# APPENDIX G

# IMPACT PROBABILITIES

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## G.1 PURPOSE OF THIS APPENDIX

This appendix describes the method by which payload and spent stage impact probabilities are calculated for National Aeronautics and Space Administration (NASA) Sounding Rockets Program launches. This information was used to support various resource area impact analyses in the *Final Environmental Impact Statement for the NASA Sounding Rockets Program at Poker Flat Research Range* (*PFRR EIS*).

## G.2 PROBABILITY OF IMPACT WITHIN DIFFERENT AREAS OF CONCERN

Typical impact points were analyzed for seven different distances from the Poker Flat Research Range (PFRR) launch site, covering a range of possible launch vehicles, both to determine the probability of a spent stage or payload landing within a number of potential areas of concern and to develop search and recovery scenarios. These impact points represent composite points for a number of rocket launches from PFRR over approximately the past 10 years. They are not intended to represent the predicted impact points for all future launches from PFRR, but are intended to show the typical distances flown by the different launch vehicles in use at PFRR and the relative uncertainty associated with predicted impact points at various distances from the launch site. The distances analyzed are as follows:

- 2 kilometers (1.2 miles) – 1st stage of Black Brant (BB) IX or BBXII
- 3 kilometers (1.9 miles) – 1st stage of BBX
- 13 kilometers (8.1 miles) – 1st stage of Terrier-Orion or Terrier-Improved Orion or 2nd stage of BBXII
- 55 kilometers (35 miles) – Orion
- 200 kilometers (120 miles) – 2nd stage of Terrier-Orion
- 300 kilometers (180 miles) – 2nd stage of BBIX or BBX
- 350 kilometers (220 miles) – 3rd stage of BBXII or 2nd stage of Terrier-Improved Orion
- 1,000 kilometers (620 miles) – 3rd stage of BBX or 4th stage of BBXII

The potential impact areas were determined using downrange and cross-range dispersion estimates from past NASA launches at PFRR. During the launch sequence, NASA calculates the estimated impact points for the stages and the payload based on information known about the launch (*e.g.*, azimuth, payload weight, direction, and wind speed). These calculations provide a starting point for any subsequent searches. Note that while these calculations provide NASA's best estimates of where these items are expected to impact the Earth, there is a level of uncertainty associated with these estimates because of the large number of variables associated with each launch. These variables include payload weight, wind, temperature, and variations in the performance of the solid rocket fuel. These variations become even more pronounced the higher the payload or spent stage is launched from the launch site. The biggest variants are thrust misalignment, which is a measure of how straight the rocket really is, and uncompensated winds. This is the change in wind from the time it is last measured prior to launch until the instant the rocket is launched (for example, a wind gust).

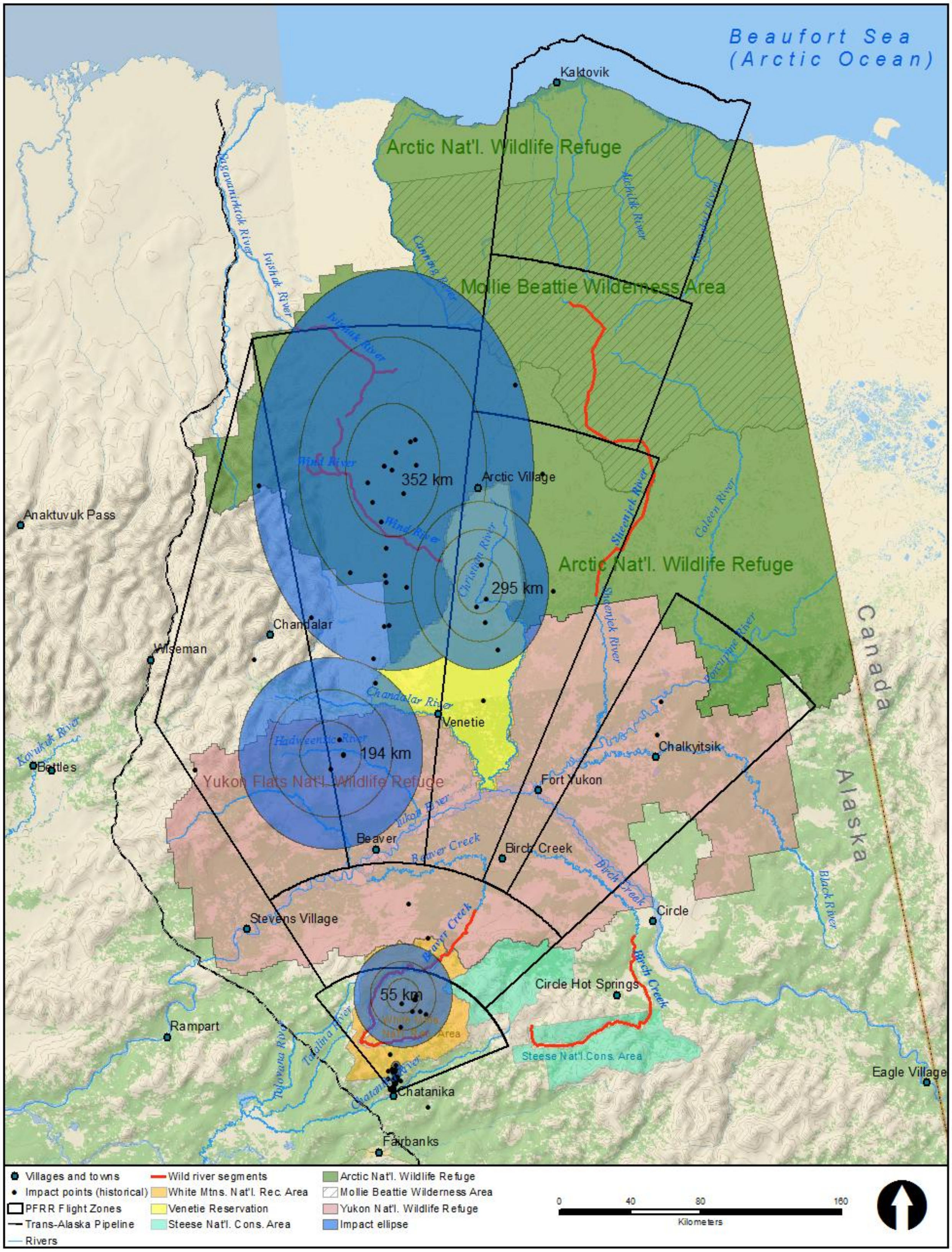
As a result, the predicted impact points have bands of uncertainty associated with them that can vary north and south (downrange) and east and west (cross-range) by relatively small amounts on a percentage basis (for example, 5 to 10 percent), but that end up being relatively large distances for spent stages or payloads that are predicted to land further from the launch site. For example, a typical BBXII launch has a third stage that would be predicted to land approximately 350 kilometers (220 miles) from the launch site with a 1-sigma[1] downrange dispersion of approximately 38 kilometers (24 miles) and a 1-sigma cross-range dispersion of 27 kilometers (17 miles).[2] Using these dispersion estimates, it is possible to estimate a predicted impact area within the ellipse formed by these dispersion factors. The 1-sigma impact area for this example would be an ellipse with an area of approximately 3,200 square kilometers (1,235 square miles).

Using a bivariate circular probability distribution, approximately 39 percent of BBXII's launches are expected to land within 1 sigma of the predicted impact point, 86 percent within 2 sigma, and 99 percent within 3 sigma. Expanding the predicted impact area to account for 2-sigma dispersion increases the potential impact area by a factor of 4, and expanding the area to account for 3-sigma dispersion increases the potential impact area by a factor of 9 compared to the 1-sigma predicted impact area.

**Figure G–1** shows the typical 1-, 2-, and 3-sigma ellipses for different distances evaluated as typical impact points for launches from PFRR within PFRR on White Mountains National Recreation Area, the Venetie Reservation, and Yukon Flats and Arctic National Wildlife Refuges. These ellipses were used to calculate the probability of a payload or spent stage landing within these areas as well as other areas of concern that may reside within these areas, such as Wilderness Areas and Wild River segments. **Figure G–2** shows the potential overlap of a typical impact point within the Beaufort Sea on the northern border of PFRR and polar bear critical habitat. **Figure G–3** shows the potential overlap of a typical impact point within the Beaufort Sea on the areas where ringed seals are known to congregate during the winter months when launches are assumed to take place from PFRR and the potential overlap with sea ice out to 200 nautical miles where ringed seals could be present during such launches. **Figure G–4** shows the potential overlap of the typical impact points within PFRR on areas where caribou herds are known to congregate during the winter months when launches are assumed to take place from PFRR. **Figure G–5** shows the potential overlap of a typical impact point within the Beaufort Sea on areas that are covered with sea ice year-round (sea ice in this region of the Beaufort Sea retreats until early September each year and then begins to freeze over again until it is hard up against the Alaska coastline during the winter months) **(NSIDC 2011).**

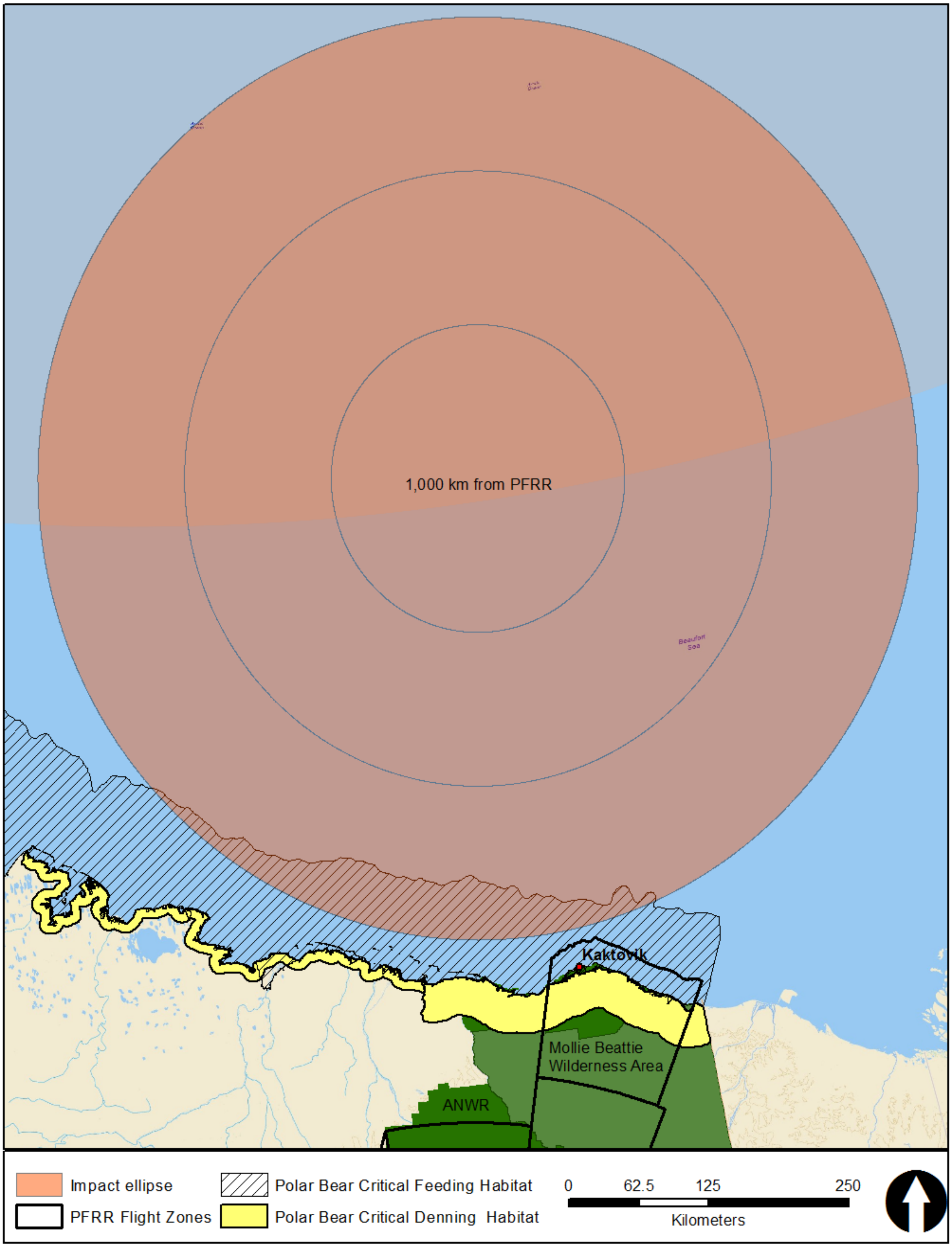
[1] Sigma or standard deviation is a measure of how much variation or "dispersion" there is from the average (the mean, or, in this case, predicted impact point).

[2] Since the launches from PFRR are generally from south to north, downrange dispersion refers to differences in the actual impact point along the south-to-north axis and cross-range dispersion refers to possible differences in the actual impact point along the west-to-east axis.




**Key:** km=kilometers.

**Figure G–1. Typical Impact Areas Within the Poker Flat Research Range**




**Key:** km=kilometers.

**Figure G–2. Typical Impact Areas Within the Beaufort Sea**

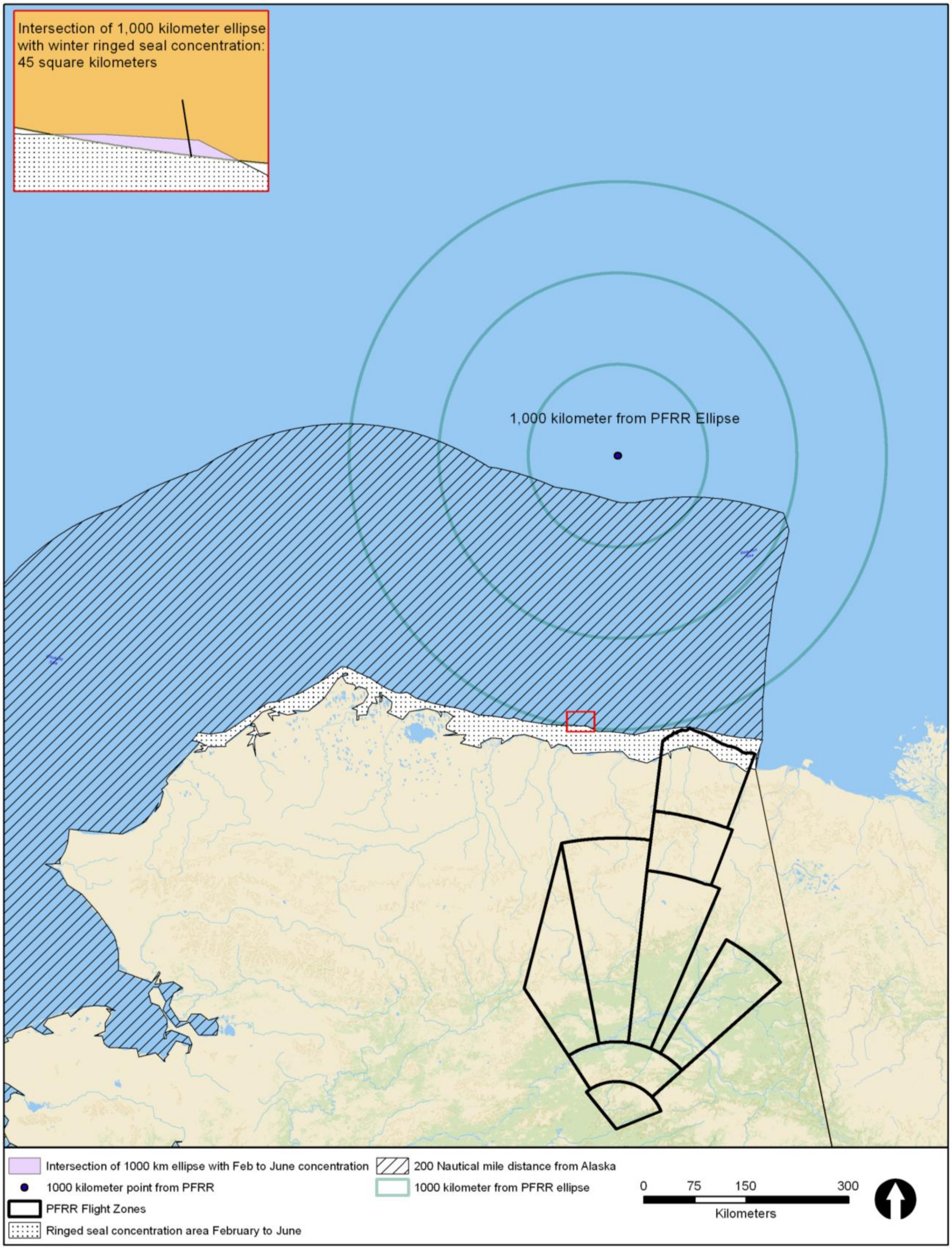
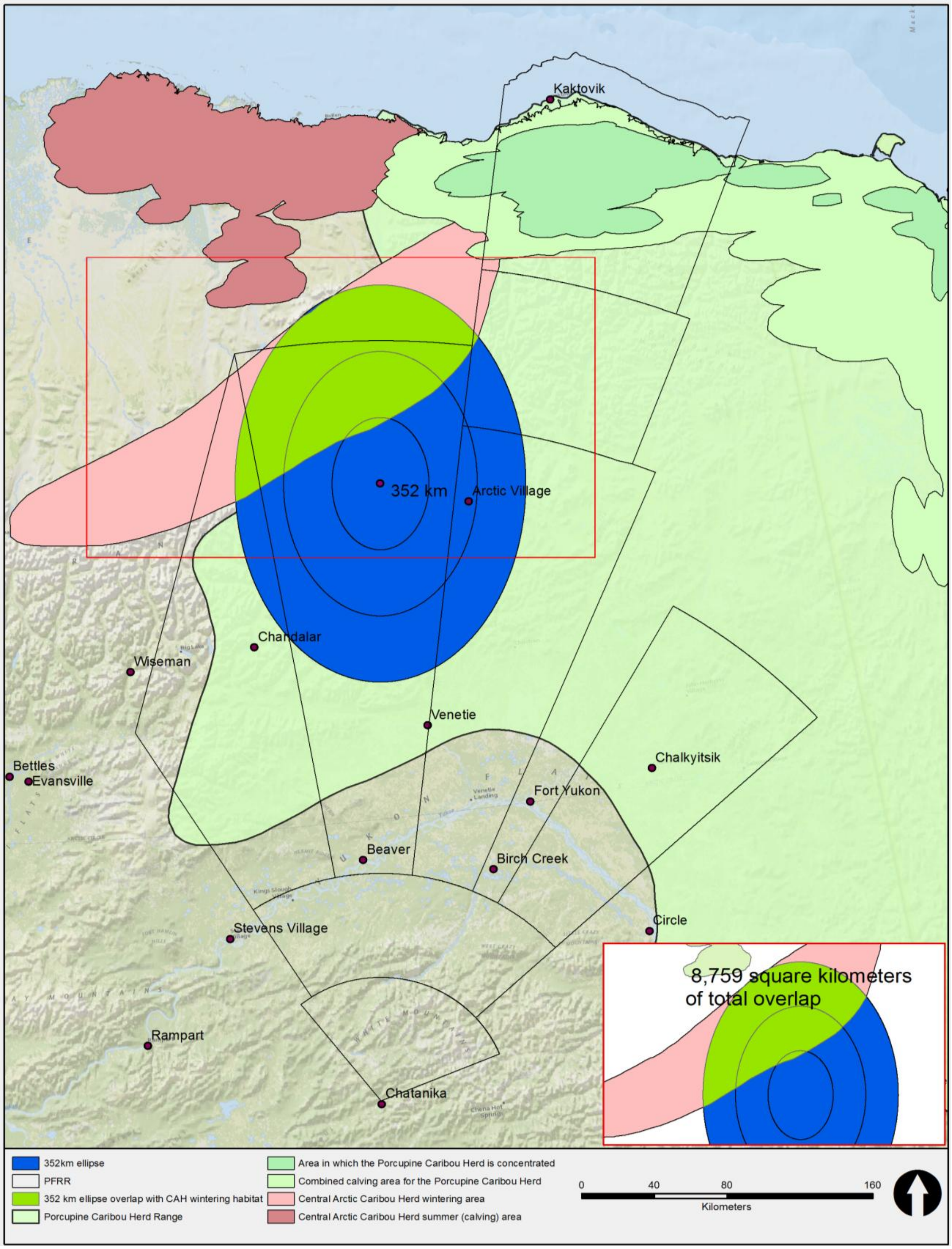
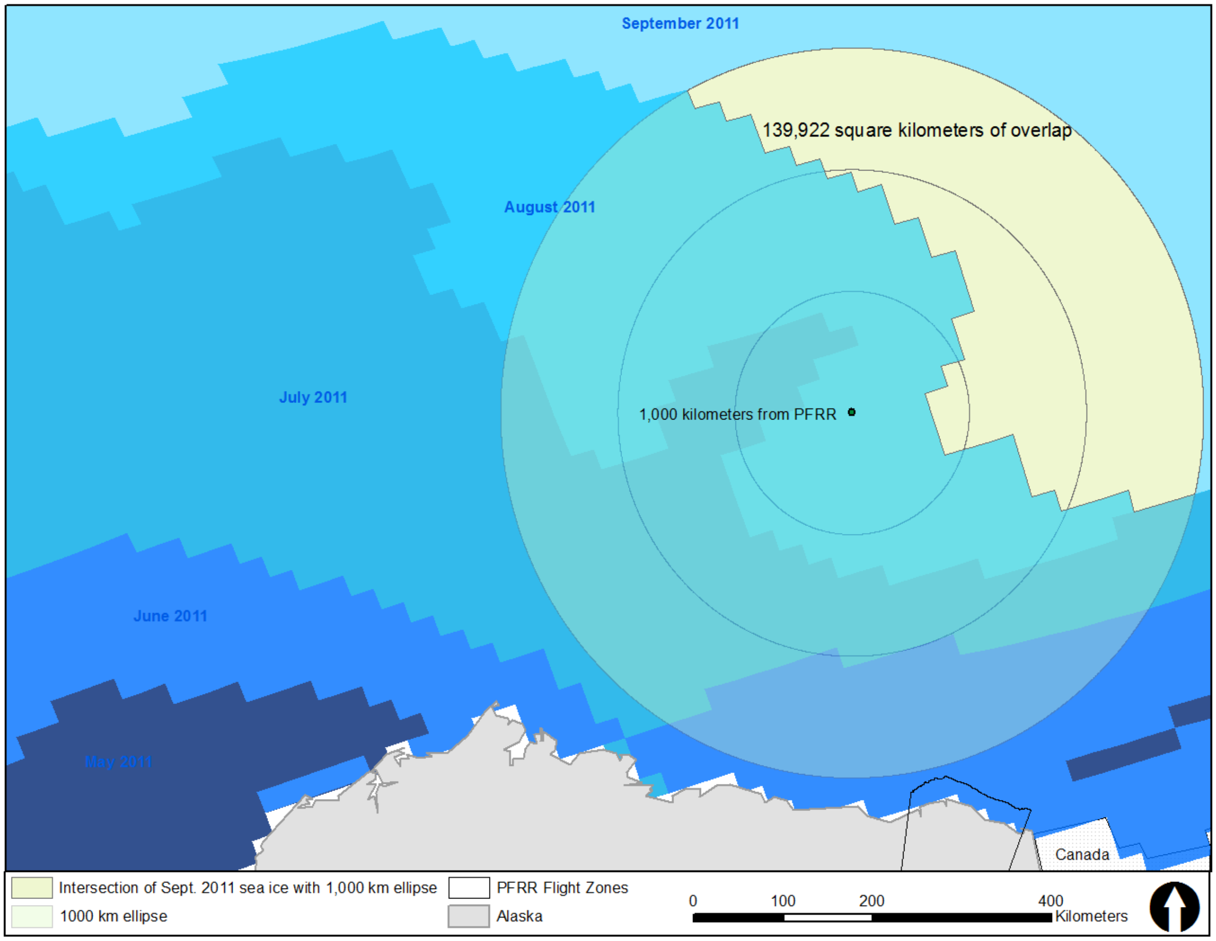



**Figure G–3. Typical Impact Points Related to Ringed Seal**




**Key:** CAH=Central Arctic Herd; km=kilometers.

**Figure G–4. Typical Impact Points Related to Caribou Herds**




**Key:** km=kilometers.

**Figure G–5. Typical Impact Points Related to Permanent Sea Ice**

The *PFRR EIS* evaluates the potential impact of these spent stages and payloads on a variety of natural areas, land ownership, land designations, and wildlife habitats. **Tables G–1 through G–7** show the probability of a typical spent stage or payload impacting in these different areas of concern.

**Table G−1** shows the probability of a typical spent stage or payload impacting Federal lands for the different potential impact points. Depending on the launch vehicle, these probabilities range from less than 1 chance in 12,000 ($8.3 \times 10^{-5}$) that an Orion rocket would land within Yukon Flats National Wildlife Refuge to a 98 percent probability that an Orion rocket would land within the White Mountains National Recreation Area.

**Table G–1. Probability of Impact on Federal Lands**

| Distance from the PFRR Launch Site (kilometers) | Federal Land | Potential Impact Ellipse (square kilometers) | Amount of Federal Land Within Ellipse (square kilometers) | Probability of a Spent Stage or Payload Landing on Federal Land |
|---|---|---|---|---|
| 13 | White Mountains NRA | 45 | 20 | 0.42 |
| 55 | White Mountains NRA | 2,551 | 2,461 | 0.98 |
| 55 | Steese NCA | 2,551 | 24 | 0.0021 |
| 55 | Yukon Flats NWR | 2,551 | 1 | $8.3\times10^{-5}$ |
| 194 | Yukon Flats NWR | 8,856 | 6,367 | 0.84 |
| 295 | Yukon Flats NWR | 5,808 | 70 | 0.0027 |
| 295 | Arctic NWR | 5,808 | 1,941 | 0.14 |
| 352 | Mollie Beattie Wilderness Area | 28,370 | 603 | 0.0047 |
| 352 | Arctic NWR | 28,370 | 21,843 | 0.91 |

**Key:** NCA=National Conservation Area; NRA=National Recreation Area; NWR=National Wildlife Refuge.
**Note:** To convert kilometers to miles, multiply by 0.62137; square kilometers to square miles, by 0.38610.

**Table G−2** shows the probability of a typical spent stage or payload impacting designated Wild River segments, including the lands on either side of the rivers, for the different potential impact points based on information provided by **USFWS (2011)**. Depending on the launch vehicle, these probabilities range from less than 1 chance in 230 (0.0043) that the second stage of a BBX would land within the designated Wind River Wild River segment to a 6 percent probability that an Orion rocket would land within the designated Beaver Creek Wild River segment.

**Table G–2. Probability of Impact on Designated Wild River Segments**

| Distance from the PFRR Launch Site (kilometers) | Designated Wild River Segment | Potential Impact Ellipse (square kilometers) | Amount of Wild River Segment Within Ellipse (square kilometers) | Probability of a Spent Stage or Payload Landing in the Wild River Segment |
|---|---|---|---|---|
| 55 | Beaver Creek | 2,551 | 216 | 0.062 |
| 295 | Wind River | 5,808 | 63 | 0.0043 |
| 352 | Wind River | 28,370 | 786 | 0.053 |
| 352 | Ivishak River | 28,370 | 795 | 0.036 |

**Note:** To convert kilometers to miles, multiply by 0.62137; square kilometers to square miles, by 0.38610.

**Table G−3** shows the probability of a typical spent stage or payload impacting lands owned by regional landowners with significant holdings within the PFRR launch corridor. Depending on the launch vehicle, these probabilities range from less than 1 chance in 2,700 ($3.6 \times 10^{-4}$) that the third stage of a BBXII or second stage of a Terrier-Improved Orion would land within Venetie lands to an 87 percent probability that the second stage of a BBX would land within Venetie lands.

**Table G–3. Probability of Impact on Regional Landowners**

| Distance from the PFRR Launch Site (kilometers) | Regional Landowner | Potential Impact Ellipse (square kilometers) | Amount of Regional Land Within Ellipse (square kilometers) | Probability of a Spent Stage or Payload Landing on Regional Lands |
|---|---|---|---|---|
| 194 | Venetie Reservation | 8,856 | 311 | $7.8 \times 10^{-3}$ |
| 194 | Doyon, Limited | 8,856 | 301 | $7.6 \times 10^{-3}$ |
| 295 | Venetie Reservation | 5,808 | 3,993 | 0.87 |
| 295 | Doyon, Limited | 5,808 | 105 | $4.1 \times 10^{-3}$ |
| 352 | Venetie Reservation | 28,370 | 3,436 | 0.054 |
| 352 | Doyon, Limited | 28,370 | 188 | $9.7 \times 10^{-3}$ |

**Note:** To convert kilometers to miles, multiply by 0.62137; square kilometers to square miles, by 0.38610.

**Table G−4** shows the probability of a typical spent stage or payload impacting polar bear critical habitat within PFRR. The only launch vehicles capable of reaching these areas would the third stage of the BBX or the fourth stage and payload of a BBXII. Typically these items would land far offshore in the Beaufort Sea or Arctic Ocean but there is a small chance that they could land along the shore that includes designated critical polar bear feeding and denning habitat. Critical denning habitat would not typically be affected by these launches. The chance that one of these launches would typically impact designated critical feeding habitat is less than 1 chance in 150 ($6.6 \times 10^{-3}$).

**Table G–4. Probability of Impact on Polar Bear Critical Habitat and Dens**

| Distance from the PFRR Launch Site (kilometers) | Polar Bear Critical Habitat | Potential Impact Ellipse (square kilometers) | Amount of Polar Bear Critical Habitat Within Ellipse (square kilometers) | Probability of a Spent Stage or Payload Landing in Polar Bear Critical Habitat |
|---|---|---|---|---|
| 1,000 | Feeding habitat | 503,375 | 14,964 | $6.6 \times 10^{-3}$ |
| 1,000 | Denning habitat | 503,375 | 0 | 0 |
| 1,000 | Polar bear dens within potential impact area[a] | 503,375 | 0.022 | $4.6 \times 10^{-8}$ |

a. An estimated 69 known polar bear dens could be within the area potentially impacted by a typical National Aeronautics and Space Administration launch into the Beaufort Sea (based on information from **Amstrup and Gardner [1994]**) based on information collected over the years by the National Oceanic and Atmospheric Administration. Assuming each den covers an area of approximately 3 square meters (30 square feet) (**Stirling 1988)**, this analysis assumes a safety zone within a 10-meter (33-foot) radius of the den. The potential area of disturbance around a polar bear den that could result in either damage to the den or injury or death to the polar bear is estimated to be approximately 315 square meters (380 square yards) per den, or 0.022 square kilometers (0.0085 square miles) for 69 dens.

**Note:** To convert kilometers to miles, multiply by 0.62137; square kilometers to square miles, by 0.38610.

The probability of one of these items actually impacting a polar bear den was also estimated using information on known polar bear dens in the area. The chance that one of these launches would directly impact a polar bear den is less than 1 chance in 21 million ($4.6 \times 10^{-8}$).

**Table G−5** shows the probability of a typical spent stage or payload impacting areas where ringed seals congregate during the winter within PFRR. Similar to polar bear critical habitat, the only launch vehicles capable of reaching these areas would be the third stage and payload of a BBX or the fourth stage and payload of a BBXII. Typically these items would land far offshore in the Beaufort Sea or Arctic Ocean but there is a small chance that they could land along the shore that includes areas where ringed seals are known to congregate during the winter when such launches would take place. The chance that one of these launches would typically impact areas where ringed seals are known to congregate is 1 chance in 50,000 ($2.0 \times 10^{-5}$). The probability of one of these items actually impacting a ringed seal was also estimated using information on ringed seal concentrations in the Beaufort Sea. Assuming a conservative density of 1 individual per square kilometer throughout the Beaufort Sea and Arctic Ocean and allowing for a 10-meter-radius (33-foot-radius) buffer zone around each seal, the per-launch chance of an impact near a ringed seal is very low, approximately $3.1 \times 10^{-4}$, or 1 chance in 3,200 (see Table G–5).

**Table G–5. Probability of Impact on Ringed Seals in the Beaufort Sea**

| Ringed Seal Resource | Potential Impact Ellipse (square kilometers) | Ringed Seal Resource Area (square kilometers) | Probability of Spent Stage or Payload Impacting Ringed Seal Resource |
|---|---|---|---|
| Nearshore ice[a] | 503,375 | 45 | $2.0{\times}10^{-5}$ |
| Individual within 3-Sigma Dispersion[b] | 503,375 | 159 | $3.1{\times}10^{-4}$ |

a. Assumed to be concentrated on the nearshore ice during the winter months. Wintering concentration areas for the ringed seal (*Pusa hispida*) were interpreted and mapped from **Smith *et al.* 2010**, Figure 37.

b. Based on information collected over the years, a population density of 1 ringed seal per square kilometer was assumed across the entire Beaufort Sea **(Ireland *et al.* 2009)** within the typical 3-sigma dispersion. Assuming a safety zone within a 10-meter (33-foot) radius of seal, the potential area of disturbance around a ringed seal that could result in either injury or death is estimated to be approximately 315 square meters (380 square yards) per seal, or 159 square kilometers (61 square miles) for the approximately 503,375 ringed seals that could be within the impact ellipse.

**Note:** To convert kilometers to miles, multiply by 0.62137; square kilometers to square miles, by 0.38610.

**Table G−6** shows the probability of a typical spent stage or payload impacting areas where caribou herds congregate during the winter within PFRR. The chance that the third stage of a BBXII or second stage of a Terrier-Improved Orion would land where the Central Arctic Caribou Herd is known to congregate is approximately 1 chance in 5 (0.20). During the winter months, the Porcupine Caribou Herd is largely located east and south of the predicted impact points; hence no additional impacts are anticipated. See Figure G–4 for more information regarding seasonal locations of the regional caribou herd.

**Table G–6. Probability of Impact on Caribou Herds**

| Distance from the PFRR Launch Site (kilometers) | Caribou Herd Area | Potential Impact Ellipse (square kilometers) | Area Within Ellipse Frequented by Caribou Herds During the Winter Months (square kilometers) | Probability of a Spent Stage or Payload Hitting the Area of Caribou Concentration |
|---|---|---|---|---|
| 352 | Central Arctic Caribou Herd | 28,370 | 8,759 | 0.20 |
| 352 | Porcupine Caribou Herd | 28,370 | 0 | 0 |

**Note:** To convert kilometers to miles, multiply by 0.62137; square kilometers to square miles, by 0.38610.

**Table G−7** shows the probability of a typical spent stage or payload impacting permanent sea ice off the coast of Alaska. The chance that the third stage or payload of a BBX or the fourth stage or payload of a BBXII would land on permanent sea ice is approximately 1 chance in 6 (0.17) based on information from the National Sea Ice Data Center **(NSIDC 2011)**.

**Table G–7. Probability of Impact on Permanent Sea Ice**

| Distance from the PFRR Launch Site (kilometers) | Sea Ice Coast of Alaska | Potential Impact Ellipse (square kilometers) | Area Within Ellipse Covered by Permanent Sea Ice (square kilometers) | Probability of a Spent Stage or Payload Hitting the Area of Permanent Sea Ice |
|---|---|---|---|---|
| 1,000 | Permanent Sea Ice | 503,735 | 140 | 0.17 |

**Note:** To convert kilometers to miles, multiply by 0.62137; square kilometers to square miles, by 0.38610.

## G.3 References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