BACKGROUND:

River overflood on the sea ice occurs annually in the nearshore region of the Beaufort Sea during a brief period in the spring when river break-up precedes the break-up of the landfast ice. Upon arrival at the coast, the river water flows on top of the grounded and floating sea ice, spreading up to 10 km offshore. This brief but energetic phenomenon constitutes a potential hazard to offshore oil and gas development in that it can impede access to facilities, disperse spilled oil, and expose buried subsea pipelines through strudel scouring.

This study was designed to map the annual extent of peak river overflooding onto the landfast ice of the Alaskan Beaufort Sea during the 13-year period between 1995 and 2007. The study area covers a 430-km stretch of shoreline between Smith Bay on the west and Camden Bay on the east. The Minerals Management Service (MMS) will use the findings for environmental assessment and hazard mitigation for present and future oil and gas facilities that may be located within or adjacent to the areas influenced by the overflood.

OBJECTIVES:

The specific objectives of the study were as follows:

1. Document the maximum river overflood boundaries (peak seaward extent) in the study area using remote sensing and historical helicopter-based survey data;
2. Assess and compare the effectiveness of different remote sensing platforms for mapping river overflood;
3. Investigate environmental factors that contribute to river overflood; and
4. Assess the hazards associated with overflood (primarily strudel scour).

DESCRIPTION:

Overflood boundaries have been mapped previously to support oil and gas development on a site specific basis using both helicopter-based surveys and visible satellite imagery. Synthetic Aperture Radar (SAR) satellite imagery has not been used in the past for overflood mapping. The ability to accurately map river overflood boundaries from various remote sensing platforms (both visible and SAR) was evaluated by comparing the results of a 2007 helicopter-based overflood survey off the Colville River Delta with the overflood boundaries mapped from a variety of satellite image platforms.

River overflood on the sea ice is a complex phenomenon that likely is affected by the interaction of multiple variables. An analysis was undertaken to search for correlations between each suspected environmental driving force and overflood area to provide a means of predicting the severity of future overflood events. The correlation between the suspected environmental driving forces also was investigated to determine if one can be used as a proxy for others.
Strudel scouring occurs when the overflood water drains through holes in the sea ice and impinges on the sea bottom. The resulting depressions can constitute significant design considerations for subsea pipelines. Strudel drain and strudel scour data obtained from various industry studies were used to provide an indication of the scour potential associated with river overflood.

The study products were incorporated into an ArcGIS database that includes satellite images, interpreted overflood boundaries, strudel drain and scour data, and an inventory of offshore ice roads. The database constitutes one of the study deliverables.

**SIGNIFICANT FINDINGS AND CONCLUSIONS:**

Salient findings from the study are summarized below:

1. **Field Survey Program and Satellite Image Validation:** Helicopter-based mapping techniques provide the most accurate depiction of river overflood limits. The helicopter-derived 2007 Colville River overflood boundary was compared to the boundaries mapped using images from three visible spectrum satellite platforms (Landsat 7, SPOT, and MODIS) and two SAR satellite platforms (ERS-2 and Radarsat) to gain an understanding of the accuracy and limitations of various image platforms. Landsat 7, MODIS, and ERS-2 performed equally well among the satellite platforms and provided the most accurate depiction of the overflood limit relative to the helicopter survey. The SPOT and Radarsat imagery provided the least accurate results. The findings suggest that satellite imagery can be used to derive overflood limits that approach the accuracy of helicopter-based results under favorable conditions. However, late in the overflood period and under unfavorable conditions, overflood boundaries derived from satellite-based imagery can differ materially from those derived from helicopter-based mapping. Because the availability of images from multiple satellite platforms in a given year is rare, however, none of the satellite platforms investigated should be excluded from consideration when mapping historical overflood limits.

2. **Historical Overflood Boundary Mapping:** River overflood boundaries were mapped for all major rivers and streams in the study area for the 13-year period between 1995 and 2007 using a combination of historical helicopter surveys and satellite images. Satellite imagery, and particularly radar satellite imagery, formed the key data source needed to develop the final mapped boundaries. To increase the probability of capturing the peak overflood, a maximum composite overflood limit was developed for each watercourse by integrating all of the mapped overflood limits for a given year. When the 11 major river systems in the study are considered, overflood limits were mapped for 129 out of 143 possible river and year combinations, resulting in a mapping success of 90%. This result exceeded expectations, and would not have been possible without having access to both the radar imagery and helicopter surveys.

3. **Correlation of River Overflood with Environmental Variables:** No meaningful correlations were identified between annual overflood areas and the corresponding values of stream flow, precipitation, and temperature. Attempts to correlate stream flow with either precipitation or temperature also proved to be fruitless. The most important implication of these findings is that the extent of river overflood onto the sea ice cannot be predicted by any single environmental variable for which historical data currently exist. The overflood phenomenon appears to be governed by complex interactions between a number of environmental forces, some of which, such as ice jams in distributary channels, roughness and snow cover on the sea ice, and the density of drainage features on the sea ice, have not been quantified to date.

4. **Hazards Related to Strudel Scours:** Strudel scouring can constitute a significant design consideration for subsea pipelines in nearshore areas adjacent to river and stream mouths. Strudel scour concerns have resulted in the burial of the two existing subsea pipelines in the Alaskan Beaufort Sea (BPXA’s Northstar and Pioneer’s Oooguruk).
In the event that a strudel drain is located directly above a buried subsea pipeline, a sufficiently deep strudel scour may expose the pipeline and lead to an unsupported span. A strudel scour that forms directly over a buried pipeline also can remove the backfill material that is needed to prevent damage from ice keels and forestall upheaval buckling. An additional concern is that strudel drainage provides a potential mechanism to transport spilled oil below the ice sheet.

5. **Strudel Scour Zonation**: Strudel scour frequency and severity can be segregated into zones according to water depth. Strudel scouring typically is most common and severe in the Primary Strudel Zone, which extends offshore from the bottomfast ice edge to approximately 6 m water depth. In the zone of bottomfast ice (the “Secondary Strudel Zone”) and offshore of the Primary Zone (the “Tertiary Strudel Zone”), scouring tends to be more modest and occur less frequently. When the major rivers in this region were considered, the Secondary Strudel Zone accounted for the greatest portion of the overflood area in any given year. On average, this zone encompassed 66% of the total average overflood area. The Primary Strudel Zone accounted for 32% of the total average overflood area, while the Tertiary Zone accounted for a mere 2%. Strudel zone information should be used to assess the risk to prospective pipeline routes posed by strudel scouring in different coastal areas.

6. **Strudel Scour Pipeline Encounter Frequency**: A case study of strudel scours in the vicinity of the BPXA Northstar Development suggests that the presence of the operational pipeline materially altered the scour regime, and has led to a substantially higher than expected scour encounter frequency with the pipelines. This phenomena is most prominent in the Secondary Zone, and is believed to be attributable to radiant heat from the pipelines propagating through the backfill and degrading the overlying ice cover. While less pronounced, a statistical analysis of strudel occurrence also indicates an increased encounter frequency in the Primary Zone. Radiant heat from the pipelines also may explain the high encounter frequency in this zone. However, it is not known whether the impact is direct (degradation of the ice sheet), indirect (increased biological activity in the warmer water), or a combination of the two. Because scouring is more severe in the Primary Zone, the potential consequences of scour depressions forming over the pipelines are greater in this zone than in the Secondary Zone.

7. **Hazards Related to Facilities Access**: Rapid deterioration of the ice sheet can render ice roads impassable within the zone of river overflood, impacting both facilities access and oil spill response.

**ACKNOWLEDGEMENTS**

The study would not have been possible without the support of BP Exploration (Alaska); Shell Exploration and Production; and Pioneer Resources in providing open access to historical overflood limits and strudel drain and scour mapping information.

**STUDY PRODUCTS**:

Final Report, bibliographic Procite database, ArcGIS containing: visible and SAR image files, metadata and shapefiles of composite overflood boundaries, overflood dimensions, strudel scour and strudel drain spatial distributions, overflood dimensions (area, lateral and seaward extent), and environmental variables.
CONTRACT NUMBER: MO6 PC 00034
SPONSORING OCS REGION: Alaska OCS Region
APPLICABLE PLANNING AREA: Beaufort Sea
FISCAL YEAR(S) OF PROJECT FUNDING: 2006-2009
COMPLETION DATE OF REPORT: est. June 2009
CUMULATIVE PROJECT COST: $474,974.00
PROJECT MANAGER: Warren Horowitz
AFFILIATION: MMS
ADDRESS: 3801 Centerpoint Drive, Suite 500, Anchorage, AK 99503-5823
PRINCIPAL INVESTIGATORS: Greg Hearon, David Dickins, Kim Morris, Ken Ambrosius
KEY WORDS: Beaufort Sea, river, overflow, helicopter surveys, satellite, remote sensing, scour, strudel, ArcGIS

REPORT AVAILABILITY:
This report, OCS Study MMS 2009-017, is available on paper from the Minerals Management Service, Public Information Office, 3801 Centerpoint Drive, Suite 500, Anchorage, AK 99503-5823, or can be downloaded from our website at www.mms.gov/alaska/ref/akpubs.htm. Report copies are available free of charge, as long as the supply lasts, from the above address. Telephone requests may be placed at 1-800-764-2627 or (907) 334-5206. E-Mail requests may be sent to akwebmaster@mms.gov. Once the limited supply is gone, copies will be available from the National Technical Information Service, Springfield, Virginia 22161, or may be inspected at selected Federal Depository Libraries.