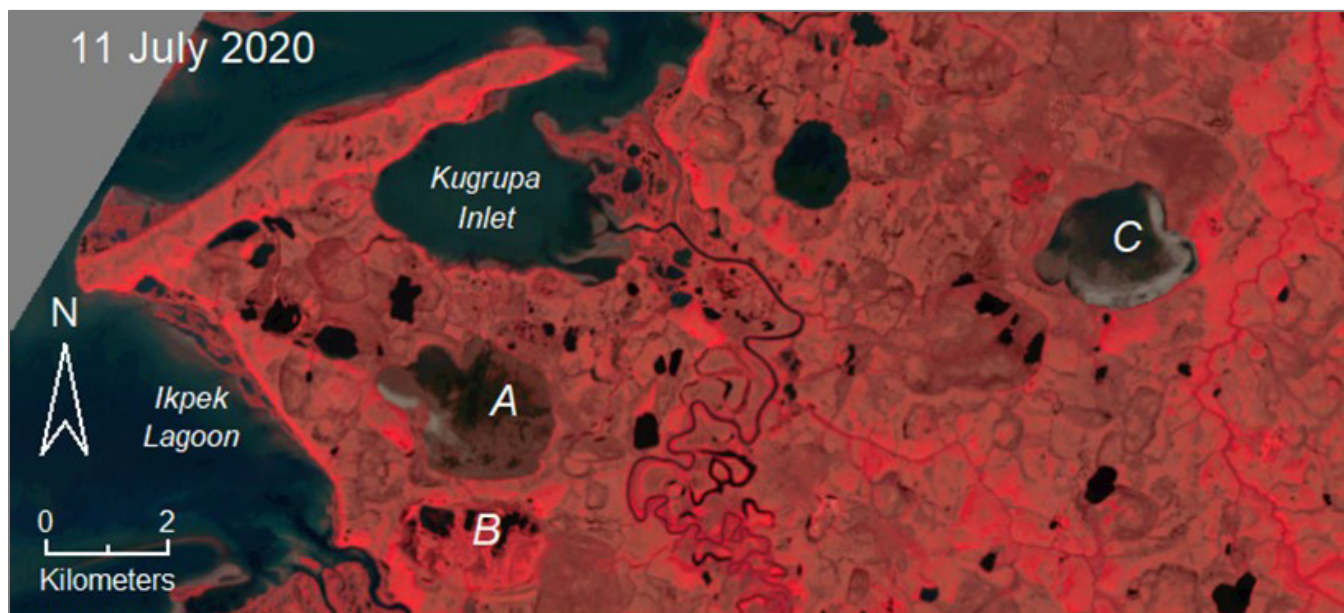




Area of Lakes and Ponds Continues to Decline in Alaska's Arctic National Parks



Example of lakes draining in western Bering Land Bridge National Preserve. This is a Landsat image, displayed using visible and infrared light data such that water is black and dense vegetation is red. In 2019, lakes A and C were water-filled, but by the date of this image (July 2020), drainage had exposed the lake bottom over most of lake A and part of lake C. The outline of a lake that drained in the 1970s is visible at B. Lake A formerly covered about 442 ha and is the largest lake to drain in ARCN to date. It is located at latitude 65.95 longitude -166.83.

NPS

Area of lakes and ponds continues to decline in Alaska's Arctic national parks

Science Report NPS/SR—2025/323

David K. Swanson 

National Park Service
Arctic Inventory and Monitoring Network
4175 Geist Road
Fairbanks, AK 99709

Please cite this publication as:

Swanson, D. K. 2025. Area of lakes and ponds continues to decline in Alaska's Arctic national parks. Science Report NPS/SR—2025/323. National Park Service, Fort Collins, Colorado.
<https://doi.org/10.36967/2313920>

The National Park Service Science Report Series disseminates information, analysis, and results of scientific studies and related topics concerning resources and lands managed by the National Park Service. The series supports the advancement of science, informed decisions, and the achievement of the National Park Service mission.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible and technically accurate.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, US Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the US Government.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

This report is available in digital format from the [National Park Service DataStore](#) and the [Natural Resource Publications Management website](#). If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Contents

	Page
Figures.....	iv
Tables.....	iv
Abstract.....	v
List of Terms.....	vi
Introduction.....	1
Study Area.....	1
Methods.....	6
Synthesis of Annual Surface Water Maps.....	6
Water Area Trend Analysis	7
Identification of Drained Lakes.....	7
Identification of “Wet” and “Dry” Periods.....	7
Results.....	9
Water Area by Subsection.....	9
Lake Drainage	17
Wet and Dry Periods	20
Discussion and Conclusions	22
Literature Cited	23

Figures

	Page
Figure 1. Study area location.	2
Figure 2. Mean annual air temperature for Bettles and Kotzebue, Alaska, 1980–2024.	3
Figure 3. Mean annual precipitation at Bettles and Kotzebue, 1980–2024.	4
Figure 4. Lake area change in the western part of the study area (BELA).	12
Figure 5. Lake area change in the central part of the study area (CAKR, KOVA, and NOAT).	13
Figure 6. Lake area change in the eastern part of the study area (GAAR and far western NOAT).	14
Figure 7. Water surface area vs. time for the years 2000–2023 for the Bering Straits Lower Coastal Plain (BSLCP) subsection in BELA.	15
Figure 8. Water surface area vs. time for the years 2000–2023 for the Kavachurak Glaciated Uplands (KGU) subsection in NOAT.	16
Figure 9. Water surface area vs. time for the years 2000–2023 in the Kotlik Coastal Plain (KOP) subsection in CAKR.	17
Figure 10. Count of new lake drainage events by year, 2000–2023, by NPS unit.	18
Figure 11. Example of lakes draining in western BELA.	19
Figure 12. In July 2020, drainage had exposed the lake bottom over most of lake A and part of lake C.	19
Figure 13. By August 2023, vegetation had colonized most of former lake A and part of C.	20
Figure 14. Multi-year trend in z-scores of area for lakes that did not drain.	21

Tables

	Page
Table 1. Dynamic Surface Water Extent (DSWE) pixel values.	7
Table 2. Summary of Water Area Change by Subsection.	10

Abstract

The area of lakes and ponds in the five National Park Service (NPS) units in northern Alaska from the 1980s to 2024 was summarized using data from Landsat satellite images. During the period for which annual Landsat data are available (2000–2024), most of the study area showed declining surface water area. The areas with rapidly declining water area had lakes of thermokarst origin in ice-rich permafrost, and sudden lake drainage events were common. The years 2017–2019 and 2021 had the most lake drainage events during the study time interval, and the majority of lake drainages occurred in the lowlands of northern Bering Land Bridge National Preserve. Analysis of water surface area, with the effect of drainage events removed, showed multi-year fluctuations in water levels, with highs centered around 2005 and 2010, and an extended low period from 2013 through 2017.

List of Terms

Ecological subsection: an area of land with a relatively uniform climate and a consistent pattern of landforms, soils, and vegetation.

Landsat: a long-running program that has been acquiring satellite imagery of the earth since the 1970s.

Permafrost: ground that has remained frozen for 2 or more years. In the Arctic Network region most permafrost has been frozen continuously for thousands of years.

Thermokarst: Subsidence due to thaw of ice in the ground, in regions with permafrost.

Thermo-erosion: loss of soil and sediment by the combined effect of moving water and melting of ice.

Introduction

Lakes and ponds in lowland permafrost regions are both abundant and uniquely dynamic. Water bodies are of great interest to the National Park Service (NPS) as habitat for aquatic wildlife and as indicators of changes in the hydrologic balance. Thus the Arctic Network (ARCN) of the NPS Inventory and Monitoring Division has included monitoring of surface water area as a part of the Terrestrial Landscape Patterns and Dynamics Vital Sign (Lawler et al. 2009; Swanson 2017). Our monitoring of water surface area is based on analysis of Landsat satellite images, which are available from 1984 to the present, with consistent year-round coverage beginning in the year 2000. We previously summarized the trends in water surface area across ARCN (Swanson 2019, 2020) and the progress of vegetation colonization in recently drained lakes (Swanson and Hampton-Miller 2023). These analyses and Nitze et al. (2020) showed that an unprecedented number and area of lakes were lost in 2018 and 2019, especially in Bering Land Bridge National Preserve. These losses were the result of rapid drainage through breaches in the lakes' banks associated with permafrost thaw. The purpose of the present report is to re-assess water surface area across ARCN by examining all available Landsat data through 2024 for the months with ice-free water bodies (June–September).

Study Area

The study area is the five National Park units that make up ARCN: Bering Land Bridge National Preserve (BELA), Cape Krusenstern National Monument (CAKR), Gates of the Arctic National Park and Preserve (GAAR), Kobuk Valley National Park (KOVA), and Noatak National Preserve (NOAT) (Figure 1). ARCN is a region of mostly arctic tundra with some boreal forest present in the low-elevation, southern parts of the non-coastal parks (Jorgenson et al. 2009). Long-term mean annual air temperatures (MAAT) in 1981–2010 were -4 to -6°C in the coastal parks (BELA, CAKR) and at low elevations in the far western NOAT, southern KOVA, and southern GAAR. Elsewhere in ARCN MAATs were -6 to -10°C (PRISM Climate Group 2020). Long-term temperature records (since 1929) at Kotzebue reveal record high temperatures since 2014 (Figure 2). The long-standing highest mean annual temperature record of -4.6°C set in 1950 was broken just prior to the study time interval (-3.6°C in 1978). This record was broken again in 2003 (-3.0°C); the new record was essentially tied in 2004, then broken again in 2014 (-2.0°C), 2016 (-1.6°C), 2018 (-0.9°C), and 2019 (-0.6°C). (Note that Kotzebue data are not available for May–August 2019, so the 2019 annual mean was computed by substituting data derived by regression of Kotzebue monthly means from 2012–2024 for the Mt. Noak NPS climate monitoring station, 33 km north-northwest of Kotzebue).

Annual precipitation fluctuated greatly, with statistically significant positive trends during the study time interval at both Kotzebue and Bettles (Figure 3).

Most of ARCN lies within the continuous permafrost zone (permafrost is present across 90% or more of the landscape; Jorgenson et al. 2008). Permafrost is discontinuous (present on 50% to 90% of the landscape) in the southern half of KOVA and the two southern lowland extensions of GAAR (Figure 1).

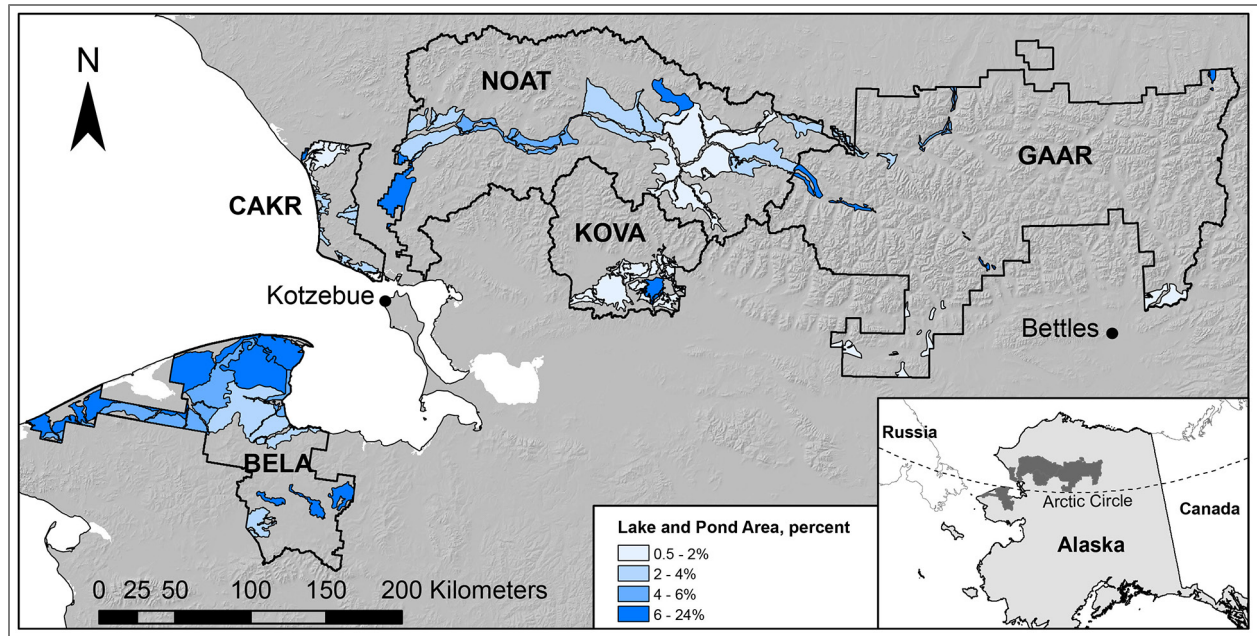


Figure 1. Study area location. The ecological subsections analyzed for water surface area are displayed, with their lake and pond surface area in percent. The excluded areas are subsections that had less than 0.5% lake and pond surface area. National Park Service unit abbreviations are: Bering Land Bridge National Preserve (BELA), Cape Krusenstern National Monument (CAKR), Gates of the Arctic National Park and Preserve (GAAR), Kobuk Valley National Park (KOVA), and the Noatak National Preserve (NOAT).

NPS

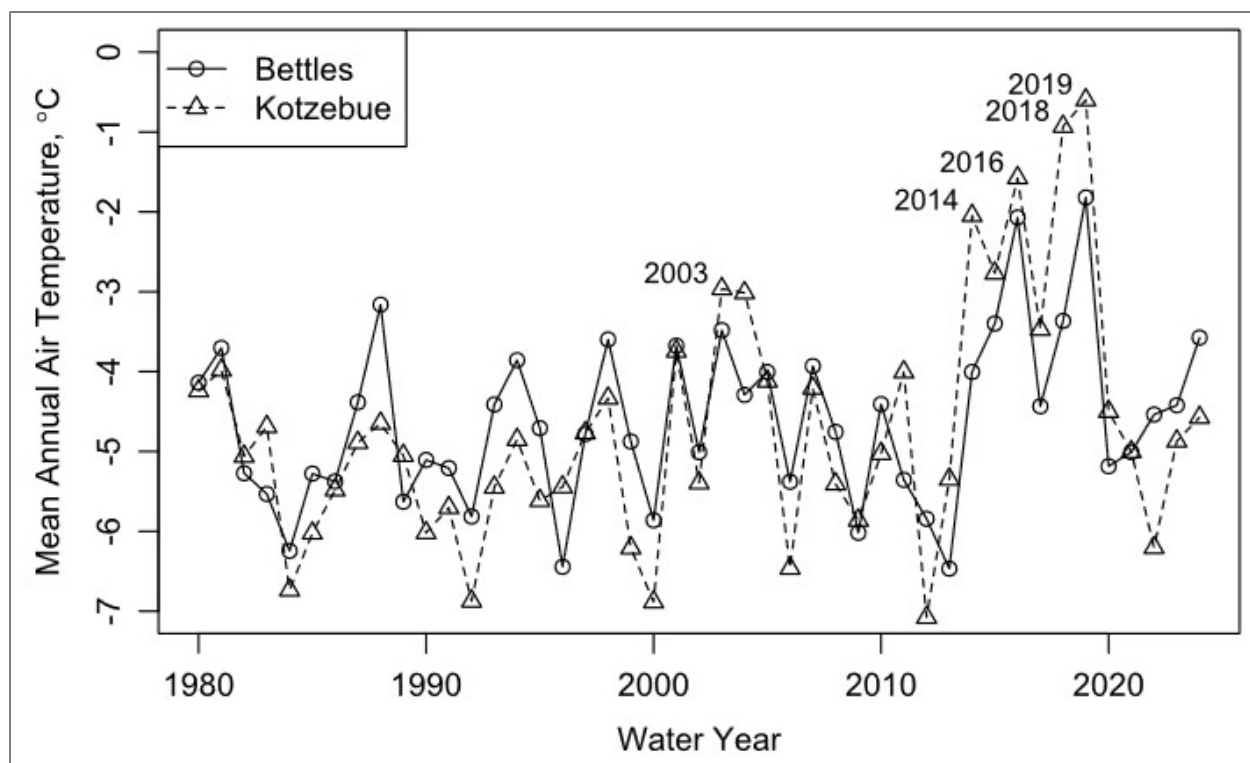


Figure 2. Mean annual air temperature for Bettles and Kotzebue, Alaska, 1980–2024. (National Weather Service data from NOAA Regional Climate Centers, 2025). Means were computed for water years (October–September). Mann-Kendall trend tests for 2000–2024 (the period with reliable annual Landsat coverage used for surface water trend analysis in this report) for mean annual temperature were positive at both stations, with $p=0.031$ at Kotzebue and $p=0.021$ at Bettles.

NPS

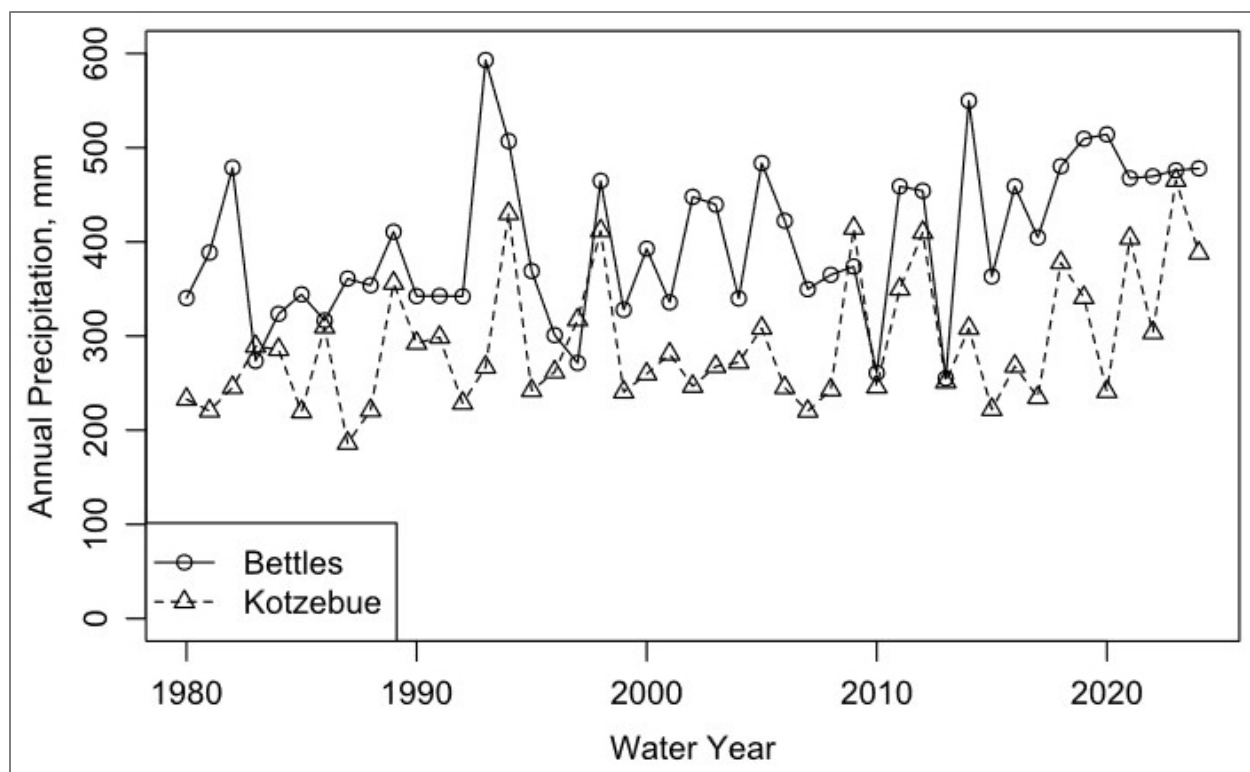


Figure 3. Mean annual precipitation at Bettles and Kotzebue, 1980–2024. Annual totals were summed for the water year, October–September. Mann-Kendall trend tests for 2000–2024 (the period with reliable annual Landsat coverage used for surface water trend analysis in this report) for precipitation were positive at both stations, with $p=0.029$ at Kotzebue and $p=0.002$ at Bettles.

NPS

Lakes of multiple origins and hydrologic conditions are present in ARCN, and ecological subsections provide a useful way to stratify the landscape into regions with relatively consistent hydrological and physiographic conditions (Larsen et al. 2017). Ecological subsections are areas of land with a relatively uniform climate and a consistent pattern of landforms, soils, and vegetation (Cleland et al. 1997). Subsection maps are available for all of ARCN (Jorgenson 2001; Jorgenson et al. 2001; Swanson 2001a, 2001b; Boggs and Michaelson 2001). In addition, subsections provide a way to avoid various non-target areas, including 1) salt water bodies (lagoons); 2) large floodplains (e.g., the Noatak River), where most of the water is in rivers and subject to large year-to-year variations associated with the timing of the images; and 3) mountainous areas, where there are very few lakes but extensive terrain shadows that confound identification of water on Landsat images. Thus I analyzed the lake area trends for all lowland subsections in ARCN with at least 0.5% cover by surface water bodies, excluding those where surface water was dominantly rivers or salt water. Note that this analysis does not include the large lakes in the foothills of southern GAAR (Narvak, Nutuvukti, Selby, and Walker); these are steep-sided, outlet-controlled lakes that fluctuate little in area while being subject to terrain shadow issues that confound water area mapping. Maps of the subsections analyzed for water surface area in this report, by NPS unit, are given in Swanson (2020),

Appendix C, and GIS data are available from
<https://irma.nps.gov/DataStore/Reference/Profile/2310969>.

The geomorphological settings of the lakes in ARCN can be joined into three broad classes, based on the subsection reports cited above and Hopkins (1963): 1) thaw-lake plains; 2) ice-rich loess over other unconsolidated deposits (glacial drift, volcanic ash and pumice, colluvial deposits); and 3) glacial drift and eolian sands with moderate to low ice content. The thaw-lake plains have ice-rich permafrost, and numerous shallow lakes overlap the outlines of older, drained lakes. Inter-lake surfaces are quite flat and only a few meters above the current lake levels. The second class, ice-rich loess and loess over other deposits, has lakes in depressions of thermokarst origin or mixed thermokarst and other (glacial, eolian) origin, separated by gently sloping uplands. Local relief ranges from a few meters to as much as 35 m on very ice-rich “yedoma” deposits (Shur et al. 2009). While drained lake basins are present in these areas, they do not blanket the surface as in thaw-lake plains. Ground ice content in the thaw-lake plains and ice-rich loess corresponds to the “High” ice content class (>40% ice by volume in the upper 5 m) mapped by Jorgenson et al. (2008). The third class, glacial drift and eolian sands, consists of late Pleistocene deposits where lake basins appear to be primary depressions that have been only slightly modified by thermokarst. The glacial drift and eolian sands fall in the “low” (<10% ice by volume in the upper 5 m) and moderate (10 to 40% ice by volume in the upper 5 m) ice content classes of Jorgenson et al. (2008).

Methods

The methods used in this study are summarized here. All image processing was done in R using the “terra” library (Hijmans 2025). See Swanson (2025, SOP E3) for R code and <https://irma.nps.gov/DataStore/Reference/Profile/2310969> for data files.

Synthesis of Annual Surface Water Maps

The area of lakes and ponds was determined from the USGS Landsat Dynamic Surface Water Extent product (“DSWE”; EROS 2022). DSWE is derived from Landsat multispectral satellite data by applying multiple water-recognition criteria (Jones 2019). The Landsat data used to produce DSWE are from Collection 2 of the “Landsat Analysis-Ready Data” (Dwyer et al. 2018), which contains atmospherically corrected surface reflectance data at a resolution of 30 m, organized into a regular grid of 150 km × 150 km tiles. To cover all of ARCN requires analysis of 13 tiles. My study area had sporadic satellite coverage in the 1980s and 1990s, and consistent coverage starting in July of 1999. Each Landsat satellite passes over any given location every 16 days, and at times there have been two functioning satellites working at once, to give an 8-day repeat interval.

I downloaded all DSWE tiles of the study area from June through September that appeared from browse images to have some cloud-free coverage of the study area. This amounted to over 1000 images per tile. I eliminated scenes from the first week of June from analysis because over much of ARCN in a typical year lakes are ice-covered at this time and indistinguishable from snow-covered land (Macander and Swingley 2012). These data were downloaded using the U.S. Geological Survey’s (USGS) Earth Explorer (<https://earthexplorer.usgs.gov/>).

To produce annual maps of water bodies across the whole study area required synthesis of many DSWE scenes, because actual data coverage on any single scene was limited by the extent of the satellite data on the scene (satellite passes do not coincide with tile boundaries) and cloud cover. The DSWE product classifies each pixel into various water or wetland classes (USGS 2022, Table 1). I recoded the DSWE pixels labeled “water, high confidence” to +2, “water, moderate confidence” to +1, and all other land and partial water classes to −2. Pixels where clouds, cloud shadows, or snow obscured the ground were recoded to “No Data”. This required downloading both the “INWAM” files (“Interpreted Layer with all Masks applied”) and the actual “MASK” files (Mask Layer). The mask layer identifies places that have no data on a particular image due to terrain, clouds or cloud shadows. It also identifies “snow” which in our case may occur either on land or on lake ice, and thus represents “No Data” with regards to surface water (because we don’t know if water or land is under the snow). The INWAM files had DSWE water determinations with the clouds and cloud shadows labeled as “No Data”, but they did not apply the snow mask, so I did that separately by overlaying the mask layers (which have snow identified). Simply summing a stack of these recoded rasters (while ignoring “No Data” pixels) for a selected time interval yields positive values for pixels that were water on a majority of scenes with data for the time interval. The effect of re-coding “water, moderate confidence” to +1 vs. +2 for “water, high confidence” was to give greater weight to pixels identified as water with high confidence.

Table 1. Dynamic Surface Water Extent (DSWE) pixel values.

DSWE Pixel Value	DSWE Interpretation	Recoded Here As
0	Not water	-2
1	Water – high confidence	+2
2	Water – moderate confidence	+1
3	Partial Surface Water - Conservative	-2
4	Partial Surface Water - Aggressive	-2
9	Cloud, cloud shadow, and snow	No Data

In my previous analyses I found that stacks of Landsat images for single years had significant areas of no data or poor quality data due to clouds and satellite malfunctions. Thus I stacked all the data for 3 consecutive years and classified as “water” any pixel for which the majority of available values were “water” for the 3 years. Each 3-year composite value was assigned to the middle year of the three. Since consistent Landsat data became available starting in July of 1999, my three-year running computations are from 2000 (1999–2001) through 2023 (2022–2024).

Water Area Trend Analysis

I examined trends in the total area of water by subsection in the 2000–2023 time series using linear regression and Mann-Kendall trend tests (R package “rkt”: Marchetto 2015; R Core Team 2023).

Identification of Drained Lakes

Lakes that drained rapidly were defined as any lake that over a period of three or more consecutive years had less than half the surface area than what was present in the highest preceding year, and that lost at least 25% of its area in a single year. Lakes that were low enough in the final 2 years (2023–2024) relative to the preceding high were also identified as “drained”. The year that a lake first lost 25% or more of its area relative to the preceding high was identified as the year of drainage. Lakes that refilled halfway back from their 3-year minimum to their preceding maximum by the last year were flagged as “refilled”. Only lakes larger than 5 ha at their maximum were tabulated as “drained”. Sporadic data from 1984–1989 were aggregated to produce a “1980s” water raster and similarly all data from the 1990s were aggregated to produce a “1990s” water raster to identify lakes that drained prior to 2000.

Inspection of lakes identified as “drained” in 2023 revealed multiple false positives, an issue that has not been a problem in the past. Note that these drained lakes were identified using a less stringent criterion (2 years of low water rather than 3). Thus I used Sentinel-2 data (10 m resolution, viewable in false-color-infrared display from the Copernicus browser at <https://browser.dataspace.copernicus.eu/>) from July 2024 to verify the 2023 drained lakes.

Identification of “Wet” and “Dry” Periods

Lake areas were used to identify regional wet and dry periods as follows. For lakes larger than 5 ha at their maximum, those identified by the previous analysis as “drained” were removed and the yearly areas of each remaining lake were converted to a z-scores (the mean water area for the lake in 2000–

2023 was subtracted from each year, and the result divided by the 2000–2023 standard deviation). Z-scores compensate for the fact that lakes inherently have greater or lesser sensitivity to changes in the water balance. For example, a lake with extensive shallows that are exposed in dry years would change greatly in area between wet and dry years. I then computed the median and various percentiles of the z-scores of all the lakes through time, to identify years when many lakes were above or below the long-term average; these correspond to regional wet and dry periods.

Results

Water Area by Subsection

Most ecological subsections showed declining water area in lakes and ponds from 2000 to 2023 (Table 2, Figures 4–6). Of the 30 subsections, 23 had linear regressions of water area vs. year with negative slope and $p < 0.05$, while 22 had negative Mann-Kendall trends with $p < 0.05$ (Table 2). While all of these declines are statistically significant, they vary greatly in the rate of loss and thus the ecological significance of the water loss. Table 2 is sorted by rate of loss as a percent of the lake area present. Eight subsections lost more than 0.5% of their lake area per year, as determined by the slope of the linear regression. In other words, they lost more than 5% of their water area per decade; these are labeled in Figures 4–6 as “Rapid Loss” (bright red). All are in ice-rich permafrost, including two that are in ice-rich thaw-lake plains. Some of these subsections had relatively little surface water to start with, so the absolute water area lost was also rather small, while others lost a great deal. The absolute rate of water area loss is portrayed by the column in Table 2 “Rate of Loss (ha yr^{-1})”, and the two subsections that stand out are the Bering Straits Upper and Lower Coastal Plains, with -48 and -176 ha yr^{-1} of water area loss, respectively. The latter subsection (BSLCP) showed a nearly linear decline from a total water cover of about 8.5% of the land surface in 2000–2005 to about 6% in 2023 (Figure 7). This is the northernmost subsection along the north coast of BELA (cross-hatched in Figure 4).

Table 2. Summary of Water Area Change by Subsection. ^A

Code	Subsection Name	NPS Unit	Permafrost	Area (km ²)	Water Area (%)	Rate of Loss (ha yr ⁻¹)	Rate of Loss (% yr ⁻¹)	r-squared	Linear p-value	M-K p-value
AKP	Akillik Plain	KOVA	ice-rich	381	0.7	-5.75	-2.02	0.81	0.000	0.000
NIP	Nigeruk Plain	KOVA	ice-rich	749	0.6	-7.39	-1.75	0.74	0.000	0.000
BSLCP	Bering Straits Lower Coastal Plain	BELA	thaw-lake plain	1637	7.4	-175.77	-1.45	0.95	0.000	0.000
WUL	Wulik Lowland	CAKR	ice-rich	351	0.7	-2.54	-1.01	0.91	0.000	0.000
KOY	Koyukuk	GAAR	ice-rich	242	1.5	-3.42	-0.95	0.70	0.000	0.000
BSUCP	Bering Straits Upper Coastal Plain	BELA	ice-rich	1329	5.1	-47.58	-0.71	0.89	0.000	0.000
GBLCP	Goodhope Bay Lower Coastal Plain	BELA	thaw-lake plain	117	4.5	-3.31	-0.62	0.56	0.000	0.007
GBUCP	Goodhope Bay Upper Coastal Plain	BELA	ice-rich	1322	2.2	-16.8	-0.57	0.70	0.000	0.000
LNМ	Lower Noatak Moraine	CAKR	ice-rich	97	3.4	-1.17	-0.35	0.54	0.000	0.001
AHW	Ahnewetut Wetlands	KOVA	ice-poor	142	9.3	-3.97	-0.3	0.73	0.000	0.000
UNB	Upper Noatak Basin	NOAT	ice-poor	2472	1.6	-11.30	-0.28	0.70	0.000	0.000
KZL	Kuzutrin Lowlands	BELA	ice-rich	226	3.5	-2.12	-0.27	0.53	0.000	0.000
NIG	Nigu	GAAR	ice-poor	85	3.5	-0.79	-0.27	0.52	0.000	0.000
ACP	Aukulak Coastal Plain	CAKR	thaw-lake plain	114	2.0	-0.55	-0.24	0.21	0.025	0.029
IGU	Iggiruk Uplands	NOAT	ice-poor	984	2.6	-6.07	-0.24	0.65	0.000	0.000
DU	Devil Uplands	BELA	ice-rich	826	8.7	-15.50	-0.21	0.60	0.000	0.001
NGL	Noatak Glaciated Lowlands	NOAT	ice-poor	655	3.6	-4.66	-0.2	0.40	0.001	0.001
LNL	Lower Noatak Lowlands	NOAT	thaw-lake plain	399	8.3	-6.31	-0.19	0.33	0.003	0.001
NGU	Nigu Mountain Valley	GAAR	ice-poor	207	3.2	-0.94	-0.14	0.37	0.002	0.002
KGU	Kavachurak Glaciated Uplands	NOAT	ice-poor	588	2.7	-2.06	-0.13	0.69	0.000	0.000
IL	Imuruk Lowlands	BELA	ice-rich	339	22.5	-8.13	-0.11	0.85	0.000	0.000
KOB	Kobuk	GAAR	ice-rich	246	0.7	-0.19	-0.1	0.04	0.349	0.309
IMP	Imikruk Plains	CAKR	thaw-lake plain	18	7.8	-0.13	-0.09	0.24	0.015	0.056
NOA	Noatak	GAAR	ice-poor	179	6.0	-0.93	-0.09	0.36	0.002	0.002

^A “Water Area”: mean of 2000–2023, Rates of loss are from the linear regression. “Rate of Loss (% yr⁻¹) is the annual loss as a percent of the water present.

Table 2 (continued). Summary of Water Area Change by Subsection. ^A

Code	Subsection Name	NPS Unit	Permafrost	Area (km ²)	Water Area (%)	Rate of Loss (ha yr ⁻¹)	Rate of Loss (% yr ⁻¹)	r-squared	Linear p-value	M-K p-value
AGU	Avingyak Glaciated Uplands	NOAT	ice-poor	231	11.4	-0.54	-0.02	0.23	0.019	0.024
ITK	Itkilik	GAAR	ice-poor	31	16.9	-0.09	-0.02	0.16	0.055	0.078
KIL	Killik	GAAR	ice-poor	101	4.2	0.00	0.00	0.00	0.984	0.921
MNU	Middle Noatak Uplands	NOAT	ice-poor	551	4.2	0.13	0.01	0.00	0.770	0.602
ALA	Alatna	GAAR	ice-poor	25	17.1	0.57	0.13	0.34	0.003	0.004
KOP	Kotlik Coastal Plain	CAKR	thaw-lake plain	122	2.7	0.51	0.15	0.16	0.054	0.026

^A “Water Area”: mean of 2000–2023, Rates of loss are from the linear regression. “Rate of Loss (% yr⁻¹) is the annual loss as a percent of the water present.

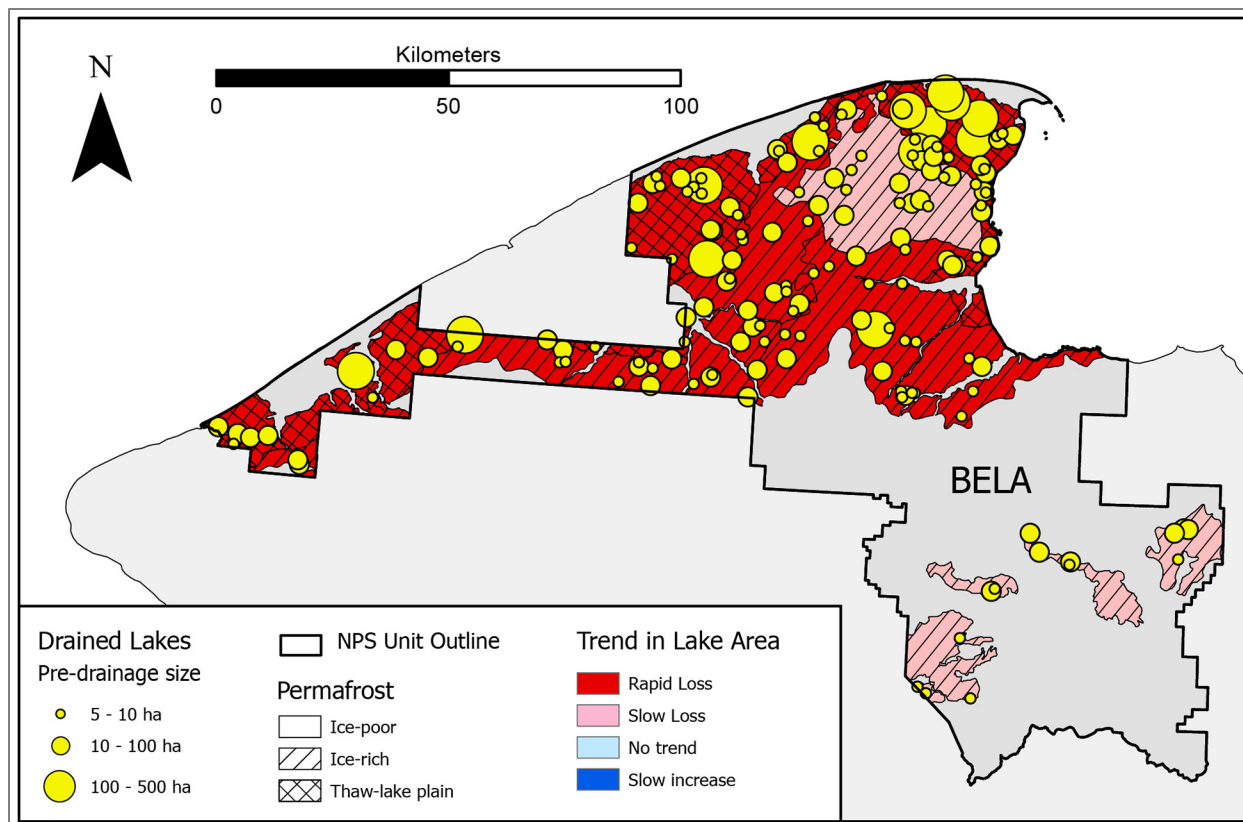


Figure 4. Lake area change in the western part of the study area (BELA). Subsection colors give the overall trend in water area 2000–2023: red for decreasing and blue for no trend or slowly increasing. Bright red indicates a relatively rapid rate of decrease (more than 5% of existing water area lost per decade), while pink indicates slower but still statistically significant rates of loss. Circles mark the location of lakes that drained, with circle size proportional to the pre-drainage area of the lake.

NPS

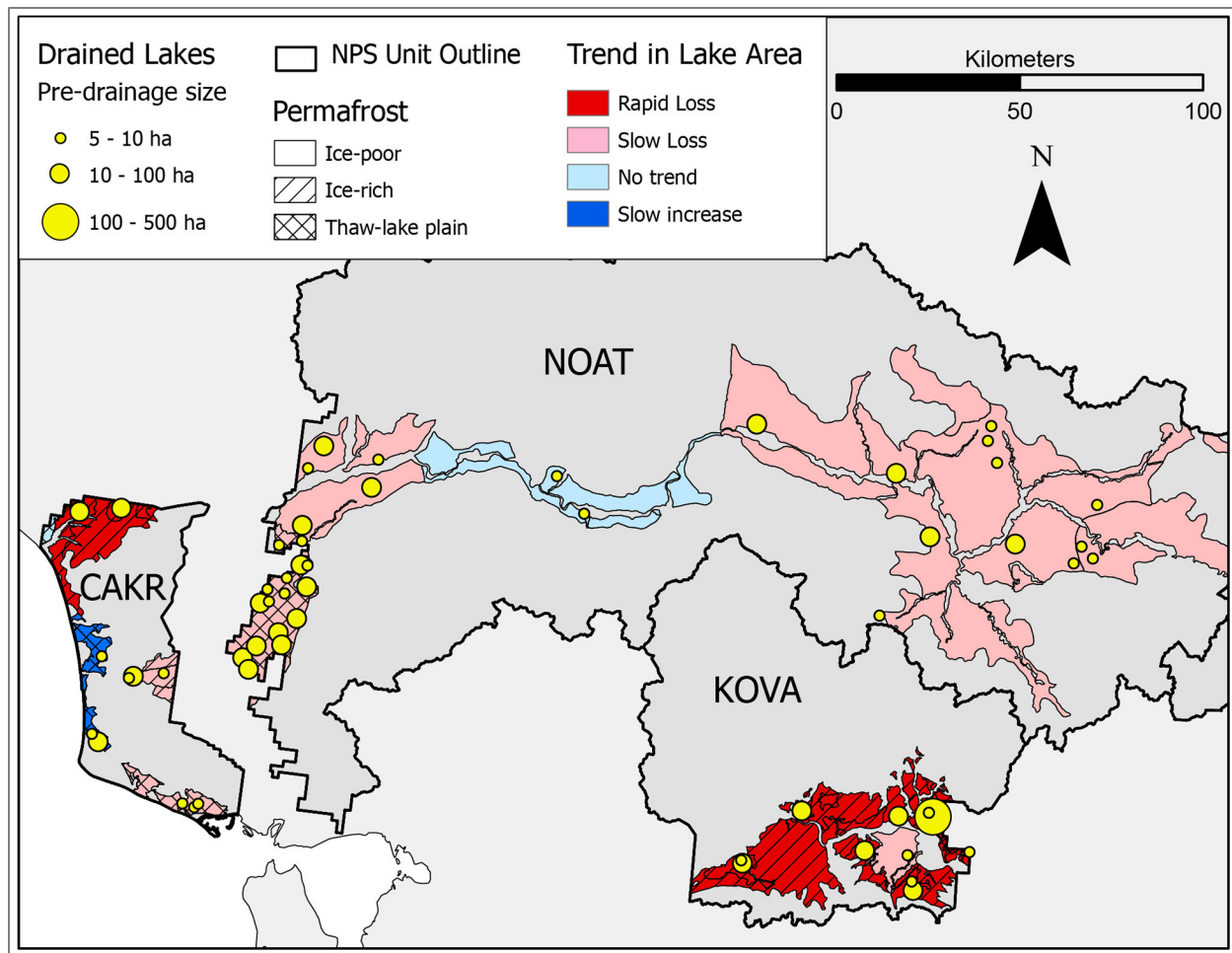


Figure 5. Lake area change in the central part of the study area (CAKR, KOVA, and NOAT). See Figure 4 for an explanation of the symbology.

NPS

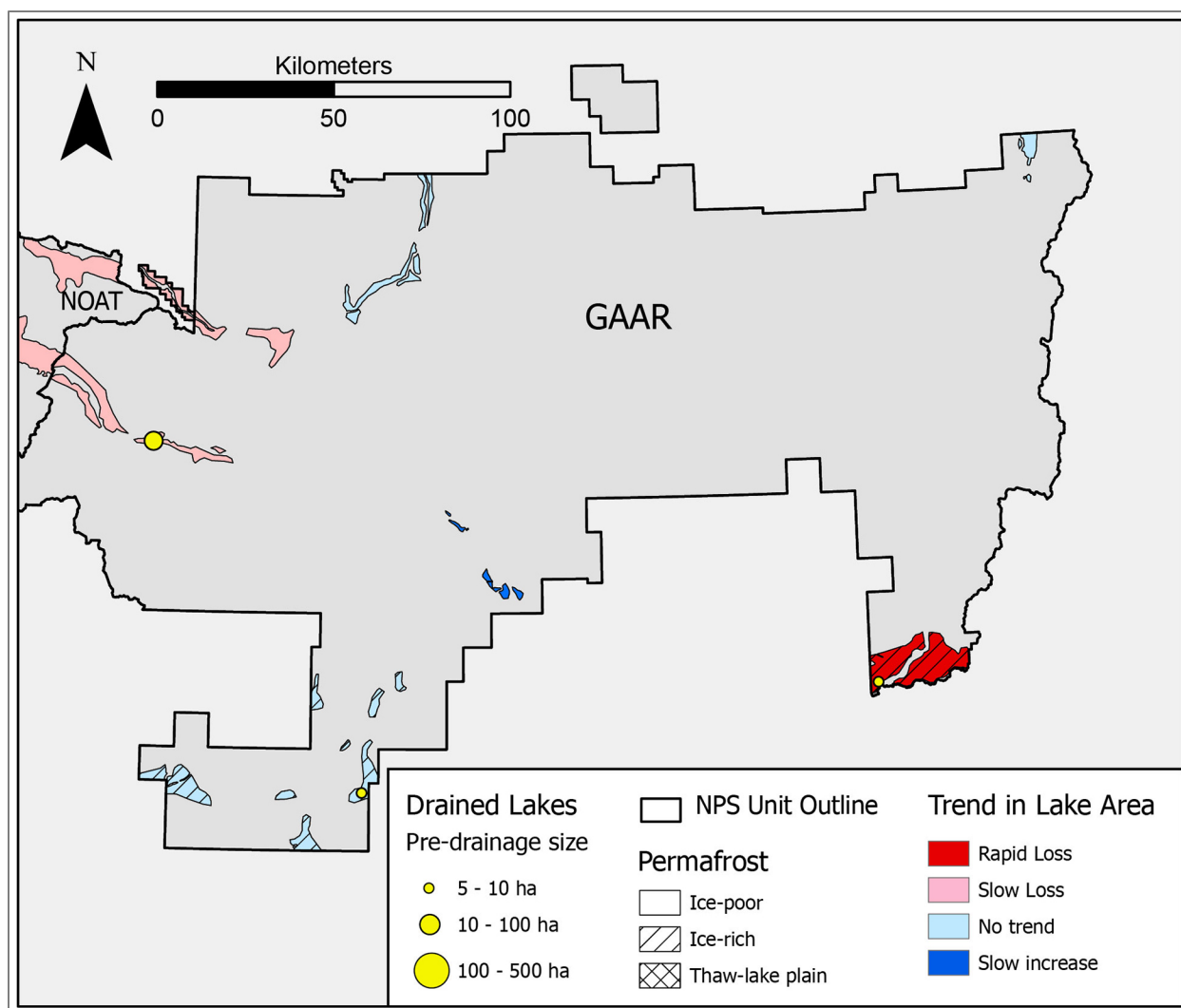


Figure 6. Lake area change in the eastern part of the study area (GAAR and far western NOAT). See Figure 4 for an explanation of the symbology.

NPS

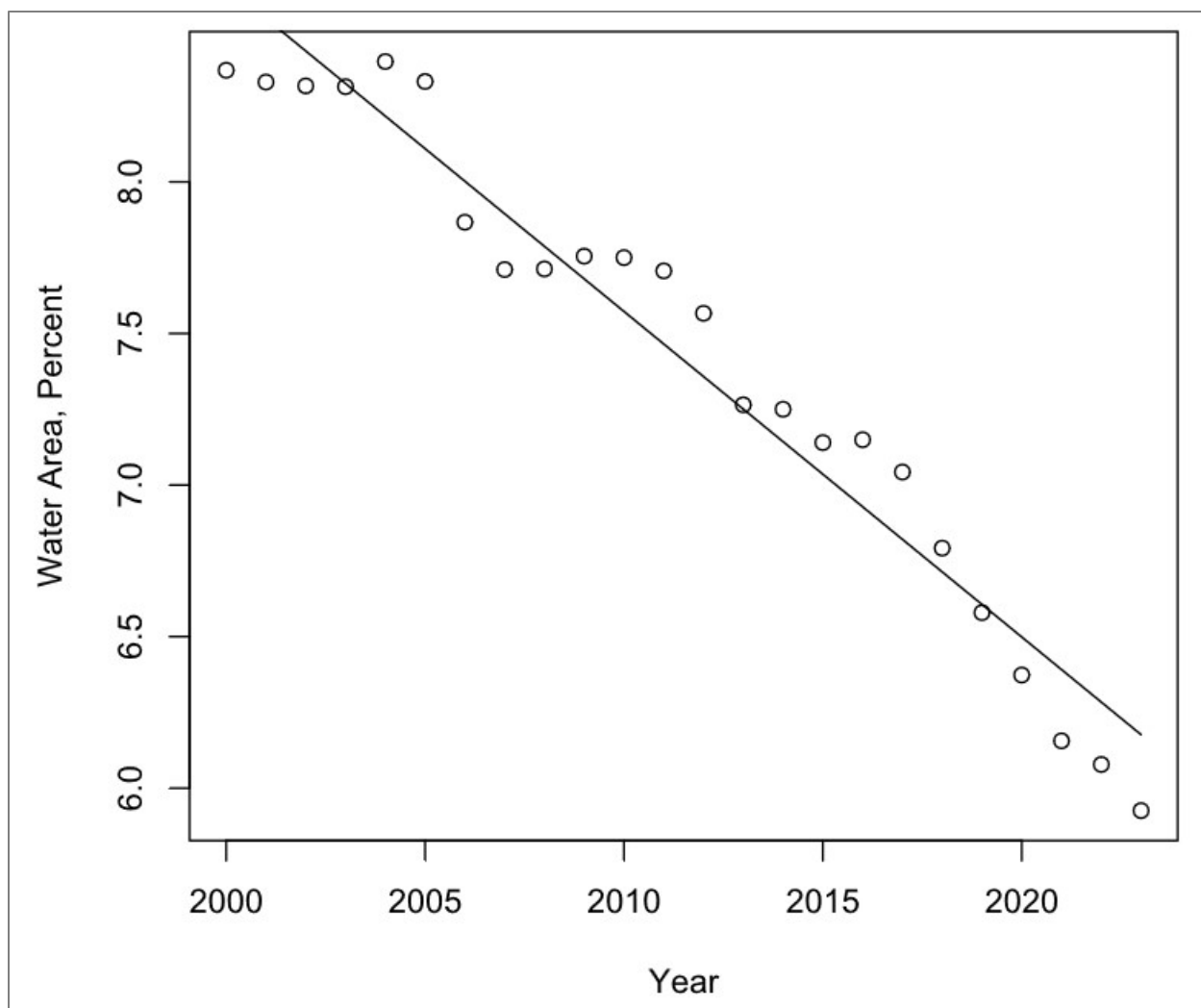


Figure 7. Water surface area vs. time for the years 2000–2023 for the Bering Straits Lower Coastal Plain (BSLCP) subsection in BELA. The trend line is a linear regression (Table 2).

NPS

Many of the subsections showed statistically significant declines in water area, but the actual amount of water area lost was rather small. An example of this is the Kavachurak Glaciated Uplands subsection in NOAT (KGU), which lost about 2 ha yr^{-1} of water and declined from just over 2.70% water area in 2000 to 2.62–2.64% in recent years (Figure 8). Subsections that lost less than 0.5% of the water present per year are labeled as “Slow Loss” (pink) in Figures 4–6. See the supplemental online materials at <https://irma.nps.gov/DataStore/Reference/Profile/2310969> for plots of water area vs. year for all of the subsections, and a GIS layer of subsection locations.

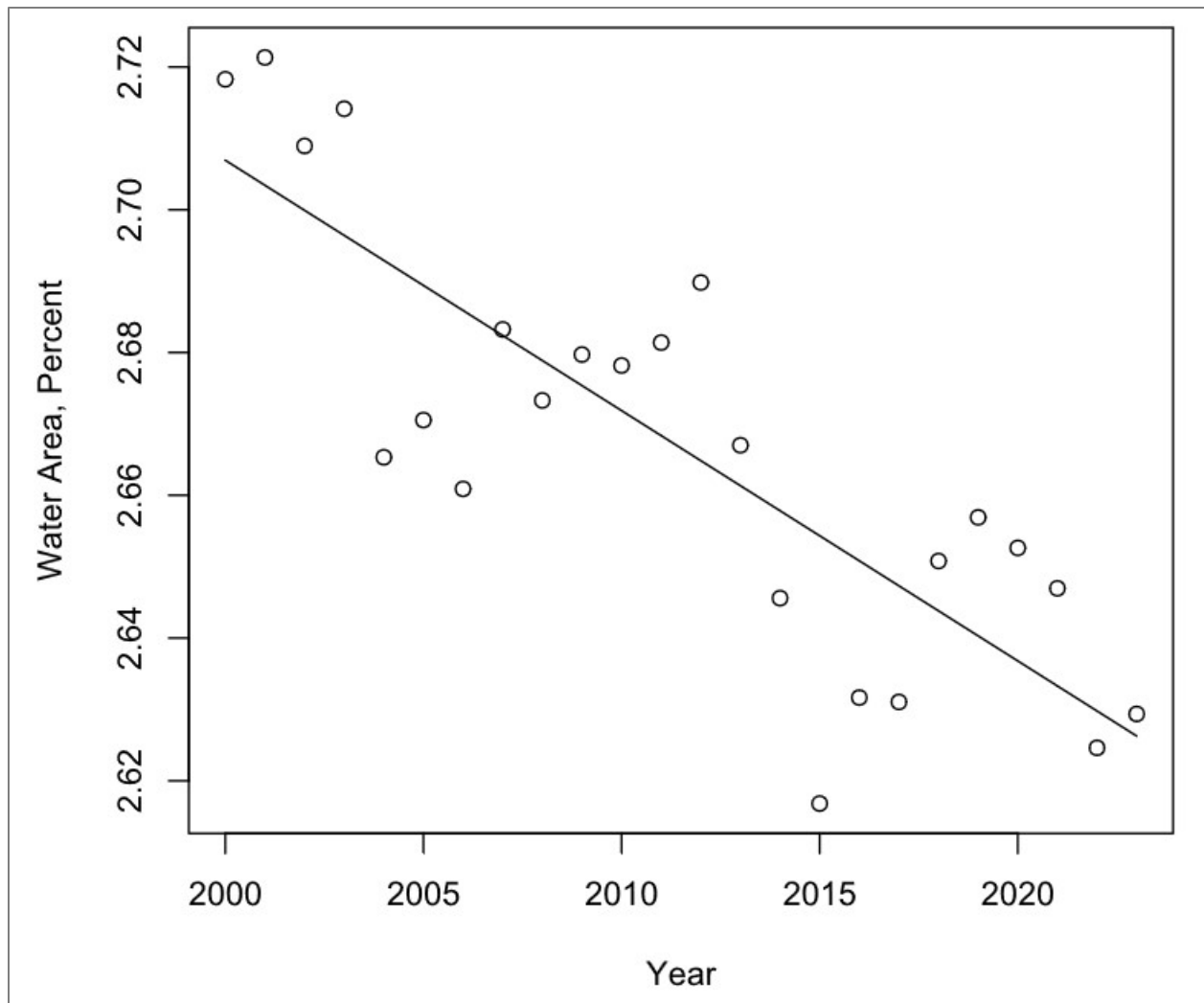


Figure 8. Water surface area vs. time for the years 2000–2023 for the Kavachurak Glaciated Uplands (KGU) subsection in NOAT. The trend line is a linear regression (Table 2).

NPS

Two subsections had significant (Mann-Kendall test $p < 0.05$) positive trends in water area, the Kotlik Coastal Plain in CAKR and the Alatna River Valley in GAAR (labeled dark blue in Figures 5 and 6). These subsections had very low overall rates of change (less than 1 ha yr^{-1}) and low regression r -squared values, indicating substantial year-to-year variation in water area. One of the larger lakes (38.4 ha) in the Kotlik Coastal Plain drained in 2022–2023, which reduced this subsection’s lake area to slightly below the level present at the start of our monitoring (Figure 9). The single low data point in the final year was not sufficient to change the positive trend as detected by the Mann-Kendall test, but in fact that lake drainage has erased the gradual gains (probably due mainly to thermokarst along lake shores) accrued across the subsection during the last two decades.

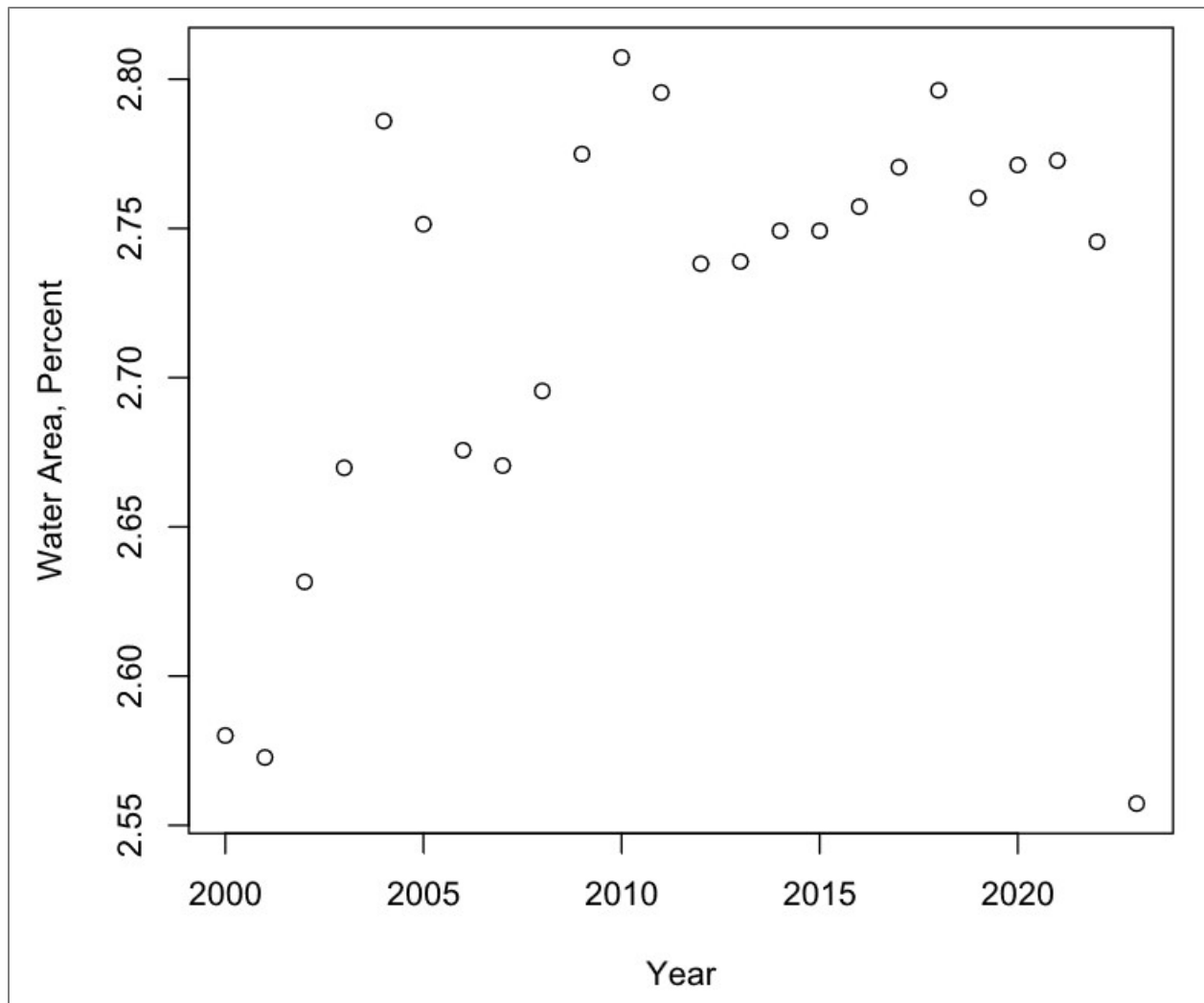


Figure 9. Water surface area vs. time for the years 2000–2023 in the Kotlik Coastal Plain (KOP) subsection in CAKR. No regression line is shown because the linear regressions was non-significant, but the Mann-Kendall test p-value was 0.026 (Table 2). The final data point for 2023 was low due to a lake drainage event.

NPS

Lake Drainage

The number of new lake drainage events was high in 2021, matching the preceding high years 2017–2019 (Figure 10). Drainage events in recent years continued to be predominantly in BELA. As was documented previously (Swanson 2019, 2020), areas with rapid loss of lake area generally coincide with areas that had multiple rapid lake drainage events (Figures 4–6). Rapid lake drainage events occurred almost exclusively in lakes of thermokarst origin, due to thermo-erosion of new outlets (Jones et al. 2011, Swanson 2019, Nitze et al. 2020). Subsections with ice-rich permafrost include thaw-lake plains (cross-hatched in Figures 4–6) and areas with ice-rich loess (hatched in Figures 4–6). Photographs depicting the drained lakes are given in Swanson (2020), and their colonization by vegetation is analyzed by Swanson and Hampton-Miller (2023).

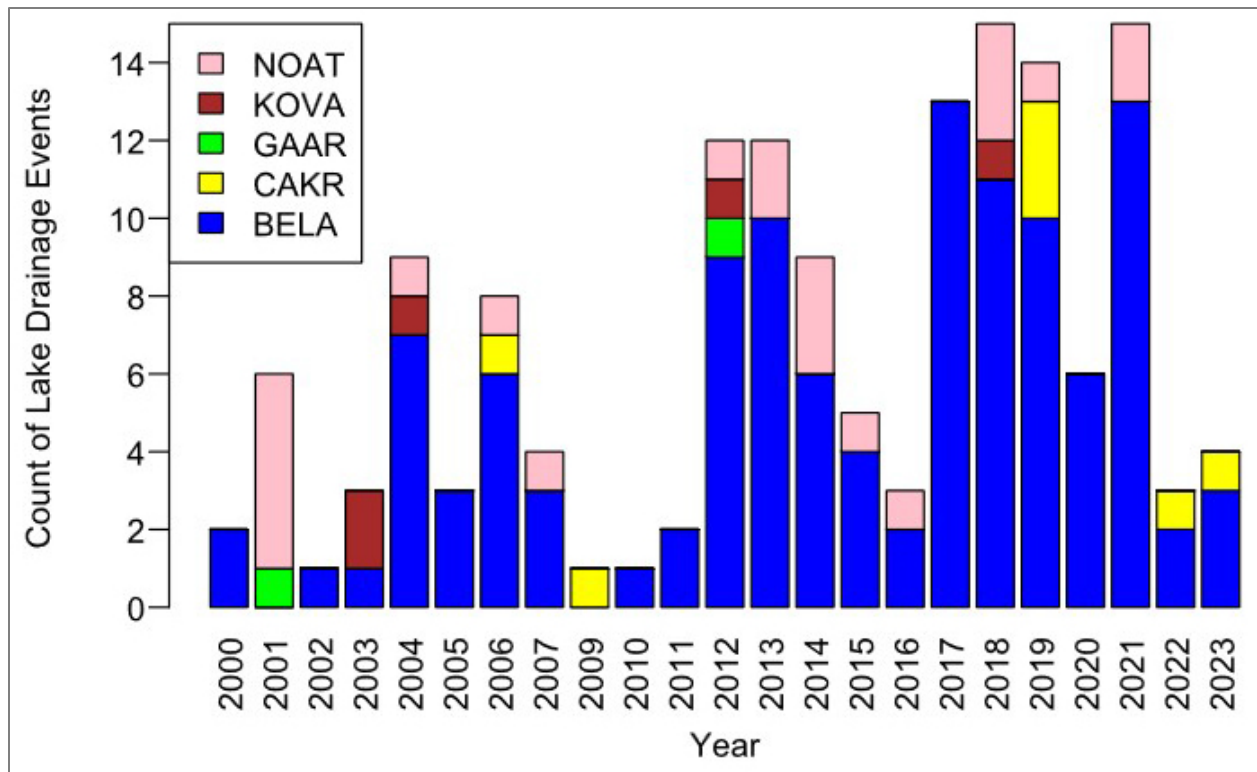


Figure 10. Count of new lake drainage events by year, 2000–2023, by NPS unit.
NPS

The largest lake to drain in the study area to date (442 ha) drained in 2020 (Figures 11–13). It was located in the far western part of BELA near Ikpek Lagoon, near another relatively large lake that drained partially in the same year. Also, in the Espenberg region of northern BELA, the sole remaining lake larger than 1.5 km across (latitude 66.55°, longitude –164.28°) drained partially in 2024. All three of these lakes were in the Bering Straits Lower Coastal Plain subsection, the area with the most rapid lake loss in the study area (Table 2).

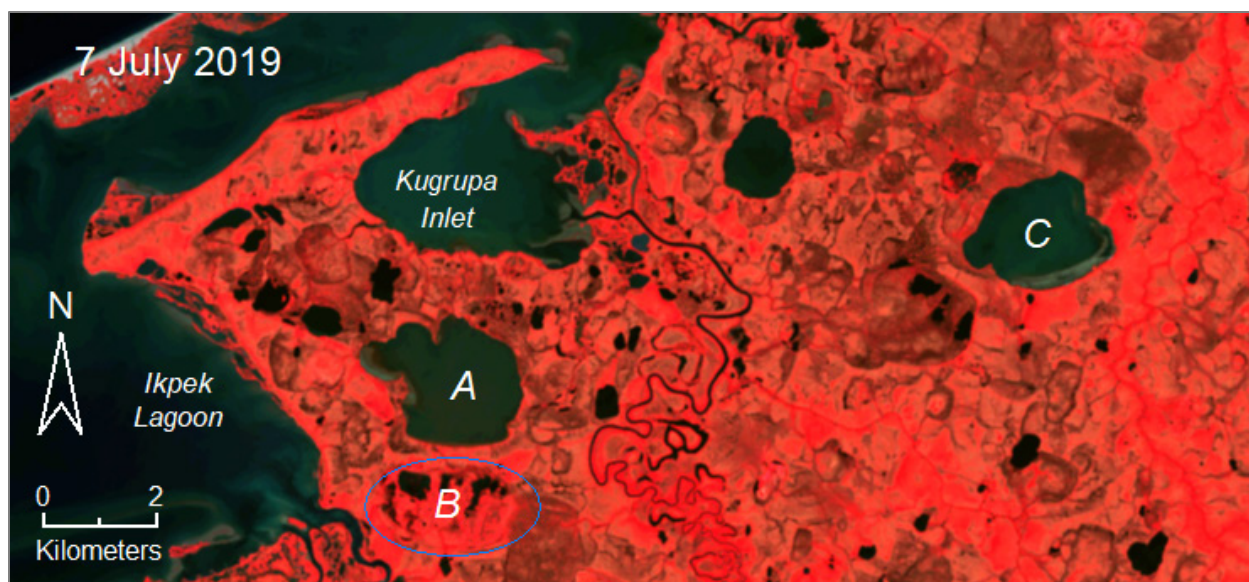


Figure 11. Example of lakes draining in western BELA. This is a Landsat image, displayed using visible and infrared light data such that water is black and dense vegetation is red. In July 2019, lakes A and C were water-filled. The outline of a lake that drained in the 1970s is shown at B.

NPS

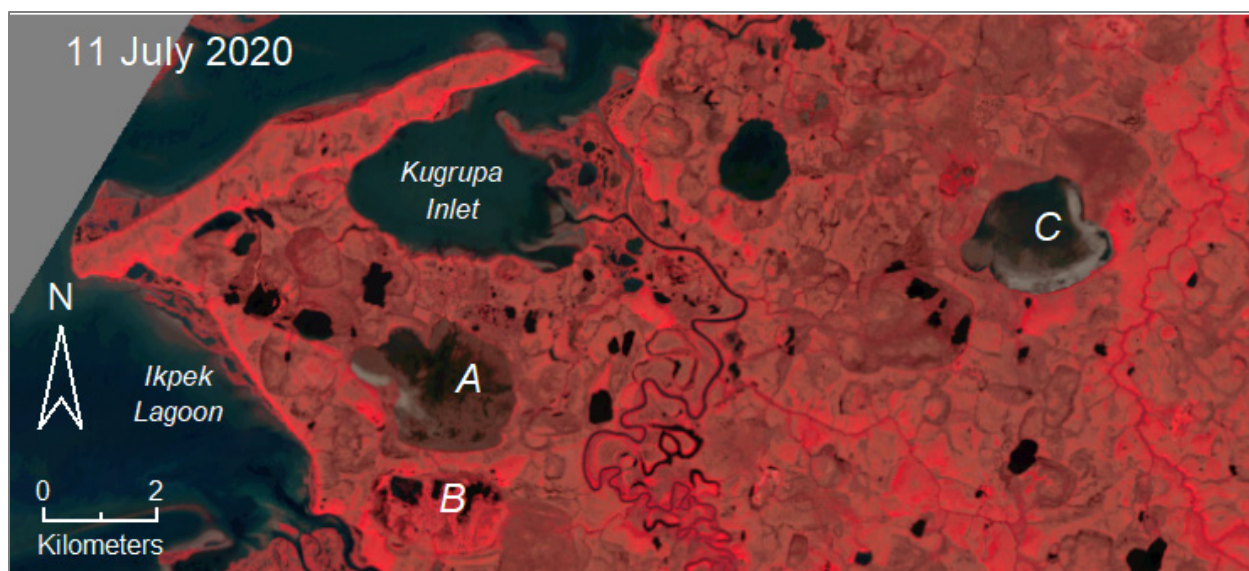


Figure 12. In July 2020, drainage had exposed the lake bottom over most of lake A and part of lake C.

NPS

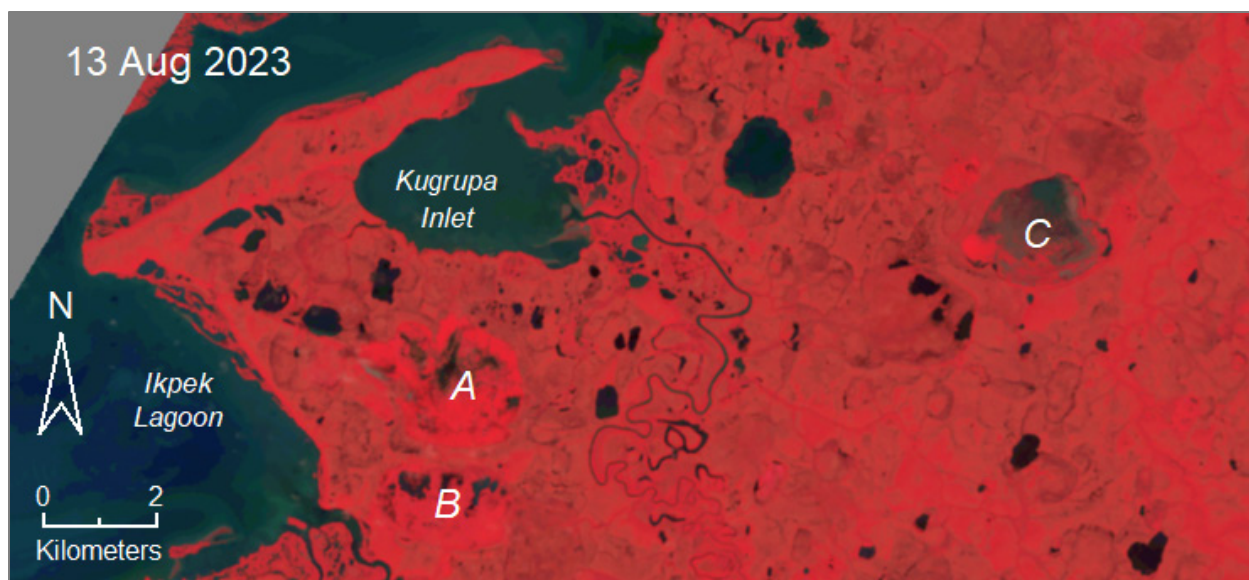


Figure 13. By August 2023, vegetation had colonized most of former lake A and part of C. Lake A formerly covered about 442 ha and is the largest lake to drain in ARCN to date. It is located at latitude 65.95° longitude -166.83°.

NPS

Of the 222 lakes larger than 5 ha that drained since the Landsat records began in the 1980s, just 5 “refilled” according to my criterion (lakes that refilled halfway back from their 3-year minimum to their preceding maximum by the last year). All were relatively small (less than 15 ha). Two were in riparian zones in NOAT and the other 3 were lakes of thermokarst origin in BELA.

Wet and Dry Periods

Multi-year wet and dry periods are apparent from the lake area data, after the effects of lake drainage have been removed (Figure 14). Figure 14 portrays the median and various percentiles for z-scores of area (lake area scaled by the mean and standard deviation) for the 1558 lakes greater than 5-ha in size that were not classified as “drained”. For example, in 2007 the median z-score of the 1558 lakes was zero, meaning the typical lake was at its long-term average level in that year. The 5th-to-95th percentile range in z-score that year was -1.5 to +1, meaning that 90% of all lakes were between 1.5 standard deviations below to one standard deviation above their long-term average area. Figure 14 shows regional high lake levels (i.e., wet periods) in 2004–2005 and 2009–2011, and an extended low water period from 2013 to 2017. The median z-scores in 2018–2023 were near zero, but the range has expanded greatly, indicating high variability in lake levels between lakes in recent years. Inspection of the data suggested that this increased variability is not related to lake size or general location in the study, and it may have to do with problems in the data due to clouds. More years of data will be needed to determine the source of this increased variability, and whether or not it is temporary. The regional high and low lake levels indicated from Figure 14 are visible as deviations from the long-term trend on plots for many individual subsections; for example, in Figure 7 the wet periods 2004–2005 and 2009–2011 fall above the regression line.

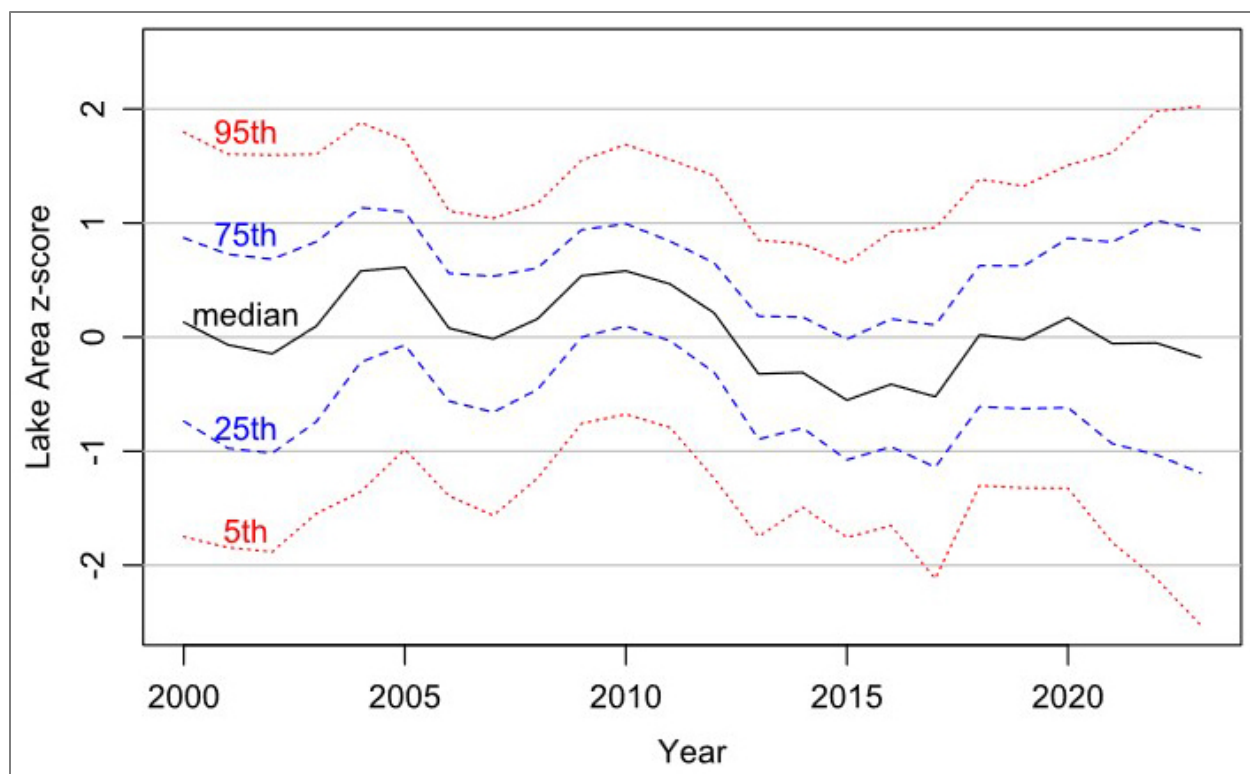


Figure 14. Multi-year trend in z-scores of area for lakes that did not drain. Data are for 1558 lakes, with z-scores computed for each lake over the period 2000–2023.

NPS

Discussion and Conclusions

The results presented here show that the trends observed in our previous analysis (Swanson 2019, 2020) and Nitze et al. (2020) are continuing: the area of lakes and ponds declined in many areas, and the most rapid loss occurred in regions of thermokarst lakes where lakes drained through outlets created by permafrost thaw. The thaw of these new outlets is likely the result of the record warm temperatures during the period 2014–2019, probably in combination with high snowfall that produced high spring water levels in the lakes and ponds (Swanson 2019, Nitze et al. 2020). The thaw-lake plain in northern BELA lost the most lake area. Similar permafrost and climatic conditions are present on the thaw-lake plains elsewhere in ARCN, and there is no reason to believe that these other areas will be immune to drainage events in the coming years.

Literature Cited

- Boggs, K., and J. Michaelson. 2001. Ecological subsections of Gates of the Arctic National Park and Preserve. Inventory and Monitoring Program, National Park Service, Alaska Region, Anchorage, Alaska. <https://irma.nps.gov/DataStore/Reference/Profile/664200>
- Cleland, D. T., P. E. Avers, W. H. McNab, M. E. Jensen, R. G. Bailey, T. King, and W. E. Russell. 1997. National hierarchical framework of ecological units. Pages 181–200 in M. S. Boyce and A. Haney, editors. Ecosystem management applications for sustainable forest and wildlife resources. Yale University, New Haven, CT.
- Dwyer, J. L., D. P. Roy, B. Sauer, C. B. Jenkerson, H. K. Zhang, and L. Lymburner. 2018. Analysis ready data: enabling analysis of the Landsat archive. *Remote Sensing* 10:1363.
- Earth Resources Observation and Science (EROS) Center. 2022. Landsat Level-3 Dynamic Surface Water Extent, Collection 2. U.S. Geological Survey. <https://doi.org/10.5066/P9DPWBUS>
- Hijmans, R. J. 2022. Package “terra.” R Foundation for Statistical Computing, Vienna, Austria. <https://CRAN.R-project.org/package=terra>
- Hopkins, D. M. 1963. Geology of the Imuruk Lake area, Seward Peninsula, Alaska. Geological Survey Bulletin, US Government Printing Office, Washington, DC. <http://pubs.usgs.gov/bul/0974c/report.pdf>
- Jones, B. M., G. Grosse, C. D. Arp, M. C. Jones, K. M. Walter Anthony, and V. E. Romanovsky. 2011. Modern thermokarst lake dynamics in the continuous permafrost zone, northern Seward Peninsula, Alaska. *Journal of Geophysical Research: Biogeosciences* (2005–2012) 116:G00M03. <https://doi.org/10.1029/2011JG001666>
- Jones, J. 2019. Improved Automated Detection of Subpixel-Scale Inundation—Revised Dynamic Surface Water Extent (DSWE) Partial Surface Water Tests. *Remote Sensing* 11. <https://doi.org/10.3390/rs11040374>
- Jorgenson, M. T. 2001. Ecological subsections of Bering Land Bridge National Preserve. Inventory and Monitoring Program, National Park Service, Alaska Region, Anchorage, Alaska. <https://irma.nps.gov/DataStore/Reference/Profile/583322>
- Jorgenson, M. T., J. E. Roth, P. F. Miller, M. J. Macander, M. S. Duffy, A. F. Wells, G. V. Frost, and E. R. Pullman. 2009. An ecological land survey and landcover map of the Arctic Network. Natural Resource Technical Report, National Park Service, Fort Collins (CO). <https://irma.nps.gov/DataStore/Reference/Profile/583322>

- Jorgenson, M. T., D. K. Swanson, and M. Macander. 2001. Landscape-level mapping of ecological units for the Noatak National Preserve, Alaska. Inventory and Monitoring Program, National Park Service, Alaska Region, Anchorage, Alaska.
<https://irma.nps.gov/DataStore/Reference/Profile/583328>
- Jorgenson, M. T., K. Yoshikawa, M. Kanevskiy, Y. Shur, V. Romanovsky, S. Marchenko, G. Grosse, J. Brown, and B. Jones. 2008. Permafrost characteristics of Alaska. Institute of Northern Engineering, University of Alaska Fairbanks, Fairbanks, Alaska.
<https://catalog.northslopescience.org/dataset/1725>
- Larsen, A. S., J. A. O'Donnell, J. H. Schmidt, H. J. Kristenson, and D. K. Swanson. 2017. Physical and chemical characteristics of lakes across heterogeneous landscapes in arctic and subarctic Alaska. *Journal of Geophysical Research: Biogeosciences*.
<http://onlinelibrary.wiley.com/doi/10.1002/2016JG003729/full>
- Lawler, J. P., S. D. Miller, D. Sanzone, J. Ver Hoef, and S. B. Young. 2009. Arctic network vital signs monitoring plan. Natural Resource Report, National Park Service, Fort Collins, Colorado.
<https://irma.nps.gov/DataStore/Reference/Profile/661340>
- Macander, M. J., and C. S. Swingley. 2012. Mapping snow persistence for the range of the Western Arctic Caribou Herd, northwest Alaska, using the Landsat archive (1985–2011). National Park Service, Fort Collins, Colorado. <https://irma.nps.gov/DataStore/Reference/Profile/2191504>:
<https://irma.nps.gov/DataStore/Reference/Profile/2203863>
- Marchetto, A. 2015. rkt: Mann-Kendall Test, Seasonal and Regional Kendall Tests. R package version 1.4. R Foundation for Statistical Computing, Vienna, Austria. <http://CRAN.R-project.org/package=rkt>
- Nitze, I., S. W. Cooley, C. R. Duguay, B. M. Jones, and G. Grosse. 2020. The catastrophic thermokarst lake drainage events of 2018 in northwestern Alaska: fast-forward into the future. *The Cryosphere* 14:4279–4297.
- NOAA Regional Climate Centers. 2025. xmACIS2. <http://xmacis.rcc-acis.org/>
- PRISM Climate Group. 2020. Alaska. <http://prism.oregonstate.edu/projects/alaska.php>
- R Core Team. 2023. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>
- Swanson, D. K. 2001a. Ecological units of Cape Krusenstern National Monument, Alaska. Inventory and Monitoring Program, National Park Service, Alaska Region, Anchorage, Alaska.
<https://irma.nps.gov/DataStore/Reference/Profile/584438>

- Swanson, D. K. 2001b. Ecological units of Kobuk Valley National Park, Alaska. Inventory and Monitoring Program, National Park Service, Alaska Region, Anchorage, Alaska.
<https://irma.nps.gov/DataStore/Reference/Profile/584437>
- Swanson, D. K. 2017. Landscape patterns and dynamics monitoring protocol for the Arctic Network: Narrative. Natural Resource Report, National Park Service, Fort Collins, Colorado.
<https://irma.nps.gov/DataStore/Reference/Profile/2238342>
- Swanson, D. K. 2019. Thermokarst and precipitation drive changes in the area of lakes and ponds in the National Parks of northwestern Alaska, 1984–2018. *Arctic, Antarctic, and Alpine Research* 51:265–279. <https://doi.org/10.1080/15230430.2019.1629222>
- Swanson, D. K. 2020. Monitoring of water surface area in Alaska’s Arctic National Parks: Update with 2019 data. Natural Resource Data Series, National Park Service, Fort Collins, Colorado.
<https://irma.nps.gov/DataStore/Reference/Profile/2272062>
- Swanson, D. K., and C. J. Hampton-Miller. 2023. Drained lakes in Bering Land Bridge National Preserve: Vegetation succession and impacts on loon habitat. Page 63. National Park Service, Fort Collins, Colorado. <https://irma.nps.gov/DataStore/Reference/Profile/2296593>
- U.S. Geological Survey. 2022. Landsat Collection 2 (C2) Level 3 (L3) Dynamic Surface Water Extent (DSWE) Data Format Control Book (DFCB). Page 21. LSDS-, US Geological Survey, EROS, Sioux Falls, South Dakota. https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/media/files/LSDS-2042_Landsat_C2-L3-Dynamic-Surface-Water-Extent_Data-Format-Control-Book-v3.pdf

National Park Service
U.S. Department of the Interior



Science Report NPS/SR—2025/323
<https://doi.org/10.36967/2313920>

Natural Resource Stewardship and Science

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525