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National Petroleum Reserve in Alaska: Legacy Wells Summary Report

By

Terra Meares

Submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Environmental Assessment

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Approved by advisory committee:

Dr. Waverly Kallestad, Chair

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ABSTRACT

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National Petroleum Reserve in Alaska: Legacy Wells Summary Report.

Between 1944 and 1982, the United States Navy (Navy) and the United States Geological Survey (USGS) drilled a total of 136 on-shore core and test wells within what is referred to today as the National Petroleum Reserve in Alaska (NPR-A), an area set aside for oil and gas exploration shortly after World War I. The 136 wells vary in site features and complexity, depending upon when the well was drilled, and can include cellars, drilling pads, and reserve pits. Upon completion of these programs, materials and debris indicative of past activities were left behind, along with scars in the delicate tundra. The NPR-A is an area consisting of nearly 23 million acres of Alaska's wilderness, a crucial habitat for caribou, polar bears, grizzly bears, and many species of raptors and other waterfowl that rely on the lands for summer migration and nesting. Additionally, local native communities rely heavily on subsistence hunting, fishing and whaling throughout the NPR-A. Each of the 136 wells, now termed legacy wells, require a thorough risk characterization due to their potential for adverse effects to human and environmental health from past oil drilling and exploration activity.

The focus of this report includes adding more precise well coordinates, defining well site boundaries, thoroughly evaluating analytical data and historical records, as well as reviewing updated site inspections and remediation efforts. This report will supply the information necessary to produce a strategic plan, obtain funds and, potentially technical assistance, in the ongoing cleanup of these wells. An overall environmental risk assessment was conducted that considered the collected data from each site. There were two main environmental risk assessments performed: surface risks and subsurface risks. Conditions that resulted in a high *surface* risk included known contaminants above Method Two Arctic Zone state cleanup levels, the potential threat from accelerated coastal erosion, significant solid waste present affecting visual resources or public safety, and/or the potential to affect air or water quality due to the discharge of hydrocarbons under pressure. A well or core test was assigned a high *subsurface* risk if there was evidence of leaking hydrocarbons, and/or if the well or core test penetrated oil or gas stratigraphy.

Of the 136 wells 81 require no additional action, 18 wells are in use by the USGS for temperature monitoring, and 3 wells are being monitored by the BLM. The remaining 34 wells currently require attention in the form of surface remediation and/or plugging of the well. Some sites exhibited extensive surface debris, were threatened from coastal erosion (with potential of releasing contaminants into the surrounding environment), or had remains of an extensive underground refrigerant system of pipes (containing unknown amounts of diesel fuel).

There is still not enough substantial information available on potential contaminants related to previous drilling operations and actions at the majority of the legacy wells in order to produce a comprehensive assessment, however this summary report has identified a clear data gap. Future opportunities include producing site maps of known surface debris, burial sites, and locations of past and/or present spills, as well as breach locations from the reserve pits. Sampling plans can then be produced and executed for each of the well sites exhibiting a low surface risk or greater. The results can then be added to this current summary report in order to both reassess the site risks, update the status of the sites, and to continue the overall efforts in managing the legacy wells.

ACKNOWLEDGEMENTS

I would first like to thank my graduate advisor Dr. Waverly Kallestad of the Department of Forestry and Environmental Resources at North Carolina State University. Having just moved to the state of Alaska at the beginning of my program, I was exceedingly fortunate to have Dr. Kallestad instill her immense knowledge and experience of the state and the oil industry to me, for which I would soon find myself deeply immersed in. She consistently allowed this paper to be my own work, but steered me in the right direction whenever she thought I needed it.

I would also like to thank the entire Bureau of Land Management (BLM) staff that assisted me in this project, with a special acknowledgement to Stacie McIntosh, Rob Brumbaugh and Don Meares, who bestowed upon me their endless wisdom of the legacy wells and entrusted me with this task. To Donna Wixon who gave me a chance and welcomed me into the best office BLM has to offer, and for her continuous support throughout the years. To Melody Debenham who was my trusted resource and confidant of all things well related, and to Lonnie Bryant who I depended on for laughter and general amusement to get through the day. Without the passionate participations and input from the BLM staff, this project would not have been successful.

I would also like to acknowledge Dr. Patterson, Alumni Distinguished Professor of Crop Science at North Carolina State University. Dr. Patterson was my undergraduate advisor who directed my path and challenged my thinking along the way. Never have I met a professor who so dedicated his life and career to his students. Dr. Patterson would be thoroughly impressed by the weight of this report.

Lastly, but certainly not the least, I must express my very profound gratitude to my boys, Matt Meares (loving husband) and Emerson and Briar (cherished sons) for providing me with unfailing support and continuous encouragement throughout my years of study and through the perpetual process of this project and in earning my degree. This accomplishment would not have been possible without them. Thank you.

Terra Meares

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1. Introduction

Alaska is the largest state in the U.S., encompassing nearly 345 million acres of land. The state is divided into six geographical regions with diverse climates and topography. Northern Alaska, referred to as the Arctic Slope, or the North Slope, begins just north of the Brooks Range and extends to the Arctic Ocean, north of the Arctic Circle. The land consists of coastal plains made of soft spongy tundra, covered in mosses and lichens, and is devoid of any trees, except for stunted willow. The earth is permanently frozen to a depth of roughly 1,000 feet, the permafrost, which prevents drainage, giving rise to wetlands when the surface ice and snow melts. Temperatures average around -17°F in the winter and only 40°F in the summers, however, there is very little precipitation and, thus, the area is considered a desert (Naske and Slotnick, 1979). In addition to the cold, winters are dark, in fact the northernmost community of Utqiaġvik (formerly known as Barrow) sees about 65 days of darkness. These are followed by long summers with extended daylight. Despite the harsh environment, wildlife is abundant and flourishing in the Arctic. The area is home to herds of caribou, musk oxen, moose, wolves, wolverines, fox, polar bears, grizzly bears, Dall mountain sheep, and many species of raptors and other waterfowl that rely on the lands for summer migration and nesting (Gryc, 1985). Evidence of early inhabitants date back at least 8,000 years, and communities of native populations continue to preserve the historical heritage of their ancestors even today. These villages blend modern conveniences with cultural traditions, where subsistence hunting, fishing and whaling continue to play an important role in the local economy. The scattered evidence of oil and gas exploration over the last 100 years have contributed to pollution of some of Alaska's pristine wilderness.

Natives and early settlers of Alaska relied on whale oil as fuel for heating however, the increased costs associated with supply shortages led to a search for an alternative source that was more abundant: petroleum (Gryc, 1985). In 1917, Alexander Malcolm (Sandy) Smith was believed to be the first white man to identify a natural oil seep in the North Slope, later sought out by Harry A. Campbell for a private company, upon which the first claims were staked (Reed, 1958). In 1923, after World War I, it was determined that the United States Navy (U.S. Navy) would require a substantial amount of petroleum products, thus President Harding declared by executive order an area of nearly 23 million acres in the northern slopes of Alaska as the Nation's fourth National Petroleum Reserve (NPR-4). Following the executive order, an exploratory program was led by the United States Geological Survey (USGS) to conduct an extensive investigation into the geology and topography of the lands, however, interest did not fully pick up until during World War II when Naval Reserve officer W. T. Foran formally addressed the need to understand the petroleum potentials within the NPR-4. Lieutenant Foran was assigned a small reconnaissance party in March of 1944 to examine the petroleum potential, signifying the beginning of the exploration program now known as 'Pet-4' (Reed, 1958). Early exploration and drilling programs have resulted in scarification of the delicate tundra, disturbances to wildlife activities and subsistence culture, and most notably contamination from millions of pounds of debris, rusted equipment, and hazardous drilling materials left behind and dispersed throughout the vast state (Hok, 1969; Husky Oil NPR Operations[1], n.d.; Husky Oil NPR Operations[2], n.d.; Husky Oil NPR Operations[3], n.d.; Gryc, 1988).

Between 1944 and 1982, the U.S. Navy and the USGS drilled a total of 136 on-shore core and test wells (shallow stratigraphic or foundation wells and deep potential production wells respectively) within the NPR-4 during two exploration periods, before the first Federal lease sale in 1982. These initial wells are now termed legacy wells (Brumbaugh and Porhola, 2004). During the first exploration program, between 1944 and 1953, the U.S. Navy and the USGS were continually learning about conducting activity in the harsh and remote areas of Alaska, therefore early drilling operations varied between sites and were inconsistent and highly unregulated. According to Hanley et al. (1981), "Most regulation before 1970 was related to technical aspects of well drilling, production, and abandonment procedures, not surface protection of the land." In 1953, the Director of Naval Petroleum and Oil Shale Reserves, the Secretary of the U.S. Navy, and the Committee on Armed Services of the House of Representatives ended the program, cutting all funds, which resulted in the immediate departure of the U.S. Navy from the field (Reed, 1958). Between 1953 and 1974, the United States Air Force and the North Slope Borough (in cooperation with the U.S. Navy) drilled a total of 8 wells in the South Barrow natural gas field, in order to replace the South Barrow 2 well that supplied gas for the Barrow base camp, but was destroyed by a fire. It wasn't until the second exploration program, beginning in 1974 when concern for the environment began to be addressed during operations, due to the regulatory agencies and acts put in place by Congress and the administration under President Nixon, including the National Environmental Policy Act (NEPA) in 1969, the Environmental Protection Agency (EPA) in 1970, and the Endangered Species Act (ESA) in 1973. The U.S. Navy began operations for a year, and then contracted the program to Husky Oil NPR Operations, Inc. (Husky). However, in 1976, when the Naval Petroleum Reserves Production Act (Public Law 94-258) was enacted, the NPR-4 was renamed the National Petroleum Reserve in Alaska (NPR-A), and the responsibilities were transferred from the U.S. Navy to the Secretary of the Interior, which were then assigned to the USGS (Gryc, 1985). In total, 37 of the legacy wells were drilled during the second exploration program. These wells differ from the earlier operations in that the wells contain pads (thin, thick, or all-season) for equipment stabilization and permafrost protection, as well as pits (reserves and flares). Many of the operations within the NPR-A were exploratory wells, drilled at varying depths to gather detailed information on the geological formations across the state, with the purpose of finding potential sources of oil and gas, as well as for gaining a better understanding of the depositional history (Gryc, 1985). This 2018 National Petroleum Reserve in Alaska: Legacy Wells Summary Report is an extensive report detailing the 136 legacy wells, including history, site characterization, previous cleanup projects, current status, and future recommendations to identify the potential risks associated with these wells.

Timeline – Legacy Wells

1923: President Warren G. Harding establishes the NPR-4[1]

1944-1952: The USN[2] drills 91 wells in the NPR-4.

1953-1975: The USN drills 8 additional wells near Barrow in support of the Barrow Gas Field development.

1959: Alaska declared the 49th state.

1968: The largest oil strike in the U.S. discovered in Prudhoe Bay.

1970: NEPA[3] signed into law requiring federal agencies to assess environmental effects of their proposed actions prior to making decisions.

EPA[4] established to ensure environmental protection.

1973: ESA[5] passes in order to conserve and protect endangered species.

1976: The NPRPA[6] of 1976 renames the NPR-4 as the NPR-A[7], and orders the transfer of jurisdiction over the reserve from the Secretary of the Navy to the Secretary of the Interior.

1977: The BLM[8] and USGS[9] enter into an MOU[10] giving USGS exclusive jurisdiction over the South Barrow Gas Field, specifying the BLM and USGS share management of the surface areas of operations. The MOU designated the USGS manager of the continuing exploration program during the interim period upon transfer of jurisdiction from the USN to the DOI[11].

1975-1982: The USN and USGS drill 37 wells through a contract with Husky Oil Company.

1980: The NPRPA is amended to direct an expedited program of leasing.

1981: The BLM conveys the W.T. Foran well to the ASRC[12].

1982: In January, the MMS[13] takes over the functions of oil and gas exploration and development from the USGS Conservation Division. In December, onshore minerals management functions are transferred to the BLM via Secretarial Order 3087.

The first BLM oil and gas lease sale is held for the NPR-A.

1984: The Barrow Gas Field Transfer Act transfers ownership responsibility of 19 Legacy Wells to the NSB[14].

1986: The BLM conveys Grandstand #1 well to the ASRC.

1995: The ADEC[15] issues final closures for 27 of the USGS reserve pits. ADEC issues one reserve pit (East Teshekpuk) conditional closure. BLM conveys Gubik #1 and Gubik #2 wells to the ASRC.

2002: Umiat #2 and Umiat #5 wells plugged by the USACE[16] under the oversight of the BLM at a cost of $25 million.

2003-2005: The BLM inspects and evaluates all 136 wells and uncased core test sites to determine the threat posted to human health, safety and the environment. The 2004 Legacy Wells Summary Report prioritized those sites with the most immediate need of corrective action.

2005-2017: The BLM conducts plugging and abandonment efforts of several high priority well sites identified in the 2004 and 2013 Legacy Wells Summary Reports.

[1] Naval Petroleum Reserve Number 4 or PET-4
[2] United States Navy
[3] National Environmental Policy Act
[4] Environmental Protection Agency
[5] Endangered Species Act
[6] Naval Petroleum Reserves Production Act
[7] National Petroleum Reserve in Alaska
[8] Bureau of Land Management
[9] United States Geological Survey
[10] Memorandum of Understanding
[11] Department of the Interior
[12] Arctic Slope Regional Corporation
[13] Minerals Management Service
[14] North Slope Borough
[15] Alaska State Department of Environmental Conservation
[16] United States Army Corps of Engineers

In general, the components of a well site usually included a drill rig, mud system, casing, wellhead, wellbore, cellar, rat hole, and flare pit, or a reserve pit, varying among sites and depending upon when the well was drilled (see Figure 1). Drill rigs were massive structures encompassing the equipment used for drilling the well, and were removed upon completion. The holes drilled by the rig bit (cutting device) are called wellbores, and may contain a casing, or steel pipe, that is cemented into the hole to prevent cave-ins, migration of fluids between rock formations, and contamination of oil and gas. The equipment installed on the surface of the wellbore is called the wellhead, which remains at many of the sites still today. Older wells usually contained some form of a cellar, which was essentially a pit in the ground surrounding the wellhead. Cellars were used to contain blowout preventers (BOPs), rat holes, mouse holes, drainage, and other fluids. Many of the newer sites contained various pits such as flare pits, fuel pits, and reserve pits. Flare pits were used to contain fluids present in the gas stream, and usually accompanied large reserve pits that held drilling muds and fluids (compared to older sites where the muds were placed directly on the tundra). In some cases, a lined fuel pit was created to store drums of fuel (Brumbaugh and McIntosh, 2013). Drilling muds (also termed drilling fluids) were essential to the operation in that they were specially formulated to cool and lubricate the drill bit, reduce friction on the drill string, support the hole integrity, and assist in removing the rock particles (or cuttings) from the hole (Gryc, 1985).

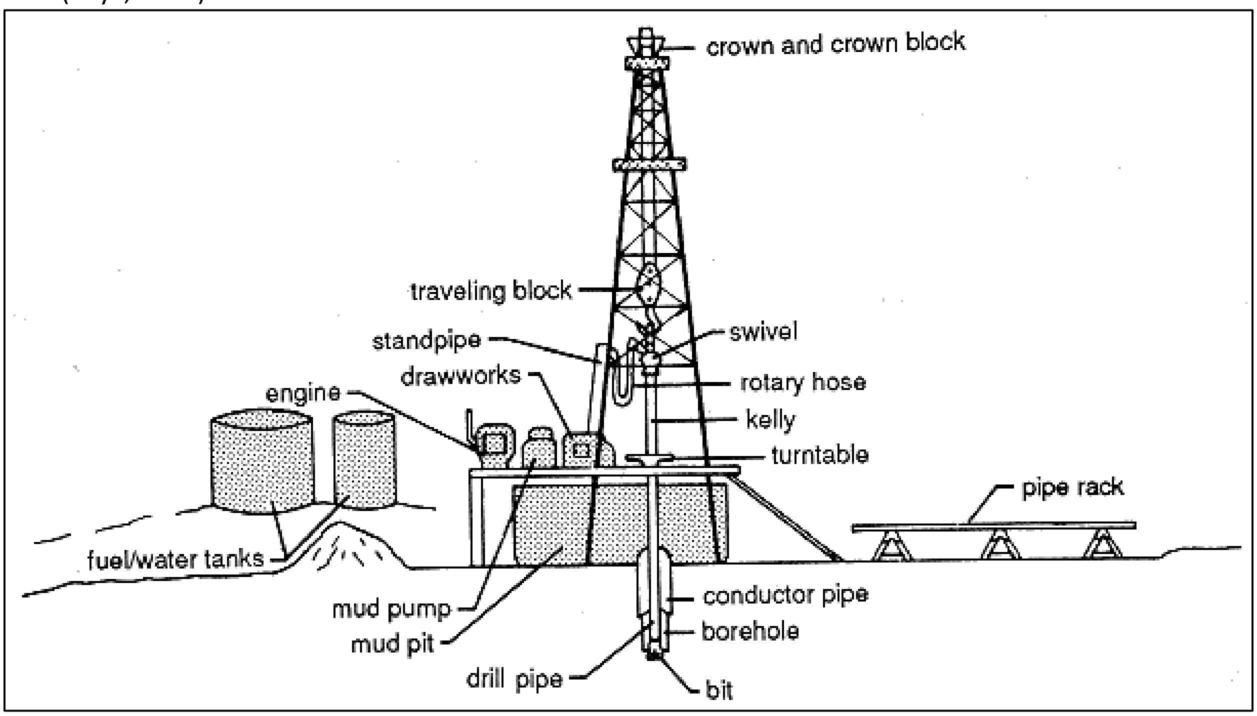
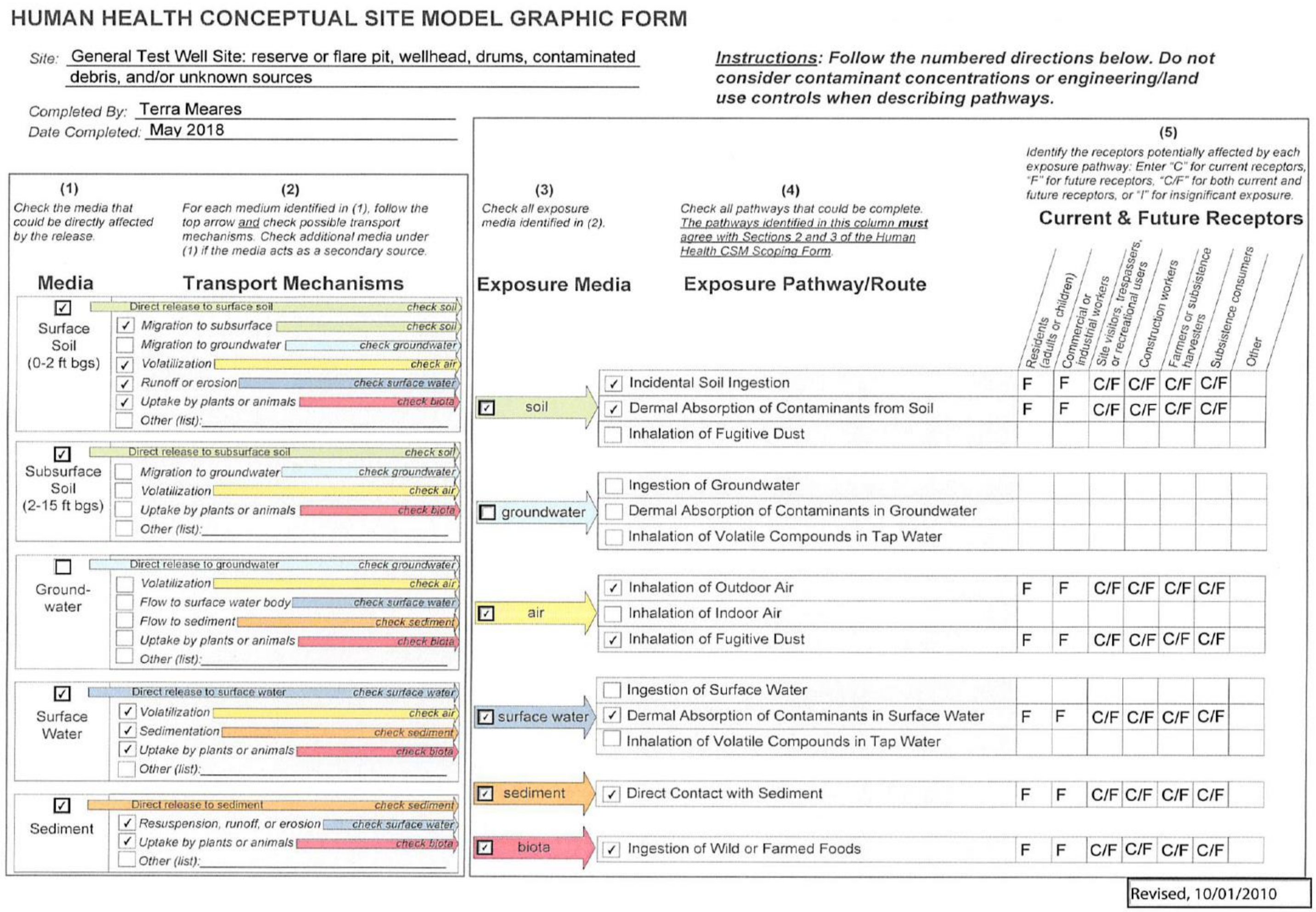


Figure 1: Major components of a drill rig. (Baars et al., Petroleum: A Primer for Kansas. Kansas Geological Survey. 1993)

There are three main types of drilling fluids (also called muds) used: water-based, oil-based, and synthetic. Water-based fluids contain an emulsion mixture of brine and small amounts of oil (lubricants) and thus tended to be less harmful to the environment, while oil-based fluids perform better in drilling operations, but contain diesel and mineral oils (Sadiq et al., 2004). The composition of fluids and cuttings from drilling can be of concern and may contain harmful components such as neat petroleum hydrocarbons (including the ecologically- and toxicologically-relevant polycyclic aromatic hydrocarbons [PAHs]), oil-based fluids (e.g., diesel or kerosene), metals occurring in drilling muds (e.g., Barium [Ba], a weighting agent, and co-occurring Cadmium [Cd], Mercury [Hg]) or additives and tracers (e.g., corrosion inhibiters, defoamers, emulsifiers, foaming agents, or nitrates). In fact, BTEX (benzene, toluene, ethylbenzene, and xylenes) are a group of Volatile Organic Compounds (VOCs) that are naturally occurring, and are commonly found in reserve pits, any oil based drilling mud, as well as in crude oil. BTEX compounds are known mutagens, carcinogens, and teratogens (Krzyzanowski, 2012). These compounds can cause neurological, renal, and hepatic effects in humans from oral or inhalation exposure (Broni-Bediako and Amorin, 2010). According to Krzyzanowski (2012), "All BTEX except for ethylbenzene are also suspected endocrine disruptors, affecting hormones, the nervous and immune systems, reproductive functions and fetal development, as well as numerous other tissues and organs." Benzene alone has been demonstrated to be a known human carcinogen due to animal and epidemiologic studies (Atari and Luginaah, 2009). Furthermore, barium and chromium (both heavy metals found in drilling fluids, barium intentionally present to serve as a weighting agent; chromium previously added when chromlignosulfonates were added for deflocculant purposes) can present serious health effects, depending on the type of exposure, including cancer to the lungs, bladder, kidneys, liver or pancreas (Atari and Luginaah, 2009). More importantly, heavy metals are dangerous due to their ability to persist in the environment and bioaccumulate within an organism, leading to increased health risks with increased exposure (Krzyzanowski, 2012).



HUMAN HEALTH CONCEPTUAL SITE MODEL GRAPHIC FORM

Site: General Test Well Site: reserve or flare pit, wellhead, drums, contaminated debris, and/or unknown sources

Completed By: Terra Meares
Date Completed: May 2018

***Instructions**: Follow the numbered directions below. Do not consider contaminant concentrations or engineering/land use controls when describing pathways.*

(1) Check the media that could be directly affected by the release.

(2) For each medium identified in (1), follow the top arrow and check possible transport mechanisms. Check additional media under (1) if the media acts as a secondary source.

(3) Check all exposure media identified in (2).

(4) Check all pathways that could be complete. The pathways identified in this column must agree with Sections 2 and 3 of the Human Health CSM Scoping Form.

(5) Identify the receptors potentially affected by each exposure pathway: Enter "C" for current receptors, "F" for future receptors, "C/F" for both current and future receptors, or "I" for insignificant exposure.

Media / Transport Mechanisms

☑ Surface Soil (0-2 ft bgs) — Direct release to surface soil — check soil
- ✓ Migration to subsurface — check soil
- ☐ Migration to groundwater — check groundwater
- ✓ Volatilization — check air
- ✓ Runoff or erosion — check surface water
- ✓ Uptake by plants or animals — check biota
- ☐ Other (list):

☑ Subsurface Soil (2-15 ft bgs) — Direct release to subsurface soil — check soil
- ☐ Migration to groundwater — check groundwater
- ☐ Volatilization — check air
- ☐ Uptake by plants or animals — check biota
- ☐ Other (list):

☐ Groundwater — Direct release to groundwater — check groundwater
- ☐ Volatilization — check air
- ☐ Flow to surface water body — check surface water
- ☐ Flow to sediment — check sediment
- ☐ Uptake by plants or animals — check biota
- ☐ Other (list):

☑ Surface Water — Direct release to surface water — check surface water
- ✓ Volatilization — check air
- ✓ Sedimentation — check sediment
- ✓ Uptake by plants or animals — check biota
- ☐ Other (list):

☑ Sediment — Direct release to sediment — check sediment
- ✓ Resuspension, runoff, or erosion — check surface water
- ✓ Uptake by plants or animals — check biota
- ☐ Other (list):

Current & Future Receptors

Exposure Media	Exposure Pathway/Route	Residents (adults or children)	Commercial or industrial workers	Site visitors, trespassers, or recreational users	Construction workers	Farmers or subsistence harvesters	Subsistence consumers	Other
☑ soil	✓ Incidental Soil Ingestion	F	F	C/F	C/F	C/F	C/F	
	✓ Dermal Absorption of Contaminants from Soil	F	F	C/F	C/F	C/F	C/F	
	☐ Inhalation of Fugitive Dust							
☐ groundwater	☐ Ingestion of Groundwater							
	☐ Dermal Absorption of Contaminants in Groundwater							
	☐ Inhalation of Volatile Compounds in Tap Water							
☑ air	✓ Inhalation of Outdoor Air	F	F	C/F	C/F	C/F	C/F	
	☐ Inhalation of Indoor Air							
	✓ Inhalation of Fugitive Dust	F	F	C/F	C/F	C/F	C/F	
☑ surface water	☐ Ingestion of Surface Water							
	✓ Dermal Absorption of Contaminants in Surface Water	F	F	C/F	C/F	C/F	C/F	
	☐ Inhalation of Volatile Compounds in Tap Water							
☑ sediment	✓ Direct Contact with Sediment	F	F	C/F	C/F	C/F	C/F	
☑ biota	✓ Ingestion of Wild or Farmed Foods	F	F	C/F	C/F	C/F	C/F	

Revised, 10/01/2010

Figure 2: Example of Conceptual Site Model identifying potential exposure pathways, however due to the varying locations and characteristics of each test well, each site would have differing exposure pathways and receptors.

In addition to the wells themselves, vehicles and construction equipment were used to create giant pads that formed the base of the drilling activity, roads for travelling the long distances between sites, as well as temporary camps and offices to house crew in these remote locations during the long seasons of operations. Due to the soft, spongy tundra that spans the majority of the NPR-A, the bulk of the work had to be conducted during the frigid winters when the tundra was frozen. The trails, called 'old tractor trails' in reports, along with the pads and reserve pits have permanently scarred the tundra, and many are clearly identifiable (especially via aerial viewing or satellite imagery), due to a lack of revegetation. Additionally, drilling muds left on the Arctic tundra have been known to alter the soil salinity, thus impacting the local flora and fauna regrowth within those areas (Johnstone and Kokelj, 2008). The combination of mechanical disturbance to the tundra and chemical contamination from oil exploration, termed chemical technopedogenesis, can severely impact the environment. According to Zamotaev et al. (2015) "The most intensive chemical disturbances and mechanical transformations of soil profiles are observed in the regions of extraction of minerals, including raw hydrocarbons" and that this "results in the development of technogenically altered and chemically modified soils, whose degree of contamination is estimated as extremely hazardous according to the current standards." Furthermore, all of this activity required a substantial amount of diesel fuel, which is evident by the millions of drums that remain stockpiled, buried, and scattered throughout the NPR-A, along with the substantial refuse leftover from past exploration. For example, in the early 1950's a first line of defense radar system, known as the Defense Early Warning (DEW) Line System was constructed across the northern coast of the Arctic along Alaska and Canada (for North America) and into Greenland (DOWL Engineers, 1992). Skull Cliff was the location of a Long Range Navigation (LORAN) radio tower as part of the DEWLine System, located on the coast of the Chuchki Sea just 30 miles southwest of Utqiaġvik (formerly known as Barrow). The site was also the location of the Legacy Well aptly named the Skull Cliff Core Test #1. This site alone contains over 4 million pounds of buried debris that was collected from nearby wells and old seismic camps by Husky during their cleanup programs (Schindler and Smith, 1983). The waste was initially stockpiled on the beach to be barged off, however it was later determined that burying the waste 1 mile inland would be more economically feasible, due to similar success at other well sites. There are numerous burial sites, such as those at Skull Cliff, throughout the NPR-A that have not been assessed (through sampling) to determine if there is any leaching of contamination from the buried waste, nor have the reserve pits been reexamined for current standards of safety (the majority were closed according to Alaska state regulations set in the early 1990s). Cleanup efforts have been conducted throughout the NPR-A since the 1970s and continue to this day.

In 1976, the Federal Government assigned to the Bureau of Land Management (BLM) the responsibility of managing the NPR-A, and then in 1982 to cleanup, plug, and abandon legacy wells, with the intent of limiting the potential for adverse effects on humans and/or the environment. This report will supply the information necessary to produce a strategic plan, obtain funds and, potentially technical assistance, in the ongoing cleanup of these wells. The report identifies the risk characterization of each Legacy Well location, due to the potential for adverse effects to human and environmental health from oil drilling and exploration activity. There is an extensive amount of information known about the wells that were drilled (including drilling pads, reserve pits, and USGS monitoring stations). There is also a general idea of the types of waste located at each site, and previous cleanup activities.

Table 1: *NPR-A Legacy Wells – Well Information Summary*

Well Name	#	LAT	LONG	Year Spud	Plugged	Wellhead	Land Conveyed	USGS Monitor Station	Last Inspection
Arcon Barrow	1	71.328	-156.668	1947	Yes				2016
Atigaru Point	1	70.556	-151.717	1977	Yes		ASRC / Kuukpik		2013
Avak	1	71.251	-156.468	1951	Yes				2016
Awuna	1	69.148	-158.024	1980		Yes		Yes	2011
Barrow Big Rig	1	71.329	-156.668	1944			NSB		2012
Barrow Core Rig Test	1	71.324	-156.651	1944			NSB		2012
Barrow Core Rig Test	2	71.317	-156.650	1944	Yes		NSB		2016
Cape Halkett	1	70.767	-152.466	1975					2010
Drew Point	1	70.880	-153.900	1978	Yes				2013
East Oumalik	1	69.791	-155.544	1950					2016
East Simpson	1	70.918	-154.618	1979		Yes		Yes	2012
East Simpson	2	70.978	-154.674	1980		Yes		Yes	2012
East Teshekpuk	1	70.569	-152.943	1976	Yes				2012
East Topagoruk	1	70.577	-155.373	1951					2016
Fish Creek	1	70.311	-151.870	1949		Yes			2016
Grandstand	1	68.966	-151.917	1952			ASRC		2003
Gubik	1	69.423	-151.447	1951			ASRC		2015
Gubik	2	69.431	-151.438	1951		Yes	ASRC		2015
Iko Bay	1	71.170	-156.167	1975		Yes			2017
Ikpikpuk	1	70.456	-154.333	1978		Yes		Yes	2017
Ikpikpuk Core	1	69.827	-155.399	1947					2012
Inigok	1	70.000	-153.095	1978		Yes			2016
J. W. Dalton	1	70.920	-153.138	1979	Yes				2011
Kaolak	1	69.933	-160.248	1951					2012
Knifeblade	1	69.151	-154.889	1951					2016
Knifeblade	2	69.139	-154.737	1951					2016
Knifeblade	2A	69.123	-154.734	1951					2016
Koluktak	1	69.770	-154.531	1981		Yes		Yes	2012
Kugrua	1	70.587	-158.662	1978		Yes		Yes	2012
Kuyanak	1	70.933	-156.032	1981		Yes		Yes	2012
Lisburne	1	68.478	-155.651	1979		Yes	ASRC	Yes	2011
Meade	1	70.042	-157.490	1950					2012
Minga Velocity	1	70.983	-154.743	1950					2013
North Inigok	1	70.258	-152.766	1981		Yes		Yes	2011
North Kalikpik	1	70.509	-152.368	1978		Yes		Yes	2017
North Simpson	1	71.057	-154.957	1950		Yes			2017
Oumalik	1	69.842	-155.971	1949					2016
Oumalik Core Foundation Test	1	69.000	-155.000	1948					2012
Oumalik Core Foundation Test	2	69.000	-155.000	1948					2012
Oumalik Core Foundation Test	3	69.000	-155.000	1948					2012
Oumalik Core Foundation Test	4	69.000	-155.000	1948					2012
Oumalik Core Foundation Test	5	69.000	-155.000	1948					2012
Oumalik Core Foundation Test	6	69.000	-155.000	1948					2012
Oumalik Core Foundation Test	7	69.000	-155.000	1948					2012

Well Name	#	LAT	LONG	Year Spud	Plugged	Wellhead	Land Conveyed	USGS Monitor Station	Last Inspection
Oumalik Core Foundation Test	8	69.000	-155.000	1948					2012
Oumalik Core Foundation Test	9	69.000	-155.000	1948					2012
Oumalik Core Foundation Test	10	69.000	-155.000	1948					2012
Oumalik Core Test	1	69.829	-155.696	1947					2012
Oumalik Core Test	2	69.838	-155.990	1947					2012
Oumalik Core Test	11	69.838	-155.990	1949					2012
Oumalik Core Test	12	69.829	-155.696	1949					2012
Peard	1	70.716	-159.001	1979		Yes		Yes	2012
Seabee	1	69.380	-152.173	1979		Yes		Yes	2016
Sentinel Hill Core Test	1	60.602	-157.450	1947		Yes			2013
Simpson	1	70.953	-155.364	1947					2017
Simpson Core Test	1	70.928	-155.289	1945					2012
Simpson Core Test	2	70.928	-155.292	1945					2012
Simpson Core Test	3	70.927	-155.292	1945					2012
Simpson Core Test	4	70.929	-155.264	1945					2012
Simpson Core Test	5	70.938	-155.279	1945					2012
Simpson Core Test	6	70.933	-155.309	1945					2012
Simpson Core Test	7	70.930	-155.303	1945					2012
Simpson Core Test	8	70.945	-155.294	1945					2012
Simpson Core Test	9	70.945	-155.292	1945					2012
Simpson Core Test	10	70.962	-155.292	1945					2012
Simpson Core Test	11	70.980	-155.292	1945					2012
Simpson Core Test	12	70.972	-155.292	1945					2012
Simpson Core Test	13	70.983	-154.645	1945	Yes				2017
Simpson Core Test	14	70.987	-154.627	1949	Yes				2017
Simpson Core Test	14 A	70.987	-154.627	1949	Yes				2017
Simpson Core Test	15	70.985	-154.636	1949	Yes				2017
Simpson Core Test	16	70.983	-154.631	1949					2012
Simpson Core Test	17	70.987	-154.643	1949					2012
Simpson Core Test	18	70.994	-154.670	1949					2012
Simpson Core Test	19	70.988	-154.716	1949					2012
Simpson Core Test	20	70.997	-154.589	1949					2012
Simpson Core Test	21	70.997	-154.589	1949					2012
Simpson Core Test	22	70.992	-154.604	1949					2012
Simpson Core Test	23	71.034	-154.634	1949					2012
Simpson Core Test	24	71.029	-154.617	1949					2012
Simpson Core Test	25	70.936	-154.703	1950					2012
Simpson Core Test	26	70.936	-154.684	1950	Yes				2017
Simpson Core Test	27	70.935	-154.668	1951	Yes				2017
Simpson Core Test	28	70.993	-154.671	1950	Yes				2017
Simpson Core Test	29	70.930	-154.692	1950	Yes				2017
Simpson Core Test	30	70.931	-154.676	1950	Yes				2017
Simpson Core Test	30 A	70.930	-154.681	1951	Yes				2017
Simpson Core Test	31	70.956	-154.629	1951	Yes				2017
Skull Cliff Core Test	1	70.900	-157.600	1947					2017
South Barrow	1	71.320	-156.704	1948	Yes		NSB		2016
South Barrow	2	71.262	-156.634	1948	Yes	Yes	NSB		2016

Well Name	#	LAT	LONG	Year Spud	Plugged	Wellhead	Land Conveyed	USGS Monitor Station	Last Inspection
South Barrow	3	71.158	-156.567	1949	Yes		NSB		2017
South Barrow	4	71.264	-156.631	1950		Yes	NSB		
South Barrow	5	71.264	-156.631	1955	Yes	Yes	NSB		
South Barrow	6	71.262	-156.615	1964	Yes	Yes	NSB		
South Barrow	7	71.251	-156.338	1968	Yes	Yes	NSB		
South Barrow	8	71.265	-156.592	1969	Yes	Yes	NSB		
South Barrow	9	71.268	-156.615	1970	Yes	Yes	NSB		
South Barrow	10	71.259	-156.626	1973	Yes	Yes	NSB		
South Barrow	11	71.257	-156.607	1974	Yes	Yes	NSB		
South Barrow	12	71.237	-156.338	1974	Yes	Yes	NSB		
South Barrow	13	71.237	-156.338	1976	Yes	Yes	NSB		
South Barrow	14	71.237	-156.338	1977	Yes	Yes	NSB		
South Barrow	15	71.237	-156.338	1980	Yes	Yes	NSB		
South Barrow	16	71.237	-156.338	1978		Yes	NSB		
South Barrow	17	71.237	-156.338	1978	Yes	Yes	NSB		
South Barrow	18	71.282	-156.546	1980	Yes	Yes	NSB		
South Barrow	19	71.282	-156.546	1978	Yes	Yes	NSB		
South Barrow	20	71.282	-156.546	1980	Yes	Yes	NSB		
South Harrison Bay	1	70.425	-151.731	1976		Yes		Yes	2012
South Meade	1	70.606	-156.876	1978		Yes		Yes	2011
South Simpson	1	70.807	-154.982	1977		Yes			2010
Square Lake	1	69.567	-153.300	1952	Yes				2017
Titaluk	1	69.423	-154.568	1951	Yes				2017
Topagoruk	1	70.625	-155.893	1950					2013
Tulageak	1	71.189	-155.709	1981		Yes		Yes	2017
Tunalik	1	70.197	-161.072	1978	Yes	Yes		Yes	2010
Umiat	1	69.396	-152.328	1945	Yes				2017
Umiat	2	69.382	-152.083	1947	Yes				2012
Umiat	3	69.387	-152.085	1946	Yes				2015
Umiat	4	69.388	-152.079	1950	Yes				2015
Umiat	5	69.384	-152.080	1950	Yes				2012
Umiat	6	69.378	-152.092	1950	Yes				2015
Umiat	7	69.375	-152.101	1950	Yes				2012
Umiat	8	69.399	-152.115	1951	Yes				2015
Umiat	9	69.386	-152.167	1951	Yes				2017
Umiat	10	69.400	-152.117	1951	Yes				2015
Umiat	11	69.124	-152.097	1952	Yes				2017
W. T. Foran	1	70.832	-152.303	1977	Yes	Yes	ASRC		2010
Walakpa	1	71.099	-156.886	1979	Yes	Yes	NSB		
Walakpa	2	71.050	-156.952	1981	Yes	Yes	NSB		
West Dease	1	71.159	-155.631	1980		Yes		Yes	2017
West Fish Creek	1	70.327	-152.061	1977		Yes		Yes	2012
Wolf Creek	1	69.386	-153.521	1951	Yes				2018
Wolf Creek	2	69.405	-153.521	1951	Yes				2018
Wolf Creek	3	69.386	-153.524	1952	Yes				2018

Current regulations were examined when reviewing and analyzing data for this report to determine if the reserve pits should remain closed, or if there is still potential harm from the pits to the environment. Furthermore, each site has varying degrees of risk depending on location, extent of drill site (only wells drilled after 1974 contain reserve pits), and levels of debris and contamination (depending on whether or not waste was buried or shipped out). Because many of the Legacy Well sites are near villages, located in areas used for subsistence hunting, or are a threat to the environment due to erosion, each site was individually analyzed for all potential concerns. The purpose of this extensive summary report is to characterize the 136 legacy wells and to identify the potential risks associated with them, in order to set precedence of future plugging and remediation of the well sites.

2. Methods

2.1. History of well site

In this report, a historical records review was conducted detailing the site and previous drilling activity, most of which were illustrated in the Geological Survey Professional Papers, the 2013 Legacy Wells Summary Report, and various other government documents that discussed the drilling operations, equipment, and processes used during the initial construction of each of the wells.

2.2. Establish site characterization

Reports and analytical data were collected and reviewed to identify surface debris, buried debris, contaminants of concern, threats from erosion, and potential impacts to humans and the environment (water sources, wildlife habitat, subsistence activity and human activity, nearby communities, etc.). Site characteristics were used to define the area of operations or boundary for each site (i.e., what is included in and constitutes the overall 'well site').

2.3. Identification of cleanup activities

Previous cleanup projects were reviewed (from past to present day), including rehabilitation and revegetation programs, to determine the current level of debris, buried waste, and potential contaminants of concern and potential for exposure currently associated with each well site.

2.4. Classification of current site status

The current site status of each well site was addressed (through literature and data) to determine whether the well was currently being used as a United States Geological Survey (USGS) monitoring well (which contain diesel fuel remaining in top of the wellbore), if the well site had been transferred (e.g., to the North Slope Borough, thus, BLM is no longer responsible for), if the well had been excavated and removed, plugged and/or abandoned, or special requirements instructed by the Alaska State Historic Preservation Office (ASHPO) due to historical relevance. It was important to identify aspects of the well that establish ownership, indicate any specific closure conditions, or determine if the wells are still in use.

2.5. Determination of associated environmental risk

An overall environmental risk assessment was conducted that considered the collected data from each site. There were two main environmental risk assessments performed: surface risks and subsurface risks. Each risk assessment was assigned an overall rating of either high, moderate, low, or none depending on the level of risk. For the surface risk assessment, a rating level of 'high' was given to sites that exhibited one of various characteristics. A ‘high’ level of risk was assigned to a site if there was known contaminants present above current Alaska Department of Environmental Conservation (ADEC) Method Two Arctic Zone Cleanup levels or if the site exhibited potential threat from accelerated coastal erosion. Other aspects included if there was a significant amount of solid waste present that could affect public safety and/or there was potential for the well to affect air or water quality due to the discharge of hydrocarbons under pressure. A level of ‘moderate’ was given to sites associated with reserve pits containing drilling wastes. Additionally, a site was also determined to have ‘moderate’ risk if there were known contaminants present below the current ADEC cleanup levels (from sampling conducted before 1995) and if the well exhibited either significant surface debris, or there was evidence of waste buried at the site. A rating of ‘low’ was assigned to sites with minor solid waste present in addition to either no evidence of sampling conducted, or sampling was performed before 1995 with known contaminants present below current ADEC cleanup levels. Lastly, a rating of ‘none’ was given to sites that were fully remediated with no surface debris, there were no known contaminants present, or if so they were below current ADEC cleanup levels (with sampling conducted after 1995), or there was no surface indication of a well site.

For the subsurface risk assessment, a rating level of ‘high’ was given to wells or core tests that penetrated oil or gas stratigraphy or water resources, and is leaking hydrocarbons. A level of ‘moderate’ was given to sites with a well or core test that penetrated oil and gas stratigraphy or water resources, and either the well or core test does not permanently isolate producible geologic horizon or casing perforations or there is a cement plug below the perforations of the producing interval, but some surface controls are in place, such as a wellhead or column of frozen drill mud that currently isolates the formation, and there is no indication of migration of fluid or gas through the frozen column of drilling mud. A rating of ‘low’ was given to well or core tests that either penetrated oil or gas stratigraphy or water resources, but the producible oil and gas formations or water resources are isolated, or there is diesel present within the wellbore, but the diesel is contained with limited risk of release. Lastly, a rating of ‘none’ was given to well or core tests that either did not penetrate oil or gas stratigraphy or water resources, or that have been adequately plugged.

When contaminants of concern and reserve pit closures were considered, current state and federal regulations were identified and formed the basis of standards to be met. A final formal report was produced from the information derived, and each site was given a final and overall rating of importance due to level of risk to be used in designing the subsequent planning report.

3. Expected Results

It is expected that three main aspects of wells sites will be associated with high potential risks: sites containing reserve and/or flare pits, sites with known buried debris or heavy surface debris, and wells threatened by erosion. Because the 28 wells drilled during the second exploration program (c. 1974) were deeper wells and were the only sites containing reserve pits, it is also expected that these wells will have higher risks associated with them compared to the earlier, shallower wells. Furthermore, because this report is conducting a more thorough investigation of subsurface debris and analytical data, compared to the two previous summary reports, it is expected that this report will identify higher risk levels to the wells than previously reported.

4. Discussion

4.1 Actual Results

The purpose of this extensive summary report was to characterize the 136 legacy wells and to identify the potential risks associated with them, in order to set precedence of future plugging and remediation of the well sites. The wells were evaluated based upon their surface and subsurface risk (*see Table 2*). Conditions that resulted in a high *surface* risk included known contaminants above ADEC Method Two Arctic Zone Cleanup levels, the potential threat from accelerated coastal erosion, significant solid waste present affecting visual resources or public safety, and/or the potential to affect air or water quality due to the discharge of hydrocarbons under pressure. Furthermore, a well or core test was assigned a high *subsurface* risk if there was evidence of leaking hydrocarbons, and/or if the well or core test penetrated oil or gas stratigraphy. Other considerations in determining the level of subsurface risk included casing and cementing depth, as well as materials and the composition of materials within the borehole.

Table 2: ***Well Status Conclusion for Surface and Subsurface Risk***

Well Name *(Ordered alphabetically)*	Surface Risk	Subsurface Risk	Reserve Pit	Well Category
Arcon Barrow Core Test #1	None	None		Cased Well, Plugged
Atigaru Point #1	None	None	Yes	Cased Well, Plugged
Avak #1	None	None		Cased Well, Plugged
Awuna #1	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
Barrow Big Rig Test #1*				Transferred to NSB
Barrow Core Rig Test #1	None	None		Shallow, Uncased Well
Barrow Core Rig Test #2	None	None		Cased Well, Plugged
Cape Halkett	Moderate	low	Yes	Cased Well
Drew Point #1	None	None	Yes	Cased Well, Plugged
East Oumalik #1	Moderate	Moderate		Cased Well
East Simpson #1	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
East Simpson #2	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
East Teshekpuk #1	None	None	Yes	Cased Well, Plugged
East Topagoruk #1	Low	Low		Cased Well
Fish Creek #1	Moderate	Moderate		Cased Well
Grandstand #1	Low	Low		Cased Well
Gubik Test #1	Low	Low		Cased Well
Gubik Test #2	**High**	**High**		Cased Well
Iko Bay Test #1				Cased Well
Ikpikpuk #1	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
Ikpikpuk Core Test #1	None	None		Shallow, Uncased Well
Inigok #1	Moderate	Low	Yes	Cased Well
J.W. Dalton #1**	None	Low	Yes	Cased Well, Plugged
Kaolak #1	Moderate	Moderate		Cased Well

Well Name *(Ordered alphabetically)*	Surface Risk	Subsurface Risk	Reserve Pit	Well Category
Knifeblade #1	Low	Moderate		Cased Well
Knifeblade #2	Low	Low		Cased Well
Knifeblade #2A	Low	Moderate		Cased Well
Koluktak #1	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
Kugrua #1	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
Kuyanak #1	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
Lisburne #1	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
Meade #1	Moderate	Low		Cased Well
Minga Test Velocity #1	None	Low		Cased Well
North Inigok #1	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
North Kalikpik #1	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
North Simpson #1	Moderate	Low		Cased Well
Oumalik #1	Moderate	Moderate		Cased Well
Oumalik Core Test #1	None	None		Shallow, Uncased Well
Oumalik Core Test #2	Moderate	Low		Cased Well
Oumalik Core Test #11	Moderate	Low		Cased Well
Oumalik Core Test #12	Moderate	Low		Cased Well
Oumalik Foundation #1	None	None		Shallow, Uncased Well
Oumalik Foundation #2	None	None		Shallow, Uncased Well
Oumalik Foundation #3	None	None		Shallow, Uncased Well
Oumalik Foundation #4	None	None		Shallow, Uncased Well
Oumalik Foundation #5	None	None		Shallow, Uncased Well
Oumalik Foundation #6	None	None		Shallow, Uncased Well
Oumalik Foundation #7	None	None		Shallow, Uncased Well
Oumalik Foundation #8	None	None		Shallow, Uncased Well
Oumalik Foundation #9	None	None		Shallow, Uncased Well
Oumalik Foundation #10	None	None		Shallow, Uncased Well
Peard #1	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
Seabee #1	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
Sentinel Hill Core Test #1	None	Low		Cased Well
Simpson #1	Moderate	Low		Cased Well
Simpson Core Test #1	None	None		Shallow, Uncased Well
Simpson Core Test #2	None	None		Shallow, Uncased Well
Simpson Core Test #3	None	None		Shallow, Uncased Well
Simpson Core Test #4	None	None		Shallow, Uncased Well
Simpson Core Test #5	None	None		Shallow, Uncased Well

Well Name *(Ordered alphabetically)*	Surface Risk	Subsurface Risk	Reserve Pit	Well Category
Simpson Core Test #6	None	None		Shallow, Uncased Well
Simpson Core Test #7	None	None		Shallow, Uncased Well
Simpson Core Test #8	None	None		Shallow, Uncased Well
Simpson Core Test #9	None	None		Shallow, Uncased Well
Simpson Core Test #10	None	None		Shallow, Uncased Well
Simpson Core Test #11	None	None		Shallow, Uncased Well
Simpson Core Test #12	None	None		Shallow, Uncased Well
Simpson Core Test #13	None	None		Cased Well, Plugged
Simpson Core Test #14	None	None		Cased Well, Plugged
Simpson Core Test #14A	None	None		Cased Well, Plugged
Simpson Core Test #15	None	None		Cased Well, Plugged
Simpson Core Test #16	None	None		Shallow, Uncased Well
Simpson Core Test #17	None	None		Shallow, Uncased Well
Simpson Core Test #18	None	None		Shallow, Uncased Well
Simpson Core Test #19	None	None		Shallow, Uncased Well
Simpson Core Test #20	None	None		Shallow, Uncased Well
Simpson Core Test #21	None	None		Shallow, Uncased Well
Simpson Core Test #22	None	None		Shallow, Uncased Well
Simpson Core Test #23	None	None		Shallow, Uncased Well
Simpson Core Test #24	None	None		Shallow, Uncased Well
Simpson Core Test #25	None	None		Shallow, Uncased Well
Simpson Core Test #26	**High**	Low		Cased Well, Plugged
Simpson Core Test #27	None	None		Cased Well, Plugged
Simpson Core Test #28	None	None		Cased Well, Plugged
Simpson Core Test #29	None	None		Cased Well, Plugged
Simpson Core Test #30	None	None		Cased Well, Plugged
Simpson Core Test #30A	None	None		Cased Well, Plugged
Simpson Core Test #31	None	None		Cased Well, Plugged
Skull Cliff Core Test #1	**High**	Moderate		Cased Well
South Barrow #1	None	None		Cased Well, Plugged
South Barrow #2	None	None		Cased Well, Plugged
South Barrow #3	None	None		Cased Well, Plugged
South Barrow #4				Transferred to NSB
South Barrow #5				Transferred to NSB
South Barrow #6				Transferred to NSB
South Barrow #7				Transferred to NSB
South Barrow #8				Transferred to NSB
South Barrow #9				Transferred to NSB
South Barrow #10				Transferred to NSB
South Barrow #11				Transferred to NSB
South Barrow #12				Transferred to NSB
South Barrow #13				Transferred to NSB
South Barrow #14				Transferred to NSB
South Barrow #15				Transferred to NSB

Well Name *(Ordered alphabetically)*	Surface Risk	Subsurface Risk	Reserve Pit	Well Category
South Barrow #16				Transferred to NSB
South Barrow #17				Transferred to NSB
South Barrow #18				Transferred to NSB
South Barrow #19				Transferred to NSB
South Barrow #20				Transferred to NSB
South Harrison Bay #1	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
South Meade #1	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
South Simpson #1	Moderate	Low	Yes	Cased Well
Square Lake #1	None	None		Cased Well, Plugged
Titaluk #1	None	None		Cased Well, Plugged
Topagoruk #1	**High**	Moderate		Cased Well
Tulageak #1	**High**	Low	Yes	Cased Well, USGS Monitoring Well
Tunalik #1	**High**	Low	Yes	Cased Well, USGS Monitoring Well
Umiat #1	Low	None		Cased Well, Plugged
Umiat #2	Low	None		Cased Well, Plugged
Umiat #3	Low	None		Cased Well, Plugged
Umiat #4	Low	None		Cased Well, Plugged
Umiat #5	Low	None		Cased Well, Plugged
Umiat #6	Low	None		Cased Well, Plugged
Umiat #7	Low	None		Cased Well, Plugged
Umiat #8	**High**	None		Cased Well, Plugged
Umiat #9	**High**	None		Cased Well, Plugged
Umiat #10	Low	None		Cased Well, Plugged
Umiat #11	Low	None		Cased Well, Plugged
W.T. Foran #1	Moderate	None	Yes	Transferred to ASRC
Walakpa #1			Yes	Transferred to NSB
Walakpa #2			Yes	Transferred to NSB
West Dease #1	**High**	Low	Yes	Cased Well, USGS Monitoring Well
West Fish Creek #1	Moderate	Low	Yes	Cased Well, USGS Monitoring Well
Wolf Creek #1	None	None		Cased Well, Plugged
Wolf Creek #2	None	None		Cased Well, Plugged
Wolf Creek #3	None	None		Cased Well, Plugged

Of the 136 wells a total of 81 (about 60% of initial wells) required no additional action from the BLM. Twenty-four of these 81 wells were adequately plugged, fully cleared of all surface debris, and in cases where there was threat from erosion, the reserve pit materials were removed. Proper plugging meant that deep cement plugs were set above formations in the well, with the final plug to the surface, thus preventing any hydrocarbons from escaping the well. All fluids, including diesel fuel, were removed before plugging. Thirty-five of the 81 wells were shallow, uncased wellbores, which have collapsed and blended into the natural landscape. Another 21 wells had either been conveyed to the North Slope Borough (NSB) through the Barrow Gas Field Act of 1984 or to the Arctic Slope Regional Corporation (ASRC), and as such were not within BLM's jurisdiction (Brumbaugh and Porhola, 2004). Contaminants in the form of polychlorinated biphenyls (PCBs) were identified at the Umiat #9 Test Well due to the use of Aroclor as an additive during initial drilling operations, however the well was adequately plugged and the United States Army Corps of Engineers (USACE) removed an extensive amount of contaminated soils, with cleanup efforts continually ongoing. In addition to wells requiring no further action, there are another 18 wells (about 13% of initial wells) that are in use by the USGS for global climate and permafrost studies and three (a little over 2% of initial wells) are being monitored by the BLM.

The remaining 34 wells (about 25% of initial wells) currently require BLM action in the form of surface remediation and/or plugging of the well. The majority of these wells exhibit moderate to low risk associated with surface debris, a lack of sampling conducted at the site (to determine if there are potential contaminants of concern), the existence of a reserve pit, and/or the wells require adequate plugging or confirmation that previous cement plugs meet current plugging standards.

The Gubik #2 Test Well was the only well that exhibited both a high surface and subsurface risk due to the fact that cement plugs were not placed above the large gas show and the wellhead contained a leak, which was currently releasing a small amount of gas into the atmosphere. Although the well did not contain a reserve pit, there was a significant amount of debris at the site, including drilling muds, and the well itself is located between the Colville and Chandalar rivers. Furthermore, historical records indicate petroleum spills occurred at the site during initial drilling operations, and nearly 800,000 lbs. of collected debris was buried within the area during cleanup operations conducted by Husky throughout the NPR-A (Husky Oil NPR Operations[3], n.d.).

The Tulageak #1 Test Well and the West Dease #1 Test Well exhibited a high surface risk due to potential threat to the well site from erosion. In 2017 the edge of the Tulageak drilling pad, closest to the reserve pit, was determined to be just 284 feet east of the Beaufort Sea, with the loss of shoreline due to erosion previously estimated at roughly 15-20 feet per year (Personal Conversation with Melody Debenham, 2018; Brumbaugh and McIntosh, 2013). The drilling pad of the West Dease #1 Test Well was determined to be ¾-mile from the coastline in 2012, with current measurements proposed for the 2018 summer monitoring program (Brumbaugh and McIntosh, 2013). Both well sites contained reserve pits. If the walls of the reserve pits become breached (eroding below the materials within the pit), the contaminants will be released into the waters, which for both sites happens to be the Beaufort Sea, thus to the Arctic Ocean. The reserve pit materials have to be excavated and transferred, and as of thus far the J.W. Dalton #1 Test Well was the only reserve pit where the materials were actually barged off. The Atigaru #1, East Teshekpuk #1, and Drew Pit #1 test wells were the only other reserve pits where materials were excavated, but were then transferred to either the Ikpikpuk #1 reserve pit or the North Kalikpik #1 reserve pit, which were only allowed as temporary solid waste facilities by the ADEC and require renewal or removal in the future (Bureau of Land Management, 2009). Furthermore, the wells were plugged back with cement plugs set above lower formations, with the upper portion of the wellbores containing diesel fuel for USGS temperature monitoring and wellheads installed. The closer these sites get to the coasts the more damage the wellheads will receive from wind and wave action of the coastal environment, and if the wellheads become compromised there is potential of the diesel fuel being released.

Another four wells contained the remnants of an elaborate refrigerant system, where a series of underground connected pipes were used to circulate diesel fuel underneath the drilling operations with the intent to prevent thawing of the tundra, thus supporting production activity. There is an undetermined amount of diesel remaining in the system of pipes, which protrude out the ground. The main wells include the Topagoruk #1, Meade #1, East Oumalik #1, and Oumalik #1 test wells. Additionally, cement plugs were never placed in the East Oumalik #1 Test Well; instead the well was left open with drilling muds placed in the hole (forming an ice plug) and no wellhead installed. The Topagoruk #1 Test Well also includes a significant amount of debris, including old battery cores and drilling muds. Furthermore, three core tests (Oumalik Core Tests #2, 11, and 12) share the same drilling area as the Oumalik #1 Test Well, and thus pose the same risks (Brumbaugh and McIntosh, 2013).

The Titaluk #1 Test Well was the only sites that had evidence of contaminants above current ADEC Method Two Arctic Zone Cleanup levels (aside from the old stock tank at Umiat #8). Sampling was conducted by the USGS in 1989 and 1990 at the site, and the results indicated high levels of both BTEX and total petroleum hydrocarbons (TPHs) at concentrations well above the current cleanup levels, 1,560 mg/kg and 114,000 mg/kg respectively (Brunett et al., 1992). The USGS also conducted sampling at the other 27 test wells containing reserve pits, however the results were all below current state cleanup levels. Initial sampling of these 28 wells were conducted before the current state regulations were first established in 1996 by the ADEC, and as such the analysis results were for total BTEX (*see Table 3*). BTEX (benzene, toluene, ethylbenzene, and xylenes) are a group of Volatile Organic Compounds (VOCs), with individual cleanup levels established for each as of current state regulations. Additionally, petroleum hydrocarbons are now divided into gasoline range organics (GRO), diesel range organics (DRO) and residual range organics (RRO). The majority of the wells, however, were drilled during the first exploration period when reserve pits were not yet incorporated at sites. Instead, the drilling materials were placed either directly on the tundra, or in some make-shift holding unit (such as welded pontoons, wooden cellars, or berms). Unless these older test or core wells have been recently plugged within the last ten years or so, there is no evidence of sampling performed at the sites.

Wells drilled during the second exploration period were associated with more complex site features such as drilling pads and reserve pits, which were used to contain drilling wastes such as muds and cuttings. In 1989 to 1990 the USGS performed a water-quality and soil assessment at the 28 wells associated with reserve pits, which included collecting and analyzing numerous samples at the various sites. It was noted during this assessment that the majority of the reserve pits had been breached, thus releasing the contents of the pits into the surrounding environment (Brunett et al., 1992). The reserve pit at the Inigok #1 Test Well was constructed with berms made of porous materials, which allowed for the fluids in the reserve pit to escape into the environment during the summer (Smith, 1986). Furthermore, this well encountered hydrogen sulfide, prompting the crew to mix a substantial amount of additives in the drilling muds and haul in special equipment to handle the highly toxic and flammable gas (Hewitt et al.[3], 1982; National Center for Biotechnology Information, n.d.). When the USGS collected samples of the reserve pit during their assessment, they identified high concentrations of chromium and zinc compounds (from the additives), as well as 'strange compounds' believed to be due to the native sulfur and hydrogen sulfide. In 1995 the 28 reserve pits were consider closed by the Alaska Department of Environmental Conservation (ADEC) under the 1991 Interim Site Assessment Guidance for Inactive Drilling Waste Sites (Chapple, 1995). The reserve pits (containing drilling fluids and wastes) were determined to be ADEC regulated special solid waste facilities under 18 AAC 60.440, and are regulated as such (Bureau of Land Management, 2010). Due to the current status and regulatory factors of the reserve pits, sites associated with these were assigned a medium surface risk.

Table 3: ***18 AAC 75 – Petroleum Hydrocarbon Soil Cleanup Levels (2017)***

Compound	Method Two Arctic Zone Screening Criteria		Method One Arctic Zone Screening Criteria	
Petroleum Hydrocarbon Range[17]	*Ingestion (mg/kg)*	*Inhalation (mg/kg)*	*Ingestion (mg/kg)*	*Inhalation (mg/kg)*
Gasoline Range Organics (GRO)	1400	1400	100	100
Diesel Range Organics (DRO) [18]	12500	12500	200	200
Residual Range Organics (RRO)	13700	22000	2000	2000
Organics				
Benzene	200	13		
Polychlorinated Biphenyls (PCBs)	1	1		
Toluene	27400	180		
Ethylbenzene	13700	89		
Xylenes (total)	274000	81		
Inorganics				
Arsenic[19]	8			
Barium	9600			
Cadmium	140			
Chromium III[19]	200000			
Lead[20]	400	400		
Mercury		26		
Selenium	680			
Silver	680			

Table 3: Alaska Department of Environmental Conservation, Petroleum Hydrocarbon Soil Cleanup Levels (Nov 2017).

[17] Use 18 AAC 75 Method One – Petroleum Hydrocarbon Soil Cleanup Levels in the Arctic Zone for petroleum hydrocarbon range contamination related to manmade pads and roads. Use 18 AAC 75 Method Two for all other petroleum hydrocarbon range soil contamination.

[18] If levels of benzene, toluene, ethylbenzene, and total xylenes (BTEX) are less than 15 mg/kg, and benzene less than 0.5 mg/kg, upon approval by the ADEC cleanup level for diesel range petroleum hydrocarbons allowance of 500 mg/kg.

[19] Arsenic and chromium III at a site are considered background levels due to prevalence of the naturally occurring compounds throughout the state, unless otherwise known or suspected anthropogenic source or activity.

[20] Cleanup levels based on land use: 400 mg/kg for residential land use and 800 mg/kg for commercial or industrial land use, unless determined and approved otherwise with the ADEC.

4.2 Limitations

Although the research has reached its aims, there were some unavoidable limitations. First, due to the amount of time spanning the existence of the legacy wells, there was a varying degree of available data and historical records for each of the sites. Information on wells drilled after 1974 exhibited greater detail, with substantial research more evident. There was evidence of sampling conducted in the late 1980's, however at the time state regulations identifying maximum contaminant levels had yet to be established (the ADEC finalized the regulations in 1996). Water samples collected at the site were analyzed and compared to contaminant levels allowable under the Alaska Drinking Water Standards. Test wells were often located in remote areas across the NPR-A, with only a few wells clustered around the community of Utqiaġvik (formerly known as Barrow). Additionally, due to the continuous permafrost throughout the entire NPR-A, freshwater aquifers do not exist. As such, communities get their drinking water from nearby surface water (Brumbaugh and McIntosh, 2013). Current regulations established by the ADEC for minimum contaminant levels (cleanup levels) are site specific, thus there are Arctic Zone Cleanup levels and Petroleum Hydrocarbon Soil Cleanup Levels for the Arctic Zone, in addition to Alaska Water Quality Standards applicable to active and inactive reserve pit closures for freshwaters (ADEC, 2018). Due to the significant change in regulation standards, especially with water quality standards, it is challenging to compare previous data with current standards (*see Table 3)*. In addition to regulation changes, technology advancements have occurred since past sampling as well. Analysis results can only identify concentrations at the lowest detection limit of the equipment used, thus the tools available today can identify compounds at much lower concentrations than what was available during the early 1990's. Furthermore, the minor sampling conducted at the test wells do not take into consideration the many burial sites that were established during the 1970's when Husky Oil NPR Operations (Husky) was performing cleanup efforts. Even with the available records from those operations, there is still evidence of undocumented burials, such as the landfill near the reserve pit of the East Teshekpuk #1 Test Well that was only evident upon erosion of the reserve pit walls, thus exposing the buried debris (Brumbaugh and McIntosh, 2013). As a result, there are still data gaps within the research that are important to fully assess the risks associated with each site, which is required when forming a strategic plan to address the wells (typically wells with higher risks first), but also to fully characterize a site in order to plug and remediate the wells properly, without encountering too many unexpected challenges. The risk assessment performed on these test wells is limited in scope to the available data.

Despite limits to the data, there is still new information to be identified within the reports that are accessible, even after the 40 years of management conducted of the BLM on these sites. For instance, it was during this report that two additional wells were identified as having the elaborate refrigerant systems below the well sites. The East Oumalik #1 and Meade #1 test wells are highly vegetated sites, and although there are metal pipes protruding from the ground, the remnants of the old refrigerant system is not as evident as that of the Oumalik #1 Test Well. In addition to the refrigerant system, the Inigok #1 well was identified to be associated with the highly toxic and flammable hydrogen sulfide gas (information that had been lost over the years), and the use of oil emulsions (a mixture of water and crude oil from other well sites) was discovered to be used at various wells, especially at the Umiat wells. This information is extremely useful, due to the evidence of PCB contamination discovered at Umiat #5, #8, and #9 test wells.

5. Conclusion

Of the initial 136 legacy wells, 34 wells (about 25%) currently require BLM action in the form of surface remediation and/or plugging of the well. The majority of these wells exhibit moderate to low risk associated with surface debris, a lack of sampling conducted at the site (to determine if there are potential contaminants of concern), the existence of a reserve pit, and/or the wells require adequate plugging or confirmation that previous cement plugs meet current plugging standards. Eventually all of the reserve pits will need to be addressed in the future, however the process is extremely costly and operations must be conducted during the winters for tundra travel, as well as stabilization during plugging operations. In order to reduce the cost involved with plugging the legacy wells, it would be economically beneficial to plug the wells at the same time based upon close proximity to each other, similar site conditions, and comparable plugging operations. This method was useful during the most recent years when the Umiat wells (numbers 1, 3, 4, 8, 10 and 11) were either plugged or the wellheads were removed in 2015. Similarly was the case with the Simpson core tests (13 through 31), which were all addressed in 2016. Some of the test wells throughout the NPR-A are located in much more remote locations, nowhere near other well sites or base camps (such as the Umiat base camp), and as such a cost analysis must also be included when producing a strategic plan to address the wells over the next several years. A risk assessment only analyzes factors that could potential cause harm to the human health and/or environment. It is challenging to factor in cost estimates as well. One could combine the risks associated with a cluster of wells and compare that to a single well to produce alternative plans for plugging operations, so that one may better identify more efficient and economically feasible solutions to reducing the overall risks associated with these wells.

The focus of this summary report was adding more precise well coordinates, defining well site boundaries, thoroughly evaluating analytical data and historical records, as well as reviewing updated site inspections and remediation efforts. Although there are limits to the data, due to varying degrees of available historical documents and a lack in current sample analysis, there is still new information to be identified within the available information, even after the 40 years of management conducted by the BLM of these sites. Past summary reports, including this one, have relied on available data and historical records to assign risks to the test wells for the purpose of establishing a strategic plan to properly plug and remediate wells, dependent upon the assigned risks, estimated costs of plugging operations, as well as available funding. There is still not enough substantial information available on potential contaminants related to previous drilling operations and actions at the majority of the legacy wells in order to produce a comprehensive assessment, however this summary report has identified a clear data gap. Cleanup levels and standards have significantly changed since the last analysis was conducted, and instrumentation has increased in both accuracy and precision with the ability to determine the lowest detection limit. Although the results from the previous analysis are now below Method Two Arctic Zone cleanup levels in soil samples, it is recommended to have current sampling conducted at the test well sites in order to perform a more thorough and complete risk assessment for each well site. Future opportunities include producing site maps of known surface debris, burial sites, and locations of past and/or present spills, as well as breach locations from the reserve pits. Sampling plans can then be produced and executed for each of the well sites exhibiting a low surface risk or greater. The results can then be added to this current summary report in order to both reassess the site risks, update the status of the sites, and to continue the overall efforts in managing the legacy wells.

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