The evolution of the Integrated Geobotanical and Historical Change Mapping (IGHCM) approach for documenting landscape change (1949-2010), Prudhoe Bay oil field, AK, USA

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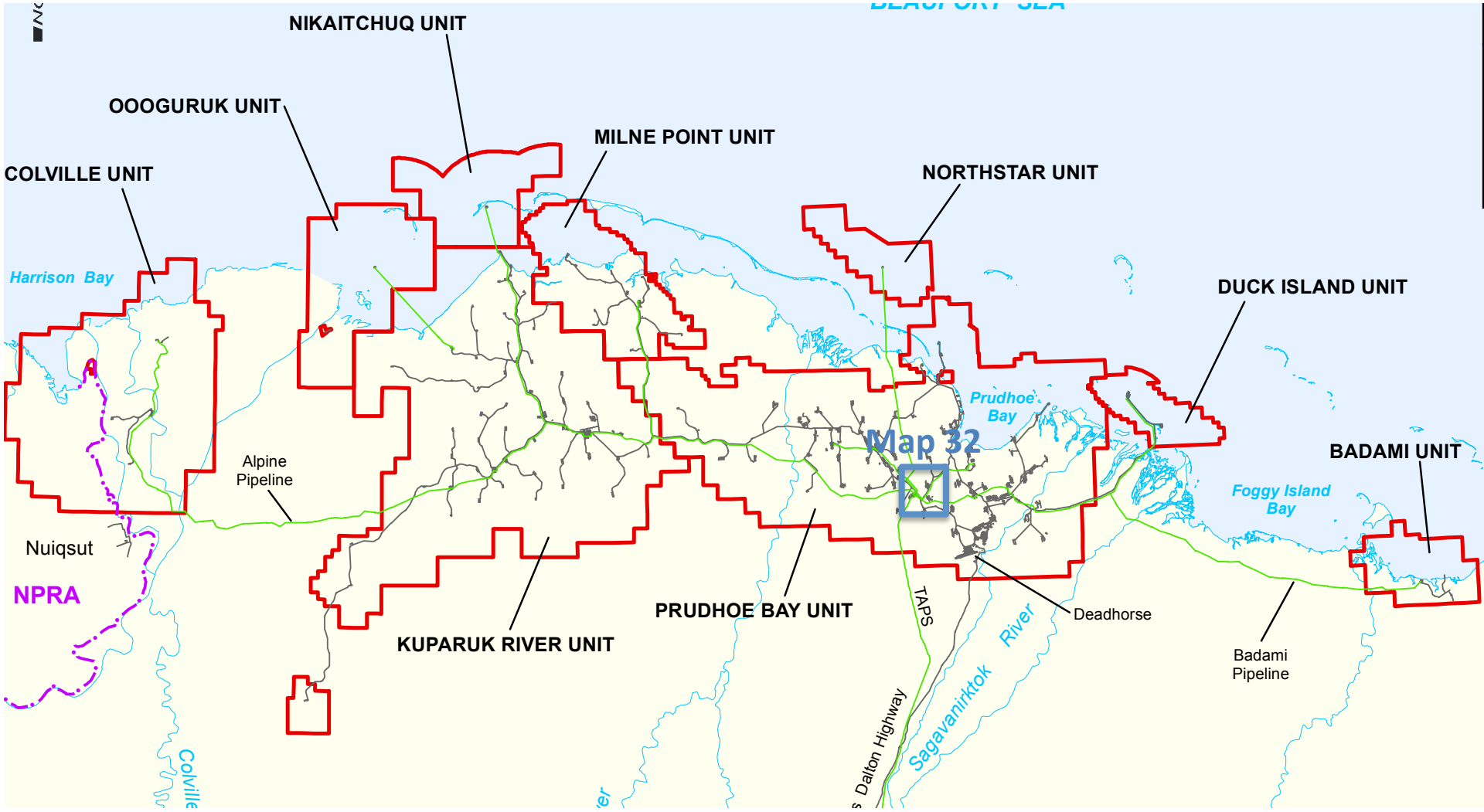
In memory of Dr. Kaye Everett (1934-1994) who played a key role in developing these methods.

12th International Circumpolar Remote Sensing Symposium, May 14-18, 2012, Levi, Finland

The oil fields near Prudhoe Bay, Alaska

- **Total area enclosed by development is about 2,600 km^2 (about the size of Rhode Island or Luxembourg.**
- **Most of this development is composed of widely dispersed drilling pads and production facilities connected by roads and pipelines.**

North Slope oil and gas production units



Courtesy of BP Alaska and Aerometric Geospatial Solutions

Introduction

- **Monitoring changes related to resource development is a key for future planning and sustainable management of Arctic natural resources.**
- **The Integrated Geobotanical and Historical Change Mapping (IGHCM) approach evolved between 1970 to the present to document land-cover and land-use changes associated with the Prudhoe Bay oil field, AK.**
- **The maps use the aerial photographic record to portray changes since 1949.**

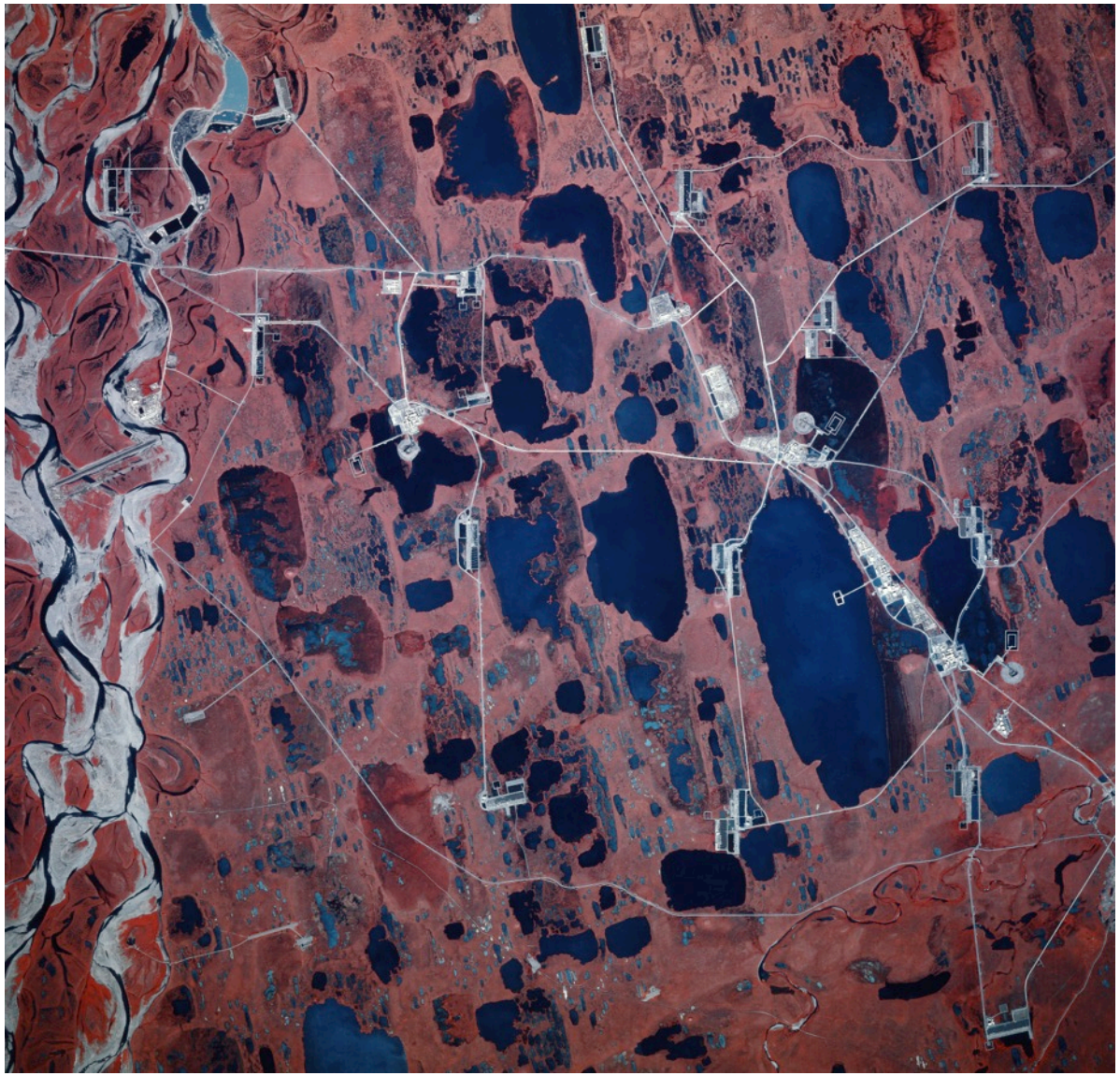
Key points of the talk

- **The IGHCM approach evolved during 40 years of mapping at Prudhoe Bay starting with the International Biological Programme in 1972. The involved:**
  - **The oil industry's regular updates of aerial imagery, topography and infrastructure maps, and analysis of their GIS database.**
  - **Development of the geobotanical mapping methods.**
  - **Incorporation of historical changes to terrain and infrastructure to make the IGHCMs.**

- **The GIS database for Map 32, made in the 1980s was recently updated with three years of imagery from 1990, 2001, 2010.**

- **Results:**
  - **Most of the direct oilfield infrastructure impacts occurred within about 15 years of the initial oil discovery at Prudhoe Bay.**
  - **Indirect impacts such as flooding and permafrost degradation continued to expand nonlinearly over the next 27 years.**
  - **Thermokarst of ice-wedges in areas non-adjacent to roads expanded dramatically between 1990 and 2001.**

Aerial image history of development



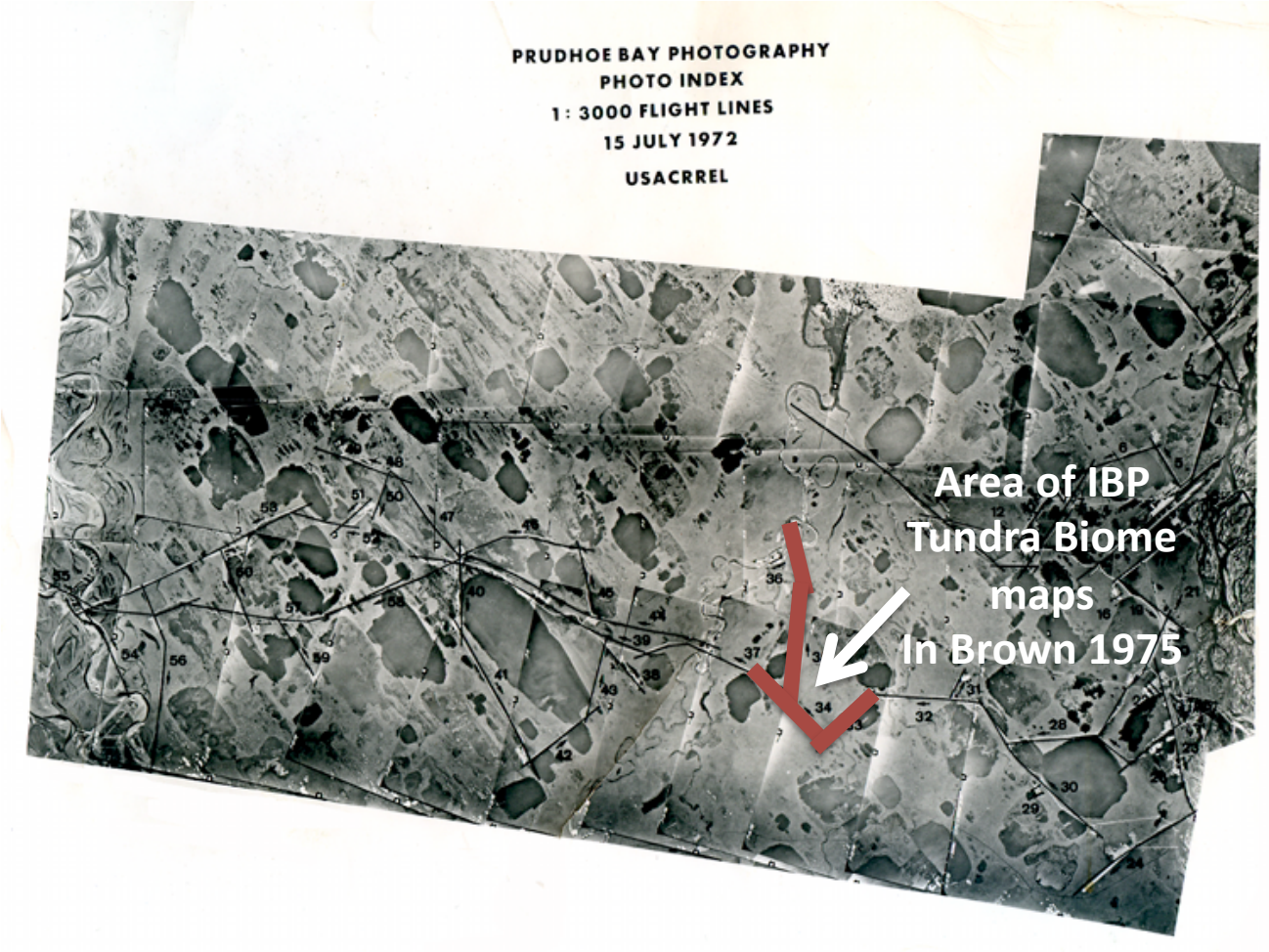
NASA CIR aerial photo. 1982

1949: U.S. Navy, B&W, 1:24,000
1968: ARCO, color, 1:12,000
1970: USGS, B&W, 1:68,000
1972: Air Photo Tech, U.S. Tundra Biome, B&W, 1:3000 & 1:24,000
1973-2011: Prudhoe Bay Unit, Color, 1:18,000 scale.
1974, 1977, 1982: NASA, CIR, 1:120,000, 1:60,000

Regular color photographs at 1:18,000 scale and maps of infrastructure and topography by the oil industry since 1973.

Aerial photos used in the first vegetation and soil mapping effort

- Aerial photos commissioned by CRREL and the oil industry in 1972, shortly after construction of the Spine Road and used in the first vegetation and soil maps in 1975.
- Two scales of photos are represented.
  - 1:12,000 scale covering the whole field.
  - 1:3000 scale (black lines) flown along the road network.



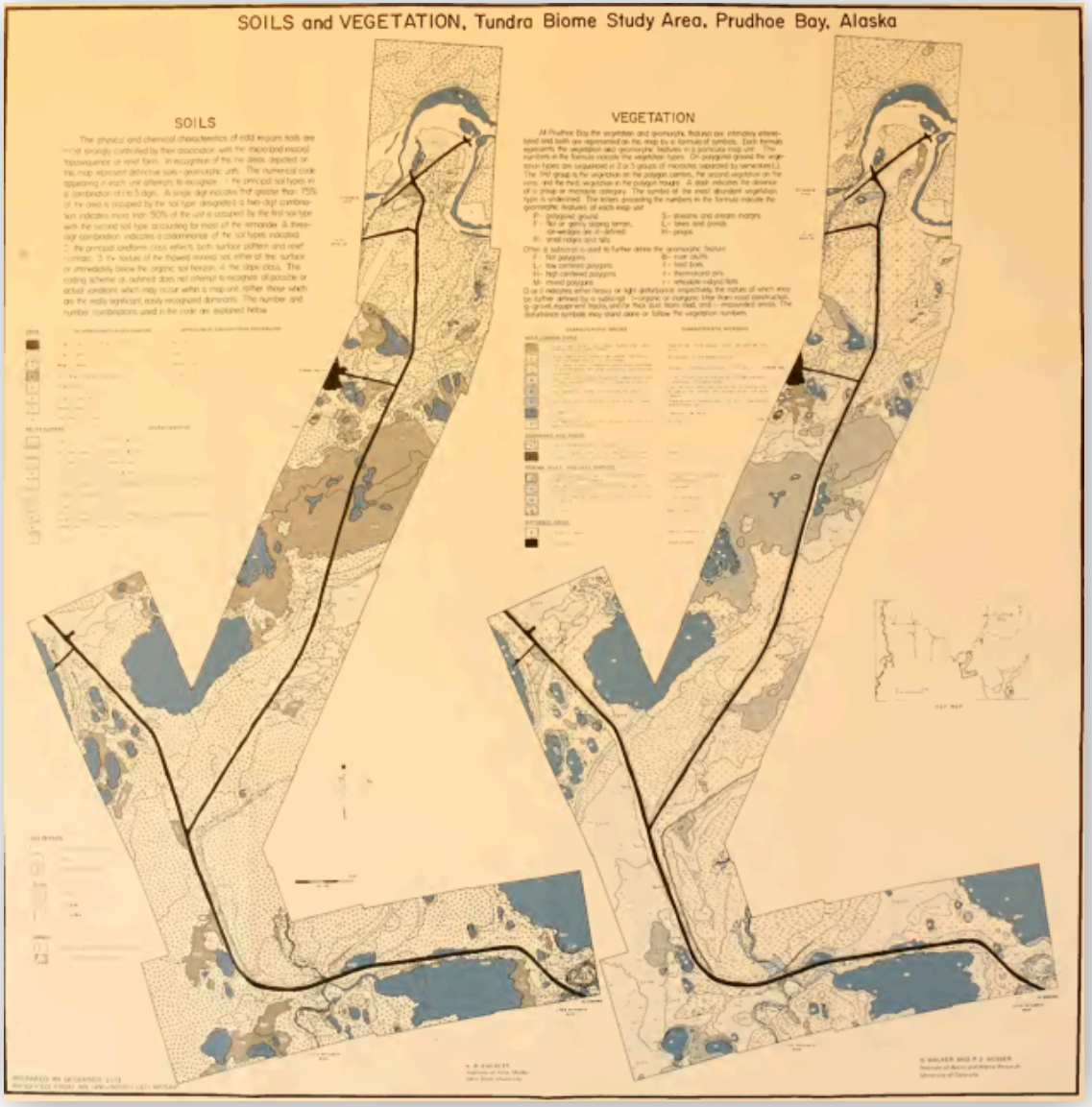
Current Aerometric Aircraft & Sensors

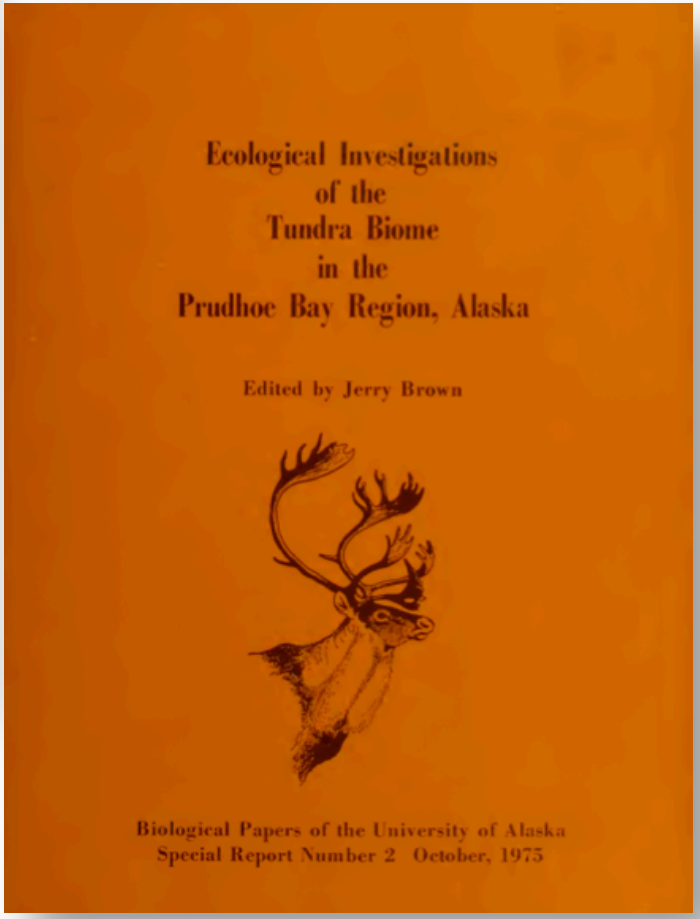
The geobotanical mapping method

Everett, K.R., Webber, P.J., Walker, D.A., Parkinson, R.J., Brown, J. 1978. A geoecological mapping scheme for Alaskan coastal tundra. *Proceedings of the Third International Conference on Permafrost. Edmonton, Alberta, Canada, 10-13 July*. 359-365.

Kaye Everett

1975: International Biological Programme, Tundra Biome Studies

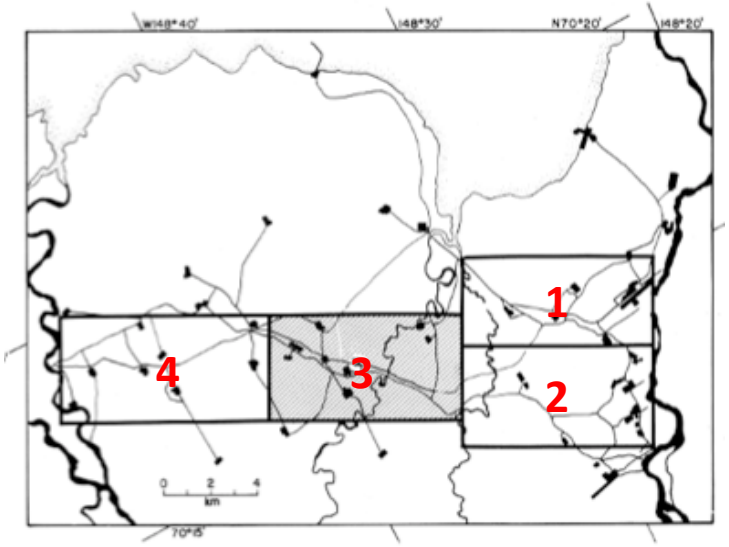


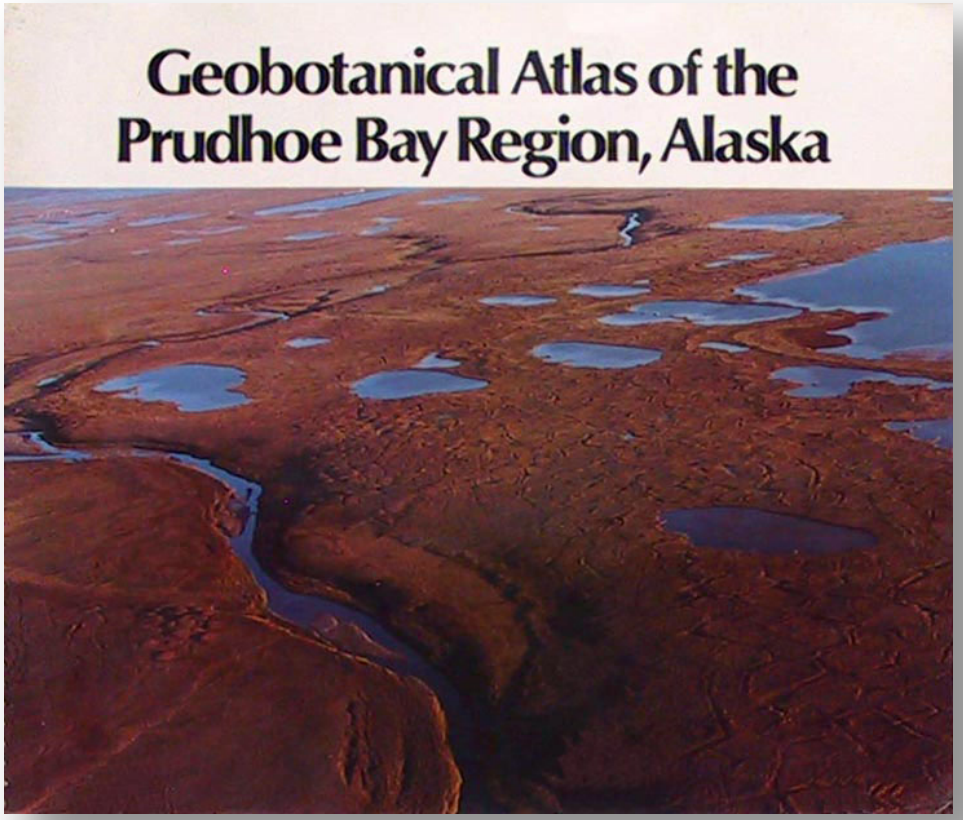


- First Prudhoe Bay maps were of the IBP study area.
- Separate maps were made for soils and vegetation/ landforms (Everett 1975, Webber and Walker 1975).

1980: Geobotanical Atlas of the Prudhoe Bay Region, AK:

Master maps coded with soils, landforms & vegetation



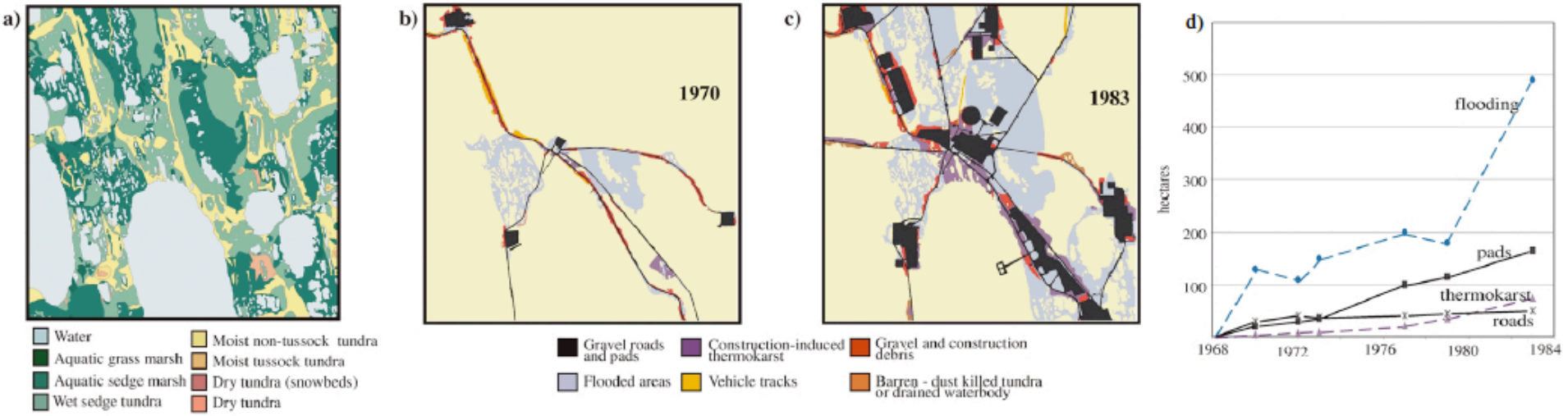


Walker, D.A., Everett, K.R., Webber, P.J., Brown, J. 1980. *Geobotanical atlas of the Prudhoe Bay Region*, Alaska. CRREL Report 80-14. 69 pp.

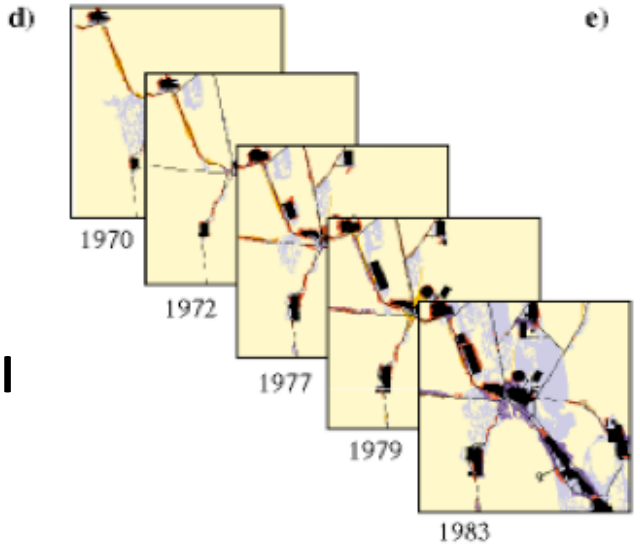
Combining geobotany with historical change

Vegetation 1949

Historic anthropogenic changes

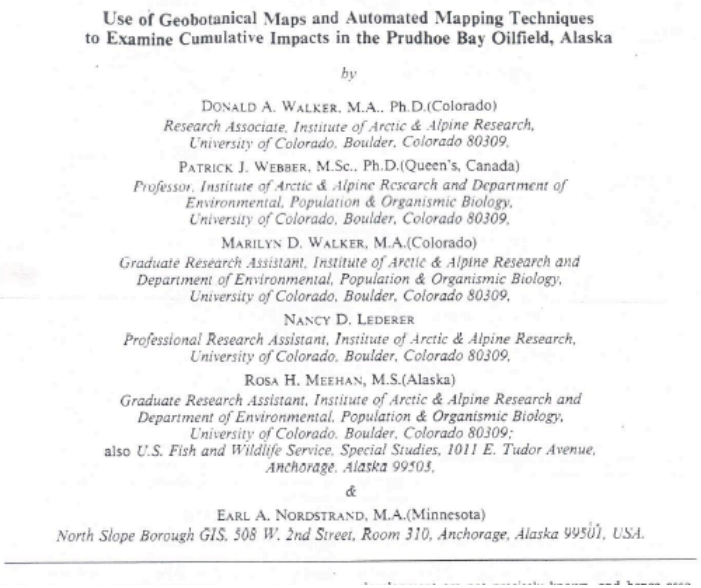


- **USFWS cumulative landscape impacts in the Prudhoe Bay Bay Oil Field 1949-1983.**
- **Study included historical mapping at two scales**
  - **1:24,000 map documented history of the main Prudhoe Bay oil field infrastructure.**
  - **1:6000 Integrated Geobotanical and Historical Disturbance Maps (IGHDMs) of three areas.**



Key papers

IGHDM mapping method



Use of Geobotanical Maps and Automated Mapping Techniques to Examine Cumulative Impacts in the Prudhoe Bay Oilfield, Alaska

by

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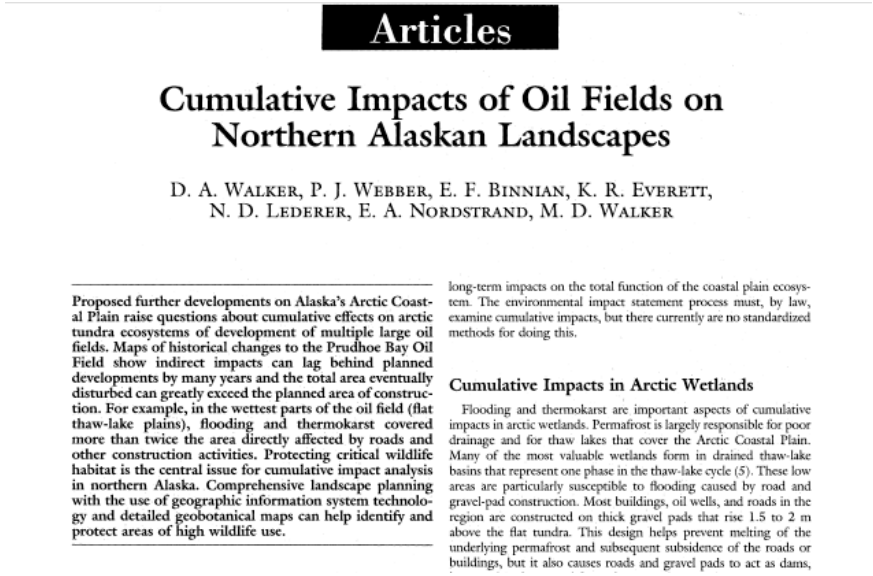
Walker, D.A., Webber, P.J., Walker, M.D., Lederer, N.D., Meehan, R.H., and Nordstrand, E.A., 1986, Use of geobotanical maps and automated mapping techniques to examine cumulative impacts in the Prudhoe Bay Oilfield, Alaska: *Environmental Conservation*, v. 13, p. 149-160.

Analysis of cumulative landscape effects at Prudhoe Bay



Articles

Cumulative Impacts of Oil Fields on Northern Alaskan Landscapes

D. A. WALKER, P. J. WEBBER, E. F. BINNIAN, K. R. EVERETT, N. D. LEDERER, E. A. NORDSTRAND, M. D. WALKER

Proposed further developments on Alaska's Arctic Coastal Plain raise questions about cumulative effects on arctic tundra ecosystems of development of multiple large oil fields. Maps of historical changes to the Prudhoe Bay Oil Field show indirect impacts can lag behind planned developments by many years and the total area eventually disturbed can greatly exceed the planned area of construction. For example, in the wettest parts of the oil field (flat thaw-lake plains), flooding and thermokarst covered more than twice the area directly affected by roads and other construction activities. Protecting critical wildlife habitat is the central issue for cumulative impact analysis in northern Alaska. Comprehensive landscape planning with the use of geographic information system technology and detailed geobotanical maps can help identify and protect areas of high wildlife use.

long-term impacts on the total function of the coastal plain ecosystem. The environmental impact statement process must, by law, examine cumulative impacts, but there currently are no standardized methods for doing this.

Cumulative Impacts in Arctic Wetlands

Flooding and thermokarst are important aspects of cumulative impacts in arctic wetlands. Permafrost is largely responsible for poor drainage and for thaw lakes that cover the Arctic Coastal Plain. Many of the most valuable wetlands form in drained thaw-lake basins that represent one phase in the thaw-lake cycle (*5*). These low areas are particularly susceptible to flooding caused by road and gravel-pad construction. Most buildings, oil wells, and roads in the region are constructed on thick gravel pads that rise 1.5 to 2 m above the flat tundra. This design helps prevent melting of the underlying permafrost and subsequent subsidence of the roads or buildings, but it also causes roads and gravel pads to act as dams,

Walker, D.A., Webber, P.J., Binnian, E.F., Everett, K.R., Lederer, N.D., Nordstrand, E.A., and Walker, M.D., 1987, Cumulative Impacts of Oil Fields on Northern Alaskan Landscapes: *Science*, v. 238, p. 757-761.

Areas of published geobotanical mapping at Prudhoe Bay

Brown (1975)
Tundra Biome

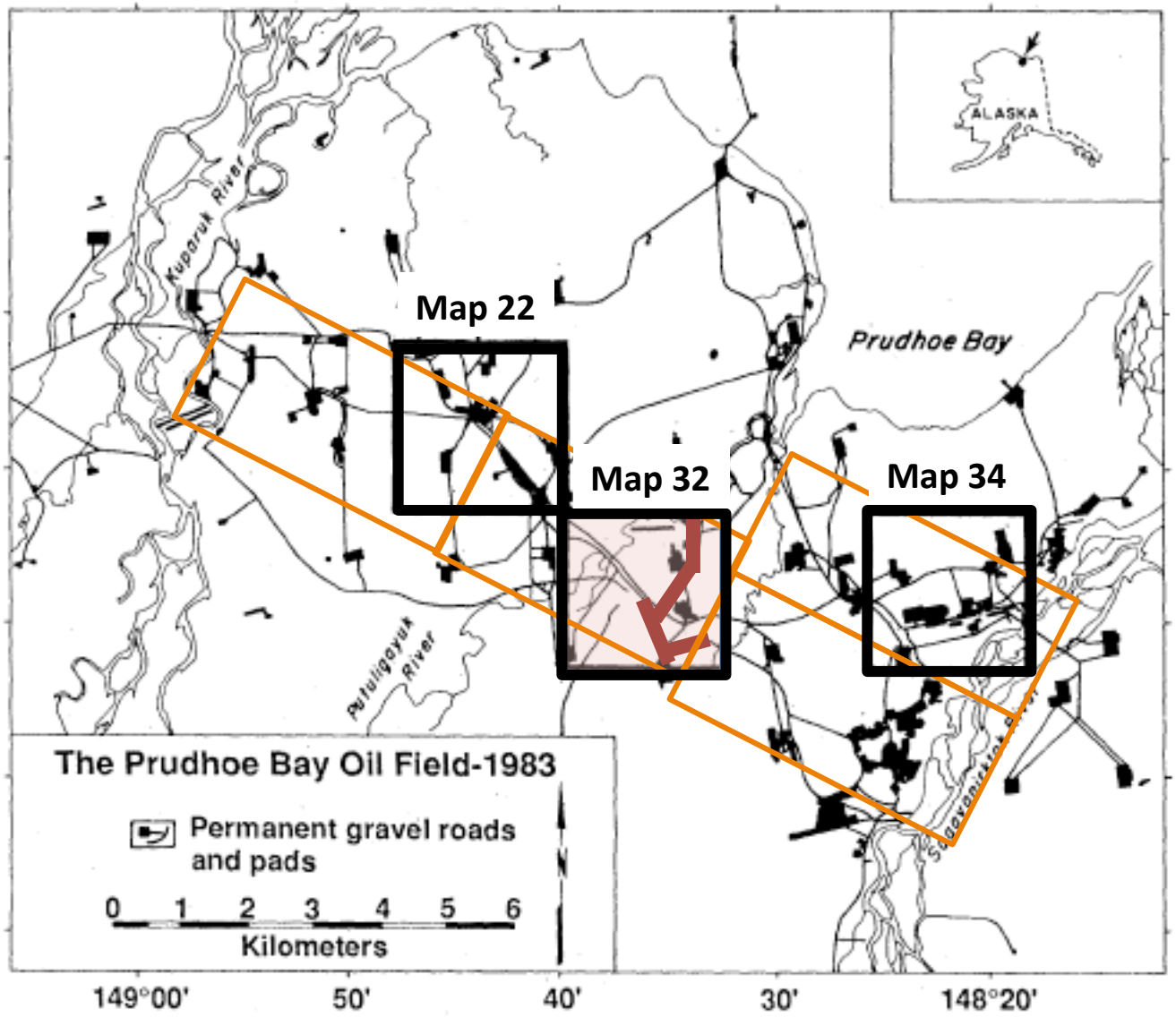
Walker et al. (1980)
Geobotanical Atlas

Map 22

Walker et al. (1987)
FWS cumulative
effects analysis

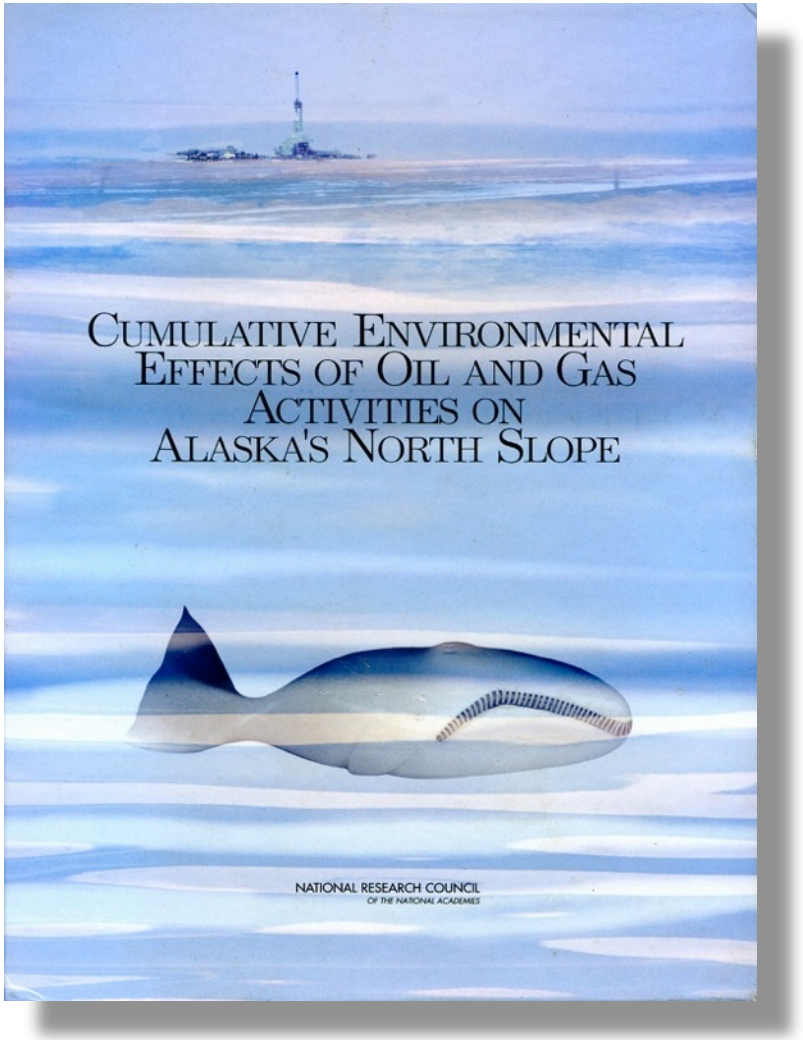
Raynolds et al.
(2012) update

History of infrastructure and roadside flooding was mapped at 1:24,000 scale for entire map area in Walker et al. (1987).

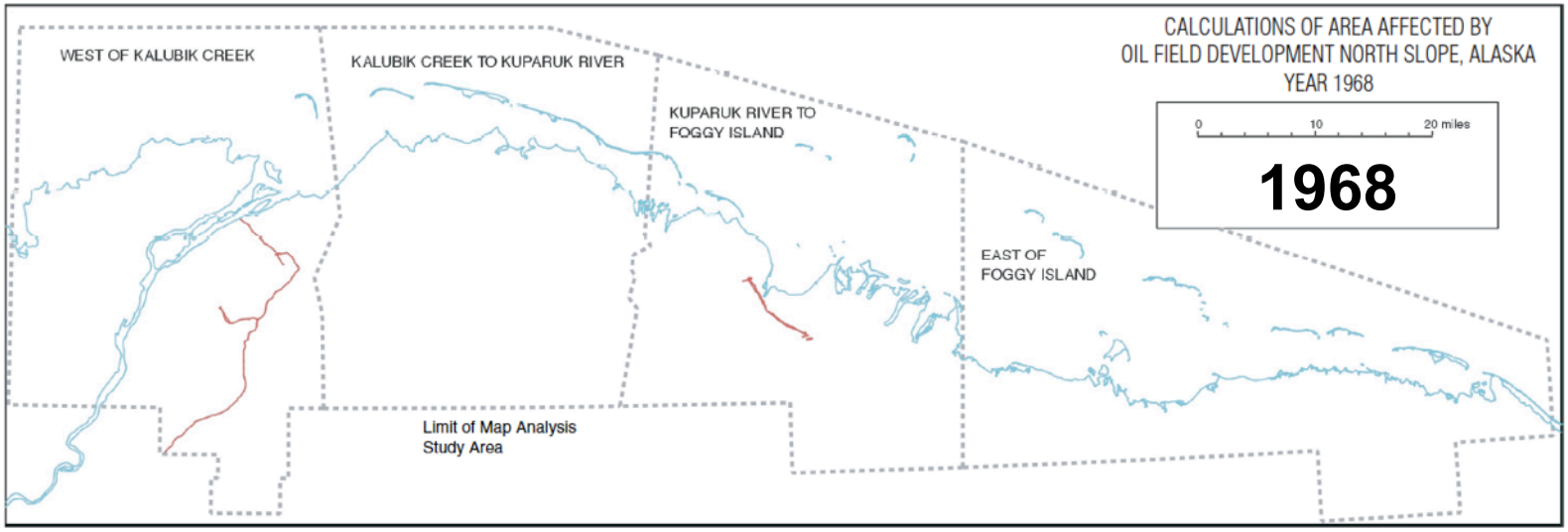


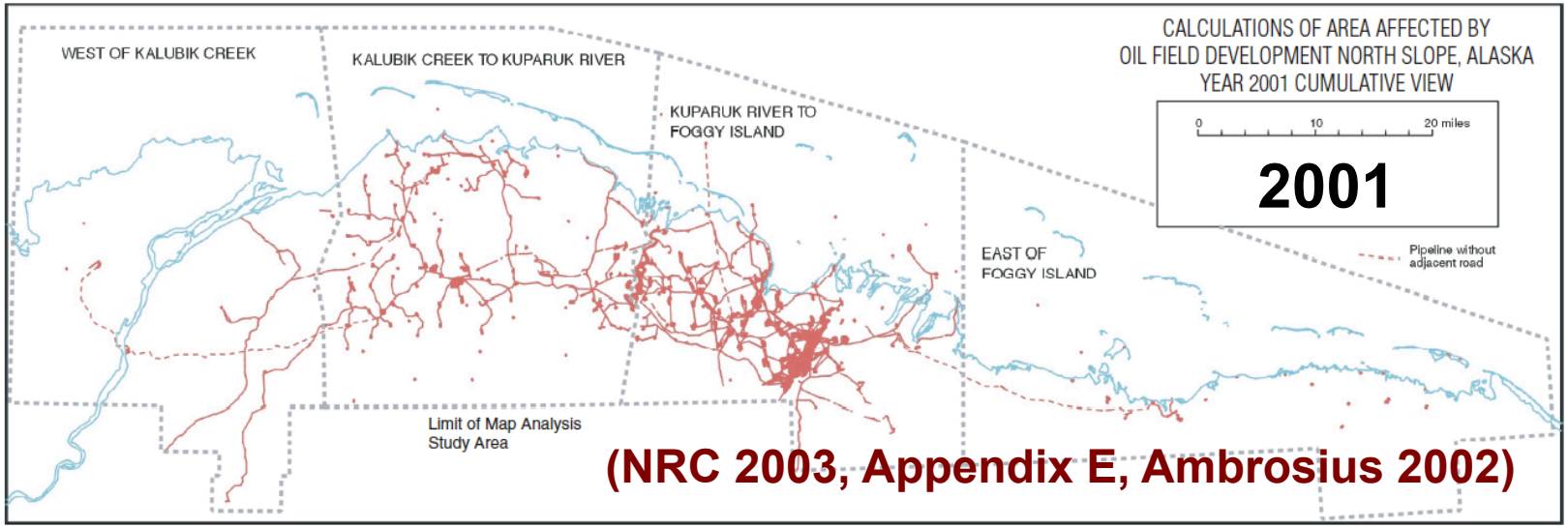
2003: National Research Council (NRC) Report

- ***Cumulative environmental effects of oil and gas activities on Alaska's North Slope.***



Aerometrics mapped the history of infrastructure for the entire oilfield for the NRC report up to 2001



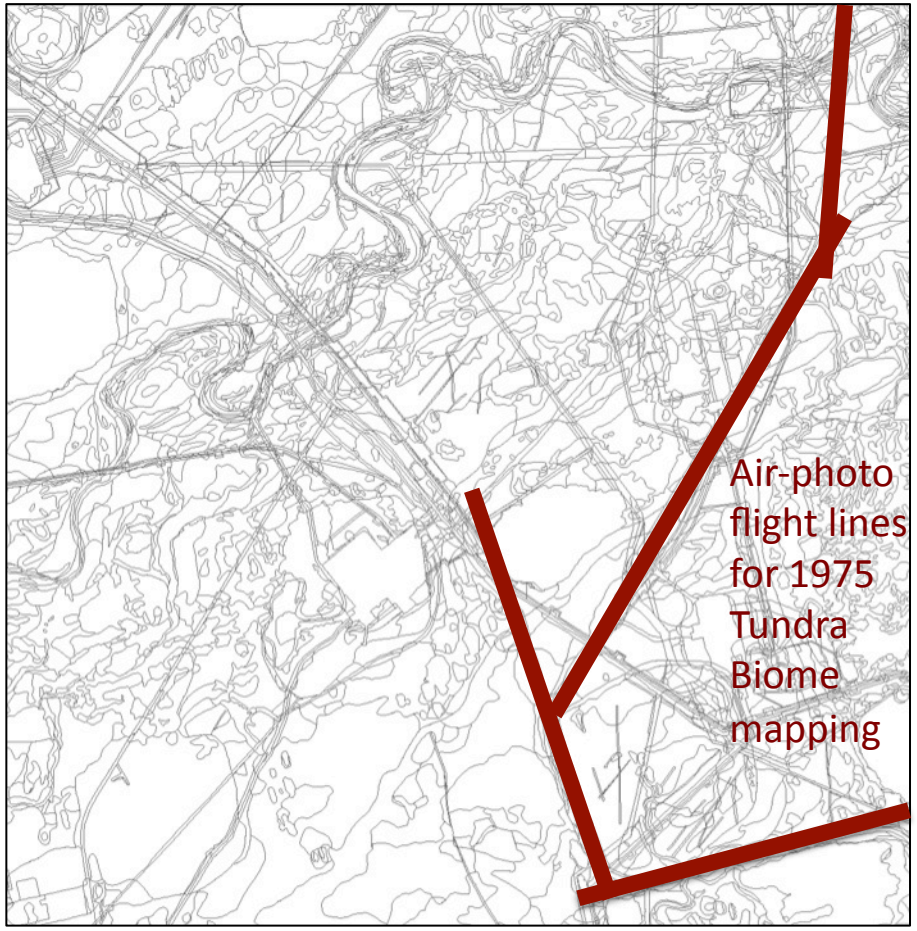


(NRC 2003, Appendix E, Ambrosius 2002)

The present study: Updating the IGHCM of Map 32 to 2010 for the MALS project

- **NSF Maps and Locals (MALS) project**
- **Will use such maps to assess local people's perceptions of the changes on the North Slope.**

Map 32:
Master map polygons



Raynolds et al. 2012 CRSS poster

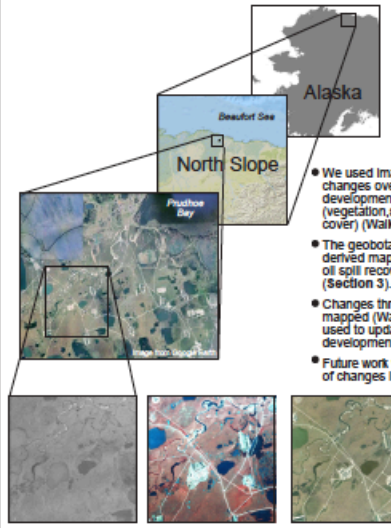
60 Years of Landscape Change within an Arctic Oilfield, Prudhoe Bay, Alaska

Martha K. Raynolds[1], Donald A. Walker[1], Gary P. Kofinas[1], Ken J. Ambrosius[2]

[1]University of Alaska Fairbanks, Fairbanks, AK USA 99775 USA, [2]Aerometric Geospatial Solutions, Anchorage, AK, 99501 USA

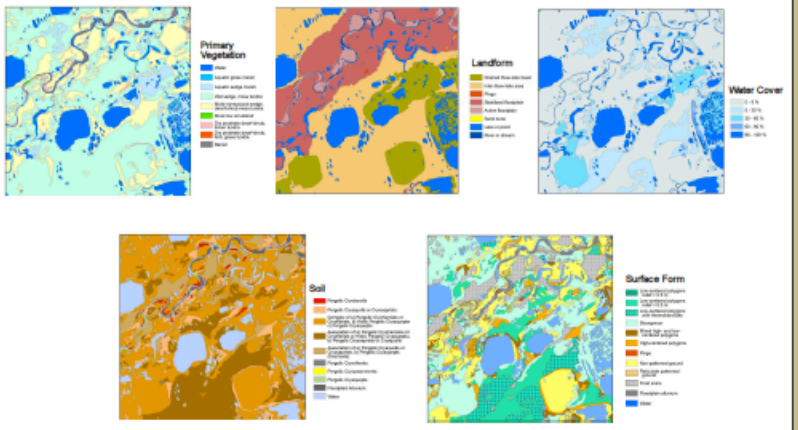
1. Introduction

We present an update of the integrated geobotanical and historical disturbance maps (Walker et al. 1986a) for a 2100-hectare portion of Prudhoe Bay Oilfield, Alaska.33% of the area has been affected by industrial development and an additional 14% of the area shows surface effects of permafrost degradation.

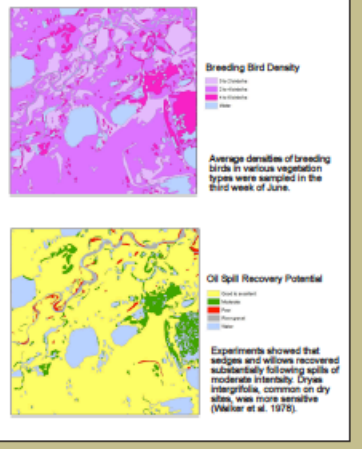


- We used imagery from 1949-2010 to quantify changes over time. Aerial photos from before development were used to map the geobotany (vegetation,soils, landform, surface form, water cover) (Walker et al. 1986b) (**Section 2**).
- The geobotanical mapping was used to create derived maps, such as breeding bird density and oil spill recovery potential (Walker et al. 1980) (**Section 3**).
- Changes through 1983 were photointerpreted and mapped (Walker et al 1987). Recent imagery was used to update the map, including oil field development and other changes (**Sections 4 & 5**).
- Future work will focus on quantifying surface effects of changes in permafrost (**Section 6**).

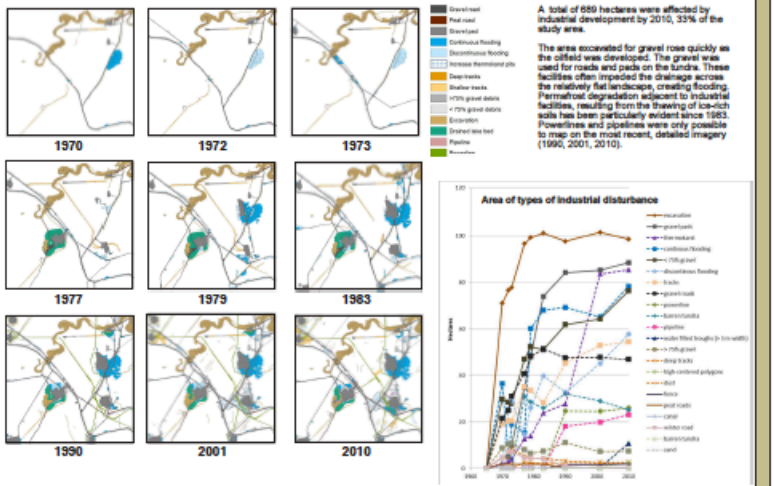
2. Geobotanical mapping of conditions in 1968, before industrial development



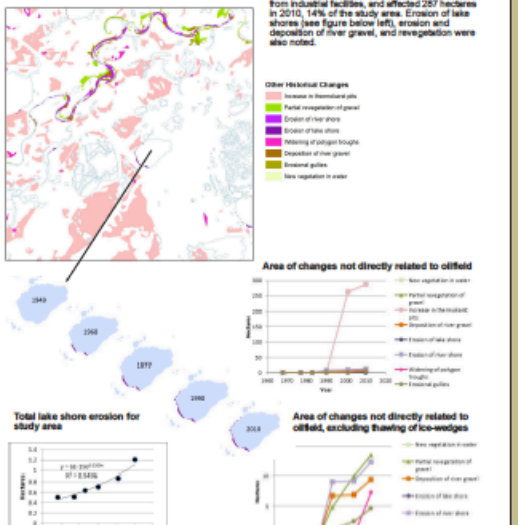
3. Example maps derived from geobotanical mapping



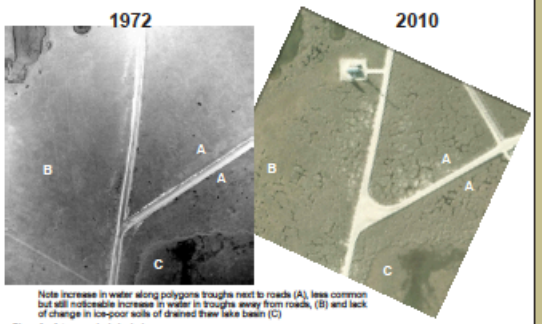
4. Oilfield Development 1972 to 2010



5. Other Changes



6. Future research



Plans for future analysis include:

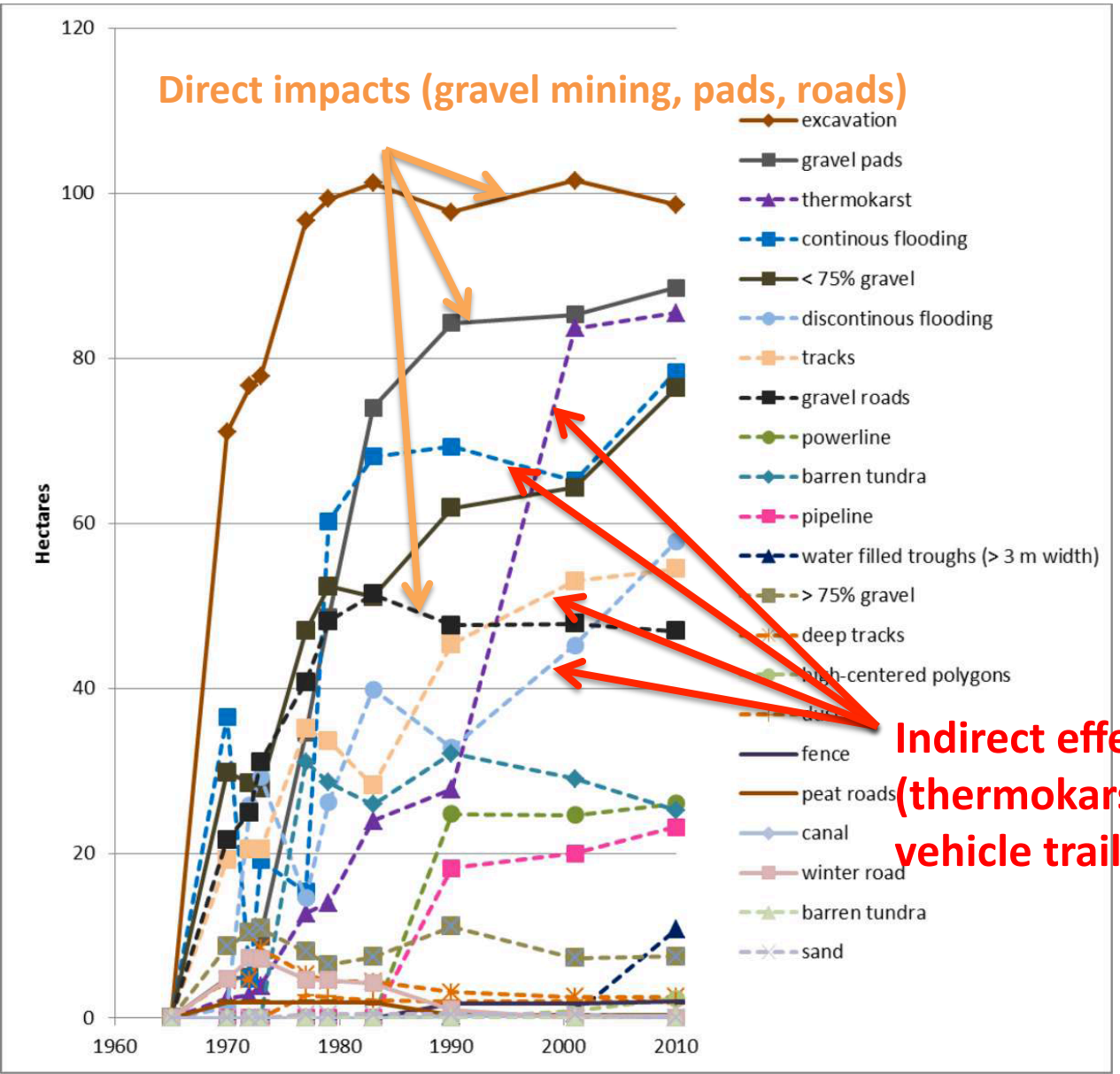
- Develop more quantitative techniques to measure changes in thermokarst features
- Assess the relationship of thermokarst to infrastructure and various geobotanical features
- Apply similar methods to the other two map areas at Prudhoe Bay and several North Slope villages
- Partner with Indigenous Knowledge holders to document local-scale observations and implications of change
- Assess the utility of Landsat and Quickbird imagery to provide broad-area assessments of infrastructure and landscape changes that could be applied to the entire area of development on the North Slope

Major Findings

- The integrated geobotanical and historical disturbance mapping can be brought into geodatabase format and updated with recent imagery to extend the time-span of the change analysis.
- Most of the oilfield infrastructure was built between 1972 and 1983, but indirect impacts such as flooding and permafrost degradation continued to expand over the next 27 years.
- Lake shore erosion continues to increase, non-linearly.
- There was a large increase in the area showing surface effects of permafrost degradation between 1990 and 2001, possibly the result of reaching some "tipping point".

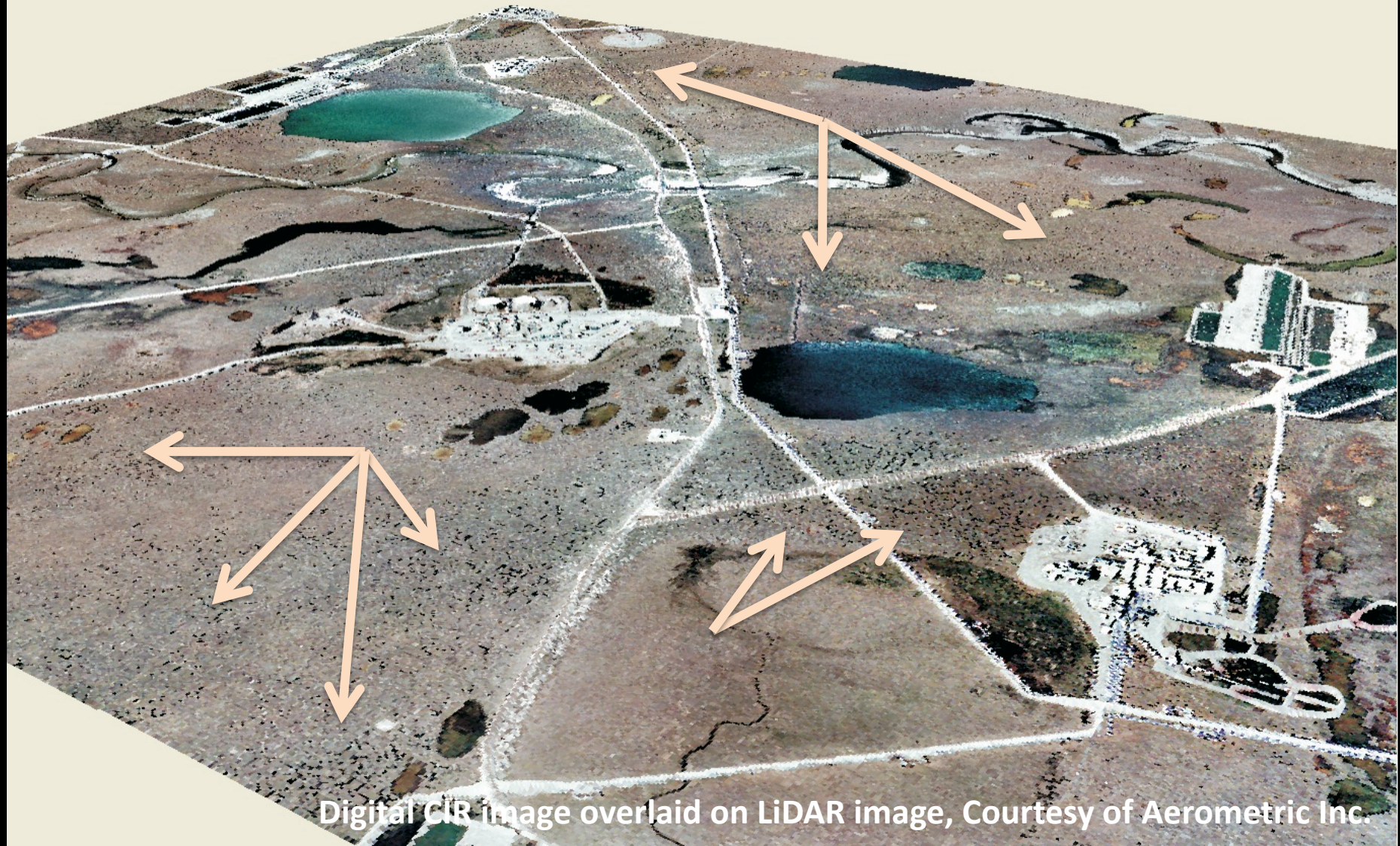
References

Trends in industry-related changes



- **Most direct impact leveled off after about 1983.**
- **Indirect effects have continued to increase.**

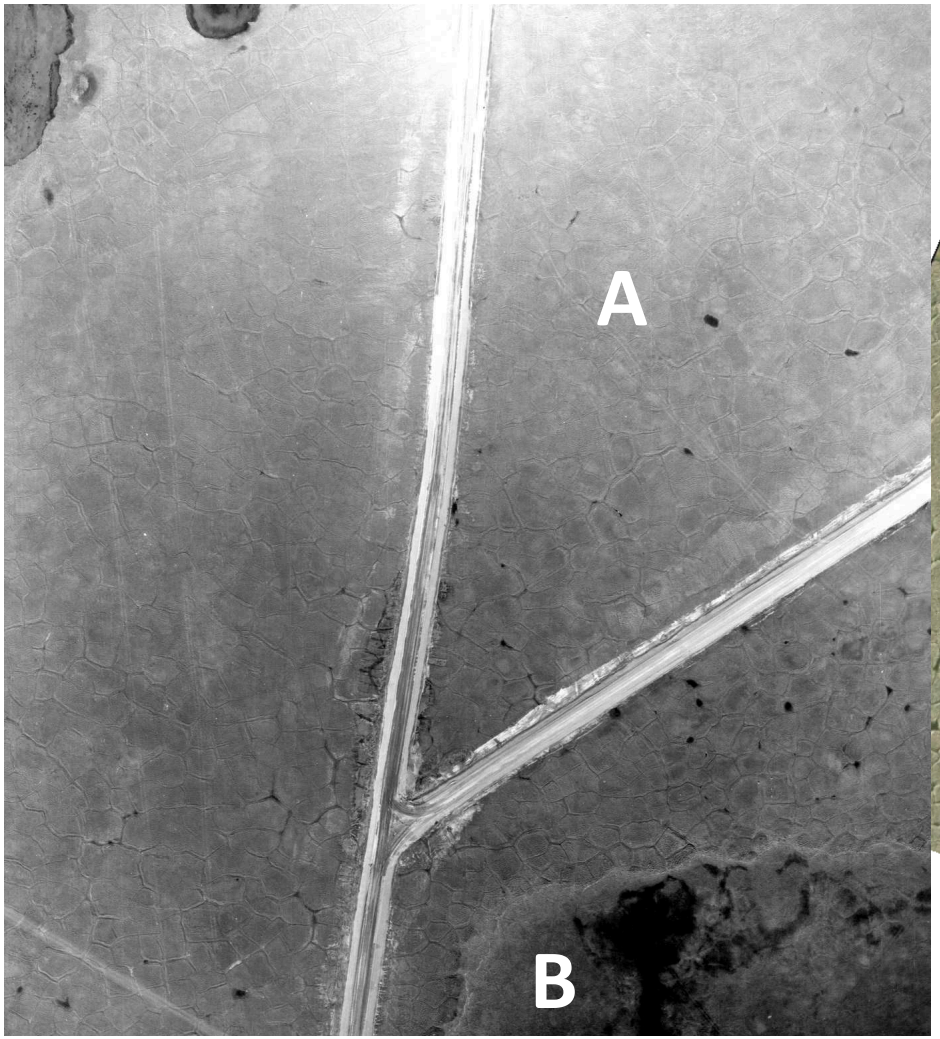
Widespread thermokarst expansion well beyond road margins between 2001 and 2010



Digital CIR image overlaid on LiDAR image, Courtesy of Aerometric Inc.

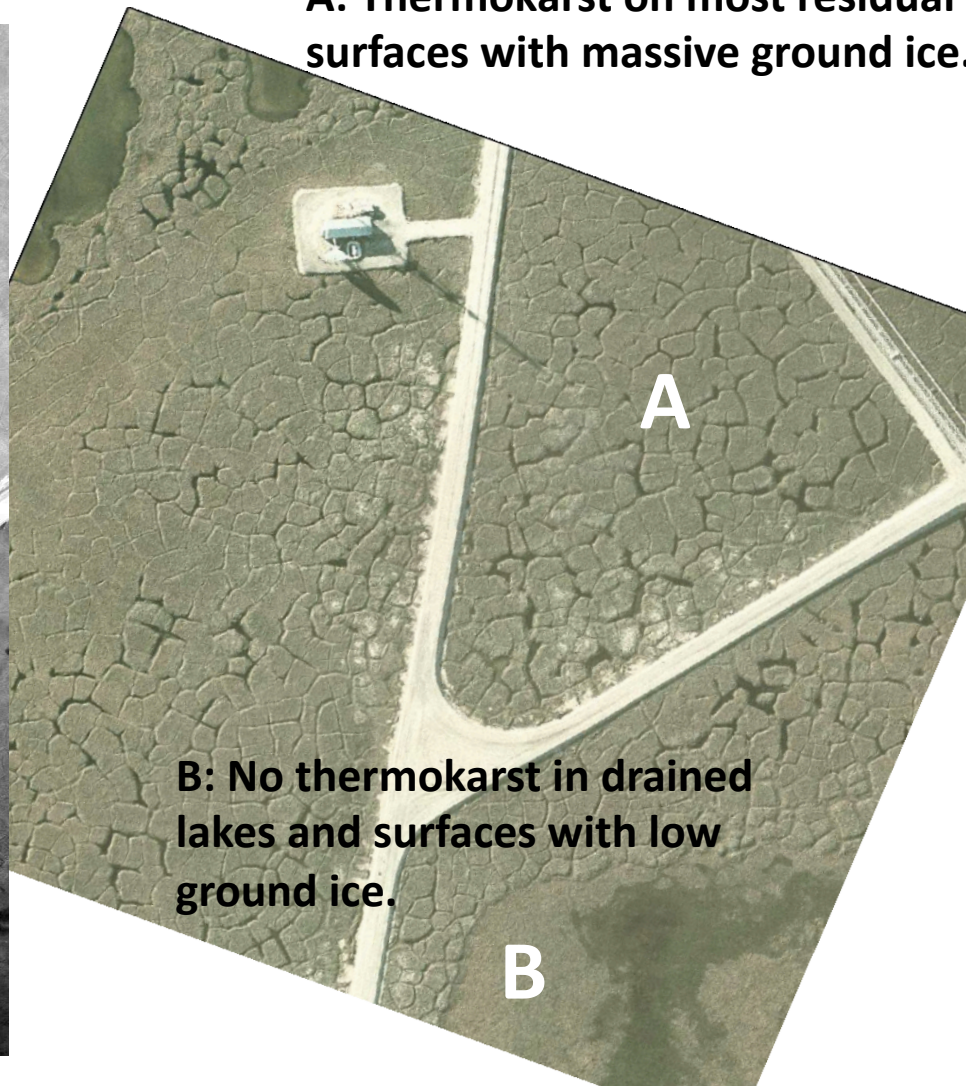
Increase in thermokarst

1972



2010

A: Thermokarst on most residual surfaces with massive ground ice.



VHR imagery documents extensive thermokarst at Nuiqsut.

2006 Quickbird image from Google Earth

Take home points

- **The IGHCM approach developed because of the coincidence of:**
  - **Evolving interest by scientific community in the geobotany, permafrost and climate change of the Arctic, starting with the Tundra Biome research in the 1970s, and includes most recently the MALS research which is bringing the relevance of this information to the people who are developing and living in the Arctic.**
  - **The oil industry's and the government agencies' evolving need for near-annual inventory of its North Slope infrastructure, which resulted in the amazing historical sequence of aerial photos and the GIS database covering the entire history of development.**
  - **Evolving techonology for acquiring, mapping, storing, and manipulating spatial data.**
  - **Many serendipitous events including the right people, such as Kaye Everett, pushing this forward and facilitating its evolution.**

- **This historical mapping is the best record in the Arctic documenting the long-term trends change related to industrial development and to climate change.**

- **VHR satellite imagery offers a means for extending the record into the future and mapping much larger areas.**