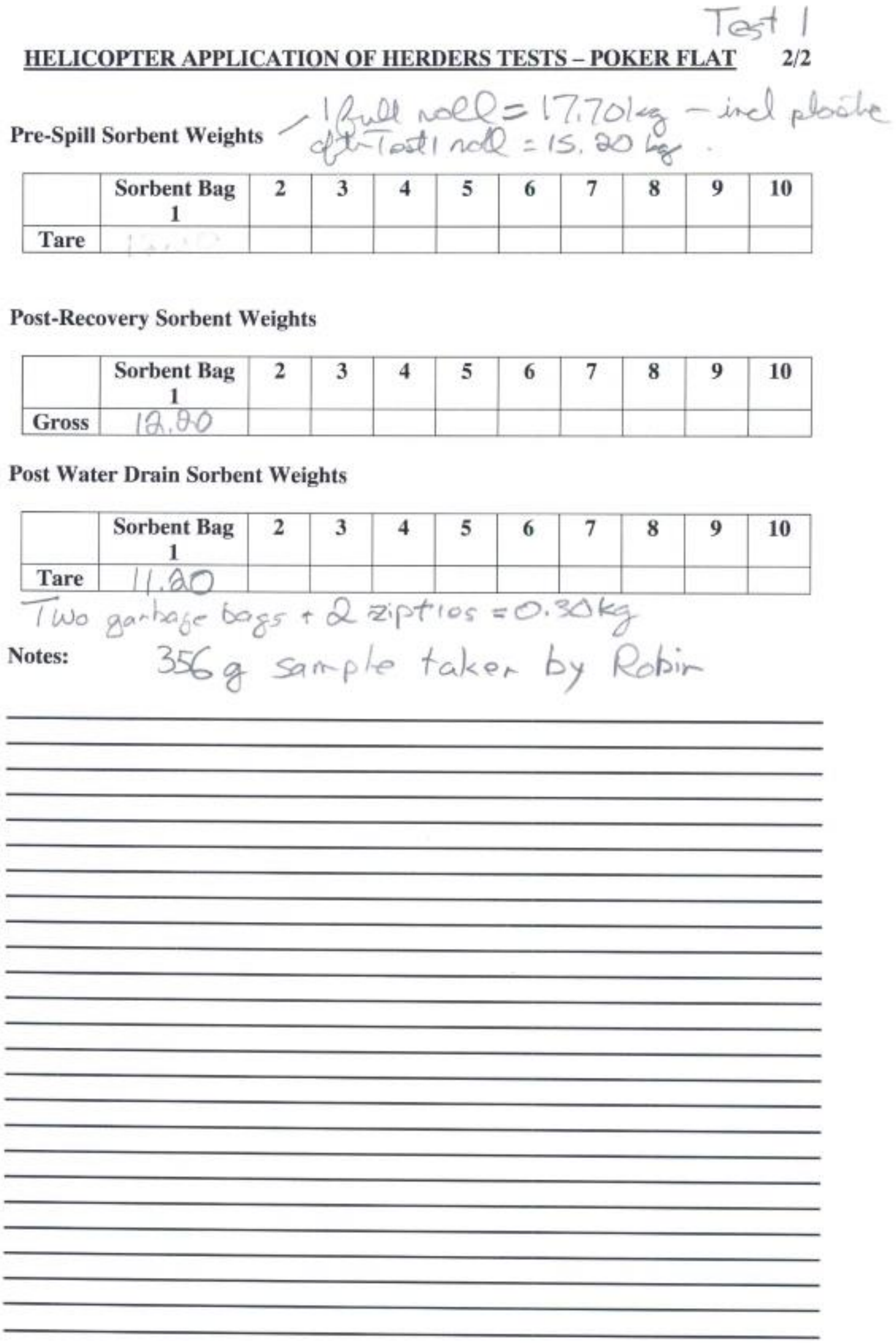
	Bell 407 Application System Fill Pail	Bell 407 Application System Drain Pail	Responder Application System Fill	Responder Application System Drain
Gross Wt.	22.08			
Tare Wt.	7.16			
Net Wt.				

approx 1 gal remaining in tank

	Hand Sprayer 1 OP40	Hand Sprayer 2 OP40	Hand Sprayer 3	Hand Sprayer 4
Gross Wt.	2.16	2.68kg		
Tare Wt.	1.94	1.48kg		
Net Wt.				

Time Calibration: Watch T.O.D. = __________ **Video Camera =** __________

	T.O.D.	T.O.D. (Hand Photo)	Comments
Release Oil			
End Oil Spread			
Begin Applying Herder			
Finish Applying Herder			
Ignition			
10% Flame			
50% Flame			
100% Flame			
95% Flame			
50% Flame			
10% Flame			
Extinguish			



Test 1

HELICOPTER APPLICATION OF HERDERS TESTS – POKER FLAT 2/2

Pre-Spill Sorbent Weights 1 full roll = 17.70 kg – incl plastic
after Test 1 roll = 15.20 kg

	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Tare	[illegible]									

Post-Recovery Sorbent Weights

	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Gross	12.00									

Post Water Drain Sorbent Weights

	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Tare	11.20									

Two garbage bags + 2 zipties = 0.30 kg

Notes: 356 g sample taken by Robin

HELICOPTER APPLICATION OF HERDERS TESTS – POKER FLAT

1/2

Date: April 23 2015 Time: 1:00 a Test #: 2

Ice Floe Coverage (% of water area): 5-10

Air temperature (°C / °F): _____ Water temperature (°C / °F) _____

Clean water IFT reading = 72.2

Fresh ANS volume (nominal): [✓ 100] / 200 L

Oil temperature in drum = ____°C

	Bucket 1	2	3	4	5	6	7	8	9	10
Gross	14.44	14.52	14.48	14.40	14.46					
Tare	1.32	1.34	1.28	1.24	1.30					
Net										

Roling sample weight =480g

Herder Type: ThickSlick / [✓ OP-40] Application: [✓ Bell 407] / Responder / Hand Spray

Ignition: [✓ Bell 407 - Helitorch] / Responder - Flare/ Hand Held Igniter

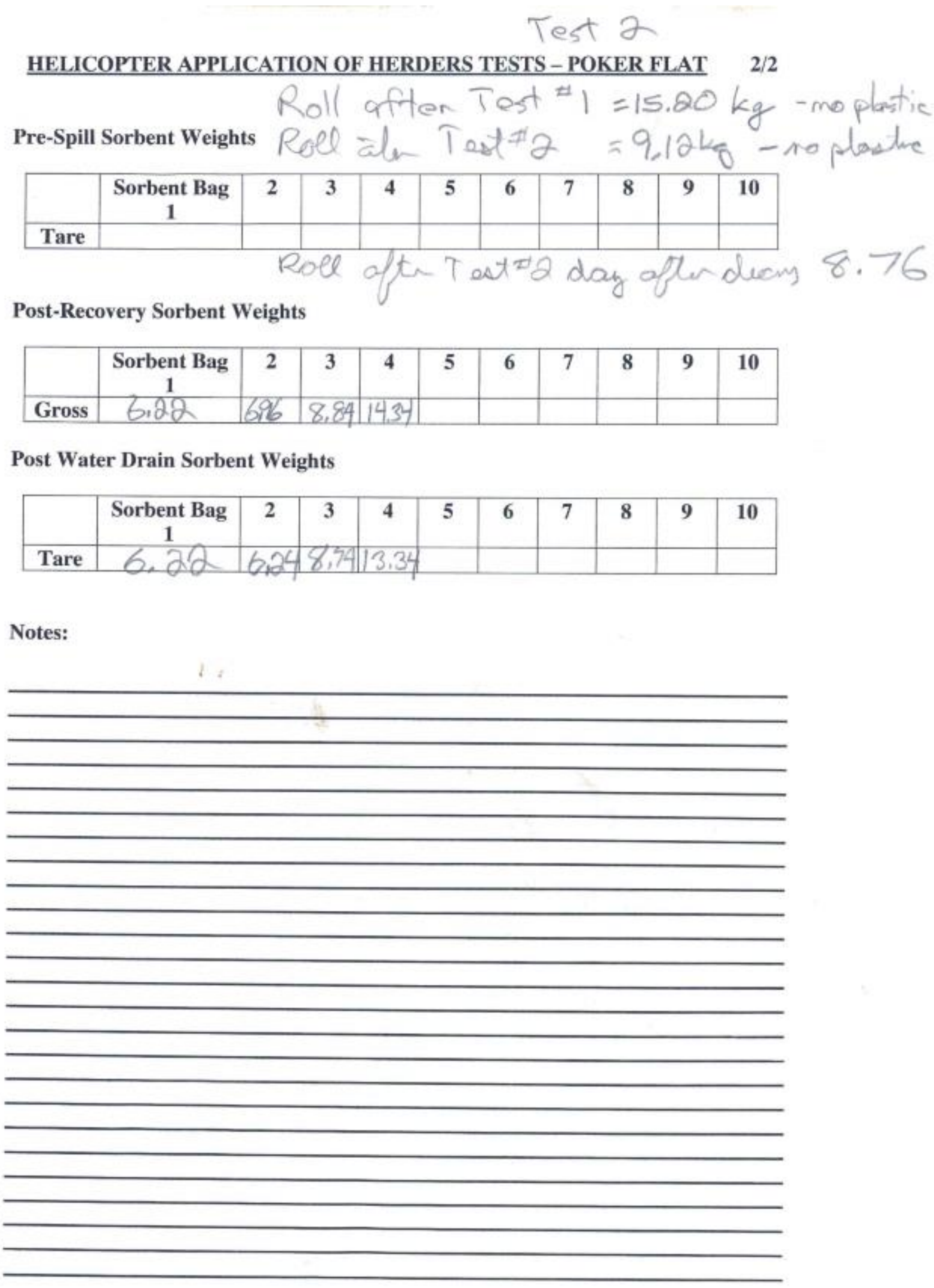
Herder volume: Nominal target = 1.2 L

	Bell 407 Application System Fill Pail	Bell 407 Application System Drain Pail	Responder Application System Fill	Responder Application System Drain
Gross Wt.	✓	✓		
Tare Wt.				
Net Wt.	Used ~1 gallon based on sight glass			

	Hand Sprayer 1	Hand Sprayer 2	Hand Sprayer 3	Hand Sprayer 4
Gross Wt.	3.14 kg	3.06 kg		
Tare Wt.	3.08	2.60		
Net Wt.				

Time Calibration: Watch T.O.D. = __________ Video Camera = ______________

	T.O.D.	T.O.D. (Hand Photo)	Comments
Release Oil			
End Oil Spread			
Begin Applying Herder			
Finish Applying Herder			
Ignition			
10% Flame			
50% Flame			
100% Flame			
95% Flame			
50% Flame			
10% Flame			
Extinguish			



Test 2

HELICOPTER APPLICATION OF HERDERS TESTS – POKER FLAT 2/2

Roll after Test #1 = 15.20 kg – no plastic

Pre-Spill Sorbent Weights Roll after Test #2 = 9.12 kg – no plastic

	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Tare										

Roll after Test #2 day after drain 8.76

Post-Recovery Sorbent Weights

	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Gross	6.22	6.96	8.84	14.34						

Post Water Drain Sorbent Weights

	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Tare	6.22	6.24	8.74	13.34						

Notes:

HELICOPTER APPLICATION OF HERDERS TESTS – POKER FLAT 1/2

Date: April 24, 2015 **Time:** 21:00 pm **Test #:** 3

Ice Floe Coverage (% of water area): 5-10

Air temperature (°C / °F): _____ **Water temperature (°C / °F)** _____

Clean water IFT reading = 69.1

Fresh ANS volume (nominal): 100 / 200 L

Oil temperature in drum = ____°C

	Bucket 1	2	3	4	5	6	7	8	9	10
Gross	14.40	14.12	14.48	14.88	14.40	14.68	14.38	14.62	14.12	15.08
Tare	1.30	1.30	1.34	1.26	1.34	1.30	1.32	1.34	1.30	1.44
Net										

Herder Type: ThickSlick / [✓ OP-40] **Application:** [✓ Bell 407] / Responder / Hand Spray

Ignition: [✓ Bell 407 - Helitorch] / Responder - Flare/ Hand Held Igniter

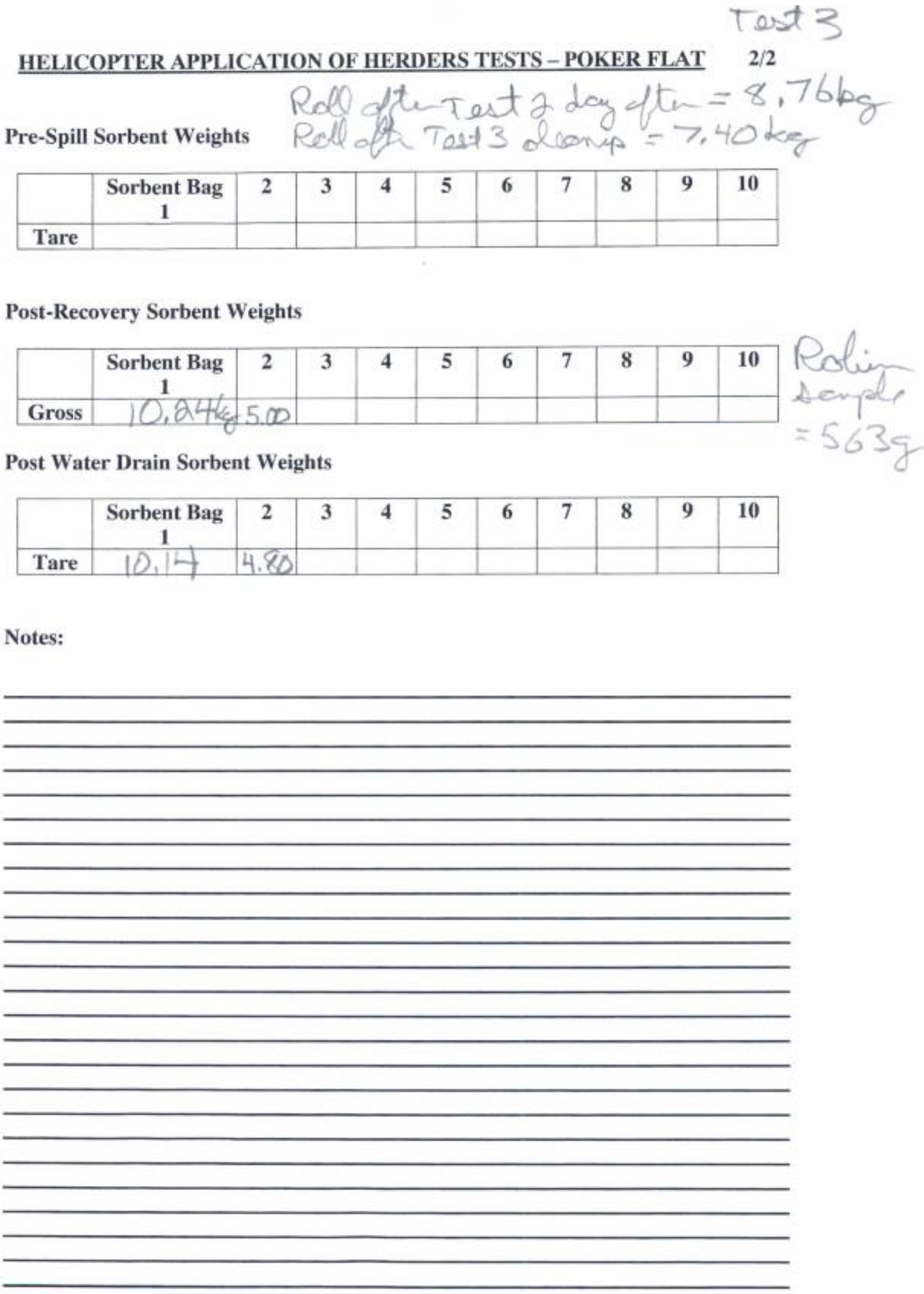
Herder volume: Nominal target = 1.2 L

	Bell 407 Application System Fill Pail	Bell 407 Application System Drain Pail	Responder Application System Fill	Responder Application System Drain
Gross Wt.				
Tare Wt.				
Net Wt.	algal on sightglass - much spray did not hit ves			

	Hand Sprayer 1	Hand Sprayer 2	Hand Sprayer 3	Hand Sprayer 4
Gross Wt.	3.06 kg	2.60 kg		
Tare Wt.	2.90 kg	2.14 kg		
Net Wt.				

Time Calibration: Watch T.O.D. = __________ **Video Camera =** ______________

	T.O.D.	T.O.D. (Hand Photo)	Comments
Release Oil			
End Oil Spread			
Begin Applying Herder			
Finish Applying Herder			
Ignition			
10% Flame			
50% Flame			
100% Flame			
95% Flame			
50% Flame			
10% Flame			
Extinguish			



Test 3

HELICOPTER APPLICATION OF HERDERS TESTS – POKER FLAT 2/2

Roll after Test 2 day after = 8.76kg
Roll after Test 3 cleanup = 7.40 kg

Pre-Spill Sorbent Weights

	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Tare										

Post-Recovery Sorbent Weights

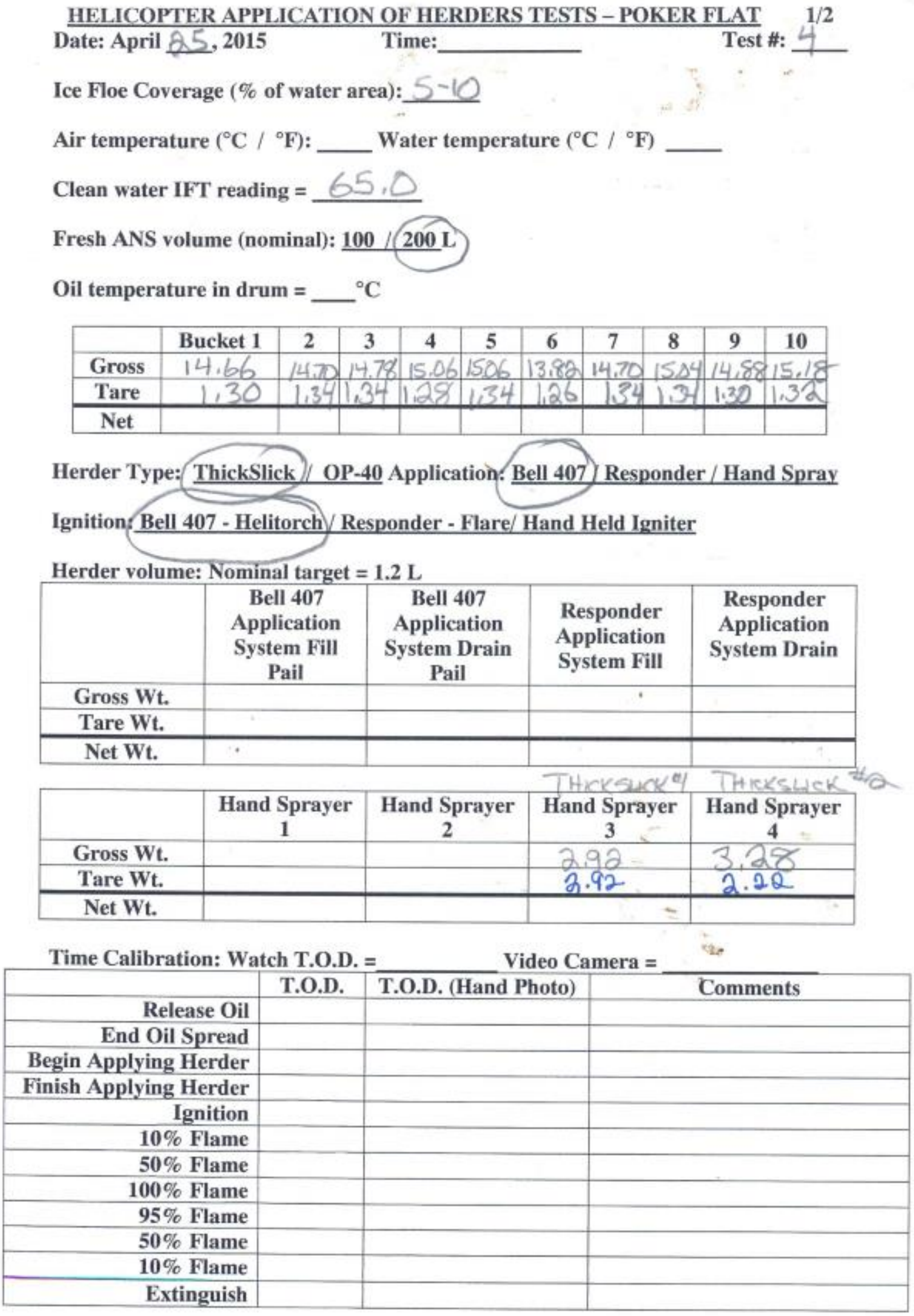
	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Gross	10.24kg	5.00								

Rolin sample = 563g

Post Water Drain Sorbent Weights

	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Tare	10.14	4.80								

Notes:



HELICOPTER APPLICATION OF HERDERS TESTS – POKER FLAT 1/2

Date: April 25**, 2015** **Time:**__________ **Test #:** 4

Ice Floe Coverage (% of water area): 5-10

Air temperature (°C / °F): _____ **Water temperature (°C / °F)** _____

Clean water IFT reading = 65.0

Fresh ANS volume (nominal): 100 / [✓ 200 L]

Oil temperature in drum = ____°C

	Bucket 1	2	3	4	5	6	7	8	9	10
Gross	14.66	14.70	14.78	15.06	1506	13.82	14.70	15.04	14.88	15.18
Tare	1.30	1.34	1.34	1.28	1.34	1.26	1.34	1.34	1.30	1.32
Net										

Herder Type: [✓ ThickSlick] / OP-40 **Application:** [✓ Bell 407] / Responder / Hand Spray

Ignition: [✓ Bell 407 - Helitorch] / Responder - Flare/ Hand Held Igniter

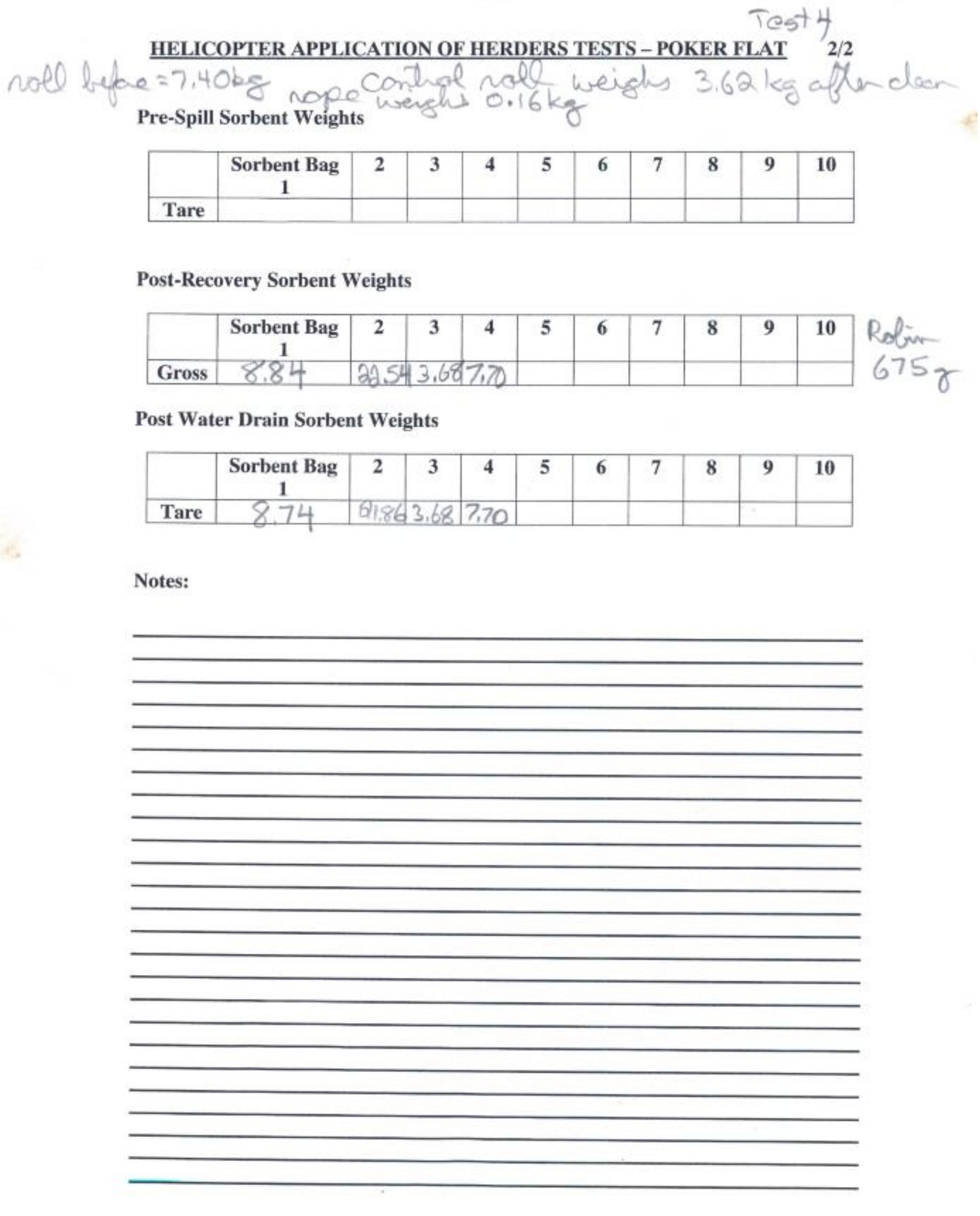
Herder volume: Nominal target = 1.2 L

	Bell 407 Application System Fill Pail	Bell 407 Application System Drain Pail	Responder Application System Fill	Responder Application System Drain
Gross Wt.				
Tare Wt.				
Net Wt.				

	Hand Sprayer 1	Hand Sprayer 2	THICKSLICK #1 Hand Sprayer 3	THICKSLICK #2 Hand Sprayer 4
Gross Wt.			2.92	3.28
Tare Wt.			2.92	2.22
Net Wt.				

Time Calibration: Watch T.O.D. =__________ **Video Camera =** __________

	T.O.D.	T.O.D. (Hand Photo)	Comments
Release Oil			
End Oil Spread			
Begin Applying Herder			
Finish Applying Herder			
Ignition			
10% Flame			
50% Flame			
100% Flame			
95% Flame			
50% Flame			
10% Flame			
Extinguish			



Test 4

HELICOPTER APPLICATION OF HERDERS TESTS – POKER FLAT 2/2

roll before = 7.40kg rope weighs 0.16kg Control roll weighs 3.62 kg after clean

Pre-Spill Sorbent Weights

	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Tare										

Post-Recovery Sorbent Weights

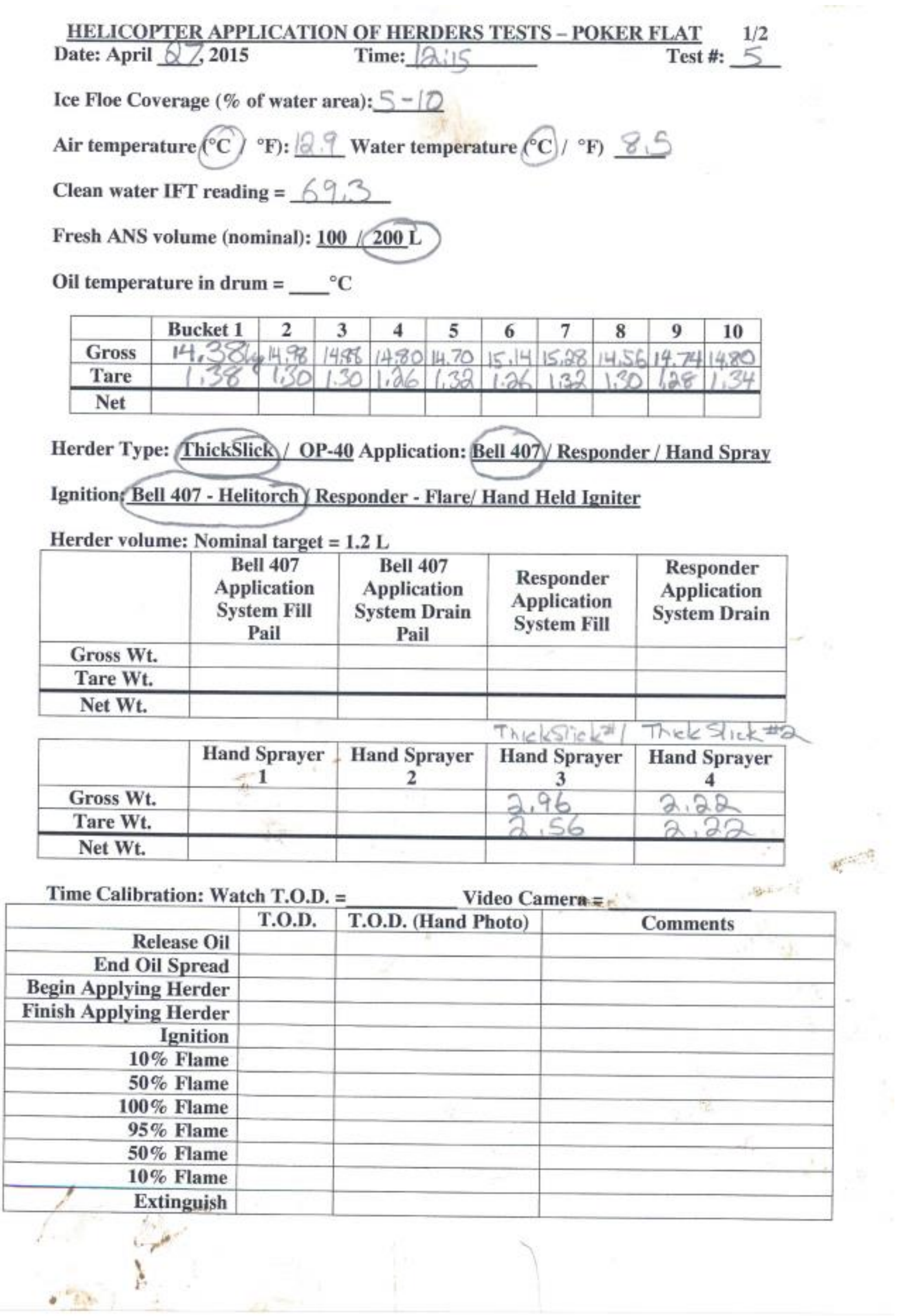
	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Gross	8.84	22.54	3.68	7.70						

Robin 675g

Post Water Drain Sorbent Weights

	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Tare	8.74	21.86	3.68	7.70						

Notes:



HELICOPTER APPLICATION OF HERDERS TESTS – POKER FLAT 1/2

Date: April 07, 2015 Time: 12:15 Test #: 5

Ice Floe Coverage (% of water area): 5-10

Air temperature ([✓ °C] / °F): 12.9 Water temperature ([✓ °C] / °F) 8.5

Clean water IFT reading = 69.3

Fresh ANS volume (nominal): 100 / [✓ 200 L]

Oil temperature in drum = ____°C

	Bucket 1	2	3	4	5	6	7	8	9	10
Gross	14,38kg	14.98	14.86	14.80	14.70	15.14	15.28	14.56	14.74	14.80
Tare	1,38	1,30	1.30	1.26	1.32	1.26	1.32	1.30	1.28	1.34
Net										

Herder Type: [✓ ThickSlick] / OP-40 Application: [✓ Bell 407] / Responder / Hand Spray

Ignition: [✓ Bell 407 - Helitorch] / Responder - Flare/ Hand Held Igniter

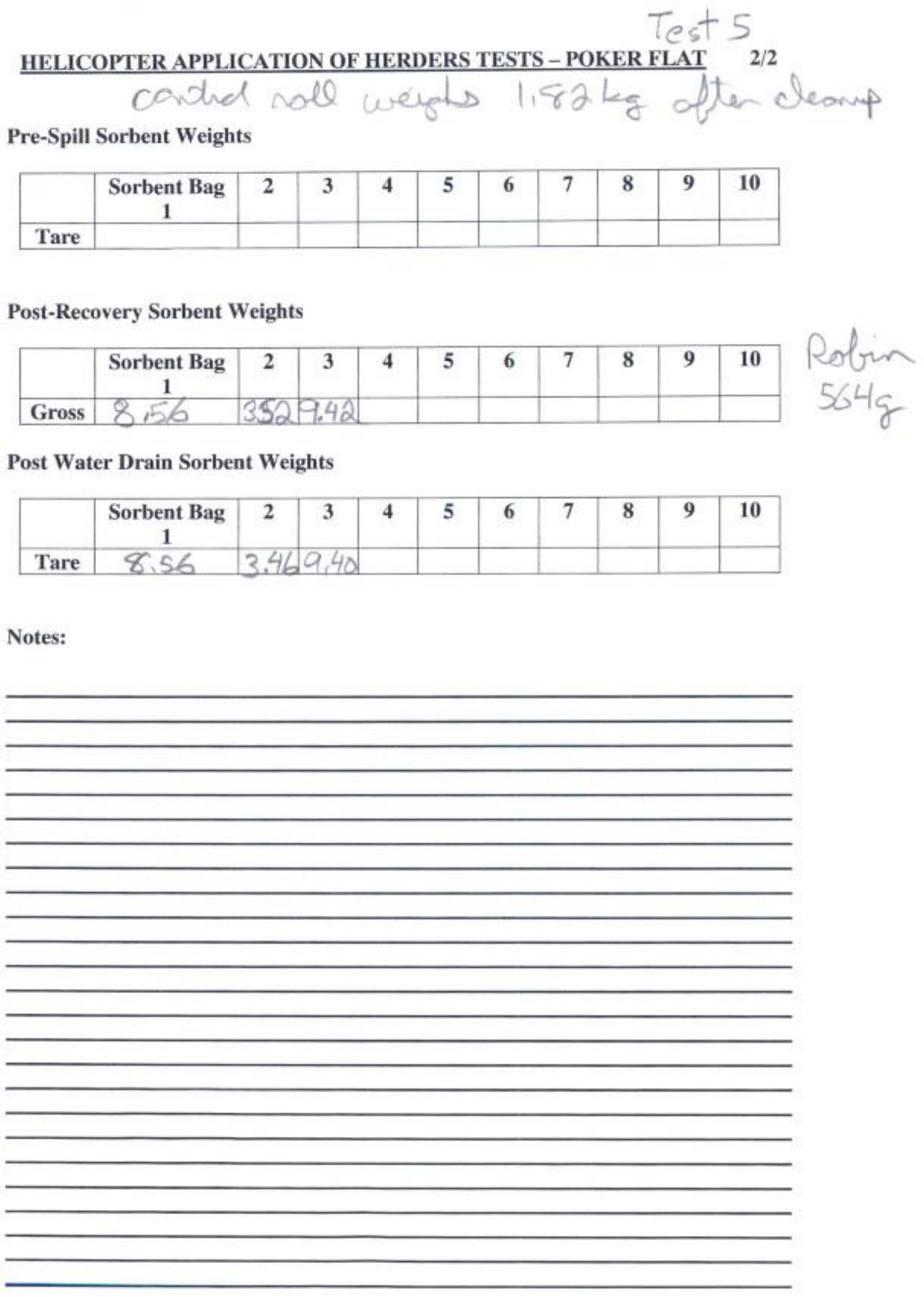
Herder volume: Nominal target = 1.2 L

	Bell 407 Application System Fill Pail	Bell 407 Application System Drain Pail	Responder Application System Fill	Responder Application System Drain
Gross Wt.				
Tare Wt.				
Net Wt.				

	Hand Sprayer 1	Hand Sprayer 2	ThickSlick#1 Hand Sprayer 3	ThickSlick#2 Hand Sprayer 4
Gross Wt.			2.96	2.22
Tare Wt.			2.56	2.22
Net Wt.				

Time Calibration: Watch T.O.D. = __________ Video Camera = __________

	T.O.D.	T.O.D. (Hand Photo)	Comments
Release Oil			
End Oil Spread			
Begin Applying Herder			
Finish Applying Herder			
Ignition			
10% Flame			
50% Flame			
100% Flame			
95% Flame			
50% Flame			
10% Flame			
Extinguish			



Test 5

HELICOPTER APPLICATION OF HERDERS TESTS – POKER FLAT 2/2

carded roll weighs 1.82 kg after cleanup

Pre-Spill Sorbent Weights

	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Tare										

Post-Recovery Sorbent Weights

	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Gross	8.56	3.52	9.42							

Robin
564g

Post Water Drain Sorbent Weights

	Sorbent Bag 1	2	3	4	5	6	7	8	9	10
Tare	8.56	3.46	9.40							

Notes:

APPENDIX I – RUN TIMING AND COMMENT SHEETS

RUN #1, T0=14:20:07.00

HELO mounted GOPRO test R1 (video fisheye corrected AVI files)

FN	START	STOP	DURATION
GOPR0921.avi	13:54:01	14:11:44	0:17:43
GP010921.avi	14:11:44	14:29:27	0:17:43
GP020921.avi	14:29:27	14:44:22	0:14:55

Helo mounted Hdcam R1

FN	START	STOP	DURATION
20150422135459.MTS	13:54:59	14:57:09	1:02:10

UAV Ptarmigan R1 (video fisheye corrected AVI files)

FN	START	STOP	DURATION
GOPR2273.avi	14:22:16	14:31:07	0:08:51
GP012273.avi	14:31:07	14:39:58	0:08:51
GP022273.avi	14:39:58	14:48:48	0:08:50
GP032273.avi	14:48:48	14:52:45	0:03:57

Nozzle mounted GOPRO R1

FN	START	STOP	DURATION
GOPR0525.avi	14:24:31	14:42:14	0:17:43
GP010525.avi	14:42:14	14:51:09	0:08:55

HD hh camera R1

FN	START	STOP	DURATION
n/a			

RUN #1, T0=14:20:07.00

COMMENTS	
T = -9:29, (14:10:37:16)	Test launch of helo to check spool extension and retrieval
T = -1:13, (14:18:53;24)	Launch of helo for test run #1
T = 0 (14:20:07)	Release of oil from containment ring
T = 1:30	Start of first herder application pass (S corner)
T = 1:50	End of first herder application pass (E corner near main ramp)
T = 3:00	Start of second herder application pass (S corner again)
T = 3:12	End of second herder application pass (E corner near main ramp) (results in 2 passes along same side of slick)
T = 5:44	Helo lands, Helitorch Igniter System is attached to airframe
T = 7:59	Helo takes off with Helitorch
T = 12:17	Helo begins ignition pass (S to N, cross tank), two short bursts of flame then… nothing.
T = 12:31	Helo ends ignition pass, no joy.
T = 12:32	Helo reverses (now second ignition pass) and continues to try to get gelled fuel to discharge and ignite.
T = 13:30	Helo fails to trigger ignition, pilot gains altitude to return to landing spot.
T = 18:56	Helo takes off with refilled Helitorch
T = 19:57	Helo begins third ignition pass, gelled fuel is seen leaving Helitorch but does not ignite
T = 20:00	Oil impacted side of tank along NE side near N corner (first visual of side impact, oil was near "fauxbergs" at 13:50)
T = 20:20	Helo hovers over oil pooled in N corner, gelled fuel dispensing, occassional small flame seen but no ignition of gelled fuel
T = 20:30	Helo fails to trigger ignition, pilot gains altitude to return to landing spot.
T = 23:10	Remote controlled boat with lit gelled gasoline payload launched from side of test basin - to be driven into oil slick.
T = 25:12	Smoke detected from Ptarmigan camera, ignition of oil slick
T = 26:12	Burn intensifies
T = 27:40	Burn splits into two distinct burning pools
T = 28:30	Intensity of burning pools lessens
T = 28:55	One of the two burning pools extinguishes
T = 29:10	Second burning pool extinguishes, small flare-up at first burning pool (duration unknown, Ptarmigan turns to land)

RUN #2 T0=13:12:17.00

HELO mounted GOPRO test R2 (video fisheye corrected AVI files)

FN	START	STOP	DURATION
GOPR1526.avi	12:58:30	13:16:13	0:17:43
GP011526.avi	13:16:13	13:33:56	0:17:43

Helo mounted Hdcam R2

FN	START	STOP	DURATION
20150423125923.MTS	12:59:23	14:44:03	1:44:40

UAV Ptarmigan R2 (video fisheye corrected AVI files)

FN	START	STOP	DURATION
GP012274sitting on ground.avi	13:00:59	13:09:49	0:08:50
GP022274application of herder and view of slick.avi	13:09:49	13:18:40	0:08:51
GP032274.avi	13:18:40	13:27:30	0:08:50
GP042274.avi	13:27:30	13:36:21	0:08:51
GP052274.avi	13:36:21	13:45:11	0:08:50
GP062274.avi	13:45:11	13:50:29	0:05:18

Nozzle mounted GOPRO R2 (video fisheye corrected AVI files)

FN	START	STOP	DURATION
GOPR0541herder application.avi	13:03:43	13:21:26	0:17:43
GP010541igniter.avi	13:21:26	13:37:12	0:15:46

HD hh camera R2

FN	START	STOP	DURATION
20150423131131.MTS	13:11:29	13:12:17	0:00:48
20150423131240.MTS	13:12:38	13:12:47	0:00:09
20150423131301.MTS	13:12:59	13:13:23	0:00:24
20150423131432.MTS	13:14:30	13:15:09	0:00:39
20150423132101.MTS	13:20:59	13:21:08	0:00:09
20150423132113.MTS	13:21:11	13:21:12	0:00:01
20150423132116.MTS	13:21:14	13:21:16	0:00:02
20150423132120.MTS	13:21:18	13:21:41	0:00:23
20150423132145.MTS	13:21:43	13:22:38	0:00:55
20150423132242.MTS	13:22:40	13:23:15	0:00:35
20150423132423.MTS	13:24:21	13:24:49	0:00:28
20150423133154.MTS	13:31:52	13:32:18	0:00:26
20150423133226.MTS	13:32:24	13:32:35	0:00:11
20150423133432.MTS	13:34:30	13:35:16	0:00:46
20150423133520.MTS	13:35:18	13:35:37	0:00:19
20150423133855.MTS	13:38:53	13:42:36	0:03:43
20150423134258.MTS	13:42:56	13:45:01	0:02:05
20150423134506.MTS	13:45:04	13:46:28	0:01:24
20150423134643.MTS	13:46:41	13:47:12	0:00:31

RUN #2 T0=13:12:17.00

COMMENTS	
T = -1:48	Launch of helo for test run #2
T = 0 (13:12:17)	Release of oil from containment ring
T = 0:45	Start of first herder application pass (S corner)
T = 1:04	End of first herder application pass (E corner near main ramp)
T = 2:25	Start of second herder applicatoin pass (W corner)
T = 2:41	End of second herder application pass (N corner)
T = 5:21	Helo lands, Helitorch Igniter System is attached to airframe
T = 7:37	Helo takes off with Helitorch
T = 9:03	Helo begins ignition pass (W to N corners, along NW side)
T = 9:04	Helitorch ignited
T = 9:15	Helitorch extinguished
T = 9:16	Helo ends ignition pass
T = 10:46	Helo begins ignition pass 2 (SW to NE sides)
T = 10:49	Helitorch stops ejecting flaming gelled fuel, sputters a bit - out of gelled fuel?
T = 10:58	Helo ends second ignition pass
T = 12:10	Oil impacts side of tank (based upon Helo view - along SW side)
T = 12:15	Helo begins third ignition pass - sputters but does not eject flaming fuel
T = 12:26	Pilot gains altitute to return to land, aborting ignition attempt.
T = 17:40	Oil impinging along SW side near W corner manually ignited
T = 18:38	Burn intensifies
T = 20:00	Smoke lightens in colour
T = 21:45	Flames extinguish from initial pool of oil near SW side
T = 22:15	Separate oil pool manually started closer to W corner
T = 27:50	Smoke lightens in colour, additional pockets of oil start to burn
T = 32:55	Flames extinguish

RUN #3 T0=14:20:46.26

HELO mounted GOPRO test R3 (video fisheye corrected AVI files)

FN	START	STOP	DURATION
GOPR2964.avi (had to trim beginning to get sync)	14:06:42	14:23:35	0:16:53
GP012964.avi	14:23:35	14:41:18	0:17:43
GP022964.avi	14:41:18	14:59:01	0:17:43
GP032964.avi	14:59:01	14:59:32	0:00:31

Helo mounted Hdcam R3

FN	START	STOP	DURATION
20150424140645.MTS	14:06:42	14:59:27	0:52:45

UAV Ptarmigan R3 (video fisheye corrected AVI files)

FN	START	STOP	DURATION
GOPR2275.avi	14:18:01	14:26:52	0:08:51
GP012275ignition.avi	14:26:52	14:35:42	0:08:50
GP022275.avi	14:35:42	14:44:33	0:08:51
GP032275.avi	14:44:33	14:46:27	0:01:54

Nozzle mounted GOPRO R3

FN	START	STOP	DURATION
GOPR0543helo liftoff herder dribble.avi	14:16:20	14:20:55	0:04:35
GOPR0544.avi	14:21:00	14:38:43	0:17:43
GP010544.avi	14:38:43	14:43:57	0:05:14

HD hh camera R3

FN	START	STOP	DURATION
20150424141902.MTS	14:18:57	14:19:19	0:00:22
20150424142009.MTS	14:20:04	14:20:26	0:00:22
20150424142037.MTS	14:20:32	14:21:45	0:01:13
20150424142319.MTS	14:23:14	14:23:52	0:00:38
20150424142530.MTS	14:25:25	14:25:32	0:00:07
20150424142954.MTS	14:29:49	14:29:54	0:00:05
20150424143001.MTS	14:29:56	14:30:05	0:00:09
20150424143015.MTS	14:30:10	14:30:39	0:00:29
20150424143059.MTS	14:30:54	14:31:06	0:00:12
20150424143126.MTS	14:31:21	14:32:17	0:00:56
20150424143440.MTS	14:34:35	14:34:45	0:00:10
20150424143454.MTS	14:34:49	14:35:02	0:00:13
20150424143525.MTS	14:35:20	14:36:18	0:00:58
20150424143625.MTS	14:36:20	14:36:26	0:00:06
20150424143634.MTS	14:36:29	14:36:39	0:00:10
20150424143648.MTS	14:36:43	14:36:47	0:00:04
20150424143757.MTS	14:37:52	14:37:54	0:00:02
20150424143801.MTS	14:37:56	14:38:08	0:00:12
20150424144032.MTS	14:40:27	14:40:58	0:00:31
20150424144117.MTS	14:41:12	14:41:24	0:00:12
20150424144154.MTS	14:41:49	14:42:05	0:00:16
20150424144226.MTS	14:42:21	14:45:01	0:02:40
20150424144526.MTS	14:45:21	14:46:05	0:00:44

RUN #3 T0=14:20:46.26

COMMENTS	
T = -2:06	Launch of helo for test run #3
T = 0 (14:20:46)	Release of oil from containment ring
T = 0:36	Start of first herder application pass (S corner along SW side)
T = 0:56	End of first herder application pass (E corner near main ramp along NE side)
T = 2:47	Start of second herder application pass (W corner along SW side)
T = 3:01	Send of second herder application pass (N corner along NE side)
T = 5:22	Helo lands, Helitorch Igniter System is attached to airframe
T = 7:52	Helo takes off with Helitorch
T = 9:23	Helo begins ignition pass (SW side)
T = 9:26	Helitorch ignited
T = 9:33	Helitorch extinguished
T = 9:34	Oil ignited
T = 9:35	Helo ends ignition pass (NE side)
T = 9:52	Burning intensifies
T = 10:33	Burning subsides
T = 10:49	Burning effectively extinguished (small "hotspot" continues)
T = 11:07	Hotspot extinguished - all burning oil extinguished
T = 11:43	Helo begins second ignition pass (SW side)
T = 11:45	Helitorch ignited
T = 11:51	Helitorch extinguished
T = 11:55	Strip of burning fuel/oil in test tank
T = 11:57	Helo ends second ignition pass (NE side), oil ignited
T = 13:00	Oil fire started from second ignition pass continues to burn, Ptarmigan overflight
T = 14:10	Oil impacts side of tank (based upon Ptarmigan view - SW side near West corner, smoke increases)
T = 14:17	Burn intensifies a bit as bulk of slick approaches SW side
T = 14:31	Burn intensifies noticeably as slick reaches SW side
T = 15:14	Helo dumps Helitorch fuel in N corner
T = 15:35	End of Helo - Helitorch fuel dump
T = 17:13	Helitorch fuel extinguished as per Ptarmigan overflight
T = 17:40	Oil from slick continues to collect and burn intensely in W corner
T = 23:34	Intensity of oil burn in W corner diminishes
T = 25:05	Flames extinguish

RUN #4 T0=12:53:15.17

HELO mounted GOPRO test R4 (video fisheye corrected AVI files)

FN	START	STOP	DURATION
GOPR3608.avi	12:31:59	12:49:42	0:17:43
GP013608.avi	12:49:42	13:07:25	0:17:43
GP023608.avi	13:07:25	13:22:31	0:15:06

Helo mounted Hdcam R4

FN	START	STOP	DURATION
20150425123236.MTS	12:32:33	13:32:31	0:59:58

UAV Ptarmigan R4 (video fisheye corrected AVI files)

FN	START	STOP	DURATION
GoPR2277.avi	12:52:45	13:01:35	0:08:50
GP012277.avi	13:01:35	13:10:26	0:08:51
GP022277.avi	13:10:26	13:18:01	0:07:35

Nozzle mounted GOPRO R4

FN	START	STOP	DURATION
GoPr0601.mp4	12:37:36	12:55:19	0:17:43
GP010601.mp4	12:55:19	13:13:02	0:17:43
CP020601.mp4	13:13:02	13:21:34	0:08:32

HD hh camera R4

FN	START	STOP	DURATION
20150425124513 Site pan run 4.MTS	12:45:13	12:45:24	0:00:11
20150425124600 Helo take off run 4.MTS	12:46:00	12:46:16	0:00:16
20150425124822 Waiting for herder application.MTS	12:48:22	12:48:59	0:00:37
20150425124921 Slow herder application practice.MTS	12:49:21	12:49:52	0:00:31
20150425125140 Helo end of herder application practice.	12:51:40	12:51:59	0:00:19
20150425125316 Helo hover.MTS	12:53:16	12:54:02	0:00:46
20150425125425 Helo hover with UAV.MTS	12:54:25	12:55:09	0:00:44
20150425125613 Herder pass 1 run 4.MTS	12:56:13	12:57:37	0:01:24
20150425125839 Herder pass 2 run 4.MTS	12:58:39	13:00:43	0:02:04
20150425130711 Igniter pass 1 run 4.MTS	13:07:11	13:09:02	0:01:51
20150425130944 Igniter pass 2 run 4.MTS	13:09:44	13:11:56	0:02:12
20150425131158 Burn ending run 4.MTS	13:11:58	13:12:05	0:00:07
20150425131221 Burn ending run 4.MTS	13:12:21	13:12:56	0:00:35
20150425131259 Igniter purge burn run 4.MTS	13:12:59	13:13:08	0:00:09

RUN #4 T0=12:53:15.17

COMMENTS	
T = -7:14	Launch of helo for test run #4, perform two herder applicator dry runs prior to start of testing
T = 0 (12:53:15)	Release of oil from containment ring
T = 3:41	Start of first herder application pass (near S corner along SW side)
T = 4:04	End of first herder application pass in a J configuration (along NE side)
T = 6:36	Start of second herder application pass (NE side heading towards SW side, herder appears viscous)
T = 6:57	End of second herder application pass
T = 9:24	Helo lands, Helitorch Igniter System is attached to airframe
T = 12:03	Helo takes off with Helitorch
T = 12:20	Oil impacts side of tank (based upon Ptarmigan view - near main access ramp)
T = 14:42	Helo begins ignition pass (NE side near ramp)
T = 14:43	Helitorch ignited
T = 14:50	Helitorch extinguished
T = 14:52	Strip of gelled fuel burning
T = 15:14	Edge of slick near ramp on NE side burning
T = 16:31	Start of second run of Helitorch pass (redundant as fire continues on slick at ramp)
T = 16:36	End of dispensing of gelled fuel
T = 16:46	Helo ends Helitorch pass and leaves tank area, burn continues
T = 17:57	Helo re-enters tank area to dump remaining gelled fuel near SW side
T = 18:07	Start of gelled fuel dump
T = 18:33	End of gelled fuel dump
T = 19:20	Two burning pools of oil, north of the ramp, one extinguishes
T = 19:24	Remaining pool of oil extinguishes.
T = 20:37	Helo touches down at landing spot.

RUN #5 T0=12:30:59.12

HELO mounted GOPRO test

FN	START	STOP	DURATION
GOPR4215.mp4	12:08:56	12:26:40	0:17:44
GP014215.mp4	12:26:40	12:44:23	0:17:43
GP024215.mp4	12:44:23	13:02:06	0:17:43
GP034215.mp4	13:02:06	13:10:56	0:08:50

Helo mounted Hdcam R5

FN	START	STOP	DURATION
20150427120926.MTS	12:09:22	13:10:46	1:01:24

Nozzle mounted GOPRO R5

FN	START	STOP	DURATION
GOPR1131.mp4	12:10:12	12:27:55	0:17:43
GP011131.mp4	12:27:55	12:29:45	0:01:50

UAV Ptarmigan R5 (video fisheye corrected AVI files)

FN	START	STOP	DURATION
GOPR2278.avi	12:25:45	12:34:35	0:08:50
GP012278.avi	12:34:35	12:43:26	0:08:51
GP022278.avi	12:43:26	12:46:40	0:03:14
GOPR2279.avi	12:48:23	12:57:13	0:08:50
GP012279.avi	12:57:13	12:57:24	0:00:11

HD hh camera R5

FN	START	STOP	DURATION
20150427123105.MTS	12:31:05	12:32:33	0:01:28
20150427123332.MTS	12:33:32	12:34:19	0:00:47
20150427123718.MTS	12:37:18	12:37:54	0:00:36
20150427123954.MTS	12:39:54	12:41:19	0:01:25
20150427124154.MTS	12:41:54	12:44:30	0:02:36
20150427124927.MTS	12:49:27	12:51:37	0:02:10
20150427125534.MTS	12:55:34	12:55:52	0:00:18

RUN #5 T0=12:30:59.12

COMMENTS	
T = -1:53	Launch of helo for test run #5
T = 0 (12:30:59)	Release of oil from containment ring
T = 0:51	Start of first herder application pass (near W corner along SW side)
T = 1:18	End of first herder application pass in a J configuration (along NE side)
T = 2:37	Start of second herder application pass (along SW side)
T = 2:57	End of second herder application pass in a J configuration (along NE side, near E corner)
T = 5:11	Helo lands, Helitorch Igniter System is attached to airframe
T = 7:30	Helo takes off with Helitorch
T = 9:07	Helo begins ignition pass (SW side)
T = 9:13	Helitorch ignited
T = 9:20	Helitorch extinguished
T = 9:21	Strip of gelled fuel burning
T = 9:28	End of first igniter pass (near ramp, E corner)
T = 9:33	Black smoke begins to form from burning oil pool
T = 10:50	Pool fire dies down, minimal flames near leading edge of oil slick
T = 10:59	Helo begins second ignition pass (SW side)
T = 11:04	Helitorch ignited
T = 11:10	Helitorch extinguished
T = 11:17	Strip of gelled fuel burning
T = 11:18	End of second igniter pass (NE side)
T = 12:01	Helo enters test tank area (N corner)
T = 12:08	Helo dumps gelled fuel from Helitorch in N corner
T = 12:20	Oil impacts side of tank (based upon Ptarmigan view - pushed by downwash as Helo dumps)
T = 12:23	Helo ends dumping flaming gelled fuel from Helitorch, a few blobs sputter out for a few seconds longer
T = 12:55	Helo migrates across tank to S corner, leaving to land.
T = 13:07	Intense burn diminishes, two burning pool areas but smoke is fading
T = 14:07	Helo lands.
T = 14:15	Burning of slick impacting the tank edge intensifies, smoke increases and turns grey-black
T = 20:35	Slick migrated to W corner, burn continues but loses intensity, smoke turns grey-white
T = 24:37	Flames go out.

APPENDIX J – HERDER EFFECTIVENESS

Table J-1: Run #1 Imaging (first 3 images)

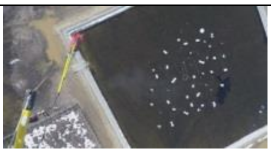
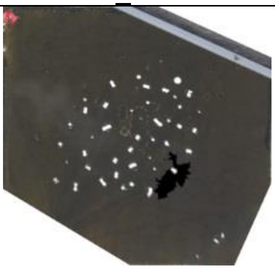
 T695_GOPROhelo	 T695_HDhelo	 T743_GOProHelo
 T695_GOPROhelo corrected	 T695_HDhelo corrected	 T743_GOProHelo corrected

Table J-2: Run #1 Calculated average thickness of the slick

Image	**Run Time (s)**	**Area (m^2)**	**Thickness (mm)**	**Oil Volume (L)**
Run1_T0	0	5.9	11.8	70.4
Run1_T695_GOPROhelo	695	76.8	0.9	
Run1_T695_HDhelo	695	80.4	0.9	
Run1_T743_GOProHelo	743	78.8	0.9	
Run1_T743_HDHelo	743	84.4	0.8	
Run1_T747_GOProHelo	747	86.8	0.8	
Run1_T759_GOProHelo	759	84.2	0.8	
Run1_T766_GOProHelo	766	77.7	0.9	
Run1_T775_GOProHelo	775	80.6	0.9	
Run1_T848_NozzleGOPRO	848	82.3	0.9	
Run1_T1201_HDhelo	1201	98.6	0.7	
Run1_T1249_GOPROhelo	1249	100.6	0.7	

Table J-3: Run #2 Imaging (first 3 images)

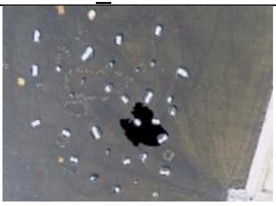
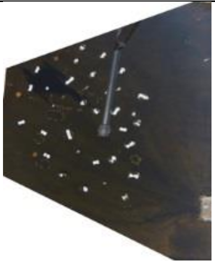
 T47_GoProHelo	 T150_GoProHelo	 T454_Ptarmigan
 T47_GoProHelo corrected	 T150_GoProHelo corrected	 T454_Ptarmigan corrected

Table J-4: Run #2 Calculated average thickness of the slick

Image	**Run Time (s)**	**Area (m^2)**	**Thickness (mm)**	**Oil Volume (L)**
Run2_T0	0	5.9	12.7	75.3
Run2_T47_GoProHelo	47	64.5	1.2	
Run2_T150_GoProHelo	150	75.1	1.0	
Run2_T454_PtarmiganT350	454	125.4	0.6	
Run2_T544_HDhelo	544	155.8	0.5	
Run2_T545_NozzleGoPRO	545	164.9	0.5	
Run2_T565_PtarmiganT461	565	182.7	0.4	
Run2_T592_PtarmiganT488	592	169.0	0.4	
Run2_T617_PtarmiganT513	617	192.8	0.4	
Run2_T647_HDhelo	647	186.1	0.4	
Run2_T669_PtarmiganT565	669	173.3	0.4	
Run2_T735_HDhelo	735	174.866	0.4	

Table J-5: Run #3 Imaging (first 3 images)

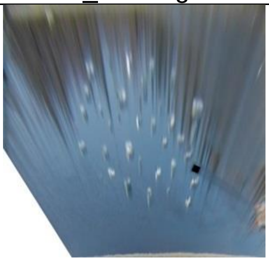
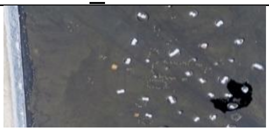
 T0_Ptarmigan	 T60_Ptarmigan	 T170_GOProHelo
 T0_Ptarmigan corrected	 T60_Ptarmigan corrected	 T170_GOProHelo corrected

Table J-6: Run #3 Calculated average thickness of the slick

Image	Run Time (s)	Area (m^2)	Thickness (mm)	Oil Volume (L)
Run3_T0_Ptarmigan	0	5.8	26.1	150.9
Run3_T60_Ptarmigan	60	105.6	1.4	
Run3_T170_GOProHelo	170	62.6	2.4	
Run3_T240_Ptarmigan	240	90.2	1.7	
Run3_T330_Ptarmigan	330	106.4	1.4	
Run3_T567_HDHelo	567	177.5	0.9	
Run3_T574_Ptarmigan	574			
Run3_T756_Ptarmigan	756	185.2	0.2	
Run3_T1070_Ptarmigan	1070	161.1	0.2	

Table J-7: Run #4 Imaging (first 3 images)

 T40_Ptarmigan	 T60_Ptarmigan	 T200_Ptarmigan
 T40_Ptarmigan corrected	 T60_Ptarmigan corrected	 T200_Ptarmigan corrected

Table J-8: Run #4 Calculated average thickness of the slick

Image	**Run Time (s)**	**Area (m^2)**	**Thickness (mm)**	**Oil Volume (L)**
Run4_T0	0	5.9	25.9	154.2
Run4_T40_Ptarmigan	40	19.4	7.9	
Run4_T60_Ptarmigan	60	73.9	2.1	
Run4_T200_Ptarmigan	200	113.5	1.4	
Run4_T240_Ptarmigan	240	138.9	1.1	
Run4_T300_Ptarmigan	300	155.0	1.0	
Run4_T360_Ptarmigan	360	209.4	0.7	
Run4_T400_HeloGOPRO	400	277.4	0.6	
Run4_T400_HeloHDcam	400	264.9	0.6	
Run4_T400_Ptarmigan	400	221.9	0.7	
Run4_T450_Ptarmigan	450	225.8	0.7	
Run4_T473_Ptarmigan	473	225.1	0.7	
Run4_T540_Ptarmigan	540	222.6	0.7	
Run4_T645_Ptarmigan	645	225.6	0.7	
Run4_T734_Ptarmigan	734	156.9	1.0	

Table J-9: Run #5 Imaging (first 3 images)

 T000_Ptarmigan	 T020_Ptarmigan	 T030_Ptarmigan
 T000_Ptarmigan corrected	 T020_Ptarmigan corrected	 T030_Ptarmigan corrected

Table J-10: Run #5 Calculated average thickness of the slick

Image	Run Time (s)	Area (m^2)	Thickness (mm)	Oil Volume (L)
RUN5_T000_Ptarmigan	0	5.7	27.3	154.7
RUN5_T020_Ptarmigan	20	37.6	4.1	
RUN5_T030_Ptarmigan	30	47.1	3.3	
RUN5_T060_Ptarmigan	60	71.3	2.2	
RUN5_T072_Ptarmigan	72	73.4	2.1	
RUN5_T072helo	72	103.8	1.5	
RUN5_T120_Ptarmigan	120	101.5	1.5	
RUN5_T163_Ptarmigan	163	134.4	1.2	
RUN5_T180_Ptarmigan	180	154.3	1.0	
RUN5_T221_Ptarmigan	221	121.7	1.3	
RUN5_T482_Ptarmigan	482	134.2	1.2	
RUN5_T490_Ptarmigan	490	110.4	1.4	
RUN5_T500_Ptarmigan	500	127.8	1.2	
RUN5_T555helo	555	156.9	1.0	
RUN5_T849_Ptarmigan	849	113.7	0.3	

APPENDIX K – WATER, OIL, HERDER AND RESIDUE MEASUREMENTS

Table K-1: Run Set-Up

Test	Herder	Air T (°C)	Water (T°C)	IFT Reading	ANS Nominal Volume (L)
Test 1	OP-40	6	5.5	72.3	95

Test	Herder	Air T (°C)	Water (T°C)	IFT Reading	ANS Nominal Volume (L)
Test 2	OP-40	10	NR	72.2	95

Test	Herder	Air T (°C)	Water (T°C)	IFT Reading	ANS Nominal Volume (L)
Test 3	OP-40	13	NR	69.1	190

Test	Herder	Air T (°C)	Water (T°C)	IFT Reading	ANS Nominal Volume (L)
Test 4	TS6535	12	NR	65	190

Test	Herder	Air T (°C)	Water (T°C)	IFT Reading	ANS Nominal Volume (L)
Test 5	TS6535	13	8.5	69.3	190

Table K-2: Oil Quantity Calculations

TEST 1	Fresh ANS Bucket Weights (kg)										Totals	
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	Weight (kg)	Volume (L)
Gross	11.95	13.4	14.7	12.92	14.98							
Tare	1.32	1.32	1.32	1.24	1.26							
Net	10.63	12.08	13.38	11.68	13.72	0	0	0	0	0	61.49	70.35

TEST 2	Fresh ANS Bucket Weights (kg)										Totals	
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10		
Gross	14.44	14.52	14.48	14.44	14.46							
Tare	1.32	1.39	1.28	1.28	1.3							
Net	13.12	13.13	13.2	13.16	13.16	0	0	0	0	0	65.77	75.25

TEST 3	Fresh ANS Bucket Weights (kg)										Totals	
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10		
Gross	14.4	14.12	14.48	14.88	14.4	14.68	14.38	14.62	14.12	15.08		
Tare	1.3	1.3	1.34	1.26	1.34	1.3	1.32	1.34	1.3	1.44		
Net	13.1	12.82	13.14	13.62	13.06	13.38	13.06	13.28	12.82	13.64	131.92	150.94

TEST 4	Fresh ANS Bucket Weights (kg)										Totals	
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10		
Gross	14.66	14.7	14.78	15.06	15.06	13.82	14.7	15.04	14.88	15.18		
Tare	1.3	1.34	1.34	1.28	1.28	1.26	1.34	1.34	1.3	1.32		
Net	13.36	13.36	13.44	13.78	13.78	12.56	13.36	13.7	13.58	13.86	134.78	154.21

TEST 5	Fresh ANS Bucket Weights (kg)										Totals	
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10		
Gross	14.38	14.98	14.88	14.8	14.7	15.14	15.28	14.56	14.74	14.8		
Tare	1.38	1.3	1.3	1.26	1.32	1.26	1.32	1.3	1.28	1.34		
Net	13	13.68	13.58	13.54	13.38	13.88	13.96	13.26	13.46	13.46	135.20	154.69

Table K-3: Applied Herder Quantity Calculations

Test 1	Herder Weights (kg)			Total
	Helicopter	Hand Spray #1	Hand Spray #2	
Gross	22.08	2.16	2.68	
Tare	7.16	1.94	1.48	
Net	11.14	0.22	1.20	12.56

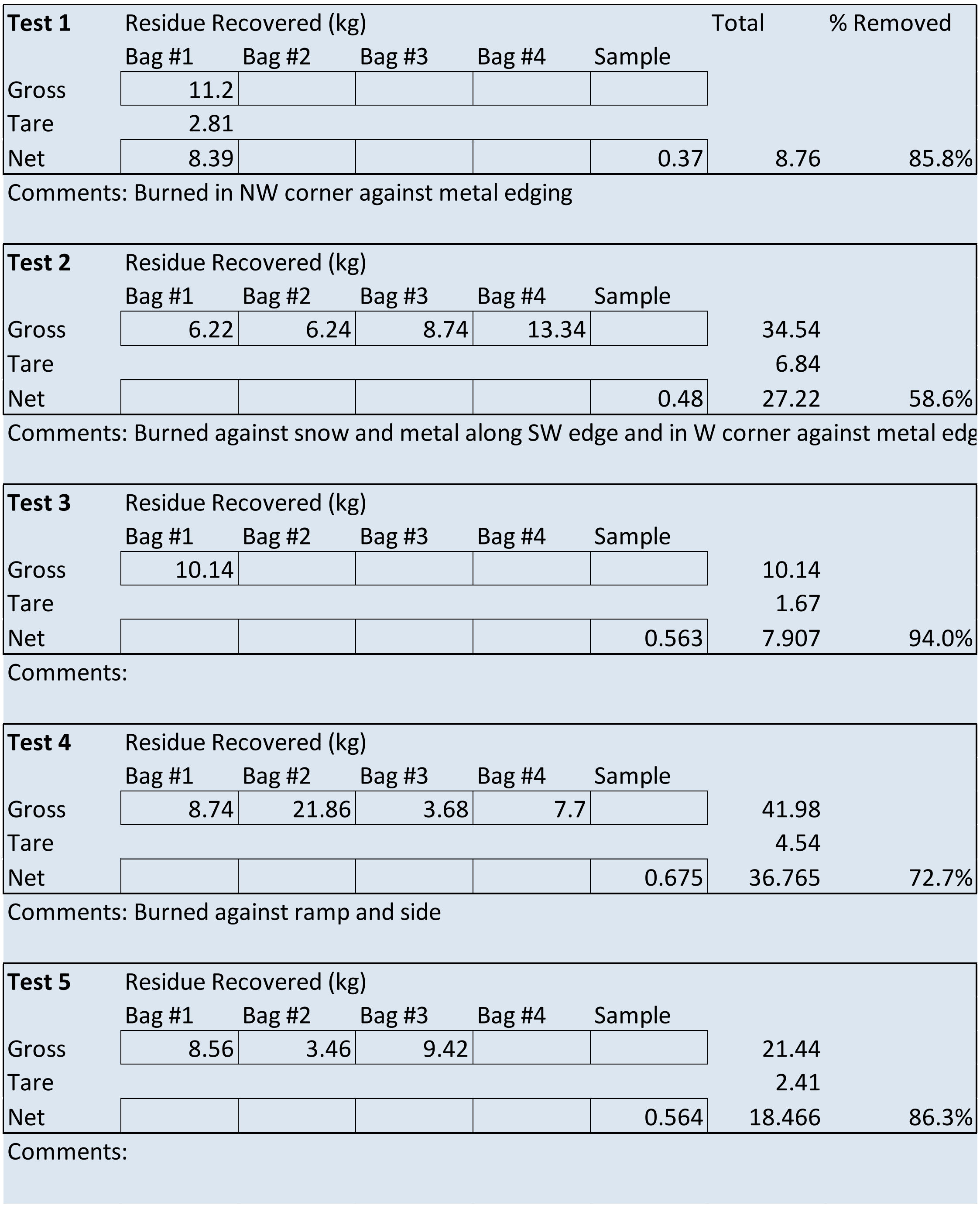
Test 2	Herder Weights (kg)			Total
	Helicopter	Hand Spray #1	Hand Spray #2	
Gross		3.14	3.06	
Tare		3.06	2.6	
Net	4	0.08	0.46	4.54

Test 3	Herder Weights (kg)			Total
	Helicopter	Hand Spray #1	Hand Spray #2	
Gross		3.06	2.6	
Tare		2.9	2.14	
Net	4	0.16	0.46	4.62

Test 4	Herder Weights (kg)			Total
	Helicopter	Hand Spray #3	Hand Spray #4	
Gross		2.92	3.28	
Tare		2.92	2.22	
Net	≈0	0.00	1.06	1.06

Test 5	Herder Weights (kg)			Total
	Helicopter	Hand Spray #3	Hand Spray #4	
Gross		2.96	2.22	
Tare		2.56	2.22	
Net	4	0.40	0.00	4.40

Table K-4: Recovered Residue Quantity Calculations



Test 1	Residue Recovered (kg)					Total	% Removed
	Bag #1	Bag #2	Bag #3	Bag #4	Sample		
Gross	11.2						
Tare	2.81						
Net	8.39				0.37	8.76	85.8%

Comments: Burned in NW corner against metal edging

Test 2	Residue Recovered (kg)						
	Bag #1	Bag #2	Bag #3	Bag #4	Sample		
Gross	6.22	6.24	8.74	13.34		34.54	
Tare						6.84	
Net					0.48	27.22	58.6%

Comments: Burned against snow and metal along SW edge and in W corner against metal edg

Test 3	Residue Recovered (kg)						
	Bag #1	Bag #2	Bag #3	Bag #4	Sample		
Gross	10.14					10.14	
Tare						1.67	
Net					0.563	7.907	94.0%

Comments:

Test 4	Residue Recovered (kg)						
	Bag #1	Bag #2	Bag #3	Bag #4	Sample		
Gross	8.74	21.86	3.68	7.7		41.98	
Tare						4.54	
Net					0.675	36.765	72.7%

Comments: Burned against ramp and side

Test 5	Residue Recovered (kg)						
	Bag #1	Bag #2	Bag #3	Bag #4	Sample		
Gross	8.56	3.46	9.42			21.44	
Tare						2.41	
Net					0.564	18.466	86.3%

Comments: