SIMULATING POTENTIAL SPILLS OF BAKKEN CRUDE OIL FROM THE DAKOTA ACCESS PIPELINE AT LAKE OAHE TO EVALUATE RELATIVE IMPACT OF SPILL SCENARIOS ON ENDANGERED BIRD SPECIES

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Table of Contents

List of Tables

List of Figures

Abstract

In this study, I set out to do what the U.S. Environmental Protection Agency, Fish and Wildlife Service, and Army Corps of Engineers have not – investigate the potential ecological consequences of a Dakota Access Pipeline rupture at the controversial Missouri River crossing near Cannon Ball, North Dakota. Of particular interest in this study is the fate of three federally-endangered bird species that breed or migrate through this critical riparian corridor: the Interior Least Tern, the Whooping Crane, and the Piping Plover. Using National Oceanographic and Atmospheric Administration oil-modeling software in conjunction with ArcGIS, I modeled thirty oil-spill scenarios at critical times for the birds that inhabit the region. These included flood simulations and three oil-spill clean-up responses. Using these maps, which overlaid oil-dispersal shapefiles onto predicted bird distributions, I found how many birds of each species were within oiling distance of the spill to create a relative index of spill severity and species-specific impacts during different times of year. I found that the Whooping Crane is unlikely to be greatly impacted, but that the two shorebirds could face substantial losses, particularly from late June to early August. Based on my results, I drafted a number of recommendations for the various governmental organizations and stakeholders that have jurisdiction or interest in this region.

Acronym Guide

ADIOS	Automated Data Inquiry for Oil Spills
AOC	Area of Concern
API	American Petroleum Institute
bbl	Barrels (of oil)
DAPL	Dakota Access Pipeline
EPA	United States Environmental Protection Agency
ESA	Endangered Species Act
ETP	Energy Transfer Partners, LLC
FEMA	Federal Emergency Management Administration
FONSI	Finding of No Significant Impact
GCS	Geographic Coordinate Systems
GIS	Geographic Information Systems
GNOME	General NOAA Operational Modeling Environment
GOODS	GNOME Online Oceanographic Data Server
IPPC	International Piping Plover Census
IUCN	International Union for Conservation of Nature
MCL	Maximum Contaminant Level
NOAA	National Oceanographic and Atmospheric Administration
OR&R	Office of Response and Restoration
PHMSA	Pipeline and Hazardous Materials Safety Administration
PIG	Pipeline Inspection Gauges
ROC	Response Option Calculator
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

Background

The Dakota Access Pipeline.

In the last decade, North America has experienced a rapid increase in domestic crude oil production and transport, primarily from Canada, Montana, North Dakota, and Texas, made possible by technological developments such as horizontal drilling and hydraulic fracturing, or "fracking" (Mitchell & Child, 2015). In fact, North American crude oil production increased by 45% from 2008 to 2013, rising from 315 million gallons per day to 462 million gallons per day in just five years (API, 2017). Behind Texas, North Dakota is the second most productive crude oil state in the country (Mitchell & Child, 2015). Much of this crude oil was previously distributed via existing infrastructure – primarily rail – but oil companies have now turned to a new form of transit: pipelines.

On January 24, 2017, the Trump administration approved the controversial $3.7 billion Energy Transfer Partners, LLC ("ETP") Dakota Access Pipeline ("DAPL"), which now extends approximately 1,168 miles from the Bakken and Three Forks production region of North Dakota to Pakota, Illinois (U.S. Army Corps of Engineers; Egan, 2017). The pipeline was designed in part to reduce railway transport of Bakken crude oil after several train explosions and subsequent oil spills (Robertson, 2014). According to the pipeline company, DAPL will take between 500-740 rail cars and/or 250 trucks carrying crude oil off the road every single day (Energy Transfer, 2017). The pipeline transports up to 570,000 barrels per day of light sweet crude oil obtained through hydraulic fracturing of Canadian underground shale (U.S. Army Corps of Engineers). While it's true that transport by pipeline is statistically safer than transport by rail, pipelines are still susceptible to damage, aging, vandalism, faulty construction, environmental disturbances, and operational errors (USFWS EA, 2016). This is evidenced by well-known spills like the 2010 Line 6B spill in Marshall, Michigan and the recent 2017 Keystone Pipeline spill in Amherst, South Dakota. In fact, DAPL itself has already experienced some minor leaks – none above 210 gallons (5 barrels), which is the quantity required by the Pipeline and Hazardous Materials Safety Administration ("PHMSA") to warrant a "significant" spill – but 84 gallons leaked from DAPL on March 3 in Watford City, ND, another 20 gallons two days later on March 5 in Mercer County, and 84 more gallons on April 4 at a pump station in Crandon, SD (Rice, 2017).

Opposition to the pipeline was widespread and related mostly to issues of siting and route selection, particularly with proximity to the Standing Rock Sioux Reservation and the crossing of the Missouri River at Lake Oahe. According to the Fort Laramie Treaty of 1868, the United States agreed that except for government employees, no non-Lakotas "shall ever be permitted to pass over, settle upon, or reside in" the reserved lands. The treaty was broken almost immediately as white folks trespassed on Native land in direct violation of the treaty. This was exacerbated in 1874 when Lt. Col. George Custer confirmed the presence of gold in the Black Hills. In 1877, Congress repealed portions of the 1868 Fort Laramie Treaty to regain access to the gold-rich hills in the Black Hills Act. The Lakotas took this to court in 1923, claiming there had not been just compensation for the takings of their land, as guaranteed by the Fifth Amendment to the U.S. Constitution. This matter was not attended to until 57 years later, in 1980, when the Supreme Court ruled in *United States v. Sioux Nation of Indians.* The U.S. Supreme Court found that the Black Hills were taken illegally and that Congress' 1877 act violated the Fort Laramie Treaty. Though the court awarded the Lakotas just compensation – $17.5 million plus 5% annual interest starting in 1877 – the Lakotas have refused the payments and instead demand the Black Hills be returned to their control. Relevant to DAPL, the U.S. Army Corps of Engineers ("USACE") easements under which DAPL passes are on lands formerly protected by the 1868 Fort Laramie Treaty which have since been taken back by the U.S. government (Finkelman & Garrison, 2009). While legally the land has been transferred and the pipeline does not run through the Standing Rock Sioux reservation, in many tribal members' eyes the land still belongs to them.

DAPL runs completely underground and ranges from 12 to 30 inches in diameter, measuring 24 inches where it crosses 2.83 miles of USACE flowage easements at the Missouri River and reaching its maximum 30-inch diameter where it crosses approximately 0.21 miles of federal lands at Lake Oahe (see Figure 1) (U.S. Army Corps of Engineers). According to the North Dakota Administrative Code, Lake Oahe is classified as a Class I stream which calls for the highest quality of waters, specifying that waters shall be suitable for, amongst other uses, city and household use and occupation by wildlife without injurious effects (Henderson, 2016). Legally, Energy Transfer Partners is required to comply with federal regulations set by PHMSA regarding pipeline design, construction, and operation, but the history of oil spills across the United States has generated concern about the safety of oil pipelines, particularly around bodies of water. Though all pipelines are held to these federal standards, pipelines are still known to leak oil. Although these regulations limit the likeliness of a spill, it is important to ask: What if it did? Are we prepared for that event, unlikely though it may be?

While the DAPL crossing of the Missouri River at Lake Oahe near Cannon Ball is the primary focus of this study, DAPL actually crosses the Missouri River twice (see Figure 1). It first crosses the Missouri River upstream of Lake Sakakawea just west of the North Dakota/Montana border (Aisch & Lai, 2017). Lake Sakakawea, like Lake Oahe, is the result of a series of six mainstem Missouri River dams constructed in the 1950s and 1960s to control flooding and allow more stable agriculture in the region (Committee on Missouri River Recovery et al. 2011). Additionally, DAPL crosses many tributaries of the Missouri River as the pipeline extends from North Dakota to Illinois, and it is very possible that oil could get to the mainstem Missouri River after a short trip down one of those tributaries, similar to how the diluted bitumen oil in the Marshall, MI spill traveled from the Talmadge Creek into the Kalamazoo River. While these tributary crossings and the river crossing upstream of Lake Sakakawea will not be thoroughly investigated in this report, many of the results found in this study can be applied there similarly, and each of the three endangered bird species researched herein also rely on Lake Sakakawea for breeding and migrating.

For the remainder of this paper, I will be focusing on the locale where DAPL crosses the Missouri River at its second location near Cannon Ball, North Dakota, about forty miles south of the state capital (see Figures 1 and 2). Here, DAPL passes under a section of the river known as Lake Oahe, another large reservoir extending from North Dakota into South Dakota (U.S. Army Corps of Engineers). Lake Oahe is a man-made reservoir that is the direct result of the Oahe Dam, located in South Dakota, that was built from 1948 to 1962. The Oahe Dam has a storage of 23,500,000 acre-feet of water (Committee on Missouri River Recovery et al., 2011). It was at the crossing of the Missouri River under Lake Oahe where the Standing Rock resistance camps took place.

On June 1, 2017, DAPL was officially operative for commercial service (Energy Transfer, 2017). Oil has been flowing through it ever since. Per Section 404 of the Clean Water Act and Sections 10 and 14 of the Rivers and Harbors Act of 1899, the USACE has jurisdiction over 37 miles of DAPL, including all 202 of its water crossings, each of which was reviewed and permitted individually by the USACE. The USACE declared on July 25, 2016 a Finding of No Significant Impact ("FONSI") in their 1,261-page Environmental Assessment of DAPL (Henderson, 2016). This finding, in conjunction with the U.S. Fish and Wildlife Service ("USFWS") Environmental Assessment regarding the DAPL crossings over USFWS wetlands and grasslands easements, permitted the construction of DAPL (U.S. Fish and Wildlife Service, 2016). However, all analysis in the USFWS Environmental Assessment and most findings in the USACE Environmental Assessment pertain to the potential ecological effects of the *construction* of DAPL – not the impacts of a possible oil spill. While it is surely important to see how soil disturbances, temporary and permanent clearcutting, noise pollution, and water reduction levels caused by construction would impact endangered species and ecosystems, *only* looking at the construction period calls into question the veracity of the FONSI by both the USACE and USFWS. While the USACE Environmental Assessment discusses at length the measures taken to prevent an oil spill event, from the fusion bond epoxy external pipeline coatings to the computerized leak detection system, their actual clean up response plan is lacking and vague. They write, "Immediately upon discovery of a release of oil that could impact the Missouri River or Lake Oahe, Dakota Access will initiate emergency response efforts, including containment and recovery" (Henderson, 2016, pp. 43). Even when they did evaluate theoretical oil releases, the USACE assumed a one-hour release period for the entire spill volume, even though the Marshall, MI Line 6B spill of 2010 lasted for 17 hours (Henderson, 2016). Knowing the specific clean up responses to different oil spill scenarios would be beneficial to accurately analyze the true environmental impact of a DAPL leak. While these organizations claim that crude oil spills are extremely unlikely, we know that several minor leaks have already taken place (Egan, 2017; Rice, 2017).

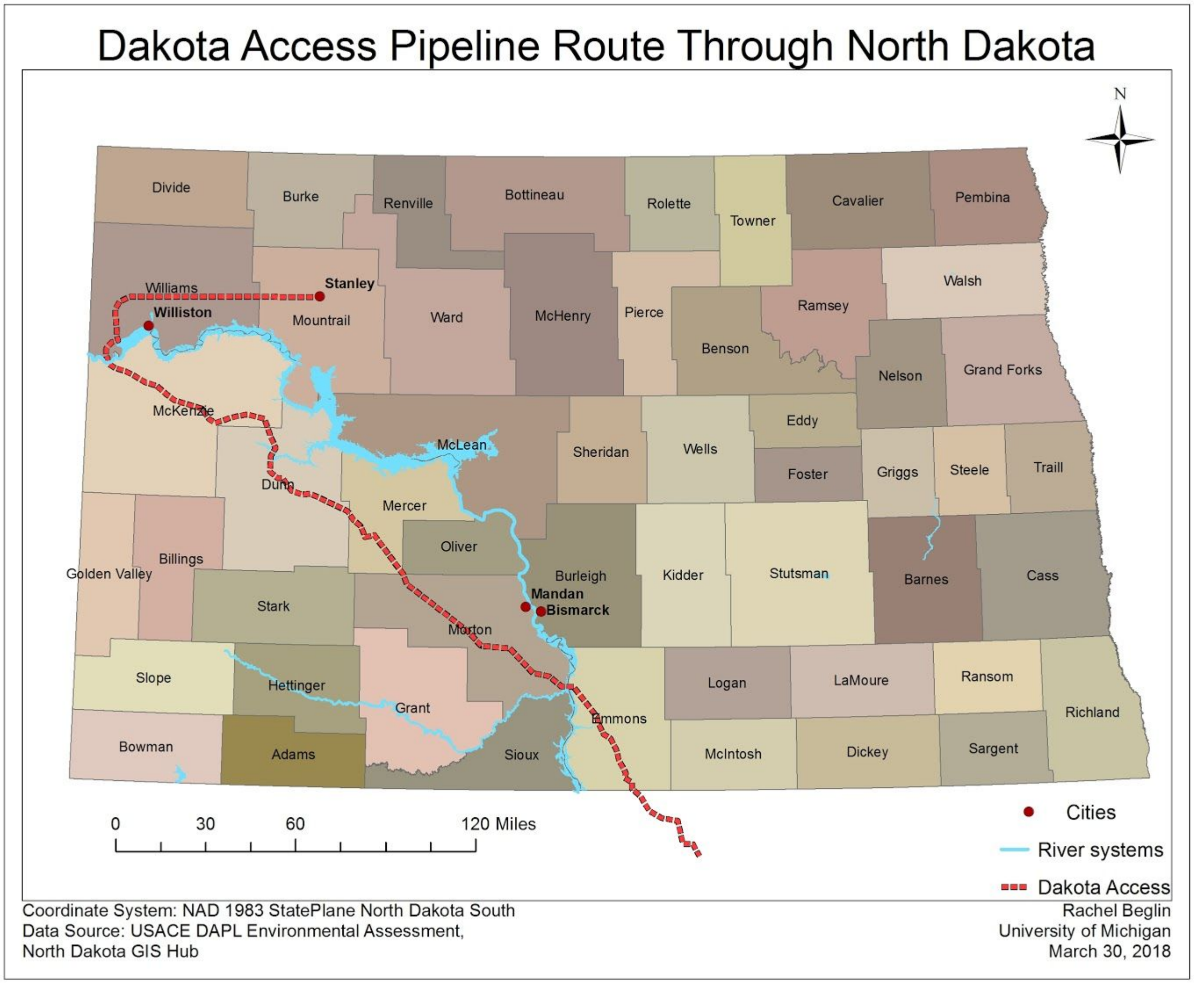


Figure 1. Map of DAPL route through North Dakota and crossing the Missouri River twice.

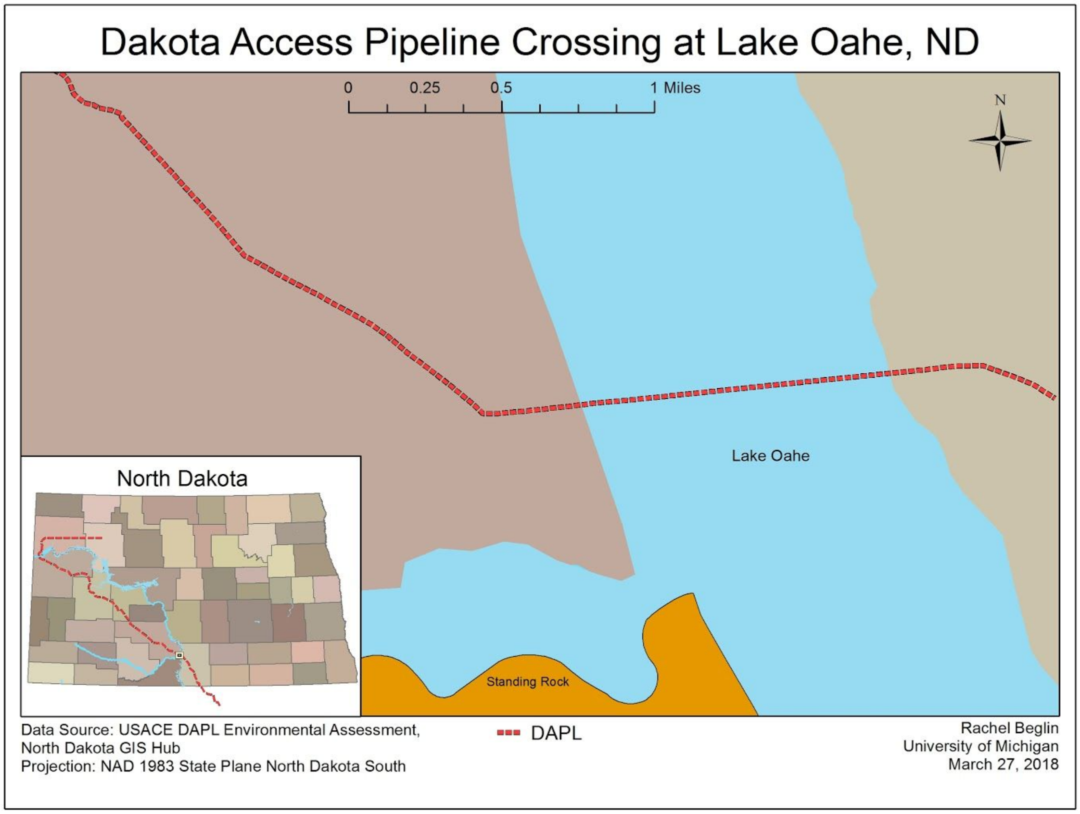


Figure 2. DAPL crossing at Lake Oahe near Cannon Ball, ND, north of the Standing Rock Sioux Reservation.

Oil spills, Bakken crude oil, and response tactics.

Although marine and coastal oil spills tend to garner the most national attention, 60% of all oil spills in the United States have actually been inland, and of all U.S. oil spills greater than 10,000 gallons, 88% have been inland (Brody et al., 2012). In the past, large spills were often the result of tankers running aground or other massive collisions, but today oil spills tend to be the result of old, ill-maintained, or sabotaged pipelines (Jernelöv, 2010). The most recent large-scale example as of this writing is the 210,000-gallon inland spill of dilbit bitumen from the underground Keystone Pipeline in Amherst, South Dakota on November 16, 2017. The likely cause of the spill was faulty construction, and although the segment of damaged pipeline was isolated within fifteen minutes of the pressure drop, 5,000 barrels of oil still surfaced (Gonzales, 2017).

While oil spills can be instantaneous or continuous, the effects of both can have widespread consequences on a region. If spilled into freshwater systems, drinking water and groundwater may become contaminated. One of the most dangerous contaminants found in crude oil is benzene, a colorless, flammable carcinogen known to have acute effects such as skin, eye, and throat irritation as well as headaches, tremors, and unconsciousness. Chronic, long-term effects of benzene exposure include anemia, low white blood cell count, and leukemia (American Cancer Association). In larger spills, this can lead to evacuations and declared states of emergencies. Other exposure media include soil and air, as petroleum hydrocarbons adhere to sediment and noxious gases are released, respectively. Photodegradation from sunlight can weather and react with oil to create new compounds as well.

Oil spills affect the biota in various ways. Initially, oil coating may lead to wildlife and plant mortality, as oiled animals may be unable to breathe, thermoregulate, or move. About four months after the 1989 *Exxon Valdez* spill in Alaska, more than 30,000 bird carcasses had been retrieved (Piatt et al., 1990). Oiled plants may experience reduced photosynthesis, transpiration, shoot height, stem density, and biomass (Lin & Mendelssohn, 2012). Depending on the extent of initial die-offs, food availability for many organisms becomes limited, lowering the carrying capacity of an ecosystem.

After the initial oiling event, many plants and animals may continue to experience the toxic effects of the oil through absorption of lingering materials; in fact, light crude oils can actually be taken up into plant bodies with water. While it is often difficult to evaluate aquatic impacts due to the lack of "before," or baseline, data, we do know that organisms can achieve high concentrations of organic contaminants relative to their environments. This is called bioconcentration, a well-known phenomenon where fish uptake chemicals from the water through respiratory surfaces or skin, resulting in the chemical concentration in the fish being higher than the chemical concentration in the water (Mackay & Fraser, 2000). Biomagnification often compounds the effects of bioconcentration wherein organisms that consume other contaminated organisms will have a higher chemical concentration than their prey due to dietary absorption (Mackay & Fraser, 2000). Essentially, organisms higher up the food chain will have higher concentrations of chemical contaminants than both their prey and the surrounding environment, which puts high trophic levels and crucial apex predators at heightened risk of chemical contamination. This can, but does not always, lead to mutations, endocrine disruption, reproductive failures, behavioral alterations, and death. Famously, the uptake of a harmful pesticide called DDT by Bald Eagles (*Haliaeetus leucocephalus*) in the 1960s led to a thinning of the eggshells, causing birds to crush their eggs while incubating and overall population decline (Sorenson et al., 2017).

In order to assess potential spill impacts in Lake Oahe specifically and advise response tactics for potential DAPL spills, it is important to account for the *type* of oil being released. There are two main kinds of oil: crude oil, which is raw from the Earth, and refined oil, or crude oil that has been transformed into ready-to-use fuel. Crude oil is a complex, heterogeneous mixture of hydrocarbons, other organic compounds, metals, and hydrogen sulfide, and the composition of crude oil varies so much that even two draws from the same well may yield distinct compositions (Mitchell & Child, 2015). That said, crude oil is typically divided into three categories: light, medium, and heavy.

Bakken crude, which flows through DAPL, is a light crude, and if released into water is expected to float, spread into a thin sheen on the water's surface, and move rapidly downstream. Light crude oils have higher evaporation rates and lower viscosities than heavy crudes, which are more black and tar-like than runny, lightweight Bakken. Light crudes also have a high acute toxicity due to their concentrations of benzene, toluene, and xylenes. In fact, one of the most dangerous parts of a Bakken crude oil spill is the toxic gas exposure. Bakken is considered a 'sweet' crude, indicative of its low sulfur content – less than 0.2 weight percentage (wt %) – as opposed to 'sour' crudes with high sulfur concentrations (Henderson, 2016). Bakken crude oil varies in color from amber to black. It has a sulfurous odor and is insoluble in water. With a boiling point of 21-43ºC and a flashpoint – the lowest temperature at which it can ignite – of <.29ºC, Bakken is especially dangerous to transport because the flammable gases in it raise the vapor pressure and lower the flashpoint and initial boiling point. It has been known to ignite and leave fires burning for several days. A recommended isolation distance of 150 feet in all directions is standard protocol in the event of a Bakken crude oil spill; if the spill is large, an evacuation distance of 1,000 feet downwind is recommended; and if the crude oil is on fire, an isolation and evacuation distance of 2,640 feet in all directions is recommended (Michell & Child, 2015). In short, a Bakken crude oil spill is not something you want to encounter. North America is no stranger to Bakken crude oil spills, as seen in Table 1.

Date	Location & Description	Volume	Impacts
August 22, 2008	**Luther, Oklahoma;** 14 unit cars derail; 3 breached and caught fire	80,746 gallons	Fire permitted to burn; 35 people evacuated
March 27, 2013	**Parker Prairie, Minnesota;** 14 cars derailed, 1 breached, 2 leaked on either side of derailment	30,000 gallons (onto frozen soil)	No fire; environmental impacts mitigated due to frozen conditions
July 6, 2013	**Lac-Megantic, Quebec, Canada;** Runaway train derailment of 63 rail cars	1.7 million gallons burned/released; 26,000 gallons spilled directly into Chaudiére River	River received non-drinking status; a massive fire started in the town center, killed 47 people; 70+ buildings destroyed; $7.6 million in initial clean up costs
November 8, 2013	**Aliceville, Alabama;** 25 unit cars derailed, and 23 of those breached into wetland areas	630,000 gallons spilled or burned	21 train cars left behind in the marsh habitat; ignited a fire that burned for two full days; leaked Bakken crude into surrounding wetlands; slow response due to the remoteness of the spill, causing significant impact to the wetlands.
December 30, 2013	**Casselton, North Dakota;** Rail car collision resulted in twenty crude oil tank cars to derail; 18 breached	400,00 gallons released	1,400 people evacuated; fire allowed to burn itself out; 9,000 cubic yards of soil removed
February 24, 2014	**Baton Rouge/New Orleans, Louisiana;** Tank Barge E2MS 303 collided with a towboat in the Lower Mississippi River	31,500 gallons	Of 31,500 gallons spilled, only 95 were recovered; reports of high concentrations of benzene, a known carcinogenic and volatile organic compound (VOC), but no reports of oiled or injured wildlife.
April 30, 2014	**Lynchburg, Virginia;** 13 unit-cars of a 105-car train derailed; 3 cars submerged in the James River	30,000 gallons released	Large fire that required six city blocks to evacuate; 17-mile oil slick in the James River; soil and vegetation coated in crude

Table 1. Bakken crude oil spills in North America (Walker et al., 2016; Mitchell & Child, 2015).

In its Environmental Assessment of the potential harms of a DAPL spill in Lake Oahe, the USACE analyzed the potential benzene concentrations in the Missouri River based on the amount of Bakken crude oil hypothetically spilled (see Figure 3). Although they found that concentrations of benzene never exceeded the acute toxicity threshold of 7.4 ppm in their study, a spill as small as 100 barrels, or 420 gallons, would put the Lake Oahe and Missouri River concentration of benzene above the maximum contaminant levels ("MCL"). Additionally, the USACE tested only up to what they categorize as a large spill of 10,000 barrels; however, the 2010 Marshall, MI spill leaked 23,810 barrels of crude oil into the Kalamazoo River, and the 2017 Keystone Spill leaked 5,000 barrels in just fifteen minutes.

River Crossing	River Flow (cfs)	Acute Toxicity Threshold (ppm)	Benzene MCL (ppm)	Estimated Benzene Concentration in Surface Water (ppm)			
				Very Small Spill: 4 bbl	Small Spill: 100 bbl	Moderate Spill: 1,000 bbl	Large Spill: 10,000 bbl
Missouri River	20,374	7.4	0.005	0.00075	0.019	0.19	1.88
Lake Oahe	22,484	7.4	0.005	0.00068	0.017	0.17	1.70

Notes:
- Adapted from Stantec, 2015
- Estimated concentration is based on release of benzene into water over a 1-hour period with uniform mixing conditions.
- Concentrations are based on a 0.28 percent by volume benzene content of the transported material (Marathon Oil 2010).
- bbl - An oil barrel defined as 42 US gallons,
- MCL - Maximum contaminant levels
- ppm – Parts per million
- cfs – Cubic feet per second
- Stream flows are measured mean discharge from the gage stations closest to the pipeline crossings located on the Missouri River at Williston (USGS Station 06330000) and Bismarck (USGS Station 06342500)(USGS 2016; 2016b).

Figure 3. Estimated benzene concentrations following a hypothetical crude oil spill at DAPL project river crossings, taken from the publicly available Environmental Assessment prepared by USACE (Henderson, 2016).

Multiple variables can alter the course of an oil spill and how it behaves in its environment. Temperature and weather conditions impact the volatility, or tendency for a substance to evaporate, and viscosity, the consistency or thickness, of the oil (Brody et al., 2012; Dew et al., 2015). Often, it is the weather conditions more than the type of oil spilled that determine its fate and persistence in the environment after a release. A spill in the the dead of winter, with ice-blocked water, overcast skies, and below-freezing temperatures, will behave differently than a summer spill in the same region on a warm, calm, sunny day. Thus, the impacts of an oil spill on flora and fauna are subject to change depending on the type of oil, quantity spilled, and environmental conditions.

Additionally, response time and the type of response can drastically change environmental impact. In the United States, the U.S. Environmental Protection Agency ("EPA") is the lead federal authority on oil spill response decisions for inland areas (for coastal spills, the U.S. Coast Guard has said authority) (Walker et al., 2016). Bringing response equipment or mobilizing crews into remote locations can complicate and delay clean up (Brody et al., 2012). Even inconveniences like holidays can postpone responses, while more serious catastrophes like earthquakes, flooding, or severe storms are almost guaranteed to delay response times. One can imagine worst-case scenarios where unfortunate circumstances compound such that response teams can't get to the site of an oil spill for several hours or even days. Oil spill clean up, while necessary, can also have its own negative impacts on flora and fauna. After the 2010 Enbridge Line 6B burst in Marshall, Michigan, tactics used to contain the spilled oil included spraying the contaminated sediment with pressurized water, dragging chains through the sediment, agitating sediment by hand with a rake, and even driving back and forth with a tracked vehicle to stir up the sediments and release the oil that had been trapped in the mud (Walker et al., 2016). These disruptive actions had significant impacts on the biota around the Kalamazoo River compounded with the negative physical and toxicological effects of the oil itself (Walker et al., 2016).

In best-case scenarios, floating oil can be skimmed off the water surface before it encounters or coats wildlife; sinking material is considerably harder to clean up before it leads to detrimental effects (Dew et al., 2015). Whether or not oil sinks or floats in water depends on a few factors, including currents, water salinity, and sediment load, but the most important factor is the density of the oil. For petroleum products, the density is represented by a specific gravity scale developed by the American Petroleum Institute. This figure, known as the API, is measured in degrees and is calculated from the arbitrary formula: API gravity = (141.5/SG) - 131.5, where SG is the specific gravity of the fluid at 60°F (Schlumberger Oilfield Glossary, 1998). Not all Bakken crude oil has the exact same API – even oil extracted from the same well can have slightly different specific gravities – but Bakken crude oil tends to be in the range of 41.0 - 43.0º (Shuler et al., 2011; Henderson, 2016). Generally, a crude oil with an API under 10.0º sinks in water and above 10.0º floats (Shuler et al., 2011). In addition to the use of skimmers, other clean up tactics include in situ burning, spraying of dispersal chemicals, bioremediation (adding biotic materials like bacteria, yeast, and fungi to spills to accelerate the natural biodegradation processes), and the use of natural sorbents, which use absorbent materials like cotton, straw, and even human hair to soak up oil in cheap, environmentally friendly ways (Pezeshki et al., 2000; Al-Majed et al., 2012).

For the purposes of this paper, Table 2 provides information on the three oil spill clean up responses available in the oil modeling software designed by the National Oceanographic and Atmospheric Administration ("NOAA") Office of Response and Restoration ("OR&R") and used in this study. This online program, General NOAA Operational Modeling Environment ("GNOME"), allows users to add in situ burns, dispersal, and skimming responses to oil simulations.

Type	**Description**	**Pros**	**Cons**	**Efficiency**	**Cost**
In Situ Burning	Helitorch, or flamethrower suspended by helicopter, ignites a thick layer of oil on water's surface within a fireproof U-shaped boom	Works well in iced areas; relatively inexpensive	Must happen before evaporation/natural dispersion; requires 2-3 mm thickness or will not ignite; smoke and airborne irritants; risk of fire spreading; oily rain	Can remove 600-1800 barrels/hour	Cheapest ($20-$50 per barrel of oil)
Dispersion	Use of surfactants (surface active soapy molecules) that are oil and water soluble and thus reduce interfacial tension between the two substances	Treat larger areas compared to other methods; applied easily by spray equipment; extremely efficient	Requires wind to mix chemicals, ineffective in calm water; chemical dispersants are extremely toxic and ecologically unsound	15 m^3 / 10 minutes by helicopter; 15 m^3/.5-1.0 hours by boat spray	Expensive ($50-$100 per barrel of oil)
Skimming	Booms spread over surface waters to prevent spread of oil combined into "V" shaped barriers which concentrate oil for pickup by skimmer boats	Little to no adverse environmental effects (relatively); most efficient with high slick viscosity and thickness	Costly; requires large number of people and equipment; some oil escapes booms; poor efficiency raises clean up costs; only effective in calm waters with little wind or currents	Unknown	Expensive ($100-$150 per barrel of oil)

Table 2. Oil spill responses and effectiveness (Al-Majed et al., 2012).

In the event of an oil spill, those responsible for the pollution pay all costs of clean up operations pursuant to the Oil Pollution Act of 1990, passed after the disastrous 1989 *Exxon Valdez* spill. However, as it takes time for insurance companies to work out legal and monetary responsibility in the courts, and time is not something to waste in the event of an oil spill, the Coast Guard and/or EPA set up an immediate source of funding for federal and state agencies and tribes who support the oil spill clean up. If the polluter is deemed liable, they then reimburse all expenses to the Coast Guard or EPA. Additionally, as per the Oil Pollution Act, parties that release hazardous materials are also responsible for restoring any injuries to natural resources that result from their spill. However, it is also possible that the polluter can be found *not* liable if, for example, the pollution was caused by an unforeseen accident, in which case the costs are covered by the Oil Spill Liability Trust Fund, which accrues from taxes on domestically produced and imported oil, paid for by the oil companies. These funds are accessible to those involved in the response and clean up if the polluter is unknown, unwilling, unable, or not liable to pay for the spill's cost in full. That said, public tax dollars are spent developing professional emergency response and restoration experts, such as the folks at NOAA (Office of Response and Restoration, 2018). While funds may not be a limiting factor in the immediate clean up response to an oil spill, there is no doubt that oil spill clean up is remarkably expensive; by 2014, four years after the Enbridge Line 6B spilled a million gallons into the Kalamazoo River, $1.2 billion had been spent on clean up which was still ongoing (Ellison, 2014). Others argue that it is the American public and the environment who pay the ultimate price, and that while companies may be responsible for restoring injuries, some ecological impacts simply cannot be reversed (Office of Response and Restoration, 2018).

In the event of a spill in Lake Oahe, data is sparse about how it would be contained. *The Dakota Access Pipeline Draft Spill Prevention, Containment, and Countermeasures Plan* prepared by pipeline owners Dakota Access, LLC and Energy Transfer Crude Oil Pipeline, LLC was, like the USFWS Environmental Assessment, only written to prepare for disturbances or spills generated by construction rather than pipeline leaks, spills, or ruptures (Dakota Access LLC, 2014). In other words, it only suggests clean up responses to construction-related spills from construction equipment and vehicles; it makes no effort to suggest a clean up plan for DAPL in the event of a moderate or severe oil spill. This is despite the fact that DAPL has already leaked (Egan, 2017). Though DAPL was constructed with Pipeline Inspection Gauge ("PIG") technology and though operators can detect pressure changes quickly, it is important to acknowledge that technology can fail, workers make mistakes, and spills at inconvenient times – holidays, government shutdowns, evenings – can mean the difference between a quick response and a delayed one.

Optimistically, U.S. District Judge James Boasberg ordered in December 2017 – six months *after* oil started flowing through DAPL at commercial rates – that the pipeline company must develop a final spill response plan for the section of the pipeline that crosses the Missouri River at Lake Oahe next to Standing Rock by April of 2018. He also ordered the pipeline company to commission an independent third-party audit of its own prior risk analysis. This decision came just two weeks after the 5,000-barrel spill of crude oil from the Keystone Pipeline (McKenna, 2017). On Monday April 2, 2018, Texas-based ETP submitted its court-ordered 270-page spill response plan for review. While under review, oil has and continues to flow through DAPL (Nicholson, 2018).

What's at stake: Missouri River ecology.

The Missouri-Mississippi river system passes through ten states, covers roughly one-sixth of the continental United States, and drains an area of 530,000 square miles (Committee on Missouri River Recovery, 2011). It begins in Three Forks, Montana at the confluence of three smaller tributary rivers and carries sediment all the way to the Gulf of Mexico. Although the Missouri River once migrated freely back and forth across a wide floodplain, the river was artificially altered in the twentieth century. With the passage of the Flood Control Act of 1944, the USACE was authorized to construct six dams along the Missouri River as a part of the Pick-Sloan Plan. The Garrison Dam near Bismarck, ND began construction in 1946 and formed the reservoir known as Lake Sakakawea; the Oahe Dam in Pierre, SD formed Lake Oahe. Lake Oahe is a 232 mile long reservoir with 2,250 miles of shoreline open to the public. More than 1.5 million visitors enjoy its facilities and beauty annually, with 44% of visitors engaging in fishing activities (Henderson, 2016).

While these dams accomplished their goals of allowing human activity and agriculture in once flood-prone areas, generating reliable hydroelectric power, creating a sustainable water supply, creating a commercial navigation channel, and offering a wide array of water based-recreation, the dams also had unintended consequences. Since the 1960s, the sediment load of the Missouri River has been greatly reduced. Before 1900, the Missouri River used to transport 400 million metric tons of sediment annually; today, it only transports 145 million (Committee on Missouri River Recovery, 2011). This is a contributing factor to the decline in bird and fish species along the Missouri River. Previously, sediment provided foundational material for islands and sandbars in the river that served as plant and animal habitat. As we will explore later, both the endangered Interior Least Tern and endangered Piping Plover nest on sandbars formed by Missouri River sediment. With lower sediment levels, many species in the region have experienced population-threatening habitat loss.

Despite the six mainstem dams, the Missouri River is still prone to flooding. These are often referred to as "One Hundred Year" floods, meaning that there is a one percent chance of such a flooding event in any given year (Henderson, 2016). The lands surrounding the Missouri River have been designated 100-year floodplains by the Federal Emergency Management Agency ("FEMA"). The Lake

Oahe crossing in Emmons County is located in FEMA Zone D, which is an area of undetermined, but possible flood hazards. Unfortunately, FEMA has not conducted a study to determine flood hazards in Morton County, ND, whatsoever (Henderson 2016). The region experienced its last disastrous flooding event in June of 2011 (FEMA, 2011). Flooding events have the capacity to exacerbate the effects of an oil spill in a number of ways, but especially by raising water levels (drowning nests and reducing available shoreline habitat for birds while extending the reach of spilled oil), increasing river surface current speeds and sediment loads, and making it more challenging for response teams to get to the site or control the situation. In situ burns, one of the most common responses to Bakken crude oil spills, may be implausible in heavy rains and flooding events. Floods may also increase ground pressure on pipelines.

The riparian corridor in question, where DAPL crosses Lake Oahe on USACE easements, is home to an abundance of Great Plains wildlife. This includes numerous fish, mammal, bird, reptile, and amphibian species. The region is also home to the Bald Eagle, which, while no longer listed as endangered, requires special considerations, such as a 660 foot distance between known eagle nests and construction (DAPL construction exceeded this distance by 340 feet, though that may not make a difference in the event of an oil spill). These added Bald Eagle protections are derived, not from the Endangered Species Act ("ESA"), but from the Bald and Golden Eagle Protection Act and the Migratory Bird Treaty Act (Henderson, 2016).

Pursuant to Section 7 of the ESA, the local USFWS office in Bismarck, North Dakota conducted an informal consultation for all federally threatened and endangered species in the relevant DAPL project areas as a part of the clearance process for the pipeline (U.S. Fish and Wildlife Service, 2016). In total, nine federally threatened or endangered species were found within project areas of DAPL that intersect with USFWS easements (U.S. Fish and Wildlife Service, 2016). For a complete list of the nine threatened and endangered species in the USFWS easement, see Table 3 below. The USFWS reported in May 2016 that there would be No Effect on any of the federally threatened and endangered species within the Dakota Access North Dakota and South Dakota USFWS easements project area (U.S. Fish and Wildlife Service, 2016). This determination, however, may be misleading. The USFWS "no effects" determination regards only the *construction* and *immediate* ecological disruption of DAPL without taking into consideration the ecological impact of a potential oil spill on any of the USFWS easements or into the Missouri River itself. They looked only at the temporary disturbances within the 125 feet right-of-way building easement. The USACE, on the other hand, was more conservative in its Environmental Assessment and found that for some endangered species, there *may* be effects, but those effects were unlikely to be adverse (Henderson, 2016). Mosbech (2000) argues that environmental assessments in general, and for seabirds especially, cannot accurately anticipate the effects that various human behaviors or pollutants will have on the populations, especially since environmental assessments only look at the effects of a single project rather than the totality of compounded impacts. While measures[1] have been taken to prevent a spill, the fact that there has been no real ecological assessment of the region in the possible event of an oil spill is cause for concern and the impetus behind this study.

Common Name	Scientific Name	Federal Status	North Dakota	South Dakota	Effect Determination
Mammals					
Gray wolf	*Canis lupus*	E	Mountrail, Williams	Not Listed	No effect
Northern long-eared bat	*Myotis septentrionalis*	T	Mountrail, Williams	Campbell, Edmunds, Faulk, Kingsbury, Lake, McPherson, Miner, Minnehaha, Spink	No effect
Birds					
Least tern	*Sterna antillarum*	E	Mountrail, Williams	Campbell	No effect
Piping plover	*Charadrius melodus*	T	Mountrail, Williams	Campbell, Kingsbury	No effect
Rufa red knot	*Calidris canutus rufa*	T	Mountrail, Williams	Campbell, Edmunds, Faulk, Kingsbury, McPherson, Miner, Spink	No effect
Sprague's pipit	*Anthus spragueii*	C	Mountrail, Williams	Campbell, McPherson	No effect
Whooping crane	*Grus americana*	E	Mountrail, Williams	Campbell, Edmunds, Faulk, Kingsbury, Lake, McPherson, Miner, Minnehaha, Spink	No effect
Invertebrates					
Dakota skipper	*Hesperia dacotae*	T	Mountrail	Edmunds, McPherson	No effect
Plants					
Western prairie fringed orchid	*Platanthera praeclara*	T	Not Listed	Lake, Miner, Minnehaha	No effect
Abbreviations: E: Endangered T: Threatened C: Candidate					

Table 3. USFWS Federally Threatened and Endangered Species within the Dakota Access Pipeline's project areas in ND and SD that fall on USFWS Easements (U.S. Fish and Wildlife Service, 2016).

Why birds?

The three endangered species from the region that were selected for this study were three migratory shorebirds: the Piping Plover, Interior Least Tern, and Whooping Crane. Each of these species is charismatic and therefore attractive for conservation efforts, has been extensively invested in by many

[1]Some of the standard measures employed by ETP to ensure the safe movement of Bakken crude oil through DAPL include: valves with remote actuators used to isolate specific sections of pipeline and minimize crude release in the event of an emergency, including 20 in the Supply Line in North Dakota; passage of internal inspection devices capable of detecting internal and external anomalies will run through pipeline, with six total pig launchers/receivers (L/Rs) located along the pipeline within North Dakota; none of the L/Rs (which are 200x400ft would be located on USFWS protected wetlands (U.S. Fish and Wildlife Service, 2016)

of the governmental organizations cited in this paper, relies heavily on Missouri River habitat for survival, and plays an important role in its ecosystem.

Birds play a critical role in ecosystem health, especially along bodies of water like the Missouri River. Avian species from seabirds to swallows are often a link between the aquatic and terrestrial food chains, giving these species the unique ability to transfer nutrients (and therefore, contaminants) from aquatic systems to terrestrial ecosystems, and vice versa (Custer, 2011).

Birds are also known to be impacted by terrestrial, marine, and coastal oil spills. Seabirds are the group most vulnerable to oil spills and should be studied both as valuable resources in and of themselves and as relatively easy-to-observe indicators of ecosystem health at lower trophic levels (Mosbech, 2000). According to Piatt et al. (1990), bird mortality in the aftermath of an oil spill is dependent on several biological factors, including the birds' foraging behavior, the size of the local bird populations, the quantity of oil spilled, the oil's persistence in the environment, and whether or not bird populations are aggregated or dispersed at time of rupture. Oil can kill birds by removing the insulative property of their feathers (inducing hypothermia), through starvation (by reducing available food resources), and through toxicological effects post-ingestion (Piatt et al., 1990). Migratory birds often have highly specialized metabolisms as part of their annual cycles, which include molting, mating, breeding, incubating, fledging, and migrating. Therefore, they often cannot afford to expend extra energy preening oil from their feathers, and the very act of preening may cause oil ingestion (Mosbech, 2000). During the 1989 *Exxon Valdez* spill, 260,000 barrels of crude oil leached into the Prince William Sound. More than 30,000 dead birds of 90 species were retrieved from polluted areas by August 1 of the same year. Many were birds that live and feed in the water, including murres (74% of retrieved bird carcasses), alcids (7.0%), and sea ducks (5.3%). A colony of 129,000 murres inhabiting the Barren Islands was completely devastated. Piatt et al. (1990) estimated that the total number of avian casualties from oil pollution was 100,000 to 300,000 birds. It is still unknown if seabirds are able to deliberately avoid oil slicks (Mosbech, 2000).

The diversity amongst bird species makes them good study subjects, as we can see how occupation of different trophic levels, different behaviors, timelines, and morphologies may alter resiliency to oil spills. Bird behaviors like colonial nesting and flocking make them more vulnerable to oil spills than birds which are dispersed. Bird populations which are believed to be the most seriously affected by acute oil spills are those with a low reproductive capacity and corresponding long life span (Mosbech, 2000). The unique and sensitive respiratory systems of birds, historically utilized in coal mines, make bird species excellent detectors of airborne toxicants like benzene released from volatile crude oils like Bakken. Other benefits to studying birds and using them as indicator species of ecosystem health is their relative visibility (compared to smaller, better camouflaged, sparsely populated, or underwater organisms) and their existing baseline data. All three birds studied in this paper have undergone extensive conservation management and observation over the last century (Henderson, 2016; USFWS, 2016).

However, there are also drawbacks to using bird species to gauge the impacts of an oil spill. Because bioaccumulation is related to trophic level (with some influence of growth rate and lipid concentration) and birds are not usually at the top of the food chain, they may not show the full extent of ecological uptake of contaminants. I intend to account for this by studying three bird species that occupy different trophic levels in the Missouri River riparian ecosystem. Another problem that researchers encounter when studying environmental impacts on bird populations is avian migration. Most bird species are not stationary, and bird exposure to different environments and toxicants on wintering and migratory grounds can create confounding variables when trying to understand the impacts of an isolated spill event on a mobile bird population.

The Piping Plover.

The Piping Plover (*Charadrius melodus;* see Figure 4) is a small, pale shorebird that inhabits open sandy beaches and alkali flats in North America. They are 17-18 cm long and weigh between 43-63 g (Elliot-Smith et al., 2004). Today, there are Piping Plover populations on the U.S. Atlantic coast, the Great Lakes, and the region of interest of this study, the Northern Great Plains/Canadian Prairie.

Piping Plovers are ground foragers who search for prey visually and feed on a diet of insects and small aquatic invertebrates. This ground foraging behavior coupled with the fact that Piping Plovers nest in nothing but scratches in sand or gravel along riverbanks or on sandbars makes this species particularly susceptible to oil spills (Cornell University). In North Dakota, these birds spend about 42% of their time at the waterline (Elliot-Smith et al., 2004). Piping Plovers typically lay four eggs per clutch. They begin appearing in the Northern Great Plains region in mid-April for breeding and leave to warmer, wintering grounds in late July and early August. In preparation for migration, Piping Plovers sometimes form flocks known as pre-migratory staging – a behavior that could put populations at high-risk in the event of an untimely oil spill while birds are locally gathered. While adults do not swim or dive, downy chicks may run into the water if trying to escape a predator. The birds bathe at the water's edge, and on hot days, incubating adults (male and female) may leave the nest, wet their feathers, and return to stand over the eggs to cool them down – a behavior that, in the event of an oil spill, could be fatal to the clutch (Elliot-Smith et al., 2004). One salvaging behavior of the Piping Plover is that pairs are typically monogamous only for a season and do not mate for life; thus, the loss of some adults to an oil spill will not inhibit surviving adults from breeding in following years. Additionally, Piping Plovers are well-adapted to flooding and predation and thus frequently re-nest, sometimes multiple times in a season. This means that even if a clutch is lost to an oiling event, the pair may re-nest and still fledge young that season. However, chick survival is lower if a family is forced to move due to a disturbance soon after hatching (Elliot-Smith et al., 2004).

Due to disturbances by human populations, *all* populations of Piping Plovers are currently classified as endangered or threatened (Cornell University). Furthermore, Piping Plovers are listed as Near Threatened on the International Union for Conservation Nature (IUCN) Red List of Threatened Species (Cornell University). In 2002, the USFWS designated Lake Oahe as critical habitat for the Piping Plover per the ESA, meaning that the region has been identified as a geographic area essential to the conservation and recovery of the species (Aron, 2005).

Piping Plover numbers have been steadily increasing since 1986, in part thanks to the Great Lakes and Northern Great Plains Piping Plover recovery plan, but are still low. The current population estimate for the Atlantic Coast breeding population of Piping Plovers is 3,600 birds, the Great Lakes population is a mere 108, and the Great Plains region is a maximum of 4,700 individuals (Cornell University, 2017). Thus, an oil spill in the Missouri River could impact the largest remaining population of Piping Plovers in North America, one that very well could be needed to sustain the other populations through reintroduction in the coming years. These ~4,700 Piping Plovers in the Great Plains include both U.S. and Canadian populations; the U.S. Northern Great Plains Piping Plover population had 2,959 adults in 2006; this included 1,212 breeding pairs (81.9% of the population) and 535 non-breeding adults (18.1%) (North Dakota Field Office et al., 2009). The loss of the Piping Plover would be devastating, as there has already been a great deal of time, effort, and money funneled into conservation efforts. The International Piping Plover Recovery Group made up of U.S. and Canadian representatives has conducted an International Piping Plover Census ("IPPC") every five years since 1991, and the USACE has been constructing Emergent Sandbar Habitat and Shallow Water Habitat projects along the Missouri River in compliance with the 2003 USFWS Biological Opinion to generate more habitat for this species (Committee on Missouri River Recovery, 2011). Additionally, the Piping Plover is one of the more well-known North American birds, and its charisma has made it a keystone species for protecting other, less attractive wildlife in the region, from gray wolves to pallid sturgeons. The Piping Plover even appeared in this popular 2016 Disney short.

Figure 4. Two-day-old Piping Plover chick found at Kings Point in East Hampton, NY, photographed by Beaun. 29 April 2008. Wikipedia.

The Interior Least Tern.

Also of the order Charadriiformes, the Interior Least Tern (*Sterna antillarum athalassos;* see Figure 5) of the Laridae family nests on sandy beaches along the southern coast of the United States as well as up major river systems far into the interior of the continent, including the Missouri River in North and South Dakota (Cornell Lab of Ornithology). Interior Least Terns winter in South America. They measure in at a length of 21-23 cm and a weight of 30-45 g (Thompson et. al, 1997). Like Piping Plovers, they nest right on the ground in a shallow scrape in the sand, soil, or pebbles, and a typical clutch is three eggs, especially for interior populations (coastal populations often have two-egg clutches). Although capable of adapting to new colony sites, Least Terns have been observed to be most productive at breeding sites that have endured for some time (Thompson et al., 1997). Least Terns breed in colonies on sparsely vegetated sand or dried mudflats along coasts and rivers, putting their populations at high risk in oil events. Colonies can range from a few pairs to more than 2,000 breeding pairs, but typically range from 25 to 500 breeding pairs. Least Terns often tolerate Piping Plovers in their colonies. If nests are damaged, re-nesting commonly follows, and Least Terns are capable of creating up to three nests per breeding season, a resilient behavior that could help populations recover from an oil spill. Most Least Terns begin breeding after their third year, as opposed to Piping Plovers who can breed after their first year. This makes Least Tern populations more vulnerable to oil spills and other stochastic events as there is a time lag between juveniles hatching and their ability to breed and repopulate (Mosbech, 2000). Additionally, Interior Least Terns sometimes bathe together in groups of 2-10 birds for 10-15 minutes, a behavior that, if performed at the wrong time, could prove fatal in an oil spill. The birds and their nests will also likely be at risk in hot weather when the birds wet their bellies and use their wet feathers to cool the eggs in their nests.

Least Terns are diurnal and roost in their colonies at night. Unlike Piping Plovers, Least Terns are higher up the food chain, their diet consisting of small fish and some invertebrates. This means that Least Terns are more vulnerable to problems associated with bioaccumulation (Mackay & Fraser, 2000). Were DAPL to burst in or around the Missouri River, their feeding behavior may endanger them, as these birds plunge into the water from flight and Bakken crude oil is known to create a sheen of oil on the water surface (Cornell Lab of Ornithology; Mitchell & Child, 2015). This has the potential to coat the birds in either floating or sinking oil particles. Today, the North American Waterbird Conservation Plan estimates a total continental population of 60,000-100,000 breeding birds; the bird is classified as threatened, endangered, or as a species of concern for most states because of loss of nesting habitat. The interior population, specifically, has been federally listed as endangered since 1985 (Cornell Lab of Ornithology). For a closer look at the Great Plains region, the South Dakota Interior Least Tern and Piping Plover Management Plan set the goal of a 1.0 fledgling-per-adult-pair ratio over a ten-year running average to maintain stable population numbers and aimed for a total South Dakota population of 653 adult birds (327 pairs), including 100 adults on Lake Oahe (Aron, 2005).

Figure 5. A Least Tern parent feeding a small chick near St. Augustine, Florida, USA. The adult is in breeding colours, photographed by Craig O'Neal, July 4, 2010. Wikipedia. Image has not been altered.

The Whooping Crane.

The final bird species considered in this study is the Whooping Crane *(Grus americana)*, the tallest bird in North America averaging a height of 1.5 m (see Figure 6). Whooping Cranes weigh significantly more than either the Least Tern or Piping Plover at 7,142-7,851 g in the fall (Urbanek & Lewis, 2015). While the Whooping Crane does not breed in the Great Plains region as the Piping Plover and Least Tern do, it does use the region as a critical flyway, or migration corridor, passing through twice per year. The birds feed on invertebrates, small fish, and plant material they find on the ground or in shallow water. The pecking and probing of sandy or flooded soils could lead to oiling of the beak, eyes, and face of the birds.

Today, the Whooping Crane is a fragile but undeniable conservation success story. In 1941, just 21 Whooping Cranes remained, and fifteen of them were migrants between Wood Buffalo Park in Canada and Aransas, Texas. All 600 of the Whooping Cranes alive today – 440 wild and 160 in captivity – are descended from that fifteen-bird flock, a population that continues to migrate approximately 2,500 miles in one week from their staging grounds in Saskatchewan, Canada to Texas through the Great Plains. This population of Whooping Cranes is the only naturally migrating population in the country. However, extensive efforts have been made to revive this species, and there are now three unnatural, introduced populations of Whooping Cranes – two stationary populations in Florida and Louisiana and a migratory population that moves between Wisconsin and Florida, whose route was famously guided by a creative conservationist operating a crane-like aircraft rig (Urbanek & Lewis, 2015).

Whooping Cranes spend their time either on the ground or wading in shallow water – they are unlikely to perch in trees. Their migration routes and nesting locations are learned from other cranes, so it is essential that the flock remains intergenerational to be viable. Due to a strong homing instinct, the Whooping Cranes are unlikely to disperse to new habitats, meaning the habitats they do occupy need to be well-maintained in order to ensure the continuation of the species. The Whooping Cranes from the wild Canada/Texas population typically arrive in the Great Plains in early to mid April on their northward spring migration, determined by both photoperiod and favorable weather conditions, and return in September on their southward fall migration back to Texas.

In the event of an oil spill, the Whooping Crane has the most to lose of the three birds included here. With a low fledging rate of one offspring per year starting at the age of five, Whooping Crane populations would need much more time than either Piping Plovers or Least Terns to recover population numbers. They care for young for 10 to 11 months, making them extremely altricial; hence, parental survival is more important to juvenile survival in this species than the others. Mosbech (2000) writes that birds with low reproductive capacity and corresponding high average lifespans are believed to be most seriously affected by acute oil spills.

Figure 6. Whooping Crane in flight in Texas. USDA Photo by John Noll. Wikipedia.

Conclusion.

The Dakota Access Pipeline, although approved by both the USACE and USFWS, poses unknown threats to native and endangered wildlife at Lake Oahe, one of the two major Missouri River crossings of the pipeline. Both Environmental Assessments generated FONSIs for the three endangered bird species in question, yet they focused almost exclusively on environmental impacts during construction rather than an actual oil spill. Even when USACE did conduct oil spill predictions, the most they ever modelled was 10,000 barrels – not even half the quantity of crude oil spilled by Enbridge into the Kalamazoo River in 2010. While ETP continues to insist that the pipeline is safe, we know that several minor spills have elapsed both before and after the pipeline became operational in June 2017. It is therefore worth investigating how a larger Bakken crude oil spill would persist in this environment given different weather and environmental conditions, and to see how that oil could impact the three endangered bird species that are the focus of this study. This study seeks not only to fill the gaps in the USACE and USFWS environmental assessments, but also to create a relative index of oil spill scenarios to see which times of year would be most detrimental for an oil spill to occur in terms of impacts on the local endangered bird populations and to suggest ways to mitigate those impacts at particularly critical times of year. These species require scientific attention both because of their status as endangered species and their ability to serve as indicator (sentinel) species, alerting stakeholders to issues regarding water and air quality for the millions of people living downstream who rely on this river for drinking, agriculture, and hydropower (Burger & Gochfeld, 2004).

Methods

To survey the population impacts of hypothetical Bakken crude oil spills in Lake Oahe on Piping Plovers, Least Terns, and Whooping Cranes, I used the online GNOME oil modeling program in conjunction with ArcGIS, a common Geographic Information System ("GIS") software. Similar to Bejarano and Mearns' (2015) study, *Improving environmental assessments by integrating Species Sensitivity Distributions into environmental modeling: Examples with two hypothetical oil spills*, I used GNOME to generate oil spill dispersal under specific conditions and then applied ecological data to those outputs to engage in a spatial analysis. This methodology varies slightly from Bejarano and Mearns (2015), who used their GNOME outputs to measure acute toxicity in the water column for aquatic organisms, and I was interested in the likelihood of the local endangered birds becoming coated with oil floating at the surface level or beaching on nesting habitat.

By inputting known data such as temperature and wind patterns from Cannon Ball, ND into the computer modeling software, I predicted the fate and transport of potential crude oil spills during different times of year that held significance for the birds. I then uploaded the oil dispersal shapefiles onto maps that displayed the predicted distribution of the three endangered bird species. Using an ArcGIS feature called Select by Location, I then found how many bird data points were in close proximity to oil data points. I compared the oil spill scenarios to find the times of year when each bird species is the most vulnerable. To do this, I ran two oil spill scenarios (Test 1 and Test 2) on ten selected dates to create 20 initial tests. Additionally, I simulated flooding events and three different clean up responses for a total of 30 tests.

Seasonal timing of oil spill scenarios.

Oil spills could occur at any time of the year. Because Bakken crude oil behaves differently in different environmental conditions, and Lake Oahe is a dynamic environmental landscape, I conducted tests under different scenarios to sample the wide array of oil spill possibilities in this region. The Northern Great Plains experiences high, variable winds, all four seasons (including icy winter conditions), and 100-year floods. Additionally, the sensitivity of bird populations to oil spills changes throughout the year as their behaviors, diets, bodies, and numbers change. The three endangered bird species of this study live only part-time in the region; Piping Plovers and Least Terns nest and fledge[2] young along the

[2] Fledging is a stage in a young chick's life between hatching and gaining flight. Altricial birds spend a longer amount of time in a vulnerable state in the nest – often the nestling and fledging stage are the same. Precocial birds develop quickly with a shorter nestling stage succeeded by a longer fledging stage.

Missouri River while Whooping Cranes only use it as a migration and staging[3] corridor. The birds arrive and leave the region at different times, as seen in Figure 7. Based on these patterns in bird distribution and behavior, I chose ten dates of the year to run the model (Table 4). I did not run any oil spills when the endangered birds were not present. Since WebGNOME modeling is unreliable in icy winter conditions, I did not think it was necessary to run the spills at this time, especially since no birds could get directly coated in oil (NOAA OR&R, 2017). This decision does not dismiss the fact that winter oil spills can leave harmful and toxic residue in their wake long after the event and impact the organisms that make up the bird diets.

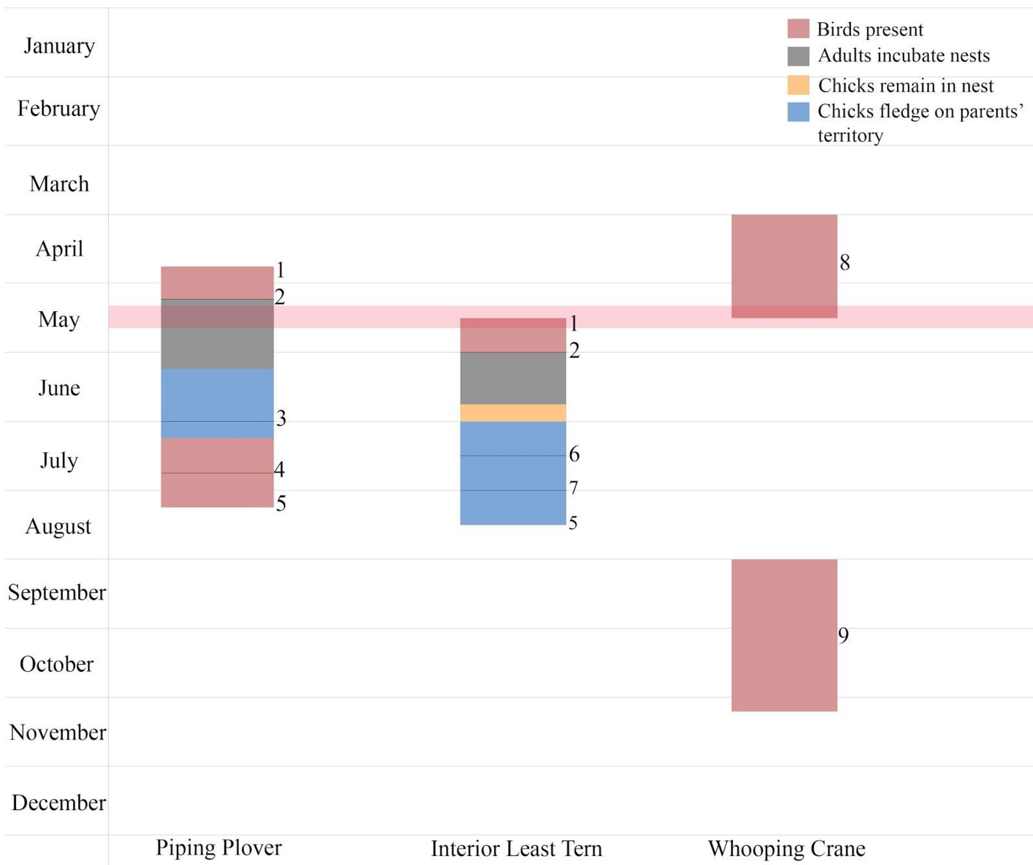


Figure 7. Piping Plover, Interior Least Tern, and Whooping Crane annual cycles in the Northern Great Plains. The red horizontal bar indicates the only time when all three endangered bird species can be found at Lake Oahe. 1) Courtship begins. 2) First egg of the season laid. 3) Unsuccessful breeding adults leave. 4) Successful adults and juveniles start to leave. 5) All birds gone for the season. 6) Chicks capable of flight. 7) Least Terns will not renest if clutches/broods lost. 8) Northward migration stopover. 9)

[3] Staging is a bird behavior in which birds stop to rest, drink, and eat at stopover/staging sites. Although staging and stopover sites are often used interchangeably, staging is generally associated with higher concentrations of birds, longer stopover duration, and places with predictable, abundant prey where birds return year after year (Warner, 2010).

Southward migration stopover (Michigan Natural Features Inventory, 2007; North Dakota Game and Fish Department, *Whooping Crane,* 2016; Texas Parks and Wildlife Department (n.d.); North Dakota Game and Fish Department, *Least Tern,* 2016).

Date	Piping Plover	Least Tern	Whooping Cranes
April 1	Not arrived	Not arrived	Begin arriving; this is the earliest point in the year that any of the three endangered birds are present
April 20	Arriving; courtship begins	Not arrived	Gradually migrating north for summer breeding
May 15	Successful plovers are incubating nests; unsuccessful individuals still in courtship	Arriving; courtship begins	Continuing migration north to Canada, last cranes are leaving the area
June 4	Incubating	Incubating	Not present
June 30	Chicks have hatched and are fledging in parents' territory	Chicks hatching; not as precocious as Piping Plovers and remain in nest	Not present
July 15	Will no longer re-nest if clutch/brood is lost; successful parents rearing young	Chicks fledge on parents' territory but still brooded by adults; chicks now capable of flight	Not present
August 1	Successful adults and young begin to leave	Adults and fledglings present; if clutches/broods lost, terns will not renest	Not present
September 1	Not present	Not present	Begin arriving again as a stopover on their migration south for winter
October 1	Not present	Not present	Continued use as staging area
November 4	Not present	Not present	The tail end of use as staging area for southward migration; latest time of year when any birds present

Table 4. Selected dates for oil spill testing in Lake Oahe based on bird annual cycles.
Using GNOME.

GNOME is the modeling tool that the NOAA OR&R Emergency Response Division uses to predict the trajectories of pollutants in bodies of water. GNOME 1.0 was first released on March 16, 1999. The current version, GNOME 1.3.10, was posted to the Web on November 30, 2017 (NOAA OR&R, 2017). The program itself is downloadable (https://response.restoration.noaa.gov /gnome) and available for public use, and NOAA has just launched their WebGNOME Preview which is still under development. While this program is in beta form and was throughout the course of this study, I chose to still use the WebGNOME platform for a number of reasons. First, it has more advanced algorithms than GNOME 1.3.10 because it incorporates the original GNOME software but additionally integrates NOAA's Automated Data Inquiry for Oil Spills ("ADIOS") program to take into account oil weathering and clean up responses. Second, WebGNOME has active developers who are extremely responsive to email, and its developers informed me that the beta version of WebGNOME may experience some bugs and instability but that the oil fate outputs were still reliable (O'Connor, NOAA OR&R, personal communication). Finally, in an effort to make this study replicable by both academic researchers and citizen scientists alike, I chose the more accessible, easy-to-use platform to encourage its further use and development.

The variables.

When running an oil spill scenario on GNOME, the program prompts for a variety of input variables. These include the location, start time (date and time of day), duration of spill, stage height *or* surface current speed, wind speed and direction, type of spill (instantaneous vs. continuous), amount released, oil type, coordinates of spill, water temperature, salinity, sediment load, and wave height. There are a number of ways to toggle with these variables, and clean up responses and other features can be added or altered after the spill runs all the way through. Once all of these variables are entered into the WebGNOME wizard, the program outputs an oil run on Map View, like that in Figure 11. NOAA provides a database, called the GNOME Online Oceanographic Data Server ("GOODS"), to help users find ocean currents and winds. This resource, while certainly helpful for some oil spill modeling, was relatively impractical for my inland riverine environment for which GNOME has nothing on file. While WebGNOME and GOODS theoretically allow users to create custom files, I did not find the program able to distinguish between the water of the Missouri River and the land of the nearby riverbanks when I attempted to use this feature, and therefore figured the Detroit River would be more reliable and user-friendly than a custom file.

In order to recreate the environmental conditions of the Missouri River near Cannon Ball, ND on each of the ten dates from Table 4, a significant amount of research was required. Although GOODS was available, I had to look outside of NOAA sources to find desired variables such as Missouri River sediment load, salinity, water temperature, wind patterns, and so forth. I was able to base most of my variables on past data and make informed estimates when such data did not exist or could not be found.

WebGNOME location file.

The first step WebGNOME prompts users to do is to choose a location file, of which they offer 29. Neither GNOME 1.3.10 nor WebGNOME have location files for the Missouri River, including where DAPL crosses USACE easements. Caitlin O'Connor at NOAA explains that NOAA only creates location files at the request of the U.S. Coast Guard and that their river modeling is less accurate than their oceanographic modeling.

Since there was unfortunately no Missouri River location file, I had two options: to create a custom file, or to use a pre-existing WebGNOME location file as a stand-in for the desired Lake Oahe location file. I chose to use the developed Detroit River location file as a backdrop for my thirty simulations because I experienced problems with creating an inland custom file and because I presumed the pre-existing Detroit River file was more reliable and peer-reviewed (see Figure 8). It is the closest location file to the Missouri River available on WebGNOME and shares a similar climate, and it's also a river, as opposed to the marine location files GNOME is better-known for. The Detroit River location file also works because it has a few islands which emulate the sandbars that form seasonally in the Missouri River and provide Piping Plover and Least Tern nesting habitat. Thus, the Detroit River set to a low discharge[4] on WebGNOME could closely imitate the Missouri River at Cannon Ball. This was the location file recommended by the folks at NOAA. I was able to input Great Plains wind and water temperature data into the Detroit River location file to mimic the Missouri River environment.

[4] "The volume of water that passes a given location within a given period of time, usually expressed in cubic feet per second" (Perlman, 2017).

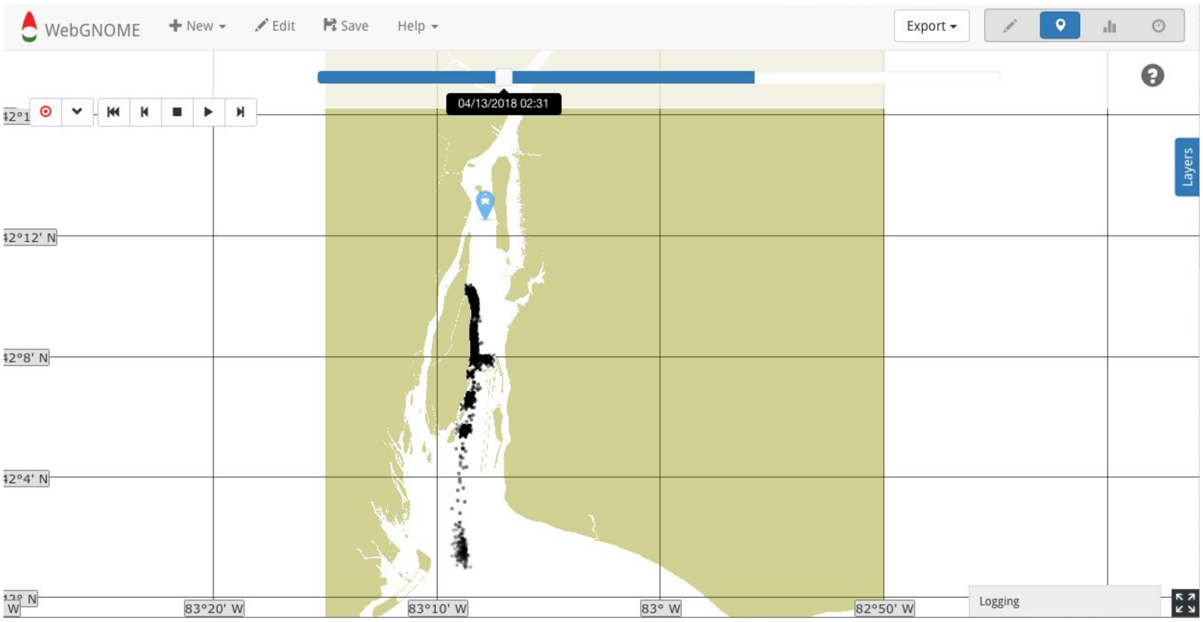


Figure 8. A sample Map View oil spill simulation on WebGNOME using the Detroit River location file.

Duration, flow, and wind.

Once the location file is selected, users are asked in the Model Settings window to provide a name for the spill, choose the date, time, and duration, and choose whether or not to include the Minimum Regret (uncertainty) solution. I started all spills at noon. I kept the year consistently 2018 and changed the dates according to Table 4. The duration of the tests varied based on which spill scenario I was conducting, which will be explained in more detail below. I turned off the Minimum Regret (uncertainty) solution for all tests. The WebGNOME User Manual does not clarify what this feature does, stating only, "Uncertainty is the only certainty there is" (NOAA OR&R, 2017).

The next window is the Setting River Flow screen. This variable can be entered as either Stage Height[5] (the default) or Surface Current Speed. Because I used the Detroit River location file, the stage height of the Missouri River recorded from the nearest U.S. Geological Survey ("USGS") Gauge at Bismarck, ND (06342500), does not match the parameters available on WebGNOME for the Detroit River (stage height for the Detroit River is significantly higher than the stage height of the Missouri River). Since that was not a viable input, I switched to Surface Current Speed. WebGNOME offers three different surface current speeds: Low (0.5 m/s), Medium (0.9 m/s), and High (1.3 m/s). Because both the Garrison Dam and Oahe Dam constrict the Missouri River on either side of the DAPL crossing, the river

[5] "The height of the water surface above the [arbitrary] gage datum (zero point). Gage height is often used interchangeably with the more general term, stage, although gage height is more appropriate when used with a gage reading" (Perlman, 2017).

moves slowly (Committee on Missouri River Recovery, 2011). Finding an accurate river speed proved difficult as most USGS gauges measure gage height in lieu of surface current speed. I eventually found that the speed of the Mississippi River where the Missouri River feeds into it is 0.537 m/s (National Park Service, 2017). For all of my models except those simulating flooding events, I used the 0.5 m/s current speed.

The next window that WebGNOME asks users to fill out is Wind. I switched to the "Variable Wind" tab for all tests to accurately convey the rapidly changing wind speeds and directions in the Northern Great Plains. The best source I found for wind data was Weather Underground, which records and saves hourly wind speed (mph) and direction. Weather Underground has only been collecting forecast data from Cannon Ball, ND (also called the Huff Hills Ski Area) since 1/29/2016, so I only had two years' worth of wind data (see Figure 9), but this was sufficient for creating realistic wind scenarios in my models (see Table 5). To capture the wind variability in the Northern Great Plains, I chose to enter new wind speed and direction entries in two hour increments.

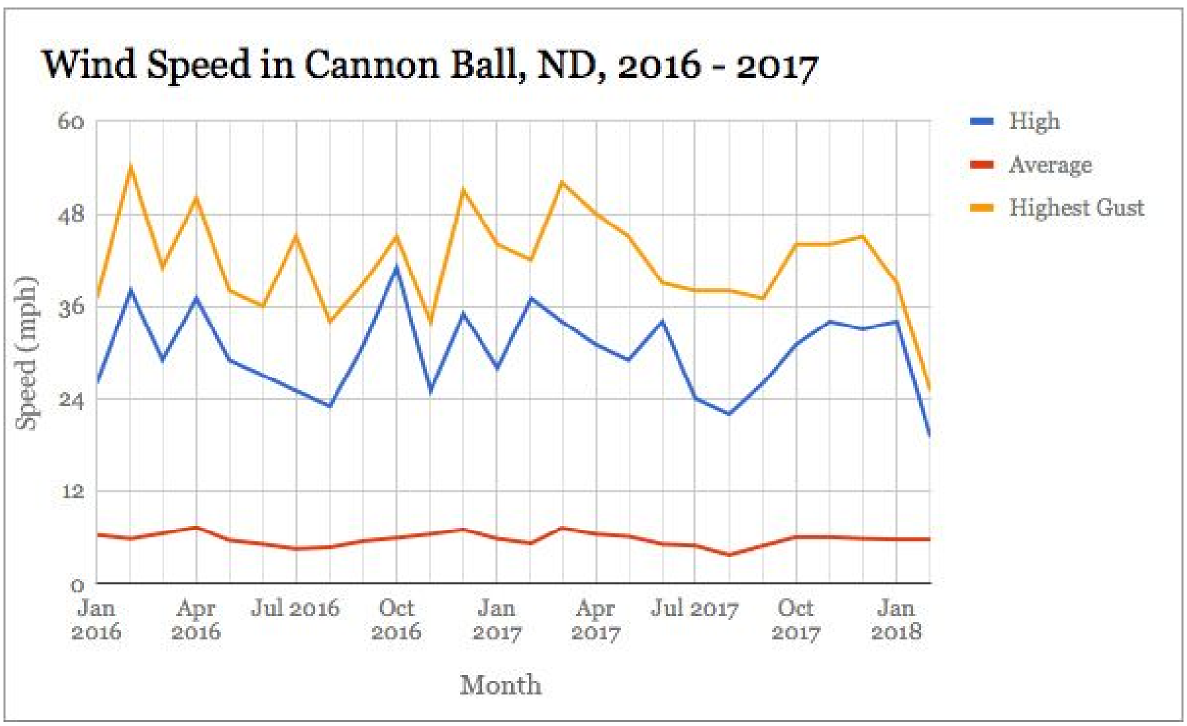


Figure 9. Wind speed trends in Cannon Ball, ND from January 2016 - January 2018 (The Weather Company, 2017).

Wind Entry	4/1	4/20	5/15	6/4	6/30	7/15	8/1	9/1	10/1	11/4
12:00	9 SSW	0 N	12 SE	0 N	16 NW	10 NE	7 NNE	6.5 W	7 SW	4.6 WSW
14:00	48 SW	4.5 ENE	16 SE	5 W	11.4 NW	11.5 NNE	7.5 NNW	9.2 NW	10 SSW	10.4 WNW
16:00	14.5 S	8 N	13.8 SSE	7 NE	12 WNW	10.4 ENE	19.6 NNE	11.5 NW	22 W	19 WNW
18:00	13 SSW	8 NW	29 S	16.1 NE	11 NW	9.8 NE	13 NE	13.8 WNW	15 W	15 WNW
20:00	11 S	8 NE	10 ESE	13.8 E	6 N	11.4 E	10 NE	9.2 NNW	16 W	20.7 WNW
22:00	12.7 S	0 N	8 SE	10.4 E	0 N	8.5 ENE	6 ENE	6.9 WNW	14 WNW	13.3 WNW
0:00	17 SSW	4 E	6.5 ESE	9.2 ENE	4.6 SW	4.5 NNW	10.4 N	15 S	7 SW	12 SE
2:00	5.8 ENE	3.5 WSW	3.5 SW	0 N	15 NW	8.5 NNE	9.2 NNE	16.1 SSE	11 SSE	10.4 ESE
4:00	5 NE	0 N	0 N	0 N	14.5 NNW	8.1 N	8 N	10.4 S	8 SE	11 ESE
6:00	5 NE	0 N	4 N	0 N	11 NNW	6 N	5 NW	8.1 SSW	6.5 ESE	8 E
8:00	5.8 ENE	3.5 W	5 ENE	0 N	14.5 NW	10 NE	5 WNW	12 S	6.5 SE	4.6 E
10:00	8.1 SSE	5.8 WSW	12 E	0 N	13.2 NNW	9.2 NNE	8.5 NNE	12 SSW	10.4 SW	3.5 SE
12:00	0, N	3.5 W	10 SE	8 SSE	21.9 NW	8.1 NE	7 NNE	6.5 SSW	7 SSW	0 N

Table 5. Wind speed and direction[6] predictions at Cannon Ball, ND for a twenty-four hour period in two-hour increments on select dates.

When I first started inputting wind data, I wanted to use the Speed Uncertainty scale at the bottom of the window to change wind uncertainty to +/-3%. This would have compensated for inevitable error on my part with the wind entries. While I still believe that that would be a more realistic and effective method, as per this writing, NOAA associates recommend that I turn this feature off and proceed to use variable wind with 100% certainty in my entries. NOAA affiliate Jay Hennen writes that wind uncertainty is a rarely used feature and has yet to be fixed after it broke in a recent update (NOAA OR&R, personal

[6] Meteorologists define wind direction as the direction from which the wind is coming

communication). This is an unfortunate side effect of choosing to use a web program still undergoing development and could be amended in future studies.

Spill Scenarios.

Next, the WebGNOME Wizard asks users to select a Spill Type – instantaneous or continuous. It was challenging to determine what kinds of spills to model, especially because no "significant" DAPL oil spills have taken place so far. I decided to run best- and worst-case scenarios based on two recent, nearby case studies: the recent November 2017 Keystone Pipeline spill, and the Kalamazoo River spill of 2010, deemed the worst inland oil spill in U.S. history.

The Keystone Pipeline spill of 2017 only lasted for 15 minutes before an operator noticed the pressure drop and isolated the damaged portion of the pipeline. In that time, 5,000 barrels of crude oil were spilled (Egan, 2017). In Marshall, MI, oil leaked from Enbridge Line 6B for 17 hours before the spill was detected and the pipeline shut off. More than 23,810 barrels (1 million gallons) of oil were spilled, and the area is still being cleaned up as of this writing (Henderson, 2016). Both crude oil incidents occurred in the Midwest within the last decade, so I found both scenarios plausible for DAPL and used them to create two spill scenarios. Thus, all tests labeled "Test 1" were based on the Keystone spill; they were 5,000-bbl instantaneous spills with a 24-hour duration. All tests labeled "Test 2" were based on the Kalamazoo River spill and were 23,810-bbl continuous spills with a 17-hour duration. I then double checked the capacity of DAPL to make sure both spills were plausible based on the quantities of oil moving through it. According to ETP, the pipeline transports approximately 470,000 barrels of Bakken crude oil daily. Assuming twenty-four hour transit, that's a transport rate of 19,583.33 bbl/hour, so the spill rates of both Test 1 and Test 2 are realistic. Knowing the industry standards and technology being used to detect leaks in DAPL, the Test 1 spill scenario is more likely than the Test 2 spill scenario, but it was important to investigate both possibilities.

Once Spill Type is selected, the WebGNOME wizard provides the spill window. It prompts for the amount of oil released. In both spill scenarios, I used the unit barrels (bbl). For reference, there are 42 gallons in a barrel. It is important to not type commas into the dialog box when entering quantity of oil spilled as the WebGNOME program cannot read them. WebGNOME automatically calculates the spill rate (bbl/hour) in continuous spills. The spill rate for Test_2 was always 1400.5882 bbl/hour. WebGNOME provides a sliding scale for users to alter their confidence in spill amount. I left all tests on 100% certainty to recreate the Keystone and Kalamazoo spills as closely as possible.

Oil characteristics.

Next, I chose the substance/oil. There is no Bakken crude oil available in WebGNOME's ADIOS oil library despite the fact that millions of gallons of Bakken crude oil are transported in the U.S. by truck, pipeline, rail, and barge every year. I brought this to the attention of the NOAA correspondents and hope to see this change in the coming months. Instead of using Bakken, I substituted a similar oil in its place. The ADIOS library of pollutants categorizes oil by API and Quality, a number between 1-100 given to each pollutant to indicate how well GNOME is able to predict its movement. I used Bent Horn, a light crude oil from the Northwest Territories with an API of 41.3º (which falls in the Bakken range of 41.0º-43.0º) and a relatively high quality over other light crudes with similar APIs, for all models. Once Bent Horn was selected, WebGNOME produced a default emulsion[7] constant of 20% (NOAA OR&R, 2017). Since the most common range of emulsified water in light crude oils like Bakken is anywhere from five to twenty percent volume, I left the default emulsion constant as is (Society of Petroleum Engineers International, 2015).

Spill location.

Users then choose the starting coordinates of the oil spill within the parameters of the location file. All of my simulations start at the same spot (42.2372ºN, -83.1303ºW), labeled "Spill Start" in the Results maps (Figures 19-33). This location is shown more closely in Figures 10 and 11. I chose this point specifically because (1) it is located where the Detroit River location file widens to a mile across, similar to the Missouri River where DAPL crosses at Lake Oahe; (2) it is located near islands, of which the Missouri River has many; and (3) I did not want the point I chose to be so low on the map that I could not trace the oil as it drifted downstream and offscreen. WebGNOME location files do not allow users to see what happens to the oil once it moves off the screen and out of the particular location file they've created, so I could learn more about how the oil persists in its environment the more upstream I placed the spill starting point. The point (42.2372ºN, -83.1303ºW) was a good compromise for all of these needs.

[7]A dispersion, in the form of droplets, of one liquid in another immiscible liquid; the liquid forming droplets is considered to be in the dispersed or internal phase, and the liquid in which the droplets are suspended is the continuous or external phase. Here, the dispersed oil forms droplets in the continuous water (the river). The amount of water that emulsifies with crude oil varies widely from facility to facility (Society of Petroleum Engineers International, 2015).

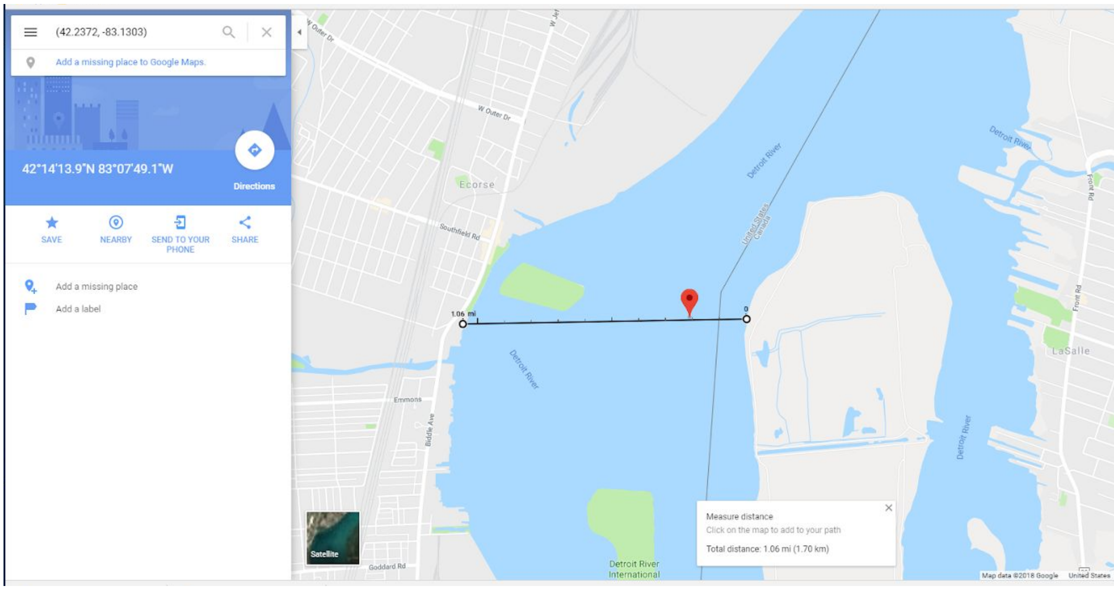


Figure 10. Google Maps view of the Detroit River. The red point is 42.2372ºN, -83.1303ºW, and the black line measures a 1.06 mile distance across the river.

Figure 11. Screen-capture of the Detroit River location file on WebGNOME wizard. The light blue marker is the the spill origin (42.2372ºN, -83.1303ºW) in all 30 of my tests.

Early in this study, I encountered a problem with WebGNOME – I could spill 5,000 barrels of Bent Horn oil into the Detroit River with no problem, but the program would stall out at 14,006 barrels in

Test 2 scenarios even though I was entering 23,810 barrels. NOAA correspondents O'Connor and Hennen offer different workarounds for this problem; O'Connor recommends altering the Time Step length of the test, but Hennen believes this may sacrifice the accuracy of the tests. Hennen's alternate workaround, which I used in all 30 tests, was to stay on the Continuous/Instantaneous Release window, scroll to the bottom, and select 'Advanced Settings - gnome.spill.spill.Spill.' As per Hennen's recommendation, I went to 'Advanced Settings - gnome.spill.release.PointLineRelease | undefined.' and increased num_elements (the number of points in the spill) from 1,000 to 2,000. This increased the oil capacity of the tests, and I was subsequently able to spill all 23,810 barrels. The only drawback of this workaround is the spills run twice as slowly (NOAA OR&R, personal communication).

Water temperature.

Finally, the WebGNOME wizard pops up its final screen. First, it asks for water temperature. The closest usable USGS gauge to the study area was 44.2 miles away in Bismarck, ND at Gauge 06342500. Although there are other, closer USGS gauges in the Missouri River between Bismarck and Cannon Ball, such as the one at Mandan, they do not collect water temperature. Data has been collected on water temperature at USGS Gauge 06342500 since October 1, 2009. Because USGS gauges measure water temperature in degrees Celsius, I changed the WebGNOME setting from Fahrenheit (the default) to Celsius. I downloaded the .csv file of all water temperature data from USGS Gauge 06342500 from October 1, 2009 to January 16, 2018. The gauge records the water temperature every fifteen minutes and has done this for almost nine years. With the help of my advisor, Dr. Breck, we found the average water temperature of each day of those nine years using R (see Figure 12).

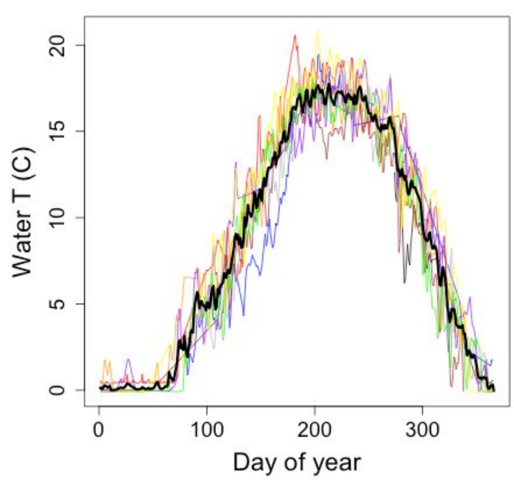


Figure 12. The average daily water temperature at USGS Gauge 06342500 in Bismarck, ND from 2009 to 2018. Each colored line represents the average daily water temperatures for each year. The black line is the average water temperature for each day of the year across all nine years.

I isolated this variable to see how much of a difference water temperature makes for the fate of Bent Horn oil in the Detroit River. I ran three controlled May 15 Test 1 tests to see if and how the water temperature affected the fate of the oil. To do this, I found the maximum, minimum, and average water temperature for every May 15 from 2010 to 2017. After testing all three of these water temperature scenarios (see Table 6, Figures 13-15), I found the differences between them to be minimal. Thus, I decided to only run my oil spill simulations with the overall mean water temperature of each date (Table 7).

Temperature	Evaporated (bbl)	Dissolved (bbl)	Beached (bbl)	Floating (bbl)
Low (5.4ºC)	1458 (29.2%)	6 (0.1%)	3493 (69.9%)	43 (0.8%)
Avg (9.7ºC)	1557 (31.1%)	6 (0.1%)	3389 (67.8%)	48 (1.0%)
High (11.5ºC)	1598 (32.0%)	5 (0.1%)	3349 (66.9%)	48 (1.0%)

Table 6. Oil fate outputs from 5_15_Test_1 to see if using the low, average, or high temperature impacted oil spill fate in a significant way.

Date	4/1	4/20	5/15	6/4	6/30	7/15	8/1	9/1	10/1	11/4
Temp (ºC)	4.9	6.0	9.7	12.3	16.4	16.6	17.8	16.7	14.8	8.7

Table 7. Average daily water temperatures from USGS Gauge 06342500 from 2009-2017.

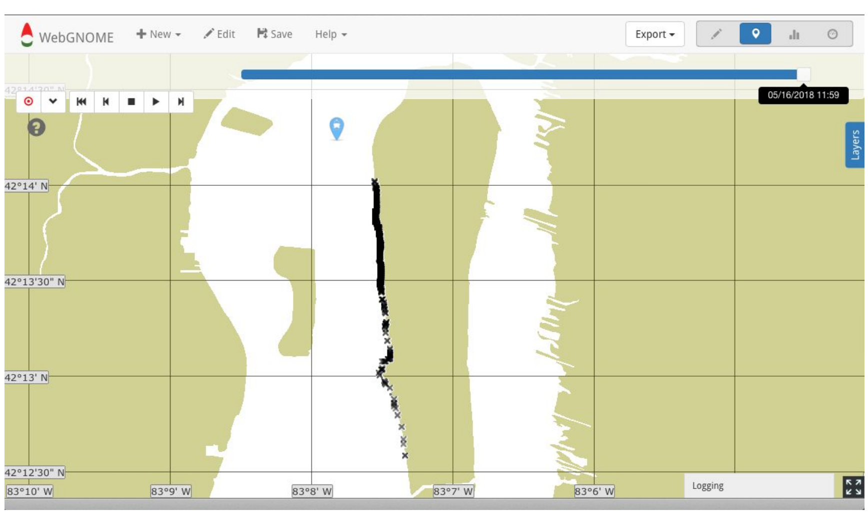


Figure 13. Oil spill run with lowest recorded water temperature for May 15 (5.4ºC).

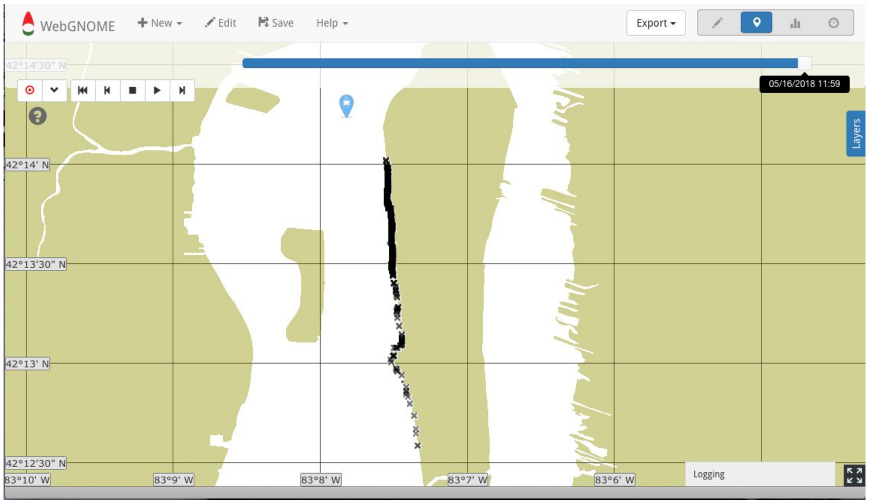


Figure 14. Oil spill run with average recorded water temperature for May 15 (9.7ºC).

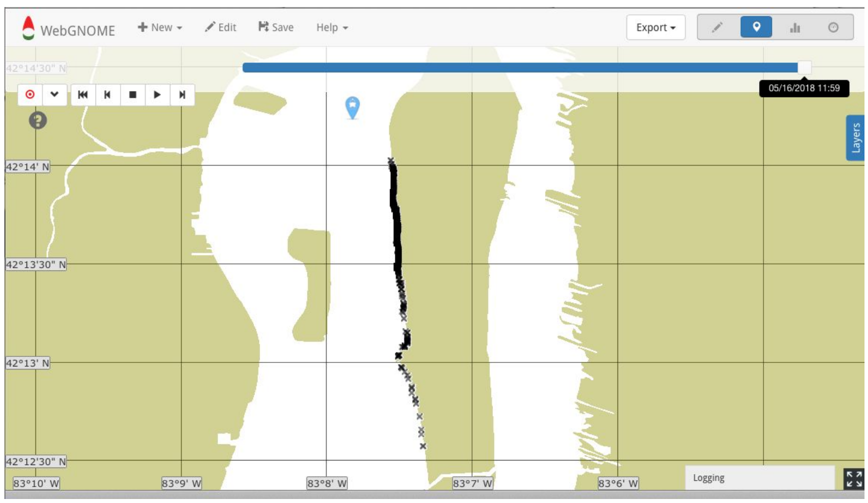


Figure 15. Oil spill run with highest recorded water temperature for May 15 (11.5ºC).

Water behavior.

The final variables that GNOME requires have to do with water behavior. These inputs were kept constant *except* in the four flood tests. The salinity (psu[8]) was set to '0 (fresh water).' The sediment load was set to 50 mg/L, since the once-muddy Missouri River has had its sediment load reduced by its six mainstem dams (Committee on Missouri River Recovery, 2011). Finally, the dialog window asks for wave height. I chose to have WebGNOME calculate the wave height based on a fetch[9] of two miles, as

[8] Practical salinity unit
[9] The distance traveled by wind or waves across open water

wave height data was not found. After these variables are entered, WebGNOME is ready to run the model.

For all 30 tests conducted, horizontal diffusion and tidal currents remained 'on' with the WebGNOME default. For horizontal diffusion, this meant a diffusion coefficient of $1.00e^4$ cm^2/s and an uncertain factor of 1. The default tide for the Detroit River is No Tide Selected, which makes sense as the Detroit River's currents, like those in the Missouri River, are not tidally-influenced. Users should always check this setting before running their models, because other river location files, such as the St. John's River which was almost used in this study, *are* influenced by tides. WebGNOME Wizard does not prompt users to make changes to these settings, but it can be done in Setup View after an oil spill model has been run.

Once the test is run, WebGNOME Fate View reports what quantity (or percentage) of spilled oil evaporated, naturally dispersed, sedimented, dissolved, beached, moved offscreen, or floated. In clean up tests, it also informs users what quantity of oil was skimmed, burned, boomed[10], or chemically dispersed. These were recorded and can be found in Results.

Flood tests.

I chose two dates to simulate flooding events – June 4 and June 30 – because of the disastrous June 2011 Missouri River floods (Przyborski & Ichoku, 2011). For these tests, all I changed was (1) Surface Current Speed from 0.5 m/s (low) to 1.3 m/s (high) to replicate higher water discharges from the anticipated opening of the Garrison Dam; (2) the water temperatures to the average water temperatures recorded on June 4, 2011 (8.4ºC) and June 30, 2011 (16.1ºC), respectively; and (3) the sediment load from 50 mg/L to 500 mg/L. However, WebGNOME does not take precipitation nor waterline changes into account, so these models cannot represent the likely loss of nests and sandbar habitat usually wrought by floods.

Adding clean up responses.

I ran six additional simulations with different clean up responses. The three clean up response possibilities available on WebGNOME are: skimming, dispersing, and in situ burning. This particularly feature of WebGNOME went through many iterations in just the few short months I was using the

[10] Booming is when large worm-like buoys are used on surface water to collect floating oil in one area and is often used to concentrate oil for an in situ burn which requires a certain thickness of oil on the surface water to be effective

program, so while interesting to toggle with, users should be wary of relying too heavily on these outputs at this time.

Clean up responses can be applied to a model in the Set Up window under the "Add Oil Removal Options" headline *after* the the test has been run. Users can apply them through the Response Option Calculator ("ROC") by clicking "Specify Equipment Parameters" or through ADIOS by clicking "Specify Recovery Rates." As there is no official, publicly available clean up response plan yet for DAPL (the court-ordered response plan submitted on April 2, 2018 is still under review), it was unpredictable which response was most likely to be employed. Thus, I tested all three clean up methods. The clean up responses only reveal their effectiveness for removing oil from the river, and do not provide information about how any of these clean up tactics may impact water quality, air quality, vegetation, or wildlife.

I ran all clean up tests on April 1 because this date had the highest and second highest quantities of floating oil at the end of the Test 1 and Test 2 simulations (see Tables 9 and 10, Figure 21). I hoped this would make the effectiveness of each clean up response more visible. For the clean up scenarios, I kept all input variables consistent with what I predicted for April 1 and then added one of the three clean up responses to the model.

Because the clean up response features were still relatively glitchy and little could be found on actual clean up response tactics in the region, I stuck to the default parameters as much as possible. For the two in situ burn tests, I used the ROC (specify equipment parameters) feature to add a prescribed burn. I kept all the default settings in place such that "ROC Burn #1" had an oil collection speed of 0.75 knots, a burning offset distance of 500 ft, a fire boom length of 200 ft and a fire boom draft of 12 in. The throughput efficiency was 75% and the burn efficiency was 0.75%. The test was active from 7 AM to 7 PM for both tests.

For the two chemical dispersant tests, I also used the ROC (specify equipment parameters) feature. WebGNOME does not explicitly state which chemical(s) is being used in this scenario, but the WebGNOME user manual hints that it may be a chemical dispersant called Corexit 9500, which was used in the 2010 *Deepwater Horizon* spill (NOAA OR&R, 2017). For "ROC Disperse #1," I also left all of the default settings on, so one-way transit distance was 10 nm, average pass length was 4 nm, dispersant/fuel load was simultaneous, the dispersant to oil ratio was 1:20, the dosage was selected as "Use ROC-recommended value," and the dispersant efficiency was 75%. For platform, I selected "typical large vessel" and left all the parameters as-is. Like the in situ burn, the chemical dispersant was active from 7 AM to 7 PM for both tests.

For the skimmer, I was unable to use the ROC (specify equipment parameters) feature like I did the other two. I believe this was because of a glitch that did not allow a skimmer to be activated until all the oil was spilled, but continuous spills on WebGNOME spill right up until the end of the simulation. Instead, I used the ADIOS (specify recovery rate) feature for both April 1 skim tests. “Skimmer #1” ran from the beginning of the test for 10 hours. It was set to 20% efficiency (the default) and had a recovery rate of 50 bbl/hour for a total recovery amount of 500 bbl (which WebGNOME calculates itself once the duration and recovery rate have been entered).

Opening ArcGIS and uploading the WebGNOME shapefiles.

Once a test was run to completion and the fate of the oil was recorded, I saved it as both a WebGNOME file (for easy re-upload into the WebGNOME interface) and as a point shapefile, a format compatible with ArcGIS. When exporting the data as a shapefile, I left all the default settings in the dialog window that pops up:

Output Start Time: The date of the test, 2018, 12:00
Output time step length: 1 hour
Output initial positions - on
Output final positions - on

I displayed my oil dispersal outputs from WebGNOME on a map of the Detroit River using ArcGIS. I used a publicly available Detroit River shapefile called the Detroit River Area of Concern (“AOC”) Boundary Map produced by the EPA. This shapefile, obtained in the geographic coordinate system GCS_North_American_1983, provided the background layer of all of my tests.

Because the WebGNOME point shapefiles are missing the projection file, the oil layer must be saved in ArcGIS using the coordinate system of the dataframe to ‘assign’ that coordinate system to the shapefile. Then, because geographic coordinate systems can warp maps at higher latitudes, I converted all of these shapefiles to a projected coordinate system, NAD 1983 Michigan GeoRef (meters).

The oil shapefiles had 2,000 points[11] for each hour of the test starting at 0, totaling 50,000 points for Test 1 scenarios and what should have been 36,000[12] points for Test 2 scenarios. For my tests, I only looked at the spatial configuration of the oil at a single moment in time, the *end* of the simulation. To do this, I Selected by Attributes to isolate the 2,000 points that represented the oil dispersal at the very end of the simulations. I selected by the attribute *time* (12:00 pm on Test 1 and 5:00 am on Test 2, since the tests

[11] Derived from changing num_elements to 2,000 in the WebGNOME wizard, as per Jay Hennen’s recommendation
[12] For some reason, the Test 2 scenarios which *should* have output 36,000-point shapefiles actually only output 18,020 points; because I left “Output Final Positions” on, I was still able to get all 2,000 points for the end of the 17-hour simulations on all 15 of my Test 2 scenarios, but I was *unable* to get the right number of data points for every hour of the test.

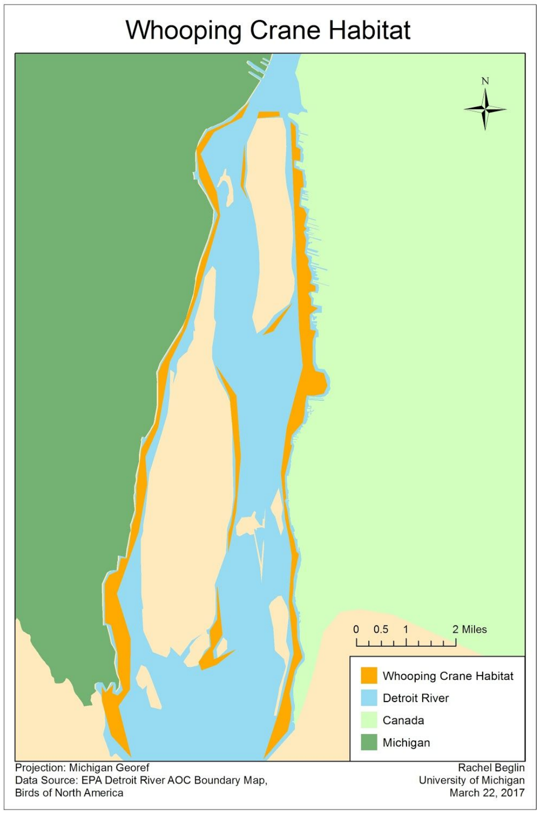
had different run times). The oil dispersal maps can be visually misleading. Because all of my oil dispersal maps have 2,000 points no matter how much oil spilled, a point on one map represents a different quantity of oil than a point on another map. In other words, the *number* of points on the maps is not indicative of the severity of the spill. Rather, it is their locations and unique symbolizations (which denote the average number of barrels per point) that inform readers as to which oil spills are more severe.

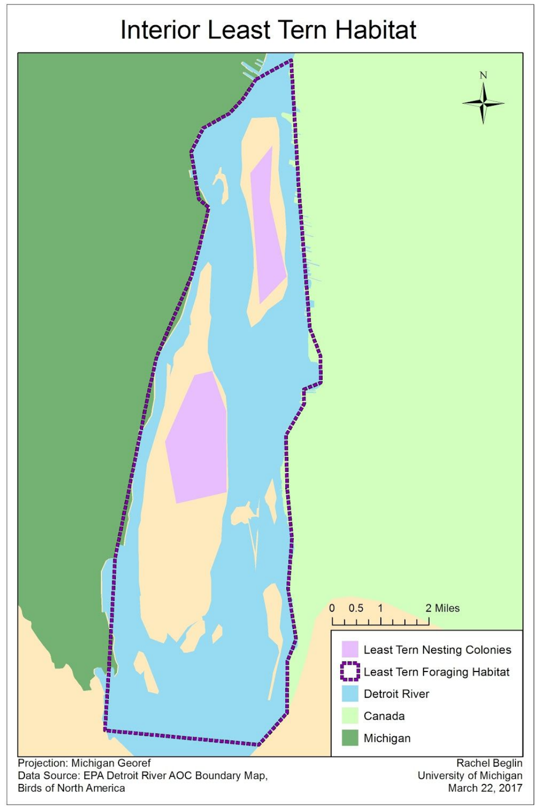
Bird shapefiles.

My approach was to use ArcGIS to place individual birds from each species into a reasonable spatial arrangement along the shoreline and sandbars of the "Missouri River" (using the Detroit River as a stand-in) based on research and observations. On any given date, I anticipated the number of bird individuals that would be present from each species and how they might spatially organize themselves at any given moment. For each test I then used my specified bird locations with the corresponding oil dispersal locations from WebGNOME to find how many bird data points were in close proximity to oil data points, categorized as oiled, high risk, and medium risk. This was done using Select by Location in ArcGIS.

I created ten bird configurations in total – one for every date in Table 4. To place the birds on the maps, I first created polygons to identify habitat for each species. Because there were multiple polygons in each shapefile, I dissolved the singlepart polygons into a multipart polygons (Figure 16).

Whooping Cranes are likely to be present from dusk to dawn, as they are diurnal migrants. They roost in shallow water, so suitable habitat for the Whooping Crane tended to follow the river shoreline and islands where water was expected to be the most shallow (Figure 16a) (Urbanek & Lewis, 2015). Least Terns nest approximately 9.2 m apart in colonies that typically have 25-500 breeding pairs, so I set up two colonies on the major islands of the Detroit River shapefile. Both colonies in my simulations had 25 nests each for a total of 50 Least Tern pairs in the region. I then created a large foraging habitat for the Least Terns that would take into account their diving foraging behavior (Figure 16b) (Thompson et al., 1997). Piping Plovers are ground foragers and spend much time along the shoreline searching for invertebrates, which their foraging habitat polygons reflect (Figure 16c). They forage approximately 1 m apart. Piping Plovers nest near Least Tern colonies, usually about 25 m away, on sandbars with little vegetation far from human disturbance (Elliott-Smith et al., 2004).





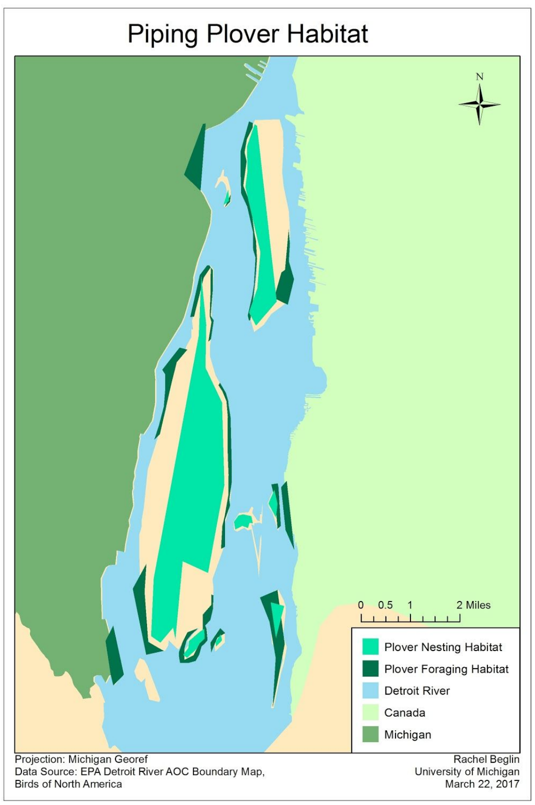


Figure 16. (top left) Whooping Crane ‘habitat’ imagined along the Detroit River as a stand-in for the Missouri River. **(top right)** Least Tern foraging and nesting habitat. **(bottom left)** Piping Plover foraging and nesting habitat.

Once the habitats were drawn, it was time to place individual birds onto the maps. To do this, I needed a good estimate of how many bird individuals make up the Northern Great Plains populations *and* how many of those individuals summer or migrate on Lake Oahe specifically. These population estimates should be adjusted annually; this study in particular operates only as a projection for the year 2018. For a look at total birds estimated to be present in the region at any given time, see Table 7 and Figure 20.

There were exactly 431 Whooping Cranes, including 50 juveniles, in the Aransas/Wood Buffalo Park wild migratory population[13] at the time of this study (McCormick, 2018). Whooping Cranes do not migrate all at once but rather in small groups such as individuals, pairs, families, and flocks of up to seven Whooping Cranes. Their arrivals and departures on Lake Oahe are staggered, so I never placed more than ten Whooping Cranes onto my maps on any given date. According to the IPPC, there are approximately 4,700 Piping Plovers in the Great Plains region (including both Canada and the U.S.), 70% of which reside somewhere along the Missouri River. Ultimately, I estimated that a total of 98 Piping Plover adults and 120 Least Tern adults would summer near the DAPL crossing in Lake Oahe. I then relied on recorded behavioral observations of the birds to predict where they might locate themselves on different dates. This included looking at nesting behavior, distance between bird individuals, roosting locations and proximity to both water and other birds, and active periods.

In order to place actual birds into these polygons based on their population estimates and behavioral studies, I used the Create Random Points tool on ArcGIS, where the bird habitat polygons were the constraining feature classes. I entered the Minimum Allowed Distance (Lineart Unit) on ArcGIS to make sure the birds were placed appropriate distances apart from one another, both interspecies and intraspecies.

Here, I outline exactly how I came to my bird configurations and population numbers for all ten dates. If these details are not of interest, the following section delves into the spatial analysis I did once the bird and oil shapefiles were both in place. The earliest day of the year that any of the three endangered bird species is present is April 1. This is when Whooping Cranes begin arriving. Because this is the earliest date at which Whooping Cranes can be seen, and we know that family groups, experienced breeders, and pairs are the first to arrive on nesting grounds in Wood Buffalo Park, it is likely these groups would be passing through Lake Oahe on April 1. Thus, I entered 5 as the "Long" input in the Create Random Points dialog box on ArcGIS to randomly place five Whooping Cranes in the habitat, at least 3 m apart, as this is their ideal roosting distance from one another (Urbanek & Lewis, 2015).

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[13] It is a testament to both the diligence of field biologists and investment of Canadian and U.S. governmental agencies that we have such precise census data on all three of the endangered species in this study, each of which has been closely monitored in the last several decades.

On April 20, Whooping Cranes are still migrating through the region (stragglers and subadult cranes linger in Texas until mid-May before migrating north for summer). Since this is peak migration for the Whooping Cranes, I placed ten into the habitat. Whooping Cranes flock up to seven birds, so there is a flock of seven on the 4/20 tests as well as three individuals. Additionally, April is when we start to see Piping Plovers arriving for the season. Although my population estimates for Piping Plovers were 40 breeding pairs and 18 non-breeding individuals (this figure was based on the 2006 estimate from the IPPC which found that 18% of Great Plains Piping Plovers were non-breeding), these birds do not arrive all at once. Thus, I estimated that by April 20, 80 of the 98 adult Piping Plovers would have migrated to the region and begun courtship. All 80 Piping Plovers were placed randomly at least 1 m apart in Piping Plover foraging habitat polygons. Least Terns have not begun arriving at this time.

On May 15, Whooping Cranes are wrapping up their northward migration; only individuals, likely subadults and stragglers, are moving through the region. Five were predicted to be present. Piping Plovers will have begun nesting, but not all 40 breeding pairs have mated yet. Thus, 30 Piping Plovers are nesting in plover nesting habitat; each nest represents an incubating adult (male or female, as pairs split incubation duties 50/50) and four eggs and has a corresponding mate in one of the foraging plovers. Ten Piping Plover pairs are mating and have yet to nest or lay eggs, so they have been symbolized as foraging Piping Plovers. Another eighteen Piping Plovers are the non-breeding individuals who are also randomly placed in the foraging habitat. At this time, all 98 Piping Plover adults have arrived from their wintering grounds. Least Terns, however, are just arriving on May 15. Thus, while I eventually predict 120 Least Tern adults to migrate to Lake Oahe, only 60 have been placed by May 15, and all 60 were placed randomly in the Least Tern foraging habitat polygon and are considered to be mating and/or foraging.

On June 4, the Whooping Cranes have all left the migration corridor. They will remain in Wood Buffalo Park in Canada until they migrate south in the September 1 shapefile. The Least Terns and Piping Plovers have all arrived from wintering grounds and are in full incubating mode. All 40 breeding pairs of Piping Plovers have laid eggs, resulting in 40 nests at least 25 m apart. The Least Terns are also incubating in their two loose colonies. Each colony has 25 nests at least 9.2 m apart. All tern and plover breeding adults *not* incubating are foraging, as are the 18 non-breeding plovers and 20 non-breeding terns, for a total of 98 Piping Plovers and 120 Least Terns.

On June 30, Piping Plover and Least Tern eggs will have have begun to hatch. Piping Plover chicks, being the more precocious of the two species, leave the nests within hours and are not closely brooded by parents after hatching. Thus, young Piping Plovers are considered ‘fledglings.’ Piping Plover fledglings often live on their parents’ territory for a few weeks, so all fledglings were placed randomly into the plover nesting polygon rather than the foraging polygon, where they will stay until they are grown. As stated previously, we began with 40 plover nests with four eggs each for a total of 160 eggs. However, due to predation, human disturbance, and a number of other factors, Piping Plovers have a fledging rate of approximately 0.5 fledgling/pair. Thus, of the 160 eggs, a predicted 20 Piping Plover fledglings are likely to survive to the end of the summer and migrate south. This is the estimated fledging rate *without* an oil spill. Since the Piping Plovers have been hatching for two weeks by June 30, I estimated that the number of fledglings would be down to 60 at this point. Of the 40 original nests, some will have failed early enough that the pairs had a chance to re-nest and try again. Therefore there are ten re-nesting plovers on June 30 as well. All 30 Piping Plover pairs who successfully hatched young do not spend time doing parental care, so these sixty birds were placed in the foraging rather than nesting habitat now that their clutches have hatched. Least Terns, on the other hand, brood their young. In order to capture this behavior, I placed three Least Tern nestlings (different from fledglings) in forty out of the fifty Least Tern nests, assuming that ten of the nests have not yet hatched or are re-nests. For each of the forty successful Least Tern nests, three nestlings were placed in the nest with one brooding parent (more likely the male of the pair – usually females/males incubate in an 80/20 ratio, but after chicks hatch the males brood the young and the females abandon the nest). Three nestlings per 40 successful nests generated 120 total nestlings and 40 brooding parents. All brooding parents and nestlings were at the sites of what used to be Least Tern nests in the June 4 shapefiles, which means they are all in Least Tern colony polygons. The remaining seventy Least Terns (mates and non-breeding adults) were placed randomly into the Least Tern foraging habitat.

On July 15, Piping Plover fledglings were down to 35 (by natural causes) and only five pairs were re-nesting at this point in time – 7/15 is the last date on which Piping Plovers will even attempt to re-nests. Re-nests are often less successful and usually have lower numbers of eggs and fledglings than nests earlier in the season. The other 93 Piping Plover adults (five of which represent the mates of the re-nesting plovers) were placed in foraging habitat. The Least Tern young are expected to be fledging and capable of flight – they have left the nests and have been randomly placed within the colony polygons as they are still being brooded and living primarily on their parent's territories. The 120 Least Tern nestlings have been reduced by natural causes down to 60 fledglings. Their 40 brooding parents have been randomly distributed in the Least Tern colonies, overseeing the 60 fledglings. Also having a low fledging rate, only 0.5 Least Tern offspring per pair will survive to migrate south; thus, only 25 fledglings are anticipated to survive the summer, even without an oil spill. The ten Least Tern breeding pairs who did not produce offspring are re-nesting. This leaves seventy terns foraging.

On August 1, all surviving chicks – Least Terns and Piping Plovers alike – were considered full grown and symbolized as adults. Twenty Piping Plover offspring survived the summer for a total of 118

Piping Plovers that would migrate south. However, by August 1, about 40% of Piping Plovers will have already taken off for wintering grounds, so only 71 Piping Plovers were randomly placed on Piping Plover foraging habitat. The Least Terns are staging at this time, so all 145 terns (120 original adults plus 25 surviving offspring) were randomly placed in tern foraging habitat.

The three remaining test dates after August 1 only have Whooping Cranes present. On September 1, the Whooping Cranes begin arriving again in their southward migration to warmer wintering grounds. Again, family groups and successful breeding pairs are the first to migrate. The 9/1 shapefile has a representative seven Whooping Cranes – two pairs and one family of three all in the Whooping Crane habitat polygon. On October 1, which is peak southward migration, ten Whooping Cranes were placed randomly in Whooping Crane habitat polygons. There were two pairs, three stragglers, and one family of three. On November 4, the tail end of Whooping Crane southward migration and the last day of the calendar year to see any of the three endangered species in the region, only the unsuccessful adults, subadults, and stragglers are migrating south. Thus, five individuals were randomly placed in the Whooping Crane habitat polygon on 11/4.

When looking at the symbology of the various points on the maps (see Figure 17 and Figures 21-35), it should be noted that here, a "Tern Nest" includes one incubating Least Tern adult and three eggs, and a "Plover Nest" indicates one incubating Piping Plover adult and four eggs. One should consider that the loss of a foraging adult tern or plover can result in the loss of a nest because when a mate is oiled while foraging, it cannot return to the nest to trade off incubation duty. The nest will likely be abandoned and the surviving mate is unlikely to mate with a new partner that breeding season, as both Piping Plovers and Least Terns usually stay with one mate for an entire summer. They do, however, switch mates between years, suggesting that birds who lose their mates in these tests can still mate successfully the following year. Additionally, there are no "Brooding Plovers" because Piping Plovers are precocious and do not care for their young.

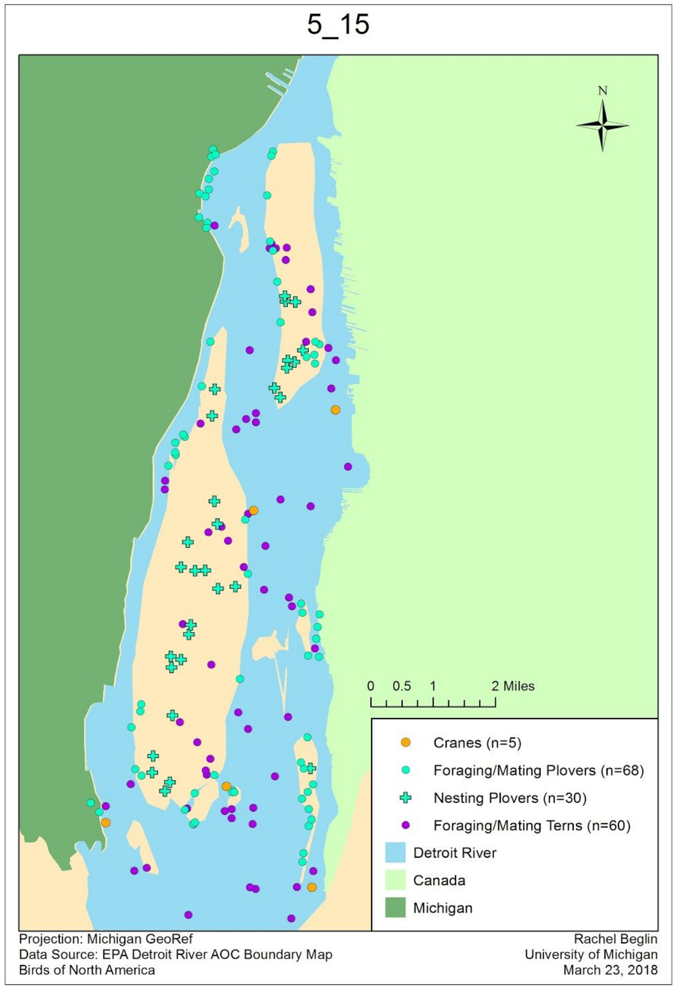


Figure 17. Sample bird shapefile of May 15 before the WebGNOME oil dispersal shapefile was added.

Spatial Analysis

When both the bird shapefiles and the WebGNOME oil shapefiles were added to the map (all 30 of which can be viewed in the following Results section), I used the Select by Location feature on ArcGIS to capture a snapshot of how many birds at a single moment in time would be in close proximity to Bakken crude oil at the end of the spill. I created three categories for proximity to oil: Oiled, High Risk, and Medium Risk.

Every single map, no matter how many barrels of oil were spilled or had evaporated, had 2,000 points of oil in the WebGNOME shapefile. The difference was how many barrels of oil were represented by each point. In order to account for these differences, I opened the attribute table for each oil shapefile, right-clicked on Mass (kg) and used the Statistics Tool to find the mean mass of the 2,000 oil points. Using Bent Horn's known API of 41.3º, I calculated backwards to find its specific gravity (0.81887), which converts to 818.87 kgm^{-3}. There are 6.2898 U.S. barrels in one cubic meter of oil. Thus, I used the following equation to calculate the average number of barrels per point in each oil test, which I included on the maps in the Results section:

$$\frac{\text{Mean Mass (kg) of each point}}{818.8657} * 6.2898 = \text{mean bbl/point}$$

Finally, I used Select by Location to find birds that were "within a certain distance of the selected layer" – namely, the oil spill dispersal. In Test 1 scenarios, when each point in the oil shapefile only represented about 1.5 bbl, birds 10 m from oil were classified as Oiled, 20 m from oil were classified as High Risk, and birds 50 m from oil were classified as Medium Risk. In order to adequately compare the spills, Test 2 had to account for the fact that each oil point represented significantly more oil (about 8.2 bbl/point) than the points in Test 1. To do this, I needed to increase the radius I was using to classify birds as Oiled, High Risk, or Medium Risk proportionately. I therefore increased the radius for each category by a factor of 2.18, which increased the area covered by a factor of 4.76 (the ratio of oil spilled in Test 2: Test 1). Thus, in Test 2 scenarios, birds within a 21.8 m radius of oil were considered Oiled, a 43.6 m radius were High Risk, and a 109 m radius were Medium Risk. Once I had conclusive numbers for the fate of the oil and the number of birds predicted to be Oiled, High Risk, and Medium risk for each scenario, I was able to compare the severity of the different models to see which times of year put the most Whooping Cranes, Least Terns, and Piping Plovers at risk.

Results

Birds present by time of year.

Test Date	Whooping Cranes	Piping Plovers	Least Terns	**Total Birds**
4/1/18	5	0	0	**5**
4/20/18	10	80	0	**90**
5/15/18	5	98	60	**163**
6/4/18	0	98	120	**218**
6/30/18	0	158	240	**398**
7/15/18	0	133	180	**313**
8/1/18	0	71	145	**216**
9/1/18	7	0	0	**7**
10/1/18	10	0	0	**10**
11/4/18	5	0	0	**5**

Table 8. Predicted population numbers by in the DAPL project area at Lake Oahe by date for each of the three bird species; numbers include adults and juveniles.

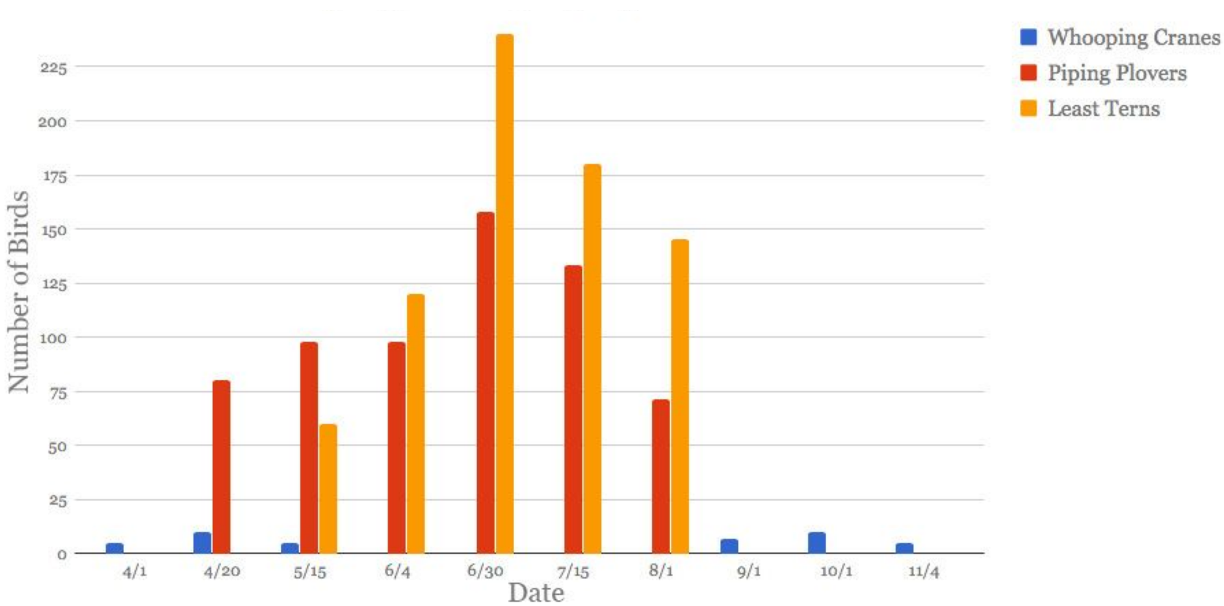


Figure 18. Estimated number of birds of each of the three endangered bird species of interest present at the Missouri River DAPL crossing on each of the ten selected test dates (4/1 - 11/4).

In Table 8, we can see the predicted local population numbers for the three endangered bird species. This is the first indicator for which times of year would be least ideal for a DAPL spill. The mean number of birds expected to be present between all ten test dates is 142.5 endangered birds. I have highlighted the dates when the most birds of each species are predicted to be in the proximity of the DAPL crossing of the Missouri River at Lake Oahe. For Whooping Cranes, both 4/20 and 10/1 are expected to have ten Whooping Cranes in the region. There are never going to be very many Whooping Cranes in the area at one time, but mid-migration is going to produce peak numbers. Since there are only 431 Whooping Crane individuals in the sole remaining wild population, losing ten Whooping Cranes in a DAPL oil spill is equivalent to losing 2.3% of the population. It could also disturb the migration of not-present Whooping Cranes if one of their reliable stopover locations is compromised, leading to additional expended energy for the migratory birds.

Piping Plover populations on Lake Oahe are likely to peak between 6/4 and 6/30 when the eggs are hatching. The highest number of Piping Plovers predicted on any of these test dates is 158 Piping Plovers on 6/30. Ninety-eight of these Piping Plovers are adults, and the remaining 60 are fledglings, 40 of which will not survive the season already due to predation, starvation, and disease. However, by 8/1, the 71 Piping Plovers on site are all slated to survive the entire summer and have begun migrating south. A loss of these plovers, especially the newly grown fledglings who were the fittest of the summer's offspring, could have much worse impacts on the population than losing plover fledglings in June when many of those young were expected to die before migration anyway. That said, their precocious nature may be a saving grace for this species; requiring almost no parental care, Piping Plover fledglings leave the nest on the same day they hatch and do not require parental care. Thus, if a Piping Plover chick hatches and its parent is oiled immediately after, the chick still has a standing chance at surviving the summer; this is in opposition to Least Tern chicks, whose altricial nature and parental reliance puts them at heightened risk.

Least Terns overall follow a similar population pattern to Piping Plovers. The most Interior Least Terns are present on June 30, right after hatching has begun, as there are three nestlings in every successful tern nest. However, only 25 of these nestlings will survive to the end of the summer to migrate south. Thus, while the Least Terns are obviously at heightened risk during hatching when 240 individuals are present on Lake Oahe, any losses to the population on 8/1 when all 120 Least Tern adults and 25 surviving chicks are gathered could have higher impact on population numbers and recovery long-term.

May 15, as discussed, poses a unique threat to the endangered birds as all three species are present, which could be more detrimental to the ecosystem as a whole if three bird populations are lowered rather than just one or two. Weeks when only the Whooping Crane is present, especially in the late fall when there are still months before the summer arrival of the smaller shorebirds, put all three birds at the least risk of an oiling event or detrimental population effects.

Oil test results.

The next dataset collected to index the severity of the different oil spill scenarios was the fate of the oil at the end of each simulation (24 hours for Test 1, 17 for Test 2). WebGNOME distinguishes between seven oil outcomes. Tables 9 and 10 indicate the fate of the oil spilled in each model.

Test 1 Scenarios	Evaporated (bbl)	Natural Dispersion (bbl)	Sedimentation (bbl)	Dissolution (bbl)	Beached (bbl)	Off maps (bbl)	Floating (bbl)
4_1	1398	0	0	1	2269	0	1331
4_20	1780	0	0	48	2242	0	931
5_15	1660	1	0	2	3259	0	78
6_4	1915	1	0	19	2500	0	565
6_4_Flood	1800	0	0	20	2174	23	983
6_30	1643	1	0	4	3302	0	50
6_30_Flood	1778	2	0	6	3038	42	134
7_15	1635	1	0	6	3149	0	210
8_1	1976	1	0	3	2503	0	517
9_1	1786	1	0	6	2839	0	367
10_1	1779	1	0	3	2301	0	917
11_4	1592	0	0	4	2686	0	718
Average	**1728.5**	**0.75**	**0**	**10.167**	**2688.5**	**5.42**[14]	**566.75**

Table 9. The fate at the end of 24 hours of the 5,000 bbl of oil spilled in the twelve Test_1 scenarios, as output by WebGNOME. Highlighted values are the maximum in each column.

[14] The mean for 'Off Maps' has been skewed right by the two outliers, 6_4_Flood and 6_30_Flood, and would otherwise be 0.

The WebGNOME simulations report the fate of Bakken crude oil following a 5,000-bbl spill into a river (Table 9). Twenty-four hours after the spill, 28-40% of the oil (depending on the scenario) will have evaporated, 43-66% of the oil will beach, and 1-27% of the oil will still be floating. None of the oil will attach to floating sediment in the water column, which is good because although sedimentation will have little immediate effect on birds, oiled sediment could settle at the bottom of the river and be absorbed by the aquatic organisms that make up the bird diets. Similarly, 0.0-0.04% will have naturally dispersed[15], and .02-1.0% will have dissolved. As evidenced in Table 9, a spill on 4/1 will have the most oil floating (27% of the spilled amount) at the end of a 24-hour period. This is likely due to both the low water temperature (4.9ºC, the lowest of any of the test dates), which makes the oil thicker and less likely to evaporate, and the fact that the wind pattern for 4/1 is predicted to be south-facing for the first half of the spill, which slows the oil's movement downstream. The more floating oil, the easier it is to contain with booms and then burn or clean up with a skimmer or natural sorbent. However, floating oil also raises the probability of an Interior Least Tern getting oiled, as they are diving foragers. Floating oil can also move downstream of Lake Oahe and affect members of these species that live further along the Missouri River that may not have been considered in this study. Floating oil is also likely to affect Whooping Cranes who primarily use this region to roost nocturnally in shallow water, potentially oiling legs and feathers. The most beached oil (66%) appears on the 6/30 simulation, with 5/15 close behind. This is highly problematic because 5/15 is the only date in the study with the possibility of having all three endangered species present. Beached oil will prove especially problematic for Piping Plovers, who spend approximately 42% of their time at the shoreline pecking at the sand for invertebrates (Elliott-Smith et al., 2004). Beached oil will also reduce available nesting habitat for the Least Tern and the Piping Plover, both of which are nesting and fledging on 6/30. The most evaporated oil is predicted to occur on 8/1 (39.5%). Bakken crude oil is highly volatile, which can be good for water systems since large quantities will evaporate from the surface. Evaporated oil cannot coat birds, but it can still have acute toxic effects from respiration in high concentrations. Thus, there is no fate of oil, be it beached, evaporated, or floating, that is necessarily *better* than another. Rather, there are species-specific tradeoffs between the different outcomes. While beached oil will have a higher impact on foraging Piping Plovers and shorebird nests, it may have little impact on Whooping Cranes. Meanwhile, floating oil will have little impact on the Piping Plovers but could oil a number of diving Least Terns. Only in flood tests did the oil ever move "off maps," in other words, so far downstream that the WebGNOME location file could no longer follow the oil. This means that the oil will stay in a relatively contained area during the first 24 hours of the spill

[15] Natural dispersion (as opposed to chemical dispersion) is the breakup of the oil layer into small droplets and the diffusion of said droplets into the water column, usually by waves.

during most of the year due to the slow surface current speed resulting from the Missouri River dam system, except in the case of flooding events that increase surface current speed and spread the oil farther.

Test 2 Scenarios	Evaporated (bbl)	Natural Dispersion (bbl)	Sedimentation (bbl)	Dissolution (bbl)	Beached (bbl)	Off maps (bbl)	Floating (bbl)
4_1	5976	3	0	0	6936	0	8108
4_20	5673	1	0	1	5882	0	9466
5_15	6145	3	0	1	9778	0	5097
6_4	6429	1	0	1	11077	0	3514
6_4_Flood	5715	1	0	1	10587	0	4719
6_30	7023	2	0	1	9220	0	4777
6_30_Flood	7161	3	0	1	9232	0	4626
7_15	6541	1	0	1	8941	0	5538
8_1	6893	3	0	1	8713	0	5413
9_1	6952	3	0	1	7927	0	6140
10_1	6372	2	0	1	9495	0	5154
11_4	5704	0	0	0	8394	0	6923
Average	**6978.75**	**2.17**	**0**	**0.83**	**9617.83**	**0**	**6,175.08**

Table 10. The fate at the end of 15 hours[16] of the oil in the Test_2 scenarios as output by WebGNOME. Highlighted values are the maximum in each column.

For the hypothetical Test 2 scenarios, after the end of 15 hours, virtually all of the spilled oil will have either evaporated (27-33%), beached (28-53%), or will still be floating (17-45%) (Table 10). The time of year of a DAPL spill could mean the difference between 3,500 bbl (17% of oil on 6/4) and 9,400 bbl (45% of oil on 4/20) floating after 15 hours! That's nearly three times as much floating oil. This highest volume of floating oil (9,466 barrels on 4/20) will be when the Least Terns, who are most likely to be oiled by floating material due to their diving behavior, have not yet migrated to the Northern Great

[16] Although all Test_2 continuous oil spills lasted for 17 hours on the WebGNOME program, the Fate table from WebGNOME would only show the first 15 hours of the test; thus, each row only indicates the fate of the 21,023 bbl of oil spilled by the fifteenth hour, rather than all 23,810 bbl spilled in seventeen hours. This was brought to the attention of NOAA correspondents (see Appendix)

Plains. Still, Whooping Cranes roosting in shallow water could be vulnerable to this floating oil depending on their proximity to the leak and the wind conditions of the day. The worst day for a Test 2 scenario is likely June 4, where a high of 11,077 barrels of oil are predicted to beach. Both Least Terns and Piping Plovers will be incubating nests on the sandbars where oil is beaching at this time. Though the nests themselves may not get directly oiled, manual oil clean up and human disturbance may cause birds to abandon nests. Although both species are capable of two or even three re-nests throughout a season, re-nests are usually less successful and have fewer eggs than first nests. Both Test 1 and Test 2 have relatively high quantities of evaporated oil from June through August as a result of the higher summer water temperatures; the effects of high concentrations of benzene, toluene, and xylenes in the air and subsequent oily rain were not captured in this study, so we can expect the results below to be conservative estimates of the immediate impacts of oil on the birds.

For obvious reasons, Test 2 scenarios are much worse than Test 1 scenarios with much higher quantities of oil present in the region. Still, like Test 1, practically all of the oil stayed regional and did not go "off maps" in the first 15 hours of the spill; this is great news for the members of the bird populations that breed and roost further downstream and for clean up groups who can concentrate on a smaller affected area.

Clean up test effectiveness.

Here are the results for the six clean up tests. All clean up tests were run on April 1. Table 11 is the control with no clean up added. Tables 12-14 reveal how effective the three clean up methods would be in mitigating the two April 1 spills. None of the oil in the April 1 control or clean up tests went Off Maps or Sedimented, so those columns were omitted.

Test	**Spilled (bbl)**	**Evaporated (bbl)**	**Natural dispersion (bbl)**	**Sedimentation (bbl)**	**Dissolution (bbl)**	**Beached (bbl)**	**Floating (bbl)**
Test_1	5000	1398	0	0	1	2269	1331
Test_2	21023	5976	3	0	0	6936	8108

Table 11. Oil fate outputs from 4_1_Test_1 and 4_1_Test_2, the baseline data for comparison with the three clean up methods.

Test	Spilled (bbl)	Evaporated (bbl)	Natural Dispersion (bbl)	Dissolution (bbl)	Beached (bbl)	Boomed (bbl)	Burned (bbl)	Floating (bbl)
Test 1 Burn	5000	1381	0	1	2238	1	66	1313
Test 2 Burn	21023	5940	3	0	7025	14	346	7685

Table 12. April 1 Test 1 and Test 2 spill scenario fate outputs with in situ burns.

Test	Spilled (bbl)	Evaporated (bbl)	Natural dispersion (bbl)	Dissolution (bbl)	Beached (bbl)	Skimmed (bbl)	Floating (bbl)
Test 1 Skim	5000	1397	0	1	2250	13	1340
Test 2 Skim	21023	5970	3	0	7203	49	7797

Table 13. April 1 Test 1 and Test 2 spill scenario fate outputs with skimmers.

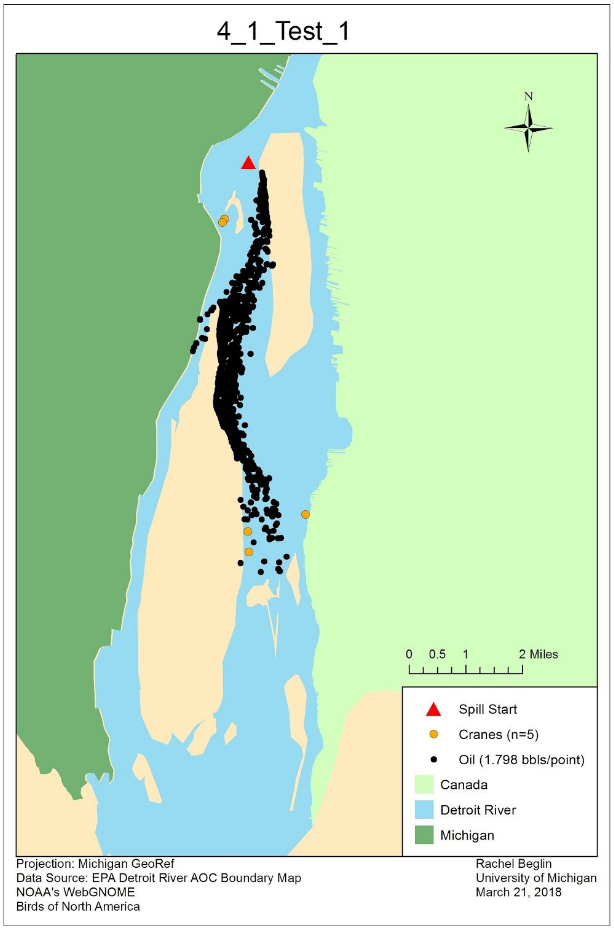
Test	Spilled (bbl)	Evaporated (bbl)	Natural dispersion (bbl)	Dissolution (bbl)	Beached (bbl)	Chemical dispersion (bbl)	Floating (bbl)
Test 1 Disp	5000	1398	0	1	2142	185	1274
Test 2 Disp	21023	5959	3	0	6832	590	7638

Table 14. April 1 Test 1 and Test 2 spill scenario fate outputs with chemical dispersants applied.

The most effective oil removal method in these tests was the chemical dispersant, which dispersed 3.7% of the oil spilled in 4/1 Test 1 and 2.8% of the oil spilled in Test 2. The least effective was the skimmer, which makes sense as this method is best for calmer waters than a moving river on a windy day. However, due to pushback on the use of chemical dispersants (which themselves can be toxic to biota), an in situ burn seems the most likely spill response at this time. The in situ burns removed 1.3-1.6% of the oil between Test 1 and Test 2. While these quantities of removed oil may seem low, they are on par with what we do know about Bakken crude oil spill clean up; for example, in the 31,500 gallon spill in Louisiana in February 2014, 0.3% of oil was recovered (see Table 1). One interesting discovery in running these clean up tests was that the oil removal rate did not remain constant over time. Upon examining the hourly breakdown of clean up response removal, I found that in Test_1_Burn, all 66 burned barrels of oil burned in the first hour of the test, when there was still sufficient oil slick thickness for a burn. In contrast, the skimmer was slow to start – in Test 1, it didn't skim anything until the third hour of the spill and had skimmed all 185 barrels it was going to remove by hour five. This suggests that there is a very short window in which these oil removal methods will be effective, so it will be important to have quick responses readily in place in the event of a Bakken crude oil spill in Lake Oahe. However, even with the use of these three clean up responses, most of the oil is not recoverable. This is consistent with Mitchell & Child (2015)'s claim that there will be practically no recoverable material 4-8 hours after a Bakken crude oil spill.

Birds and oil spatial analysis.

The third and final form of data collected was the maps themselves. These can be found in Figures 19-33. Once oil dispersal shapefiles and bird distribution shapefiles were both uploaded onto ArcGIS, I found the number of birds in each test that were (1) Oiled, (2) High Risk, and (3) Medium Risk (see Tables 15 and 16). All maps are scaled at 1:100,000.



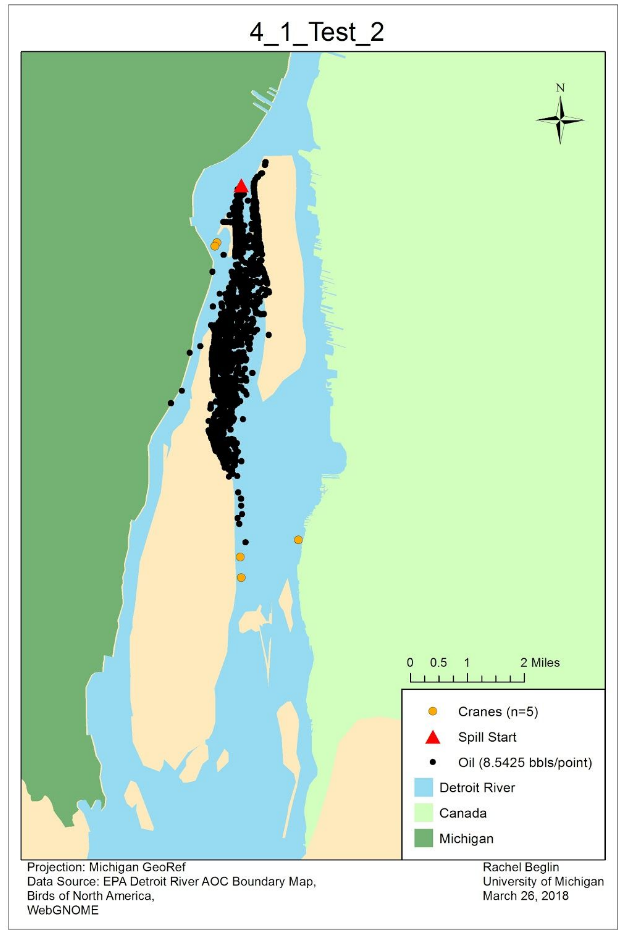


Figure 19. (left) Detroit River map overlaid with both the WebGNOME 4_1_Test_1 oil dispersal and the 4/1 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 4_1_Test_2 oil dispersal and the 4/1 bird distribution shapefile.

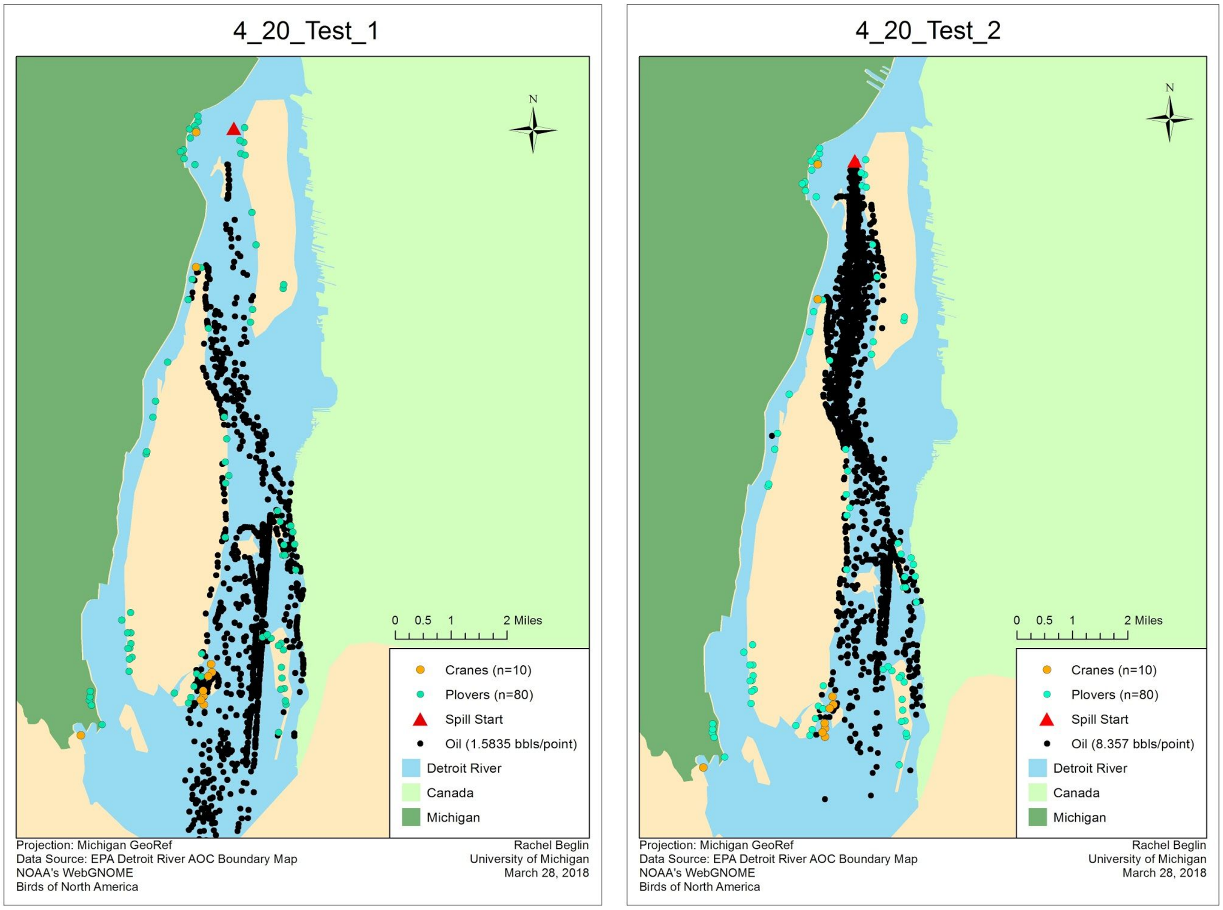


Figure 20. Detroit River map overlaid with both the WebGNOME 4_20_Test_1 oil dispersal and the 4/20 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 4_20_Test_2 oil dispersal and the 4/20 bird distribution shapefile.

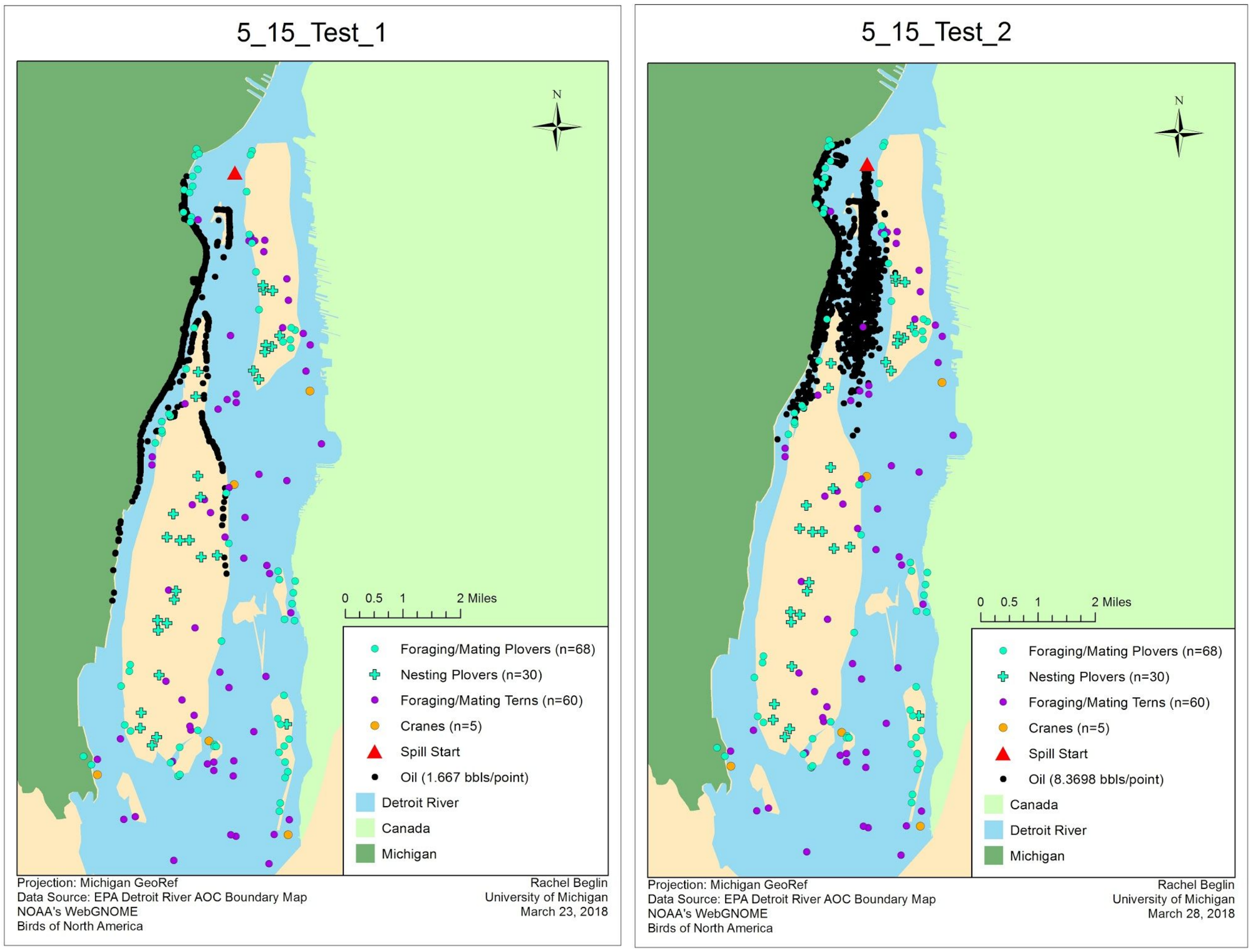
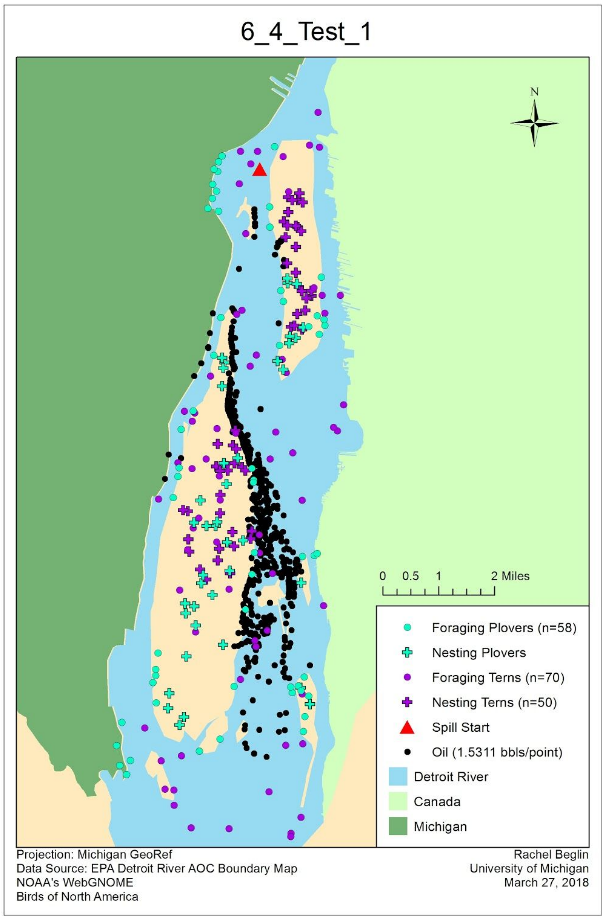


Figure 21. Detroit River map overlaid with both the WebGNOME 5_15_Test_1 oil dispersal and the 5/15 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 5_15_Test_2 oil dispersal and the 5/15 bird distribution shapefile.



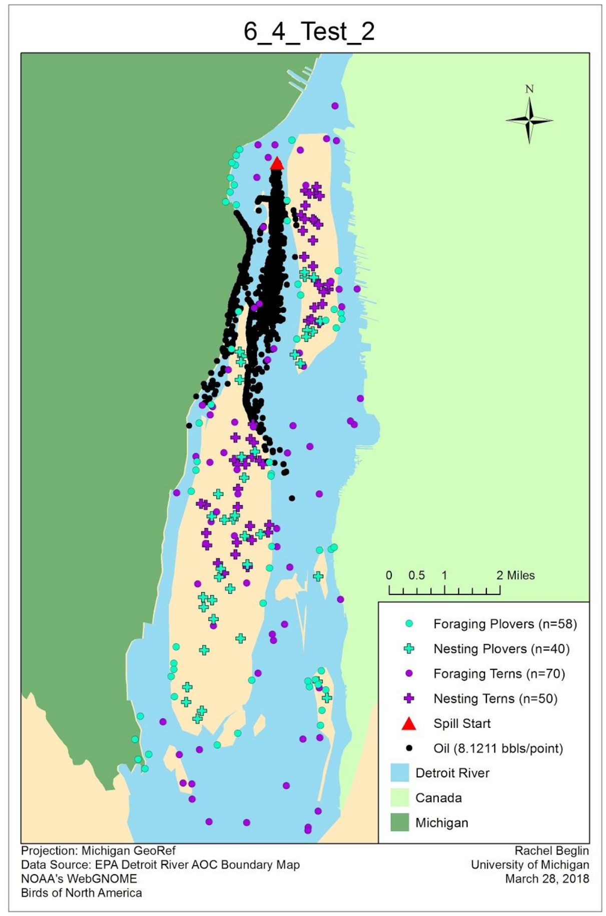


Figure 22. Detroit River map overlaid with both the WebGNOME 6_4_Test_1 oil dispersal and the 6/4 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 6_4_Test_2 oil dispersal and the 6/4 bird distribution shapefile.

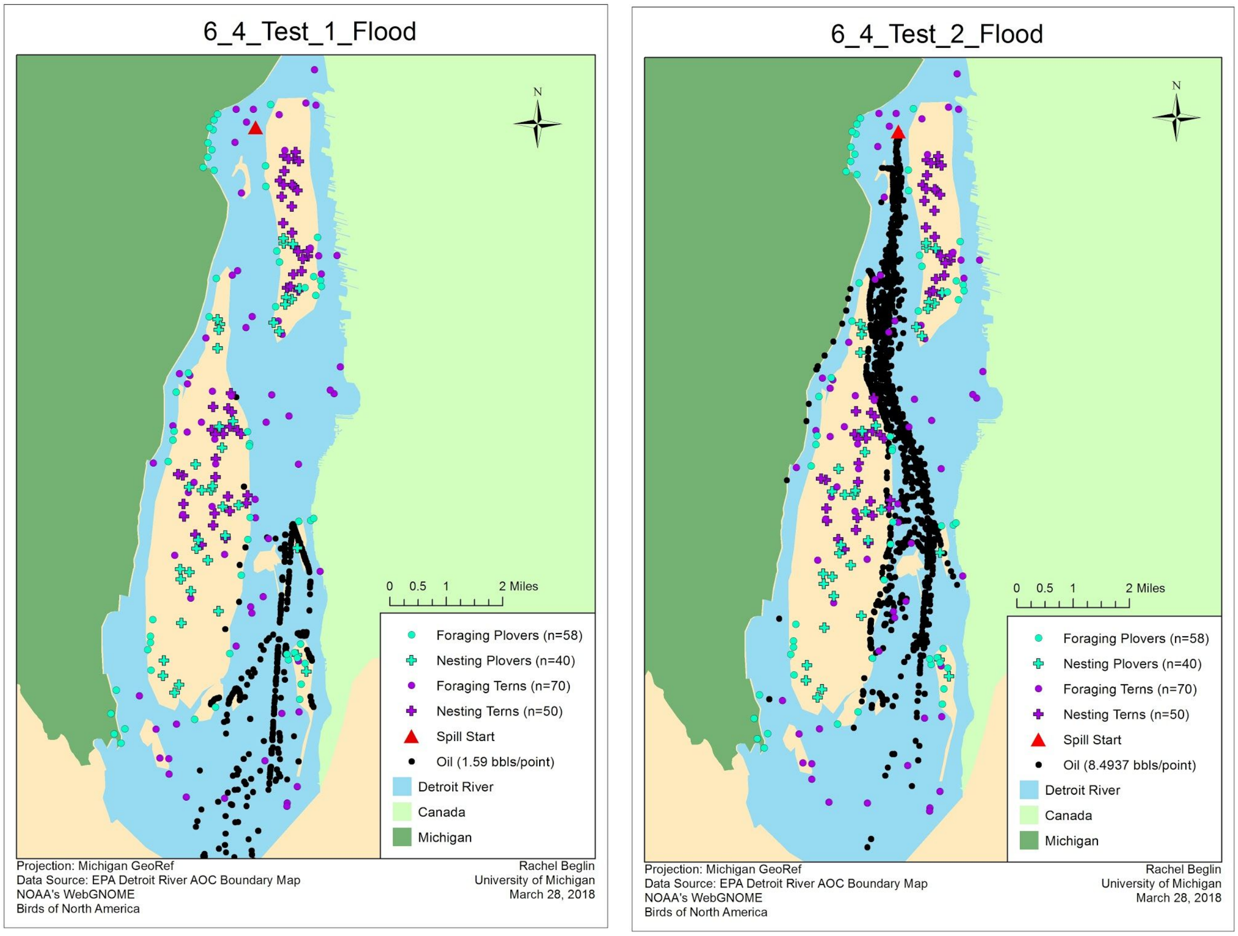
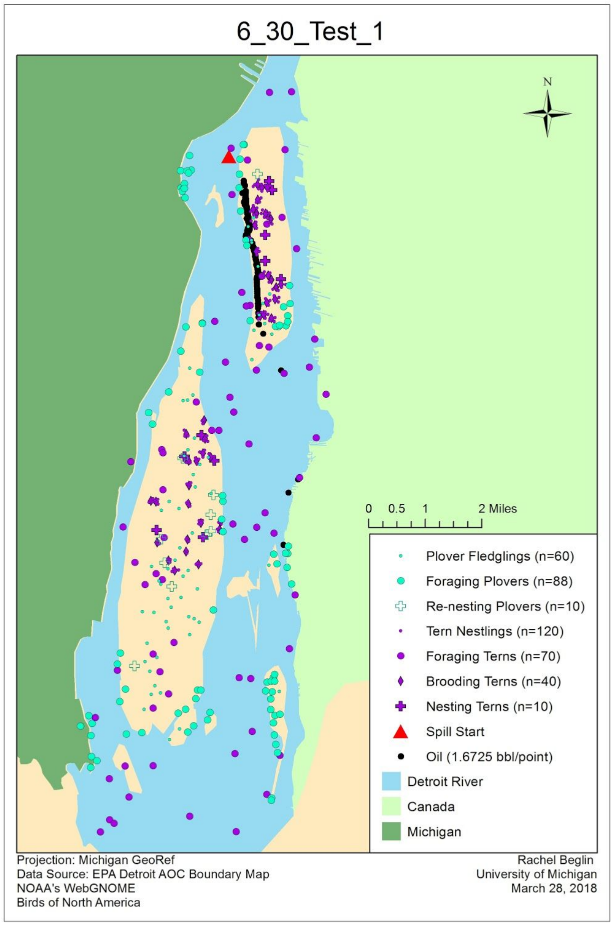


Figure 23. Detroit River map overlaid with both the WebGNOME 6_4_Test_1_flood oil dispersal and the 6/4 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 6_4_Test_2_flood oil dispersal and the 6/4 bird distribution shapefile.



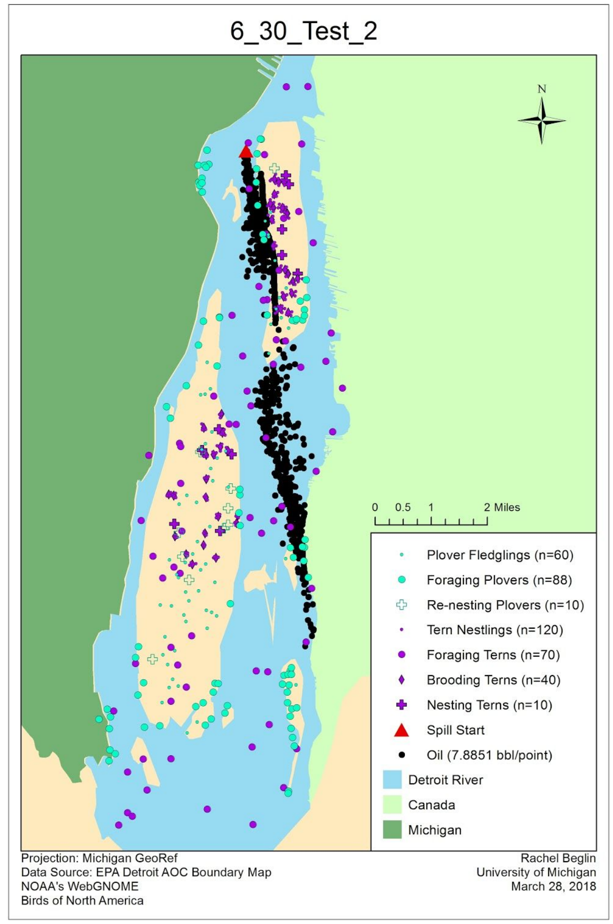


Figure 24. Detroit River map overlaid with both the WebGNOME 6_30_Test_1 oil dispersal and the 6/30 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 6_30_Test_2 oil dispersal and the 6/30 bird distribution shapefile.

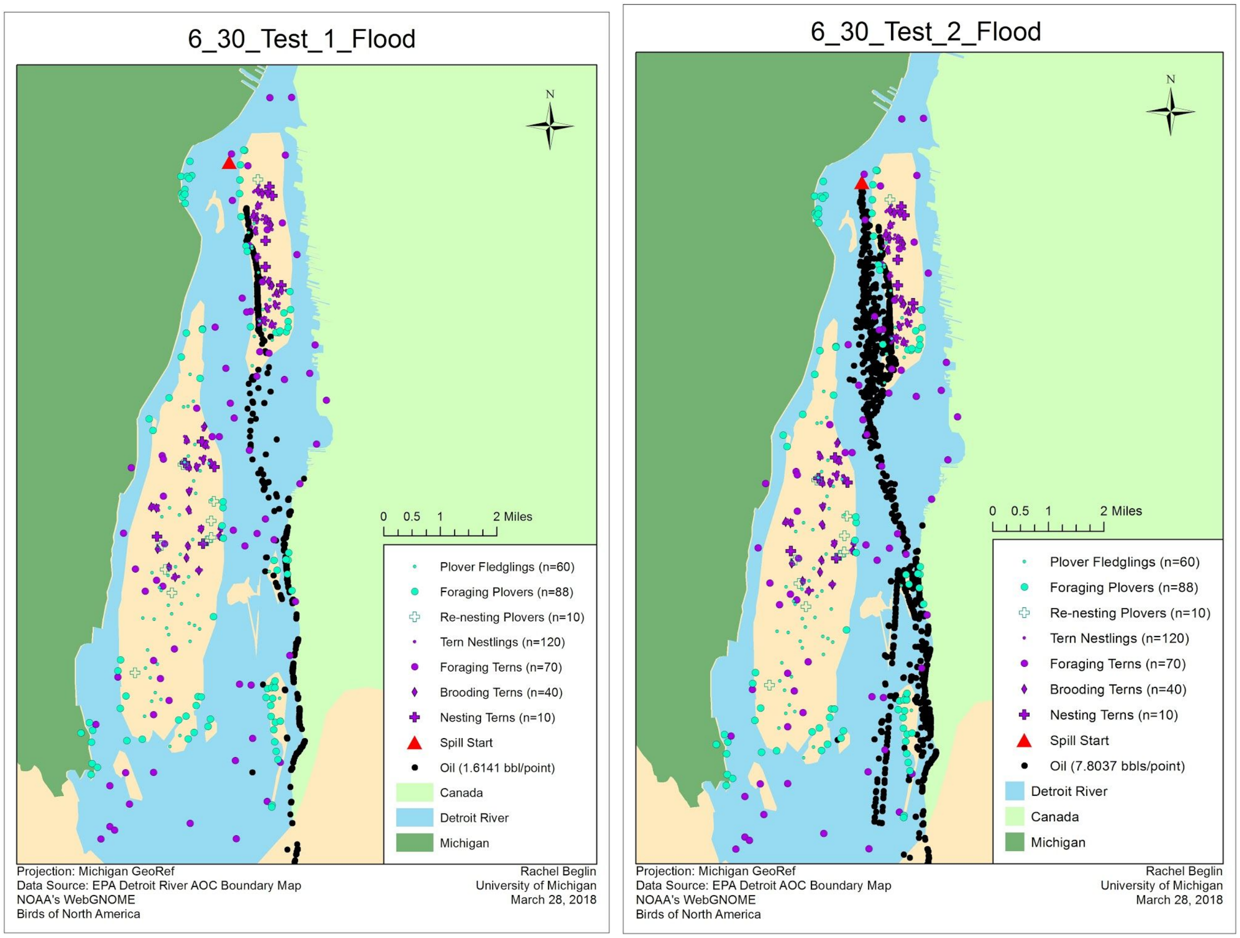


Figure 25. Detroit River map overlaid with both the WebGNOME 6_30_Test_1_flood oil dispersal and the 6/30 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 6_30_Test_2_flood oil dispersal and the 6/30 bird distribution shapefile.

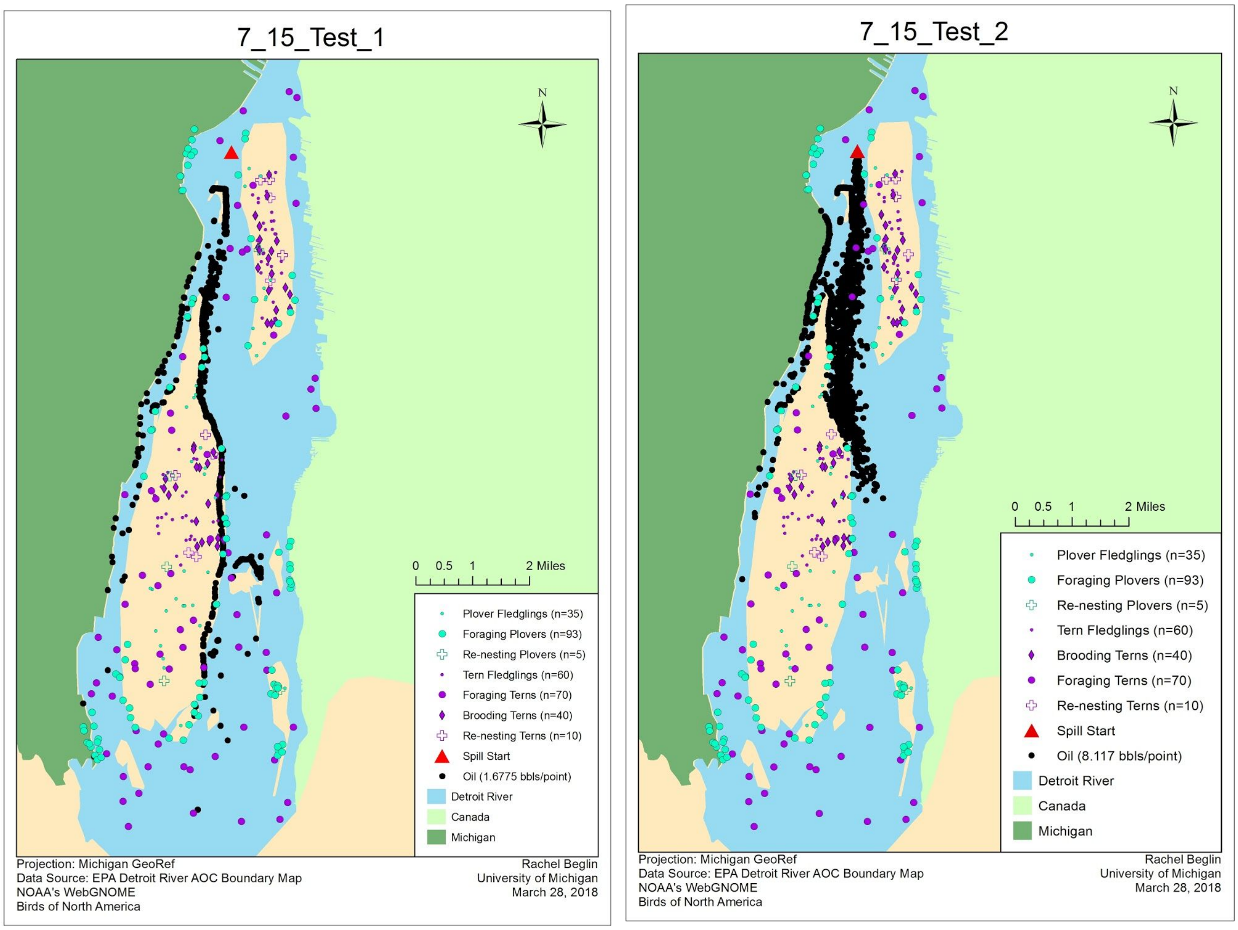


Figure 26. Detroit River map overlaid with both the WebGNOME 7_15_Test_1 oil dispersal and the 7/15 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 7_15_Test_2 oil dispersal and the 6/30 bird distribution shapefile.

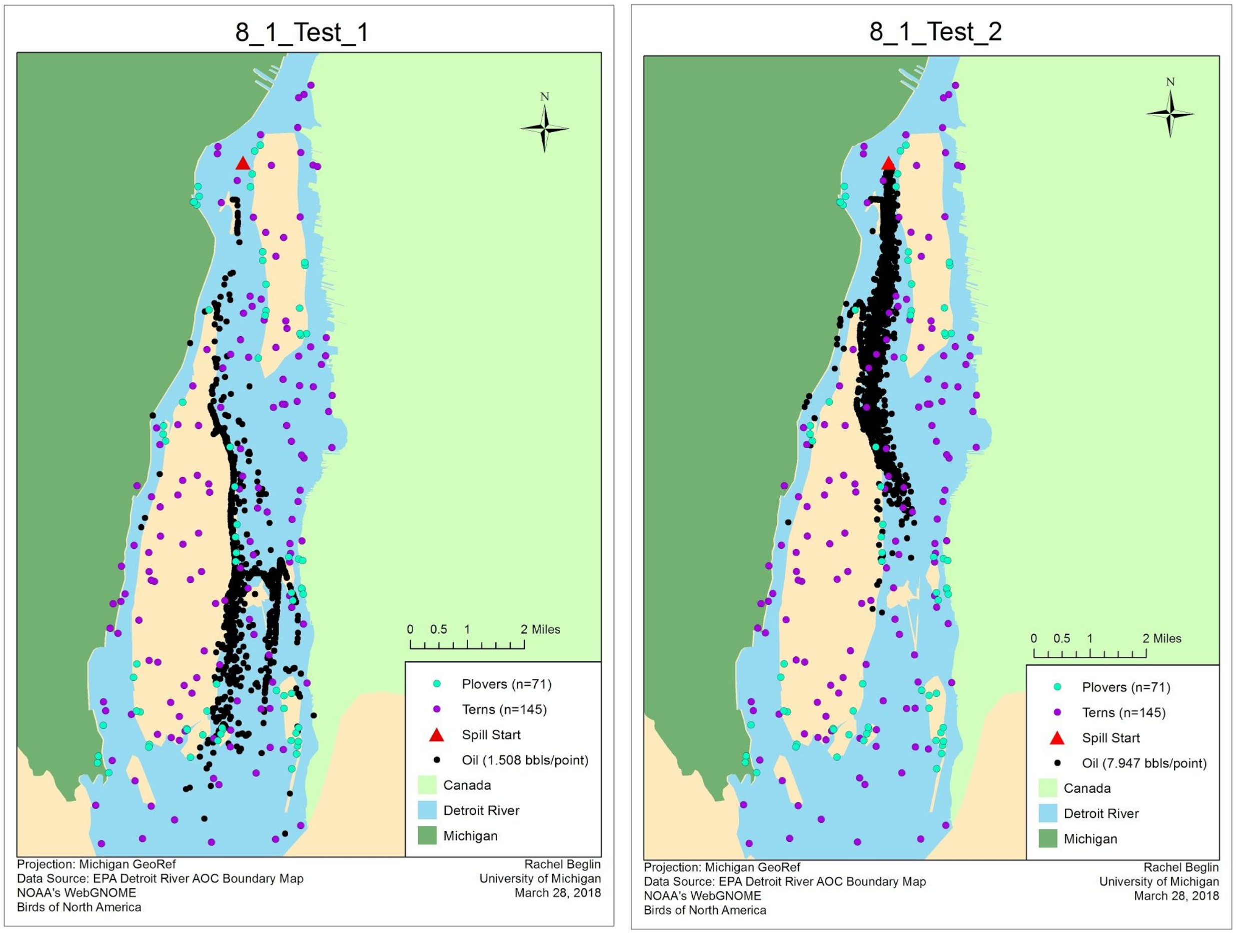
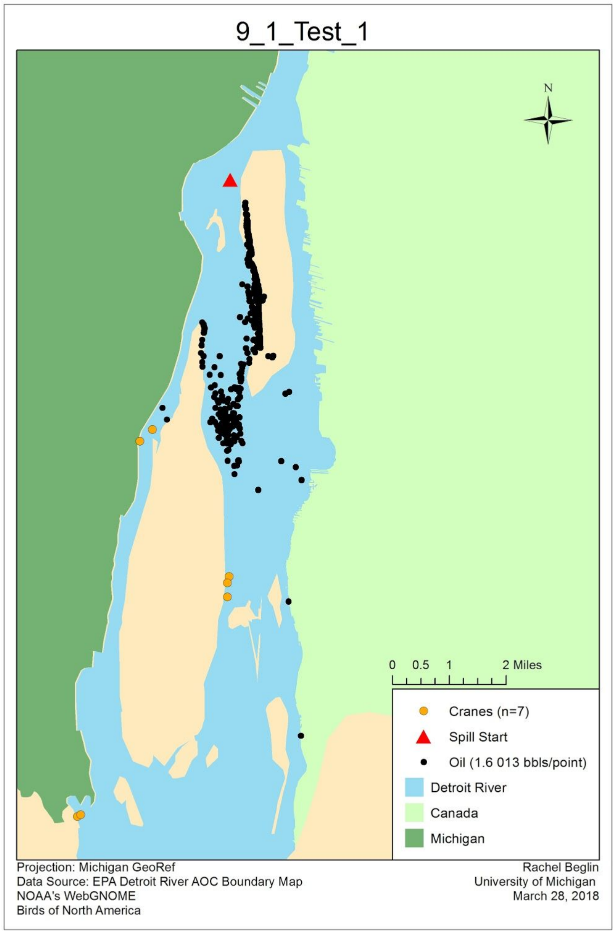


Figure 27. Detroit River map overlaid with both the WebGNOME 8_1_Test_1 oil dispersal and the 8/1 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 8_1_Test_2 oil dispersal and the 8/1 bird distribution shapefile.



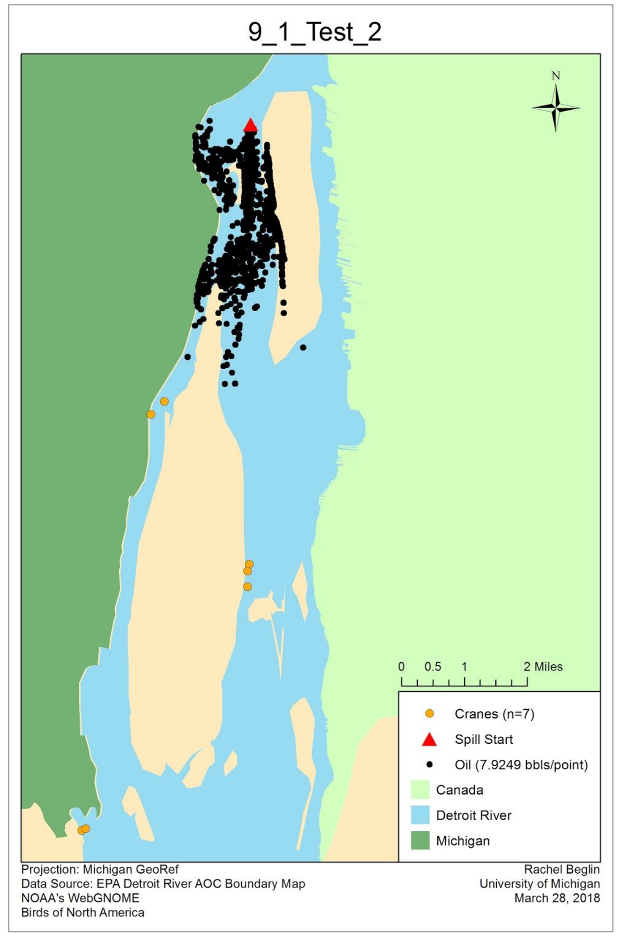
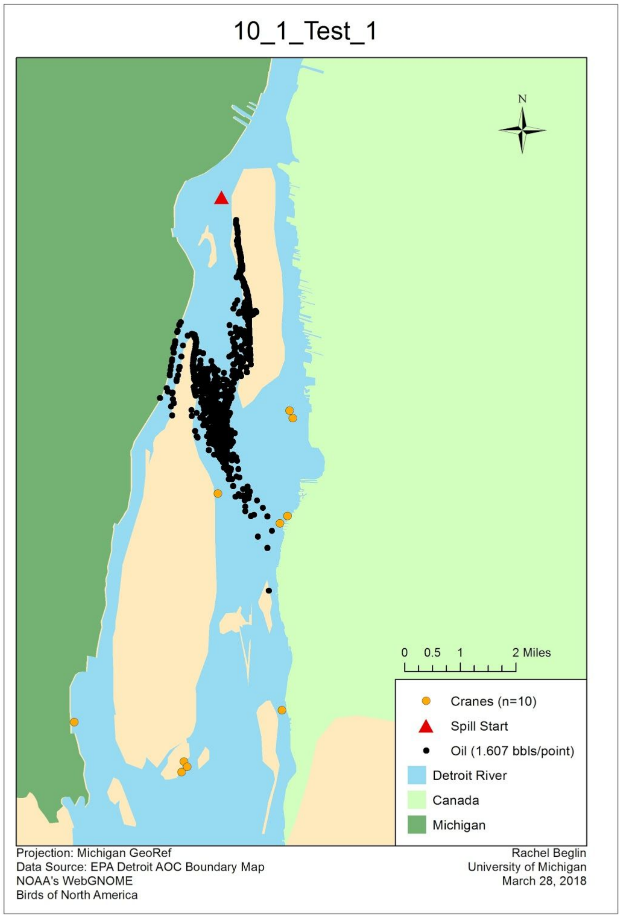


Figure 28. Detroit River map overlaid with both the WebGNOME 9_1_Test_1 oil dispersal and the 9/1 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 9_1_Test_2 oil dispersal and the 9/1 bird distribution shapefile.



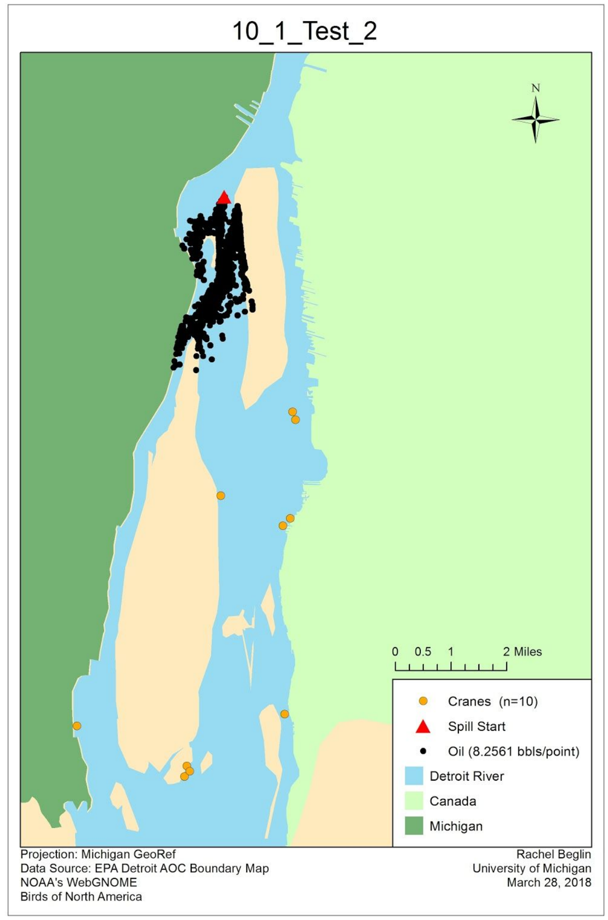


Figure 29. Detroit River map overlaid with both the WebGNOME 10_1_Test_1 oil dispersal and the 10/1 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 10_1_Test_2 oil dispersal and the 10/1 bird distribution shapefile.

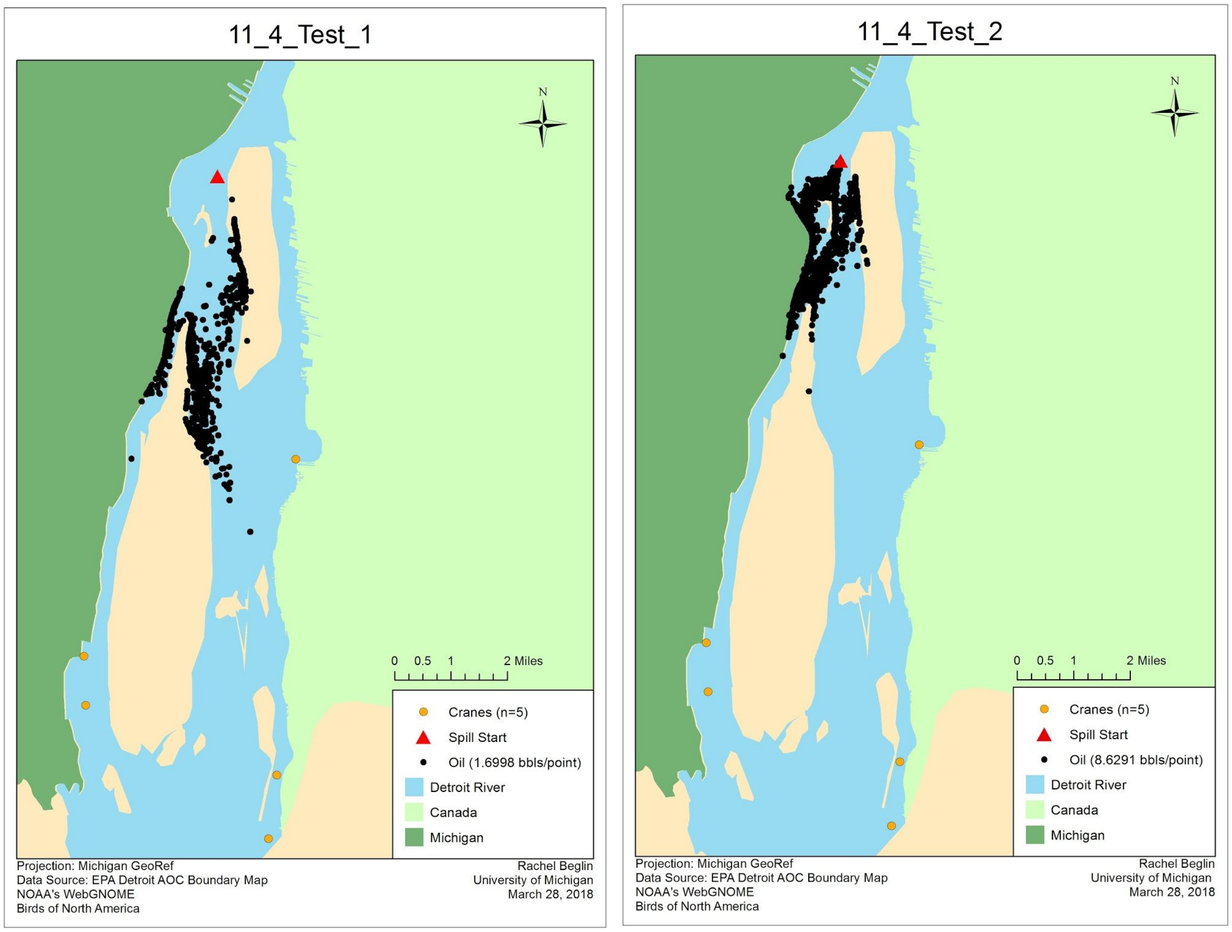


Figure 30. Detroit River map overlaid with both the WebGNOME 6_30_Test_1 oil dispersal and the 6/30 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 6_30_Test_2 oil dispersal and the 6/30 bird distribution shapefile.

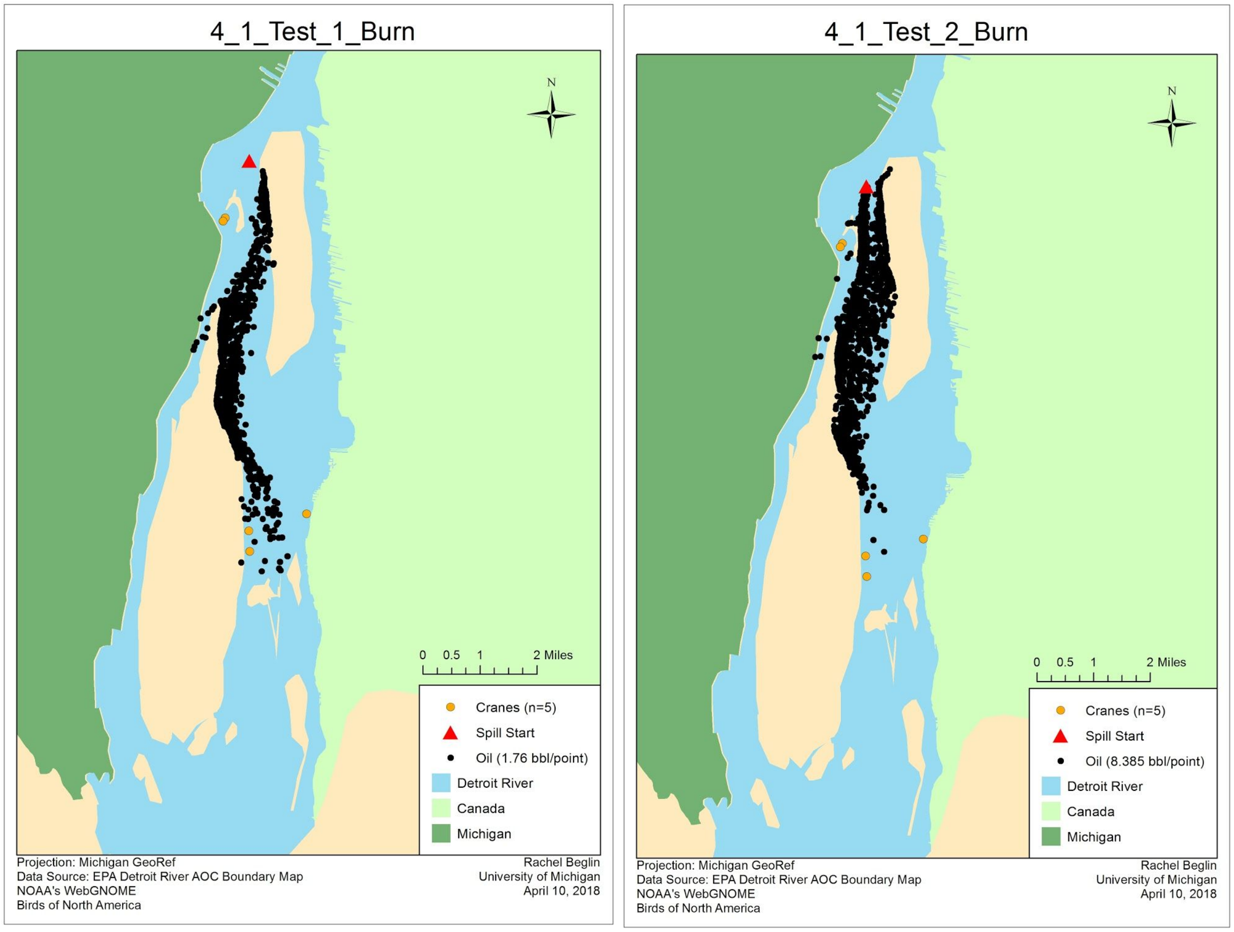


Figure 31. Detroit River map overlaid with both the WebGNOME 4_1_Test_1 oil dispersal with an added in situ burn and the 4/1 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 4_1_Test_2 oil dispersal with an added in situ burn and the 4/1 bird distribution shapefile.

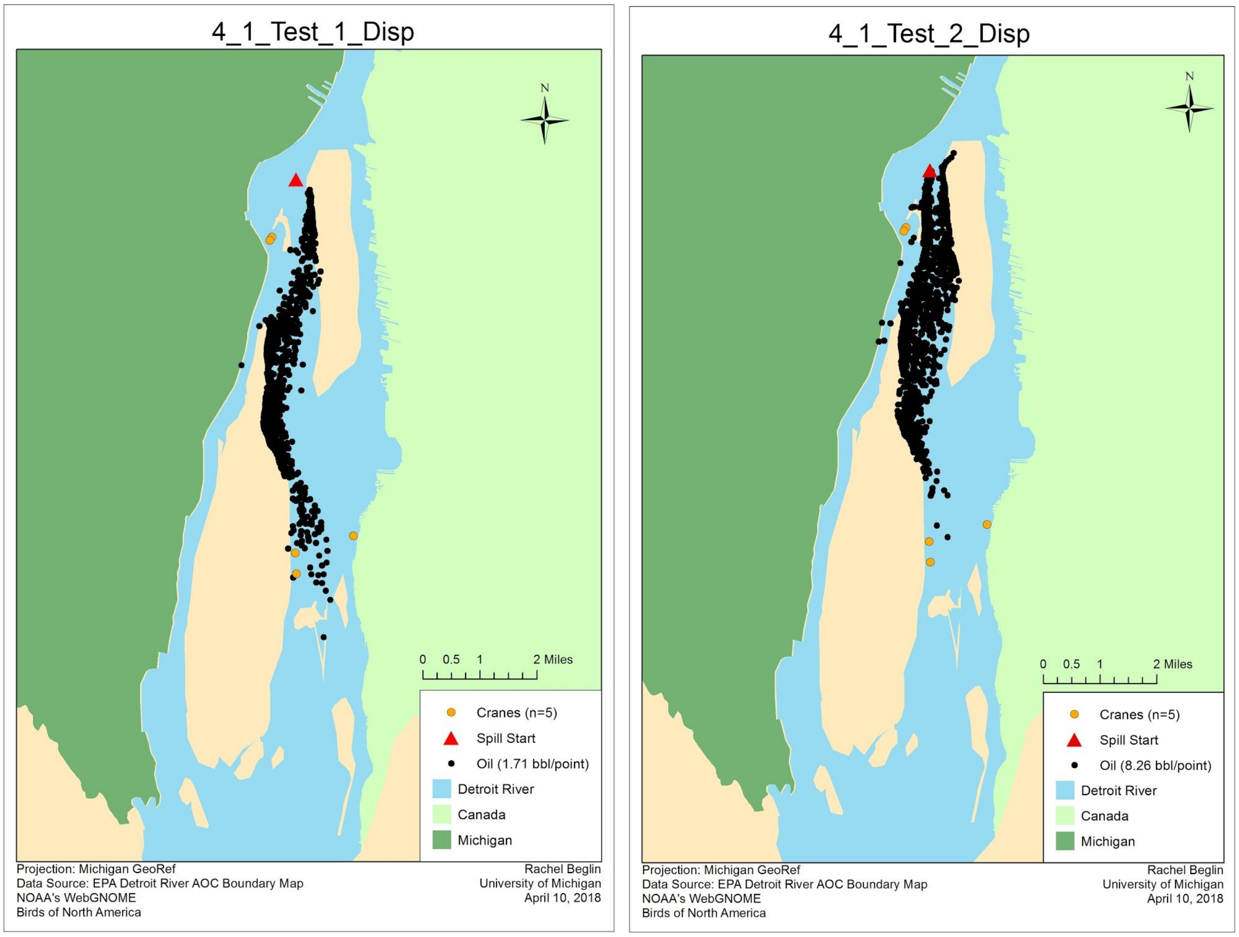


Figure 32. Detroit River map overlaid with both the WebGNOME 4_1_Test_1 oil dispersal with an added chemical dispersant and the 4/1 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 4_1_Test_2 oil dispersal with an added chemical dispersant and the 4/1 bird distribution shapefile.

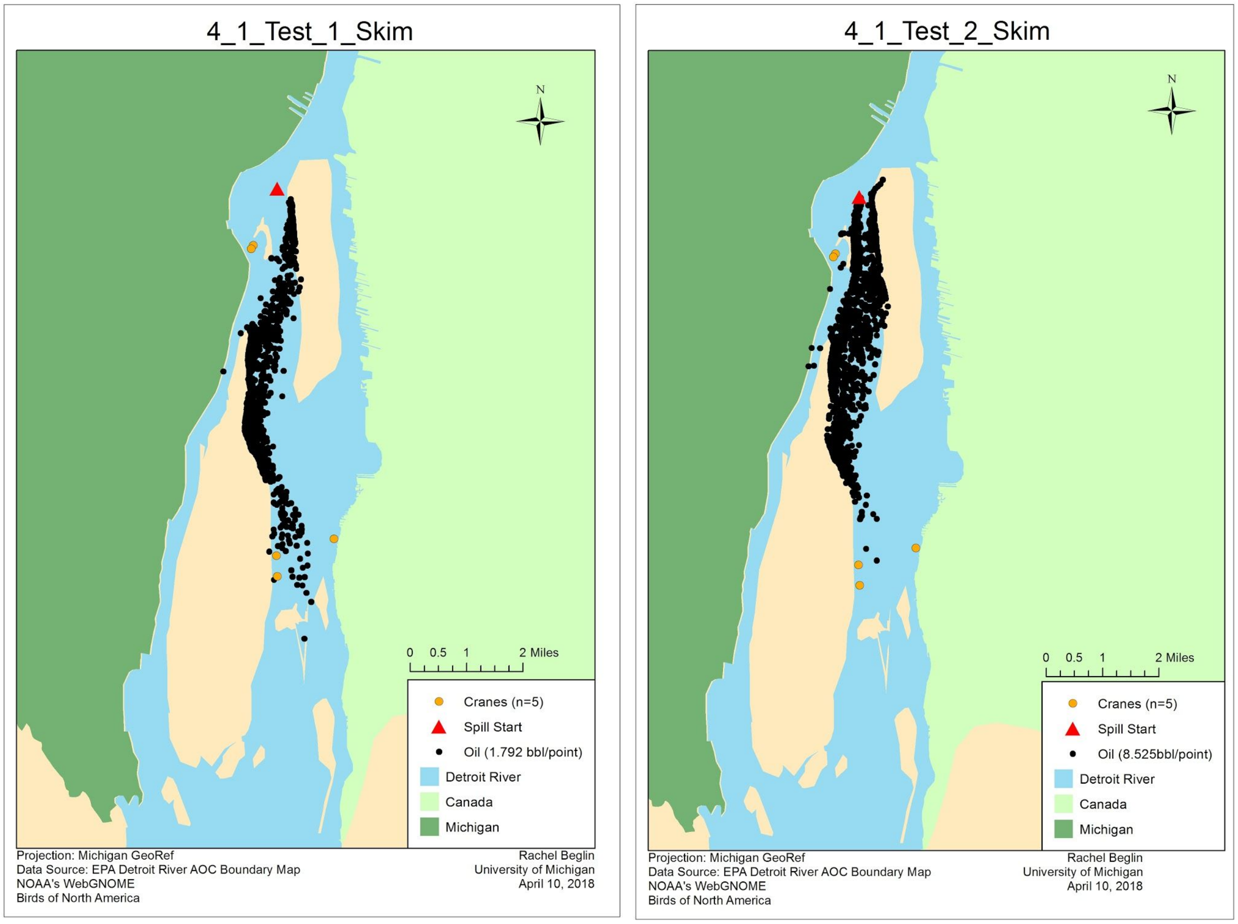


Figure 33. Detroit River map overlaid with both the WebGNOME 4_1_Test_1 oil dispersal with an added skimmer and the 4/1 bird distribution shapefile; **(right)** Detroit River map overlaid with both the WebGNOME 4_1_Test_2 oil dispersal with an added skimmer and the 4/1 bird distribution shapefile.

Summary

Before going further into the summary and analysis of these maps, readers should heed the caveat that these oil spill tests should be taken only as a relative index of severity amongst a variety of imagined spill scenarios. While each of these spills and bird configurations is *plausible*, these are just thirty of many possible scenarios. As denoted in the Methods section, the birds were placed onto the map using the Create Random Points tool in ArcGIS based loosely on observational and census data. These are *not* recorded observations of actual bird individuals. Additionally, each of the maps below is only a snapshot of oil and bird locations at a split second in time. Thus, the maps do not account for the entire route of the oil, only where it existed at the very end of the spill run. Additionally, while I did the best I could with the Detroit River location file, these maps are not of the actual location where DAPL passes under Lake Oahe and are therefore only a representation of what something in the Missouri River *might* look like.

That said, there is great value and necessity in modeling. While these maps may not be able to tell us *exactly* what an oil spill of Bakken crude oil on the Missouri River will look like, what they *can* tell us is how the spill scenarios compare to one another in terms of oil arrangement, severity, and bird vulnerability. For example, although not many birds were Oiled in the flood tests, we can see that the oil traveled a much longer distance in those tests than in others. We can see how foraging birds may be impacted differently than nesting birds, and we can compare the number of birds who are within oiling distance across the different tests. With this information, I was able to make some recommendations about how the pipeline might be able to operate during different times of year to account for the changes in biota and environmental conditions that alter the risk of oiling.

One of the most noticeable differences amongst Figures 19-33 is the locations of the oil (black symbols). As expected, the oil covered the most latitudinal distance in the two June flooding scenarios where the surface current speed was increased. However, when surface current speed remained constant, the main factors causing these differences was wind direction, though water temperature was also influential. For example, in the two 11/4 tests we observe the oil concentrated near the spill start. This makes sense given the strong western winds for the first half of the spill and the strong eastern winds for the second half of the spill which serve to keep the oil from moving downstream, combined with the fact that this was the third coldest day for water temperature. Several hours of calm predicted on June 4 allowed the oil to be moved more steadily downstream by the currents. May 15, with almost exclusively eastern winds, appears to be the only test in which the west riverbank gets oiled significantly. Additionally, we should look closely at the influence of islands and turns in the river. The proximity of the two major islands in this model to the spill start certainly increase the likelihood of the oil beaching, as opposed to a river without any islands. Lake Oahe does have a few islands near the DAPL crossing, but they are much smaller than the two in the WebGNOME Detroit River location file. The number of islands in different parts of the Missouri River fluctuates annually and depends on operation of the dams and the subsequent current speeds and sediment loads. Thus, some years the region observed in this study may hold more suitable nesting habitat than other years. It is also important to note the sinuosity, or curviness, of the Missouri River, which slopes in a general southeast direction toward the Mississippi River. Places where the river turns may increase the likelihood that floating oil will become beached along that location.

Bird breakdown.

From the above maps, I found how many birds in each species could be considered Oiled, High Risk, and Medium Risk based on their distance from the oil points (Tables 15 and 16). None of the Whooping Cranes in the six clean up spill tests fell into any of these categories, so they were not included in the tables.

		Least Terns					Piping Plovers					
Test_1 Dates	Distance from oil (m)	Adult Terns	Tern Nests	Brooding Terns	Young Terns	**Total Terns**	Adult Plovers	Plover Nests	Plover Fledgling	**Total Plovers**	**Whooping Cranes**	**Total Birds**
4_1	10	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	20	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	50	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
4_20	10	n/a	n/a	n/a	n/a	**n/a**	3	n/a	n/a	**3**	**0**	**3**
	20	n/a	n/a	n/a	n/a	**n/a**	3	n/a	n/a	**3**	**0**	**3**
	50	n/a	n/a	n/a	n/a	**n/a**	6	n/a	n/a	**6**	**1**	**7**
5_15	10	0	n/a	n/a	n/a	**0**	1	0	n/a	**1**	**0**	**1**
	20	0	n/a	n/a	n/a	**0**	3	0	n/a	**3**	**0**	**3**
	50	0	n/a	n/a	n/a	**0**	5	0	n/a	**5**	**0**	**5**
6_4	10	0	0	n/a	n/a	**0**	0	0	n/a	**0**	**n/a**	**0**
	20	0	2	n/a	n/a	**2**	1	0	n/a	**1**	**n/a**	**3**
	50	3	2	n/a	n/a	**5**	2	0	n/a	**2**	**n/a**	**7**
6_4_Flood	10	0	0	n/a	n/a	**0**	0	0	n/a	**0**	**n/a**	**0**
	20	0	0	n/a	n/a	**0**	0	0	n/a	**0**	**n/a**	**0**
	50	0	0	n/a	n/a	**0**	0	0	n/a	**0**	**n/a**	**0**
6_30	10	0	0	0	0	**0**	0	0	0	**0**	**n/a**	**0**
	20	0	0	0	1	**1**	0	0	1	**1**	**n/a**	**2**
	50	1	0	0	1	**2**	0	0	4	**4**	**n/a**	**6**
6_30_Flood	10	0	0	0	2	**2**	0	0	0	**0**	**n/a**	**2**
	20	0	0	0	2	**2**	1	0	1	**2**	**n/a**	**4**
	50	2	0	0	2	**4**	2	0	5	**7**	**n/a**	**11**
7_15	10	0	0	0	0	**0**	0	0	0	**0**	**n/a**	**0**
	20	0	0	0	1	**1**	2	0	0	**2**	**n/a**	**3**
	50	1	0	2	2	**5**	7	0	0	**7**	**n/a**	**12**
8_1	10	0	n/a	n/a	n/a	**0**	0	n/a	n/a	**0**	**n/a**	**0**
	20	1	n/a	n/a	n/a	**1**	0	n/a	n/a	**0**	**n/a**	**1**
	50	2	n/a	n/a	n/a	**2**	6	n/a	n/a	**6**	**n/a**	**8**
9_1	10	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	20	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	50	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
10_1	10	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	20	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	50	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
11_4	10	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	20	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	50	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**

Table 15. Synthesized spatial analysis bird data for Test 1 scenarios. "Young Terns" includes both Least Tern nestlings (<1 week old and still living in the parents' nest with one brooding adult) and tern fledglings (1 week < terns <1 month old randomly placed in the tern colonies off the nests). Some foraging birds are members of breeding pairs, others are not. Nests represent both an incubating adult and its clutch.

In terms of overall bird casualties, it is at once apparent that the June 30 flood and July 15 test are comparable in terms of worst day for an oil spill, with eleven and twelve endangered birds at Medium Risk, respectively. The Whooping Crane population is at the lowest risk of the three species of being in close proximity to oil during the smaller, 5,000 barrel spill. Only one Whooping Crane individual is predicted to even be at Medium Risk in any of the Test 1 scenarios, and that is on 4/20 during peak Whooping Crane northward migration. That said, a look at 10_1_Test_1 shows that oil moving downstream may intercept roosting Whooping Cranes after the first twenty-four hours if spill containment is unsuccessful (which the six clean up tests tell us is highly probable). Taking a look at Piping Plovers, there are seven at Medium Risk of getting oiled on both the June 30 flood simulation and the July 15 simulation. On closer look, however, five of the seven Piping Plovers at risk on 6/30 are fledglings, while all seven of the Piping Plovers at risk on 7/15 are foraging adults. While the numbers may be similar, the impacts on the local populations are completely different. It is almost always worse to lose a breeding adult bird than a fledgling, as the fledglings are already prone to predation while the adults on 6/30 still stand a chance of re-nesting. Still, an instantaneous, Keystone-like spill anywhere from late June to mid July in this region appears to put the most birds at risk. Not a single Piping Plover nest was oiled in any of the twelve Test 1 scenarios, though this may be a conservative estimate since the flooding tests, which suggest rising water levels, do not actually account for the phenomenon. Two Least Tern nests were at High Risk in the June 4 tests, though this is hopefully early enough in the season that those breeding pairs would be able to re-nest elsewhere.

		Least Terns					Piping Plovers					
Test_2 Dates	Distance from oil (m)	Adult Terns	Tern Nests	Brooding Terns	Young Terns	**Total Terns**	Adult Plovers	Plover Nests	Plover Fledgling	**Total Plovers**	**Whooping Cranes**	**Total Birds**
4_1	21.8	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	43.6	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	109	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
4_20	21.8	n/a	n/a	n/a	n/a	**n/a**	0	n/a	n/a	**0**	**0**	**0**
	43.6	n/a	n/a	n/a	n/a	**n/a**	2	n/a	n/a	**2**	**0**	**2**
	109	n/a	n/a	n/a	n/a	**n/a**	13	n/a	n/a	**13**	**1**	**14**
5_15	21.8	0	n/a	n/a	n/a	**0**	4	0	n/a	**4**	**0**	**4**
	43.6	1	n/a	n/a	n/a	**1**	7	0	n/a	**7**	**0**	**8**
	109	4	n/a	n/a	n/a	**4**	15	1	n/a	**16**	**0**	**20**
6_4	21.8	0	1	n/a	n/a	**1**	0	0	n/a	**0**	**n/a**	**1**
	43.6	2	1	n/a	n/a	**3**	1	0	n/a	**1**	**n/a**	**4**
	109	7	1	n/a	n/a	**8**	5	0	n/a	**5**	**n/a**	**13**
6_4_Flood	21.8	0	2	n/a	n/a	**2**	1	0	n/a	**1**	**n/a**	**3**
	43.6	3	2	n/a	n/a	**5**	2	0	n/a	**2**	**n/a**	**7**
	109	13	3	n/a	n/a	**16**	5	0	n/a	**5**	**n/a**	**21**
6_30	21.8	1	0	0	2	**3**	3	0	1	**4**	**n/a**	**7**
	43.6	4	0	0	2	**6**	5	0	5	**10**	**n/a**	**16**
	109	9	0	2	7	**18**	10	0	6	**16**	**n/a**	**34**
6_30_Flood	21.8	2	0	0	2	**4**	0	0	1	**1**	**n/a**	**5**
	43.6	2	0	0	2	**4**	4	0	4	**8**	**n/a**	**12**
	109	13	0	2	8	**23**	6	0	8	**14**	**n/a**	**37**
7_15	21.8	0	0	0	0	**0**	1	0	0	**1**	**n/a**	**1**
	43.6	3	0	0	0	**3**	3	0	0	**3**	**n/a**	**6**
	109	4	0	0	0	**4**	8	0	1	**9**	**n/a**	**13**
8_1	21.8	1	n/a	n/a	n/a	**1**	0	n/a	n/a	**0**	**n/a**	**1**
	43.6	6	n/a	n/a	n/a	**6**	0	n/a	n/a	**0**	**n/a**	**6**
	109	17	n/a	n/a	n/a	**17**	6	n/a	n/a	**6**	**n/a**	**23**
9_1	21.8	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	43.6	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	109	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
10_1	21.8	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	43.6	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	109	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
11_4	21.8	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	43.6	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**
	109	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a	**n/a**	**0**	**0**

Table 16. Synthesized spatial analysis data for Test 2 scenarios from ArcGIS derived from the Select by Location feature used to count bird individuals within a specified distance from the oil points.

Similar to the Test 1 scenarios, no birds were within Medium Risk (109 m) distance of oil on April 1, September 1, October 1, or November 4 in the Test 2 scenarios. These are times of year when there are few birds present, so their likelihood of encountering oil is low. June 30, both with and without a flood, stands out as the worst possible time for an oil spill. At this point, both Least Tern and Piping Plover chicks have hatched and the adults' likelihood of renesting in the case of a lost clutch or brood is getting lower. On June 30, a total of 34 birds stood Medium Risk of getting oiled, and a June 30 flood test had an even higher 37 birds. These included brooding adult terns (likely males) whose death implies the death of their offspring who rely on them for food and protection. Because there is already a low survival rate of both Least Tern and Piping Plover chicks, a June 30 spill mid-flood where eight tern nestlings and eight plover fledglings are at Medium Risk of oiling compounded by the large number of oiled adult terns responsible for caring for the other tern nestlings could make for a disastrous breeding year for these two species. Currently, Least Terns require only a stabilizing fledging rate to maintain steady, healthy population levels, but Piping Plover populations still need to grow to meet population goals set by USFWS. Thus, a bad breeding year, while not necessarily causing these species to spiral toward extinction, would certainly slow or even reverse conservation progress that have been made since the 1980s. While June 30 stands out, 5/15, 6/4, and 8/1 all have more than 20 birds at Medium Risk of being oiled. If we look closer at *which* birds are getting oiled for the sake of population resilience, though, we can find that 5/15 and 8/1 may actually be the most devastating to the Piping Plover and Least Tern, respectively. A singular die-off of five percent of the adult population may actually have a greater effect than a complete breeding failure (Mosbech, 2000). On 5/15, a whopping 13 Piping Plover adults are at Medium Risk of getting oiled – that's 13.3% of the local population. Similarly, on 8/1, 17 Least Tern adults (14.2% of the population) stand a Medium Risk of becoming oiled.

Overall comments.

What we see between the differences in bird population numbers, in the fate of the oil, and in the proximity of the birds to the oil is that the date of the spill matters. Higher water temperatures in summer months increase oil evaporation rates and reduce the quantity of oil left floating on the surface, while the high variable winds of the region have the capacity to spread oil downstream or concentrate it near the spill site, depending on its direction. Since the oil stays relatively localized in the first twenty-four hours of a spill, it has the capacity to do substantial damage to these local populations. In a river environment, the three clean up methods available on WebGNOME proved to be rather ineffective, leaving the spilled oil largely at the whim of its environmental conditions and placing even more importance on the date of the spill. While floating oil is problematic, especially for the Least Terns, beached oil causes the most problems across the three species who all spend at least some time at the shoreline and riverbank. In both

Test 1 and Test 2, the highest quantity of beached oil took place in June, which is also when Least Tern and Piping Plover populations peak as chicks hatch and fledge.

Conclusions

Although these models are the result of a number of assumptions and extrapolations, the objective of this study was to make predictions about what Bakken crude oil spills in the Northern Great Plains region could look like under different conditions and how susceptible populations of already-endangered birds will be under those different conditions. While all models simplify reality, they are still our best way to make quantitative predictions about real-world scenarios without actually, for example, dumping thousands of barrels of Bakken crude oil into the Missouri River. The gaps in the determination of input variables do reflect holes in the study worth critiquing, but they also reflect lapses in the availability of data and information regarding pipelines and oil spills to ordinary citizens, which is even more consequential when considering the large numbers who came out in opposition to this pipeline at this site in particular. In doing the best I could with the resources available, I aimed to find not only what an oil spill in this region might look like but also to see what kind of information an engaged citizen could find on the subject and what information remained inaccessible to the public. From there, I developed several recommendations for various stakeholders based on my experience in conducting this study and on the results themselves.

Of course, there is no "good" time for an oil spill. Neither Energy Transfer Partners nor any of the aforementioned government agencies want to see a DAPL leak, especially near the controversial crossing of Lake Oahe where the three endangered bird species discussed in this paper live and breed. However, after conducting thirty oil spill runs across ten dates of the year, I was able to look for patterns and trends across the tests to see which dates may be better and worse in terms of bird survival for an oil spill to occur. Based on my results, it appears that the month of June is overall the worst possible time for an oil spill to occur. It's in June that the highest number of bird individuals are present in the region, and they are at critical times in their annual cycles; incubating, fledging, and brooding nestlings. With already low fledging rates for both species, neither can really afford to lose additional chicks in the summers if either population is to see increased numbers over the next several years, which is the conservation goal for both species as set out in the USFWS 2003 Biological Opinion (Elliott-Smith et al., 2004; Thompson et al., 1997). While it's true that the loss of adults is often more detrimental to overall population recovery than the loss of juveniles, we can see losses of both in the June tests, compounded with high evaporation rates and beached oil – indicating that on top of high numbers of birds in proximity to oil in June, it will be accompanied by acute toxic effects from gaseous carcinogens and extensive human disturbance to remove beached oil.

Another interesting discovery I made while running these oil spill tests was that the most influential variable for predicting the movement of oil once spilled was not, as I had hypothesized, water temperature (which does impact the physical properties of oil, thickening it in colder weather and thinning it in warmer temperatures), but wind. Bakken crude oil floats. It spreads out in a thin sheen across the water surface, and the Missouri River only moves at about 0.5 m/s owing to the dams along the mainstem. Thus, the high gust winds of the region can send the oil out across the water or concentrate it on a single sandbar. Concentrating the impact on a smaller area might be better than if the oil were dispersed across a large number of locations, exposing more birds to the chemical; alternatively, if the oil concentrates on a small area or stretch of shoreline hosting, say, a large Least Tern colony, that could be more devastating to population numbers than a more dispersed scenario. Thus, high winds can minimize or drastically increase bird exposure, depending on where exactly they move the oil in relation to the birds – something almost impossible to predict in advance.

Finally, one finding that I did not fully expect, though perhaps in retrospect makes sense, was the lack of transparency in the oil industry. Two units that oil is measured in, as mentioned throughout this paper, are barrels (bbl) and API (º). Neither of these units are household measurements. A barrel of oil is 42 gallons, and API is just a transformed version of specific gravity. These unit conversions seem completely arbitrary and only serve to decrease transparency between oil companies and the public.
In addition, I was able to find ArcGIS shapefiles for analysis for almost everything I needed throughout this study, but I was never able to download a shapefile of the route of the Dakota Access Pipeline. This goes against the spirit of data-sharing and the use and availability of GIS shapefiles by states. While vandalism is a valid risk for pipelines, especially controversial ones like DAPL, the fact that ordinary citizens cannot download these shapefiles for personal use or research is concerning, especially considering the fact that PHMSA has created them and explicitly states that they are not available for public download.

Recommendations

While efforts can and will surely continue to be made to reduce the risk of an oil spill from DAPL, particularly after the nationally-covered protests that took place, an oil spill event is still entirely possible. Often, it is a matter of when, not if. In that case, we need to enhance the timeliness of responses to oil spills. I wholeheartedly recommend increased coordination between clean up responders and the many stakeholders involved, particularly the government agencies with jurisdiction in the region and the local tribes. Those who are operating the skimmers or setting up the booms for an in situ burn should have a basic working knowledge of the three endangered bird species in the region and their importance. Even making sure to not step on nests during clean up could be a simple way to reduce unnecessary additional bird casualties. Having members of USFWS working with EPA correspondents and advising based on bird locations could make a huge difference in how the populations recover. While increased transparency, coordination, and communication between the different parties below is crucial to developing and implementing the most sophisticated oil spill prevention and response tactics, there are also steps that individuals and organizations can take to continue to mitigate the risks and impacts of a DAPL spill in Lake Oahe.

For Energy Transfer Partners.

If June is the worst month of the year for a DAPL oil spill and windy days pose their own special risks to these three species, ETP should take measures to reduce this heightened risk. First, ETP could increase pipeline vigilance throughout the month of June. It took a Keystone Pipeline operator fifteen minutes to notice that the pressure had dropped due to a leak, and even then, 5,000 barrels had spilled. By hiring extra pipeline operators (or minimizing time off, etc.) in the Lake Oahe region during particularly sensitive times for the birds, a spill or leak is more likely to be detected early. Additionally, the company could lower the pipeline transport capacity during June to ensure that if there is a spill, it will be less severe.

If Energy Transfer is feeling particularly compassionate toward our endangered birds, they could also do what Enbridge now does for Line 5 in the Straits of Mackinac of Lake Michigan: shutting off the pipeline during adverse weather conditions (Snyder et al., 2017). During time periods where wind is strong (especially northern winds which propel oil downstream), the pipeline could be temporarily shut off to ensure that no oil can be spilled in these less-than-ideal conditions. This is certainly advisable in the event of another one-hundred-year flood like those of 2011. These temporary shutdowns could also align with bird behavior; if ETP is in communication with the USACE and USFWS offices who census birds in the area, they can shut DAPL down temporarily when the first eggs begin to hatch, if a Whooping Crane flock roosts close to the pipeline, or when birds start staging in late summer before their southward migration. I suggest that the pipeline company set up a fund to help with conservation recovery of endangered and threatened species that occur along the pipeline route. This would preemptively mediate any adverse effects of the pipeline, from construction to operation to leaks.

For government agencies.

First, I recommend increased wind-monitoring (or better: weather-monitoring) stations at critical places along the Missouri River (namely the crossings upstream of Lake Sakakawea and through Lake Oahe) so that oil movement can be better predicted. Although the station at the Huff Hills Ski Area provided wind estimates for this study, local topography greatly influences wind speed near the water surface. Thus, wind-monitoring stations closer to the coordinates of interest would give more appropriate data than monitoring stations even just a few miles away. Furthermore, these stations would provide more accurate information so that emergency responses to oil spills can be done with better information. This wind data should be explicitly shared with Energy Transfer Partners and those monitoring the pipeline at all times so that they may predict oil movement in the event of a spill and be more responsive to its movement. Along those lines, the more USGS gauges, the better, and placing one near the site of the river crossing of DAPL under Lake Oahe and near other important river crossings could be helpful for more accurate predictions of the persistence of oil in this particular environment.

A number of tactics are already being employed by the USACE to conserve the Least Tern and Piping Plover on federal lands along the Missouri River. This includes creating artificial nesting habitat, putting cages over nests to reduce predation (though this could be harmful to the birds in the event of an oil spill if they are unable to move their eggs), limiting public access to prime nesting habitat, and relocating nests. This last conservation method – relocating nests – could be a powerful tool for reducing the impacts of a DAPL oil spill in Lake Oahe. If all Piping Plover and Least Tern nests were carefully relocated to locations upstream of the DAPL river crossing, the birds would be much less likely to encounter Bakken crude oil than the nests downstream. Continuing to fund conservation efforts and collect baseline population numbers on these three bird species is necessary for the continued ability to both predict oil spill impacts and, in the event of a spill, accurately measure the impact for future use.

One of the biggest flaws I found throughout this research was in the USACE and USFWS Environmental Assessments. While they may have deemed an oil spill extremely unlikely, the pipeline has already spilled several times. Yet when they decided that the endangered species in the region would not be affected or would be affected, but not adversely, they primarily considered how construction and construction workers' temporary presence in the region would impact these species. While that is important, the risks of DAPL do not end when the last construction unit rolls out of town. I recommend increasing the scope of the Environmental Assessments to include a more comprehensive assessment of pipeline operation as well as construction.

Furthermore, DAPL should not have been constructed without a formal response plan in the event of an oil spill. While it's hard to say who is responsible for holding Energy Transfer accountable to this – is the onus on the company to self-regulate? the lobbyists who brought the issue to court? – there is certainly a governmental role in approving and regulating pipelines. PHMSA in particular should not sign off on pipeline construction projects before receiving a complete, formal response plan that has been audited by a third party. Even now, as concerned citizens await the court-ordered Energy Transfer clean up response plan, the impacts of a Bakken crude oil spill could be exacerbated with no formal plan or equipment on hand. This study could have been much more thoroughly fleshed out with access to information on the precise clean up responses that stakeholders would use in this region.

Finally, these flood-prone areas are severely underregulated by the Federal Emergency Management Agency. Flood hazards were either inadequately assessed or not assessed at all in Morton County and along both the Missouri River and Cannon Ball River. In a region prone to hundred-year floods with three endangered bird species breeding along the riverbanks, this is certainly an oversight and one that should be corrected as soon as possible so that county officials, the pipeline company, and other stakeholders can accurately assess the added oil spill risks and trajectories in the event of flooding.

For NOAA.

After working intimately with the NOAA OR&R web-based GNOME operating system, I have also come up with several recommendations for their organization. While I appreciate the accessibility of this free software and find it an amazing tool for citizen scientists and researchers alike, a few improvements could make it even better. I acknowledge that the program was in a beta format during my use and that many of the bugs are being worked on by professionals at this time. For a complete list of recommendations suggested to NOAA correspondents, see Appendix.

First, NOAA should make more location files. The DAPL crossing at Lake Oahe is just one of many water crossings by pipeline systems in the United States. NOAA affiliates should create a database of all major water crossings of pipelines and prioritize the creation of location files for these intersections. The fact that NOAA only creates location files for the Coast Guard suggests that many inland locations where oil spills have taken place or could take place are not being investigated or monitored thoroughly. To enhance inter-agency collaboration on oil spill prevention, I recommend that NOAA allow the EPA and even USFWS to request the creation of location files on GNOME. This may require legislation or changes to administrative rules, so conservation groups could lobby our political representatives to make this change. As the NOAA correspondents are so responsive, citizen scientists should email these representatives and request the location files they have a specific interest in. In the meantime, I recommend NOAA make it easier for the public to learn how to make custom location files, a feature that is available but confusing on WebGNOME.

For river location files specifically, the 2D shapefile options work for now, but shapefiles are static representations, and rivers are dynamic. To account for this, a more sophisticated WebGNOME program would include information about river height and flood stages. They should include a Digital Elevation Model for the area so that both high-water and low-water conditions can be handled. Coordination between NOAA OR&R and FEMA could produce dynamic flood maps that could also be used for oil spill modeling. Furthermore, the WebGNOME manual states that NOAA oil modeling is inaccurate during icy conditions – but that's not to say that oil spills can't happen in icy conditions! More development to increase the accuracy of oil modeling in rivers, from changing water levels to icy conditions, would be a great improvement to this program.

To increase the reliability of these tests, I recommend that NOAA add Bakken and other missing crude oils to its ADIOS oil library. Bakken crude oil is being transported at increasingly high rates by both rail and pipeline in the United States, and it is truly a loss that this study was not able to be performed with the correct oil.

Another recommendation I have for upgrading WebGNOME is to include a projection file with the oil dispersal shapefile that can be downloaded. These shapefiles upload to GIS without any spatial data.The point shapefiles describing oil dispersal need the correct coordinate system to be properly specified so that the shapefiles can be used in ArcGIS or other GIS software. At present, the oil points do project onto maps with Geographic Coordinate Systems ("GCS"). If NOAA is running its models in a GCS coordinate system, which the shapefiles imply, this may be giving inaccurate spatial results. GCS coordinate systems tend to warp maps at high latitudes, and it took some effort to convert all my models into projected coordinate systems.

While this may still be a while off, I recommend the future development of an ecological extension to GNOME that would use the physical and chemical dispersal output from GNOME to actually predict biological and environmental impacts, similar to the way I did in this study. Users or OR&R could create "ecological location files" that would describe the species present, life stages, and likely locations – potentially automating the analysis that I did by hand. Having an easy-to-use gauge of the concentrations of toxic substances (in all states, not just the liquids in the water) and the distribution of flora and fauna would make it much easier for users to contextualize and analyze their oil models.

Although it may be a small thing, for the sake of transparency I recommend that NOAA also include the conversions of oil-specific units into other available units on their program so that users may easily understand these potentially unfamiliar numbers. Otherwise, barrels and API may confuse users. Already, some of my recommendations have been implemented by the OR&R as they continue to update their interface. I pointed out that their three options for surface current speed lacked a unit of measure, and they immediately added that to the program. They are also currently working on creating a feature where users can export only the oil at the end of the model upon my request. Overall, I support the folks at NOAA for making it easier for citizen scientists and concerned individuals to design location files and run oil spill tests at home.

For bird researchers.

I recommend the continued collection of census and observational data on not only these three bird species but other Threatened and Endangered birds. Without baseline data, it is impossible to measure the ecological impacts of events such as oil spills, and accurate reporting of ecological impacts post-spills can be the impetus for increased regulations and more stringent Environmental Assessments.

It would also be helpful to create a database of past oil spills and their impacts on local bird populations. This should include a compilation of information on the number of individuals affected of each species, how they were affected, and how they responded behaviorally to the spill and emergency response. The idea would be to increase our ability to predict and mitigate impacts on birds for spills that occur at different locations and times of the year with different spill sizes and oil types. This does not have to be limited to birds, either, as many other plants and animals are of concern to different interest groups.

For concerned citizens and tribal members.

It is because of the diligence and persistence of both concerned citizens and tribal members that this pipeline even came to my attention and this study took place. Simply by increasing the visibility of what is usually a largely invisible issue is critical to turning the attention of the public and the government on the risks posed by pipelines and oil transport. Continued organizing around this issue until civilians are satisfied with the ETP response plan and USACE and USFW Environmental Assessments is critical to maintain pressure and momentum. Already, we have seen courts sympathize with the civic concerns of both tribal and non-tribal members in the region, and change has stemmed from that applied pressure. As discussed, Judge James Boasberg of the U.S. District Court for the District of Columbia ordered three different measures regarding clean up response plans at Lake Oahe – all of which were requested by the Standing Rock Sioux Tribe (McKenna, 2017). Continuing to attend public hearings and comment periods on proposed construction projects like DAPL is still one of the best ways to voice concerns and challenge inadequate Environmental Assessments and Environmental Impact Statements. Additionally, I recommend that concerned citizens and citizen scientists familiarize themselves with the software available to them. Programs like WebGNOME and even eBird (2002), an online real-time database of bird distributions and abundance by researchers and amateur naturalists alike, can be powerfully used to lobby government agencies into taking these issues more seriously. Long-term, I recommend that concerned citizens and conservationists also put pressure on the oil industry writ large to be more transparent about their own data. Citizens should lobby for PHMSA to release its oil pipeline shapefiles to the public so that those concerned about pipelines that run where they live, work, and play can see exactly where the materials are being transported and what is at risk. It does not take a Ph.D. to operate these programs or uncover and investigate problems and public health risks in your community!

Future research.

I only scratched the surface of looking into the impacts of potential Bakken crude oil spills in Lake Oahe. A flood in April or a late start to the breeding season could create entirely new scenarios that I never considered. These alternate scenarios are worth attention and follow-up, especially to ensure that the USACE and USFWS Environmental Assessments were accurate and considered the full breadth of oil spill possibilities. Additionally, oil spill scenarios when the birds are not present – from mid-November to late March – are still worth investigating. Although these three endangered species in particular are less likely to be directly affected during a winter spill, other wildlife will be present, including other endangered species (see Table 3) and some of the species that make up the diets of the endangered birds. While I gathered three types of data (birds present, oil fate, and bird distribution relative to oil distribution), a fourth type of data I would like to see collected in the future is the predicted length of shoreline impacted. Shoreline data like this was collected in an influential study by David Schwab and Jennifer Read (2016) by modeling oil spills from Line 5 in the Great Lakes, and Line 5 is now one of the leading topics in Michigan's 2018 gubernatorial election.

Additionally, my approach to finding the number of birds in close proximity to oil only considers each bird at a single point (or circle) in time, and only considers the oil locations at a single time (at the end of the spill). It would be helpful for researchers to evaluate different techniques for estimating the number of birds likely to get contact-exposures in different oil spill scenarios, especially methods that can more adequately account for the different foraging, wading, bathing, and roosting behaviors of the birds.

Finally, more research on the acute and long-term toxicological effects of Bakken crude oil is needed at this time. We know very little about how inhaling or ingesting Bakken crude oil would affect members of these three endangered species, but its carcinogenic properties could devastate local populations in the long-term, and these impacts may not be adequately measured because of the time lag between the oil spill and population losses.

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Appendix A

Itemized list of specific WebGNOME recommendations sent to NOAA correspondents.

1. Bakken crude oil should be added to the ADIOS library.
2. More location files should be made available, perhaps prioritizing large bodies of water, drinking water, and water crossed by hazardous materials/pipelines.
3. GOODS should provide more information on the inland shapefiles; the database seems helpful but marine-centric and still somewhat confusing; it's not nearly as easy-to-use as WebGNOME.
4. I had trouble with the custom location file feature. WebGNOME did not appear capable of distinguishing the water (Missouri River) from nearby landscape. This feature could be really great, especially as new pipelines are built, and I encourage you to make it easier to use.
5. One inconvenience for continuous spills was that I wanted to spill oil for 17 hours, but I wanted to run the simulation for 24. WebGNOME does not allow users to do this, and it seems like a fixable limitation.
6. Include conversion tables for the different units, especially the oil-specific units that users may be unfamiliar with.
7. The program can't read commas when inputting the quantity of oil spilled.
8. The "uncertainty" features are *very* unclear. What do they do? How are they different from regular models?What is a red "x" on GNOME vs. a black "x"? The manual only says, "Uncertainty is the only certainty there is," which is not helpful.
9. The Fate View tables did *not* run to completion for my seventeen hour duration, 23,810-barrel tests. They only ran to hour 15 and spilled ~21,000 bbl.
10. Some of the default units are counterintuitive (like a river system that has oceanic settings as the default).
11. Right now, there is no way to account for changing water levels in a river environment, even though rivers are not static.
12. Exporting shapefiles.
    a. WebGNOME did not always generate the correct number of points in its shapefiles. Since I set num_elements to 2,000, I should have gotten 50,000 points in a 24-hour scenario and 36,000 points in a 17-hour scenario (considering there are 2,000 points at Time 0). When I spilled only 5,000 barrels of oil, I got all the points in my shapefile; but when I spilled 23,810 barrels of oil, I only got 18,020 points in my shapefile.
        i. As an aside, the 23,810 barrel continuous spill was always glitchier than the 5,000-barrel spill.
    b. In general, I recommend against having all oil spills have the same number of points and attributing a different mass to each point. I think this is not intuitive, especially visually. Because when I had the same number of points (2,000) for two different spills, when one had about 5 times the spill quantity as the other, it makes it seem like they will have the same impact when in reality they will not.
    c. The shapefiles give users the mass of oil per point (kg). But kilograms of oil is a relatively useless measure and is the only time WebGNOMe uses kg, and it took a lot of work for me to convert kg to bbl. I think it would be more intuitive, especially the way the WebGNOME interface asks for input variables, to output the oil in bbl. Also, there is

no metadata on the files, so I didn’t actually know that the mass was in kg until I emailed NOAA.

   d. What coordinate system is WebGNOME operating in? It appears to be a geographic coordinate system of some sort, but this was not written anywhere. The points for the Detroit River shapefiles exported would only upload to a GCS map, not a Michigan GeoRef map. Additionally, the points need a projection file – currently they have no spatial data attached.
      i. I believe using projected coordinate systems would be better than using GCS to preserve the integrity of the maps.

13. The clean up responses.
   a. The ROC clean up response active periods are unclear. The default is 7 am to 7 pm. But if my spill starts at 3 pm, it seems unrealistic that the clean up response would begin immediately at 3, go until 7, and then start back up again the next morning at 7 am. Additionally, this doesn’t match the wind wizard, which uses military time.
   b. The skimming clean up response, more than the other two doesn’t work. Lots of errors popped up, especially on continuous spills.
   c. The ROC/ADIOS distinction is still very unclear. It would be helpful to see what the pros and cons of each feature are.
   d. Unfortunately, WebGNOME does not detail exactly what chemical(s) are being used in this scenario, which I recommended they do.
   e. For the skimmer, I was unable to use the ROC (calculate based on equipment parameters) feature like I did the other two. I believe this was because of a glitch that did not allow a skimmer to be activated until all the oil was spilled, but continuous spills on WebGNOME spill right up until the end of the simulation, so there were a lot of errors popping up in the Test 2 scenario. I have brought this possible glitch to the attention of NOAA correspondents and hope to see it resolved in the future.

14. Future iterations
   a. Work with USFWS and EPA to create ecological extension such that users can track concentrations of toxic chemicals and impacts on wildlife.
   b. Work with FEMA to incorporate floodplain assessments into the modeling.