SURFACE WATER DYNAMICS OF SHALLOW LAKES FOLLOWING WILDFIRE IN BOREAL ALASKA

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Abstract

Wildfire is ubiquitous to interior Alaska and is the primary large-scale disturbance regime affecting thawing permafrost and ecosystem processes in boreal forests. Since surface and near surface hydrology is strongly affected by permafrost occurrence, and wildfire can consume insulating organic layers that partially control the thickness of the active layer overlying permafrost, changes in the active layer thickness following fire may mark a distinct change in surface hydrology. In this study, we examined surface area dynamics of lakes following wildfire in four regions of Interior Alaska during a 25-year period from 1984 - 2009. We compared the surface water dynamics of lakes in burned areas relative to lakes in adjacent unburned (control) areas. Lake area changes in the short-term (0-5 years), mid-term (5-10 years), and long-term (>10 years) were analyzed. Burn severity, as a function of radiant surface temperature change, was also explored. Surface water changes were greatest during the short-term (0-5 years) period following fire, where burn lakes increased 10% and control lakes decreased -8% (P=0.061). Over the 5-10 year post-fire period, there was no significant difference in lake dynamics within burned areas relative to control unburned areas. On average, there was an 18 percent decrease in surface water within burned areas over the >10 year post fire time period, while unburned control lakes averaged a 1 percent decline in surface water. The long term declining trend within burned areas may have been due to talik expansion and/or increased evapotranspiration with revegetation of broadleaf plants. Fire had the greatest effect on radiant surface temperature within two years of a fire, where radiant temperatures increased 3-7˚C in the most severely impacted areas. Temperature differences between burn and control areas remained less than 1˚C as vegetation re-established. There was no correlation between radiant temperature change and decreasing lake area change. Conversely, there was a trend between lake area differences increasing in size and increases in temperature. While fire displayed the greatest effect on lake area in the short-term, a combination of fire, climate, and site-specific conditions dominate long-term lake area dynamics in Alaska boreal forest.

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Chapter 1 Introduction

Wildfire is the primary disturbance regime affecting thawing permafrost and ecosystem processes in boreal forests. In recent years, the fire regime in the boreal forest of interior Alaska has displayed a potential shift as significant increases in burned area and burn severity have occurred (Kasischke et al., 2010; Chapin et al., 2008; Johnstone et al., 2010; Balshi et al., 2009). Since the region is widely associated with discontinuous permafrost, which is often warmer than -1° C and especially prone to thawing after wildfire disturbance, increases in burn severity may lead to increases in active layer thickness, which may in turn, affect dynamics in surface and near surface hydrology (Roach et al., 2012).

One of the most readily observed indicators of hydrologic change are the numerous lakes covering ~10% of the boreal area (Schindler, 1996). In Alaska, over 400,000 lakes greater than 1Ha account for 3.3 percent of the state's total surface area (Arp & Jones, 2008). These surface features provide essential ecosystems for aquatic and terrestrial biota, and their dependence on local and regional climate make lakes and ponds increasingly accepted as indicators of climate variability (Hood & Bayley, 2008). In recent studies, regional drying and shrinking of lakes has been observed throughout the boreal areas of Alaska (Yoshikawa & Hinzman, 2003; Riordan et al., 2006; Rover et al., 2012; Corcorran et al., 2009, Chen et al., 2013), Canada (Labrecque et al. 2008; Carroll et al., 2012) and Siberia (Smith et al., 2005; Karlsson et al., 2012). Mechanisms driving perceived decreases in lake areas have been primarily attributed to climate warming and drying and include: (1) expanding floating vegetation coverage misinterpreted as reduction in lake area (Klein et al., 2005; Roach et al., 2011); (2) surface water evaporation exceeding water inputs (Anderson et al., 2013; Chen et al., 2013; Smol & Douglas, 2007); and (3) permafrost thaw increasing subsurface drainage (Yoshikwawa & Hinzman, 2003; Jepsen et al., 2013; Hinzman, 2006; Jorgenson et al., 2001; Osterkamp et al., 2000; Karlsson et al. 2012; Roach et al., 2013). Assuming a fixed lake bathymetry, lake area declines when lake water outputs (evaporation + surface outflow + subsurface outflow) are greater than lake water inputs (rainfall + snowmelt + surface inflow + subsurface inflow) over a designated period of time. Of course, if lake bed morphology changes from erosion or sedimentation, lake surface area might change even without changes in inputs or outputs of water.

Previous studies on northern lake dynamics have been conducted in three principle geographic provinces: the mostly permafrost free areas in southern boreal woodlands (Klein et al., 2005; Schindler et al., 1996); the greater boreal region associated with discontinuous permafrost (Riordan et al., 2006; Yoshikawa and Hinzman, 2003; Smith et al., 2005; Roach et al., 2011; Jepsen et al., 2012; Rover et al., 2012); and the continuous permafrost of the Arctic (Smith et al, 2005; Hinkel et al., 2005; Hinkel et al., 2010; Jones et al., 2011; Arp et al. 2011; Carroll et al., 2012). In the permafrost-free areas, increases in temperature and decreases in precipitation over the past 50 years have led to decreased stream flow (Schindler et al., 1996), vegetation encroachment, and subsequent terrestrialization (Klein et al., 2005), resulting in a substantial reduction in lake areas. In areas of discontinuous permafrost, lake dynamics are largely controlled by the presence of permafrost, active layer depth, and soil moisture. Regional trends have identified lake area shrinkage (Riordan et al., 2005; Smith et al., 2006), and both lake area shrinkage and expansion (Rover, et al, 2011; Roach et al., 2011; Chen et al., 2013; Jepsen et al., 2013), often resulting from development and deepening of the active layer. Expansion of the active layer results in thermokarst failure around the edges of lakes, and the loss of soil mass results in lake area expansion as water fills in the voids (Osterkamp et al., 2000; Jorgenson et al., 2001). In regions of groundwater upwelling, thermokarst activity is particularly prevalent due to relatively warm (2-4^{o} C) ground water temperatures that persist year-round (Jorgenson et al., 2001). The lake area decreases and drainage have been attributed to a deepening of the active layer, leading to breaching of the permafrost and subsequent drainage to the underlying water table (Smith et al., 2005; Hinzman, 2006; Karlsson et al., 2012; Jepsen et al., 2013). Expansion of unfrozen soil/thaw bulb (talik) that persists under deeper lakes that do not completely freeze in winter may result in lateral and vertical drainage from lakes perched above permafrost (Yoshikawa & Hinzman, 2003; Jepsen et al., 2012). Lake areas in Arctic continuous permafrost tend to fluctuate with annual precipitation since shorter growing seasons and lower temperatures result in less evaporation and active layer deepening (Jones et al., 2011; Plug et al., 2008). In lakes where vegetation mats are present, evapotranspiraton from floating sedge fens and sphagnum bogs may exceed evaporation from an open water surface and significantly contribute to lake area reduction (Roach et al., 2011; Smol & Douglas, 2007). Conversely, in continuous permafrost regions, floating vegetation mats may be indicative of lake expansion due to rapid thaw and bank failure along lake margins (Parsekian et al., 2011).

Comparisons of lakes in continuous and discontinuous permafrost display a continuum of effects. Lake areas in continuous permafrost tend to be stable, or when subjected to warming, increase from thermokarst activity and thermal erosion along lake edges (Arp et al., 2011). Conversely, there is widespread evidence of lakes in continuous permafrost regions that experience catastrophic drainage due to lateral discharge from thermokarst activity resulting in bank failure along a lake basin boundary (Mackay, 1988; Labrecque et al., 2009; Marsh et al., 2009; MacDonald et al., 2012). In discontinuous permafrost, decreases in lake area may result as drainage via talik is promoted by further warming (Yoshikawa & Hinzman, 2003; Smith et al., 2005; Jepsen et al., 2013). In addition to increased drainage, warmer temperatures and a longer growing season may result in ET increases and lower soil moisture (Wendler & Shulski, 2009; Riordan et al., 2006). Furthermore, explorations of the interactions between wildfire and permafrost may indicate changes in surface hydrology by removal of insulating vegetation, decreasing surface albedo, increasing thermal conductivity, and dramatically changing soil moisture profiles. For instance, Yoshikawa et al. (2003) observed decreased transpiration led to increases in soil moisture following fire. Since active layer depths are significantly deeper when insulating vegetation is completely consumed by fire, these changes are likely to be more pronounced in more severely burned areas (Yoshikawa et al. 2003; Viereck, 1982; Brown, 1983).

Fire has a profound influence on permafrost degradation. Since lakes have been shown to respond to permafrost degradation (Smith et al., 2005; Riordan et al., 2006), and permafrost degradation is expected to continue in marginal areas of discontinuous permafrost (Osterkamp & Romanovsky, 1999), we anticipate that fire will enhance this response of lakes in discontinuous permafrost where permafrost temperatures are warmer and more prone to thawing. In this study, the effect of wildfire on lake and pond surface area was examined in four sub-arctic boreal forest regions in interior Alaska (Fig. 2.1).

1.1 Objectives

We hypothesize that 1) ponds and lakes affected by fire will display greater surface area variability in the short term (0-5 years) period after a burn due to decreased transpiration and thus an increase in soil moisture compared to ponds located in the adjacent unburned control area. 2) In a longer period of > 10 years following fire, we expected a decrease in surface water due to establishment of early succession broadleaf vegetation and increased transpiration. Finally, 3) lakes displaying the greatest losses in surface area would occur in the most severely impacted thermal regimes due to permafrost degradation and drainage via taliks. To test these hypotheses, we use remote sensing and provide a multi-temporal examination of lake dynamics in disturbance areas (burned) and control areas (unburned).

1.2 Physiography and Climate

Interior Alaska is part of the larger circumpolar boreal forest, or Taiga, which covers 17 million km^2 of the Northern Hemisphere and accounts for approximately one third of Earth’s total forest area (http://www.lter.uaf.edu/about). Extensive vegetated landscapes, long cold winters, and low decomposition rates combine to cause the boreal biome to be the world's larges terrestrial carbon sink. The boreal forest occupies 60-70% of the land area in Alaska (Nowacki et al., 2001) and is predominately associated with Alaska's interior, which includes a total area of approximately 1,367,996km^2 (Van Cleve et al. 1983). This area is contained within the Northern Plateau's Physiographic Province and consists of several broad, nearly level lowlands with elevations mostly below 500m, as well as rounded mountains with elevations up to ~2000m (Ping et al., 2006; Wahrhaftig, 1965).

The continental climate of interior Alaska is strongly influenced by the orographic effects of the bounding Brooks Range to the north and Alaska Range to the south, which result in semi-arid conditions with annual precipitation rates ranging from < 200 mm to > 500 mm (Fleming et al., 2000; Hammond and Yarie, 1996). The two-year, 30-minute maximum precipitation intensity for Fairbanks, a site representative of boreal Alaska, is 1.306 cm/hr (NOAA Atlas 14 PFDS, 2012). Widely varying amounts of solar radiation throughout the year create large seasonal fluctuations in temperature, with absolute extremes ranging from -51 to 38 ˚C (Alaska Climate Center, 2005). Interior Alaska experiences 18 to 21 hours of sunlight per day during the summer months of June, July, and August with daily temperature highs reaching the mid 20s ˚C. In contrast, winter months have only 4-10 hours of sunlight per day and low temperatures below -40 ˚C. A mean annual temperature that is near freezing results in the formation of discontinuous permafrost throughout this region (Flemming et al., 2000) (Fig. 1.3).

Surface hydrology in Interior Alaska is characterized by several large, braided rivers, streams, lakes, ponds, fens, and bogs occurring throughout the region. Large meandering rivers draining the Yukon River basin flow along a low, east-to-west gradient from Canada to the Bering Sea (Fig. 1.1). The numerous lakes found across the landscape are largely due to the presence of permafrost, which acts as an aquiclude, limiting subsurface and surface water exchanges. Principal lake types in Alaska include thermokarst lakes, fluvial lakes, glacial lakes, and moraine lakes (Arp & Jones, 2009).

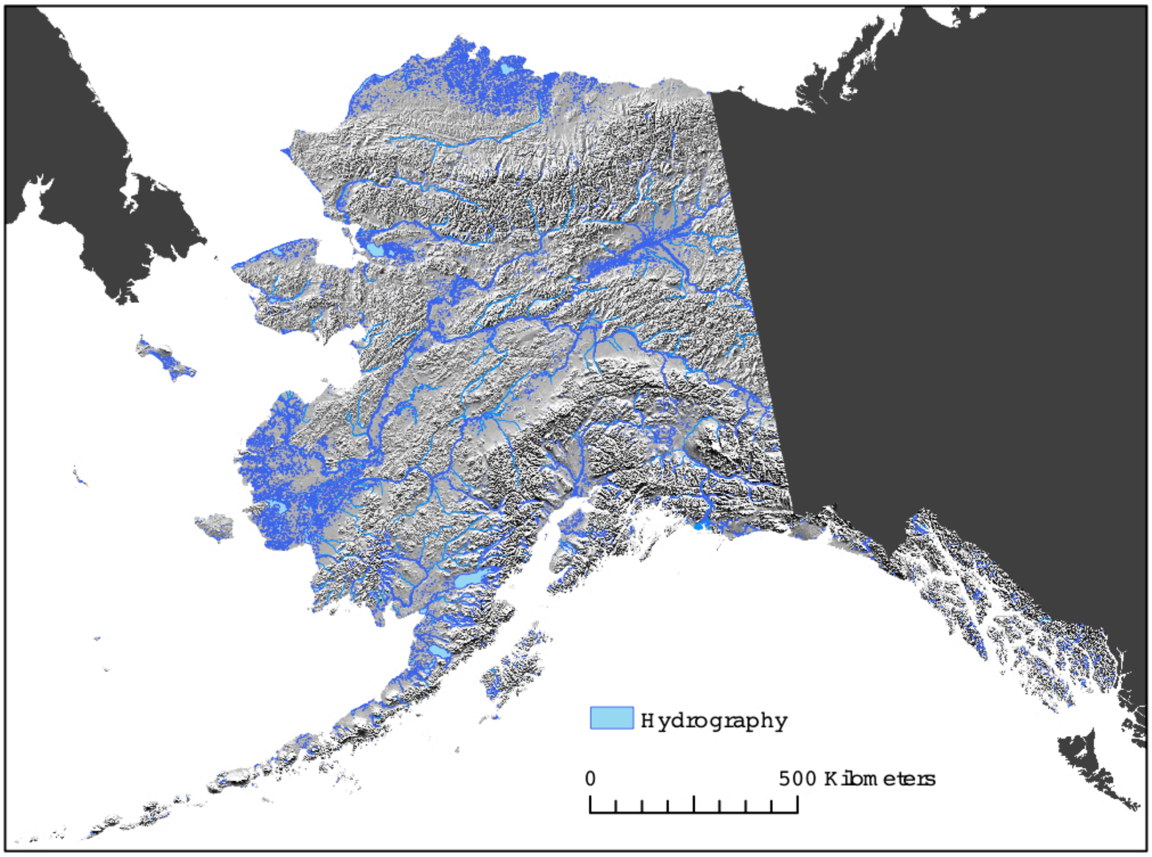


Figure 1.1 Alaska surface hydrology. Derived from the USGS 1:1,000,000 scale hydro data set. Shaded relief base map is based on a 300-meter digital elevation model (DEM).

Surface geology throughout our four lowland study areas consists of alluvial or lacustrine plains mostly derived from glacial sediment (Pewe, 1975). Vegetation community in this region is controlled by aspect, elevation, soil type, soil moisture, permafrost, and succession stage following disturbance (Chapin et al., 2004). These factors result in a complex mosaic of black and white spruce forests, birch and aspen woodlands, sedge meadows, and grasslands persisting throughout the study area. Wildfire, floods, and highly diverse and variable insect outbreaks are the major disturbance mechanisms affecting successional processes in Alaska boreal forest (Chapin et al., 2004). This paper will focus on disturbance by fire.

1.3 Fire History

Wildfire is ubiquitous to boreal Alaska and is the primary large-scale disturbance regime affecting upland successional trajectories in boreal forests (Johnstone, 2003). The combination of semi-arid climate conditions and flammable vegetation throughout Interior Alaska lend itself as the region in Alaska where the majority (96%) of wildfires occur (Fig. 1.2). The fire season lasts from April to September with the greatest activity from May to July, as high-pressure systems over the interior bring warm temperatures and low humidity (Viereck, 1973). From 1950-2009, 14 large fire years (>470,000ha burned) account for the majority of total burned area when examining decadal averages (Kasischke et al., 2010), and an average area of 400,000 ha burned annually. The highest average annual burned area was 767,000 ha in 2004.

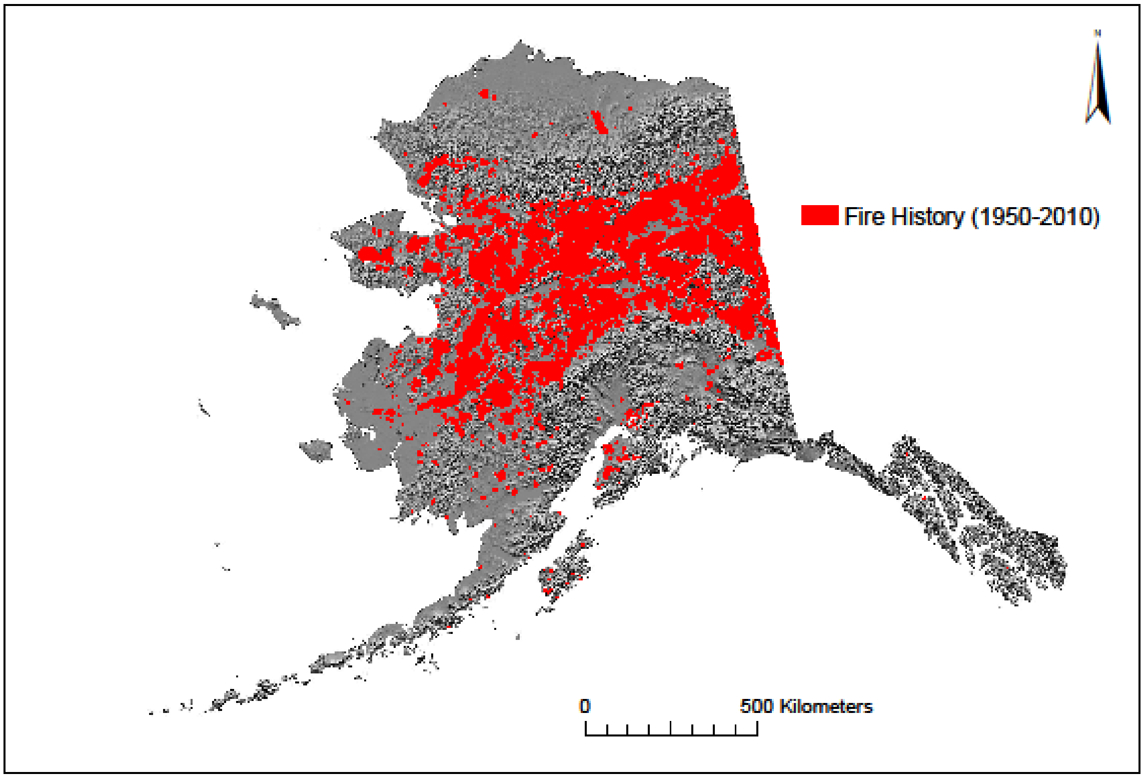
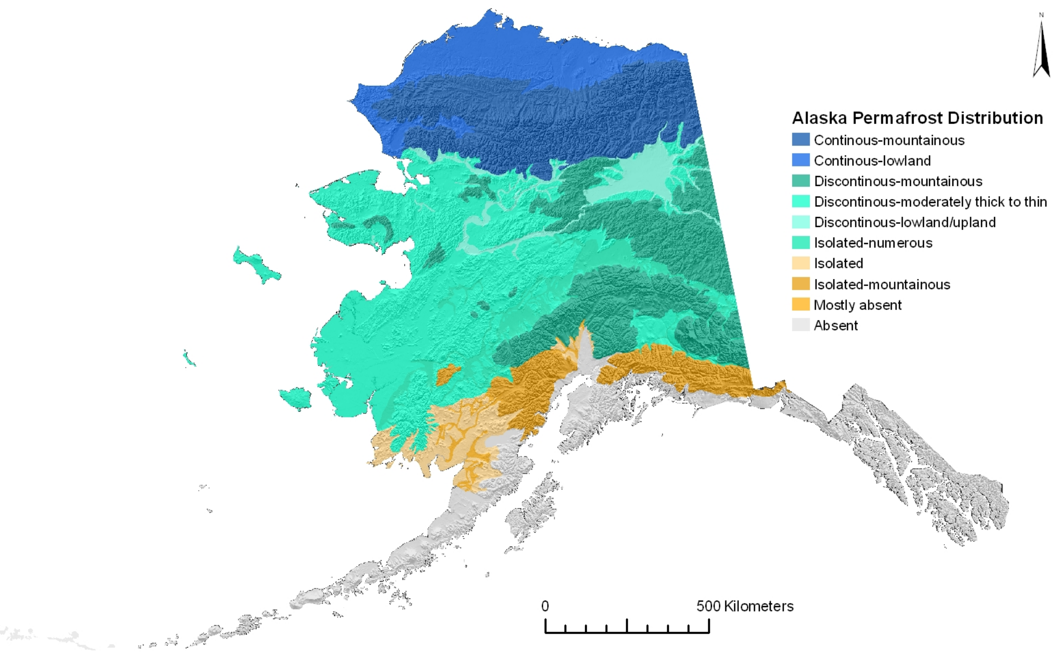


Figure 1.2 Alaska Fire History from 1950 – 2009. The majority fires (~96%) occur in the interior portion of the state.

1.4 Permafrost

Permafrost is defined as material confined below the Earth's surface in which temperatures have remained at or below 0 ˚C for two or more years. Approximately 24% of the World's non-glacierized land area (25.5 million ha) and an estimated 18-24% of the Northern Hemisphere is underlain with permafrost (Brown, et al., 1998; Zhang et al., 2008). Permafrost extent is divided into four classes, based upon the estimated percentage of the ground that is underlain by permafrost: continuous (90 to 100%); discontinuous (50 to 90%); sporadic (10 to 50%); isolated patches (0 to 10 %); and no permafrost (Brown et al., 1998). Alaska's Interior is widely associated with discontinuous permafrost, which encompasses 17% of global permafrost areas (Fig. 1.3). At least half of all permafrost areas are covered with boreal forest (Osterkamp et al., 2000).



Ferrians, O., 1998: Permafrost Map of Alaska, USA. NSIDC, Boulder, CO, USA.

Figure 1.3 Permafrost map of Alaska (Ferrians, 1998). The region of discontinuous permafrost is predominantly associated with interior Alaska.

1.5 Active Layer

Overlying permafrost is the active layer that seasonally thaws during the summer months and refreezes during the winter. The active layer thickness varies annually in response to air and surface temperature and is strongly influenced by the thickness of the organic layer. Usually only 1 or 2 m at the surface is subject to thaw (Osterkamp, et al., 2000). When fire reduces or completely consumes the organic layer, active layer depths may increase significantly due to a reduction of the insulating affect of the organic material; an increase in solar radiation incident on the newly exposed mineral soil; the increased absorption of that solar radiation due to the decreased albedo, i.e., a blackening of the surface after fire; and a possible increase in heat flux into the ground due to increased soil thermal conductivity as soil moisture content increases in response to reduced transpiration from killed vascular plant cover (Yoshikawa et al., 2003).

Soil moisture in the active layer may be moist to saturated as the permafrost table acts as an impermeable layer, or aquiclude, reducing infiltration and percolation from precipitation and snowmelt water (Riordan et al., 2006; Hinzman et al., 2006). When permafrost thaws substantially, or becomes discontinuous, downward percolation of near surface water and soil water can occur. This may result in drier surface conditions and lake shrinking as water is able to drain laterally and vertically through the active layer or connections with unfrozen patches of ground known as 'talik' formations (Yoshikawa & Hinzman, 2003). In areas of groundwater upwelling, lake area expansion may occur as thermokarst features develop around lake edges from the warmer groundwater thawing ice rich permafrost and subsequently filling in the voids (Jorgenson, 2001).

Chapter 2 Methods

A multi-temporal analysis using remote sensing and Geographic Information Systems (GIS) was performed to examine the effects of wildfire on pond dynamics. An observation period of 25 years (1984-2009) was selected based upon temporal overlap of historical fire data (http://fire.ak.blm.gov/) and acquisition of Landsat imagery (Appendix A).

2.1 Study Areas

Four lowland regions in the interior of Alaska were selected for this study: The Yukon Flats; Tanana Valley; Minchumina Basin; and Innoko Flats (Fig. 2.1).

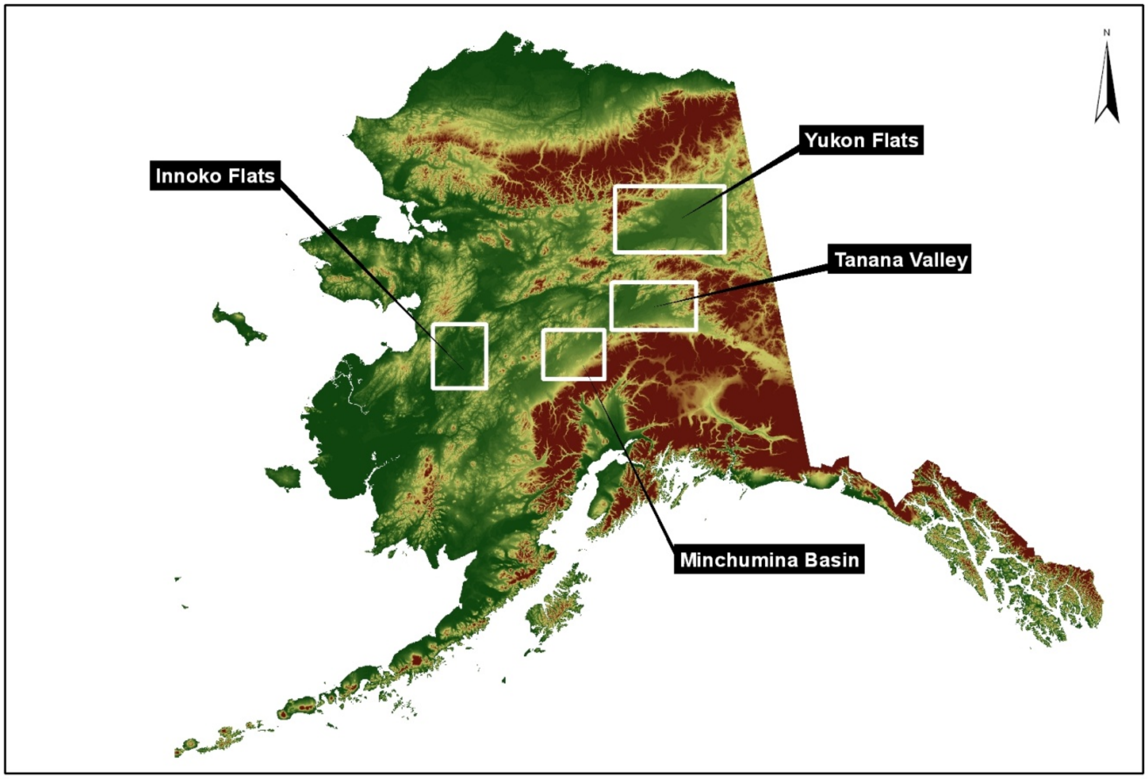


Figure 2.1 Study area. Four areas were selected in for this study: Yukon Flats, Tanana Valley, Minchumina Basin, and Innoko Flats. The study areas are contained in the boreal region of interior Alaska.

Study area selection was based on site association with discontinuous permafrost according to map by Brown et al., 1998 (Fig. 1.3), lake and pond abundance, previous lake studies, and historical fire incidence between 1950 and 2009. Surface geology in our four study regions consists of alluvial or lacustrine plains mostly derived from glacial sediment. Our analysis was constrained to nearly level areas with slope gradients of less than 5 percent. Site comparability to similar regions based on this criterion was also considered to allow a landscape-scale analysis. Agencies responsible for managing the lands associated with these study regions include the U.S. Fish & Wildlife Service, U.S. National Park Service, U.S. Bureau of Land Management, U.S. Army Lands, Alaska State Forestry, and multiple Native Corporations.

2.2 Lake area selection

Within each study area, a random sample of lakes in each burn area (burn lakes) since 1981 was extracted with a manually selected sample of control lakes and ponds in adjacent non-burned areas (Fig. 2.2). Criteria for selecting control lakes were based on proximity to burn area (< 5 km), lake size (< ± 25% change in relation to the mean lake area for all observations), hydrologic similarity (proximity and connectivity with other features), vegetation, and topography. Pond variability in control areas was expected to reflect local climate and site characteristics, independent of disturbance regime, therefore lakes that became inundated by alluvial flooding within any image were rejected. By comparing lakes in burn areas to lakes in unburned control areas, we sought to capture the effects of fire on lake dynamics. Because deeper lakes are likely to be more stable and mask the effects caused by a disturbance, our analysis focused on using shallow lakes (lakes displaying >10% surface area variability in the time series) in both burn areas and control areas in order to maximize any effect from fire or natural variability.

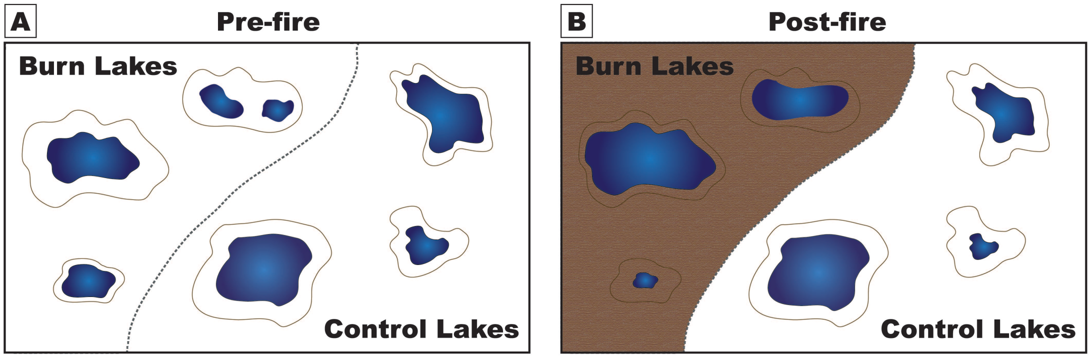


Figure 2.2 Burn lakes and control lakes selection. By selecting burn lakes (lakes contained within burn scars) to control lakes (lakes outside burn scars, the effect of fire on individual lakes could be assessed.

An initial review of lakes in 86 burn areas was performed to visually identify individual lakes in burned areas displaying non-synchronous changes in lake area (i.e. shrinking, growing, or completely drained) in comparison to control lakes and other burned lakes associated with the same site. The water bodies displaying such change were initially tagged to provide a visual estimate of how many fires may be dramatically influencing lake areas. Available satellite imagery was reviewed for each fire site (see Appendix A), and a total of 20 fire sites were selected for lake area extraction. A total of 249 individual lakes were extracted from these fire sites, with 147 lakes in burned areas and 102 lakes in adjacent unburned control areas.

Table 2.1 Summary of selected fire sites and total observed lakes (≥ ± 25%) within each study area. A total of 249 lakes were examined, with 147 occurring in burn areas and 102 in control areas.

Total lake observations

Region	Fire Year	Fire Name	Lakes		Imagery	
			burn	cntrl	pre-fire	post-fire
YF	2004	Lower Mouth	6	5	7	6
YF	2005	John Herberts Village	3	2	4	5
YF	1988	832015	6	6	1	6
YF	2005	Squirrel Creek	3	3	2	2
YF	2004	Dall River	10	8	2	4
TAN	2001	Teklanika	9	6	2	7
TAN	2001	Survey Line	4	4	3	6
TAN	2005	Parks Highway	11	4	4	3
TAN	1998	Carla Lake	15	10	4	4
TAN	1995	Minto Flats	7	5	2	4
TAN	1983	BIG W 17	7	3	0	10
MIN	1986	631010	11	6	2	5
MIN	1990	TAL S76	4	4	2	4
MIN	1990	TAL SE 87	9	6	2	4
MIN	2000	Foraker	5	7	2	4
INN	2000	Yukon Creek	9	6	3	3
INN	2004	Big Yetna	6	4	3	3
INN	2002	Yetna River	7	3	3	3
INN	2004	Bonanza Creek	10	7	3	2
INN	1997	Magitchlie Creek	5	3	2	3
		sum	147	102	53	88
		total	**249**		**141**	

2.3 Remote Sensing Techniques

Images from the Landsat Thematic Mapper (TM) and the Enhanced Thematic Mapper Plus (ETM+) sensors were used to examine changes during the 25-year observation period. Landsat-4 (L4) was launched on 16 July 1982 and Landsat-5 (L5) entered orbit on 01 March 1984. Both satellites operated with the TM Earth-imaging sensor on board. L4 operations ended on 14 December 1993 when the sensor lost its ability to transmit data, while the L5 satellite and TM sensor continued to be operational until November, 2011. The Landsat-7 (L7) satellite with the ETM+ sensor was launched in 1999 and recorded reliable imagery prior to scan-line correction failure in May 2003.

With repeat coverage since 1984 and a nominal resolution of 30m, Landsat provides an effective platform for investigating long and short-term trends throughout the remote regions of Alaska. Appendix A lists each sensor, scene, date, and region covered. We began by georeferencing each satellite image to the UTM coordinate system, with a minimum of 28 control points and a root-mean square (RMS) error of < 30. Despite resolution limits for detecting subtle (<30m) changes at the site level, Landsat TM/ETM+ imagery has been > 96% effective in detecting trends in small (> 0.4 ha) lakes and ponds at both site specific and regional scales (Frazier and Page, 2000; Gilmer and Work, 1977). To examine open water changes, imagery was obtained from the summer months of May to September and included over 700 individual clipped scenes for this study (Appendix A). Applicable scenes were constrained temporally by limited scene availability during the privatization periods of Landsat from 1992 to mid-2001, and spatially from the presence of clouds, or smoke from wildfires. Due to high latitude solar elevation angles, shadows produced by clouds are usually larger than the cloud themselves, resulting in extensive shadowing on the land surface (Riordan et al., 2006).

2.4 Radiant Temperature Analysis

Surface temperatures from burn and control areas were attained from pre- and post-fire observations. Thermal observation dates coincide with lake area observation dates. Pre-fire observations are from an acquisition date most proximal to burn date and post-fire imagery is selected from observations 1-8 years following a burn. Temperature differences between images are determined by comparing control areas outside the burn between the two periods. The imagery temperature difference between control areas is subtracted from the burn area temperature difference to calculate the thermal impact of fire within the burn area.

To calculate the radiant surface temperature change associated with each fire, we applied Landsat TM/ETM+ thermal infrared (band 6) as an estimate for burn severity. Level 1 (L1) reflectivity from band 6 was radiometrically calibrated using the updated tables in Chander et al. (2009) and converted to radiance at the sensor using the following (eq. 1):

$$L_{\lambda =} G \times Q_{cal} + B \qquad \textbf{(1)}$$

Where G is the band specific gain factor (W/(m2 sr µm)/DN), and B is the band specific bias factor, and Q_{cal} is the calibrated Digital Number (DN) (note that the pixel values of Landsat level-1 product is given in Q_{cal} values). The band specific gain G is defined as follows (eq. 2):

$$G = \frac{L_{max_{\lambda}} - L_{max_{\lambda}}}{Q_{cal_{max}} - Q_{cal_{min}}} \qquad \textbf{(2)}$$

Where $L_{max_{\lambda}}$ and $L_{min_{\lambda}}$ (W/(m2 sr µm)), are the minimum and maximum spectral radiances at the sensor respectively, and $Q_{cal_{max}}$ and $Q_{cal_{min}}$ $Q_{cal_{min}}$ (W/(m2 sr µm)) are the maximum and minimum calibrated pixels values corresponding to $L_{max_{\lambda}}$ and $L_{min_{\lambda}}$, respectively. The band specific bias is defined as follows (eq. 3):

$$B = L_{min_{\lambda}} - \left(\frac{L_{max_{\lambda}} - L_{max_{\lambda}}}{Q_{cal_{max}} - Q_{cal_{min}}}\right) X\ Q_{cal_{min}} \qquad \textbf{(3)}$$

The computed radiance values (L_{λ}) were then converted to radiant temperature (Kelvin) using (eq. 4):

$$T = \frac{K2}{\ln\left(\frac{K1}{L_{\lambda}} + 1\right)} \qquad \textbf{(4)}$$

Where T is the effective at-satellite temperature in Kelvin, K2 is the calibration constant-2 obtained from Table 7 (Chander, 2009), K1 is the calibration constant-1 obtained from Table 7, and L_{λ} is the spectral radiance at the sensor (W/(m2 ·sr · μm)).

For the surface temperature analysis, radiant temperature (Kelvin) values were converted to degrees C as (eq. 5):

$$C^{\circ} = {}^{\circ}K - 273 \qquad \textbf{(5)}$$

To assess the thermal impact on individual lake surroundings, radiant surface temperatures were assessed at 100-meter distance intervals from the lake shoreline to determine the buffer distance that maximized the thermal impact from fire in comparison to an unburned lake (Fig. 2.3). A buffer distance of 400 meters was used because maximum temperature change was relatively constant at distances > 400m. In the event an adjacent lake or wetland was present, the buffer distance was lowered to a distance ≥ 100m to minimize the effect of low temperature values associated with an adjacent riparian area.

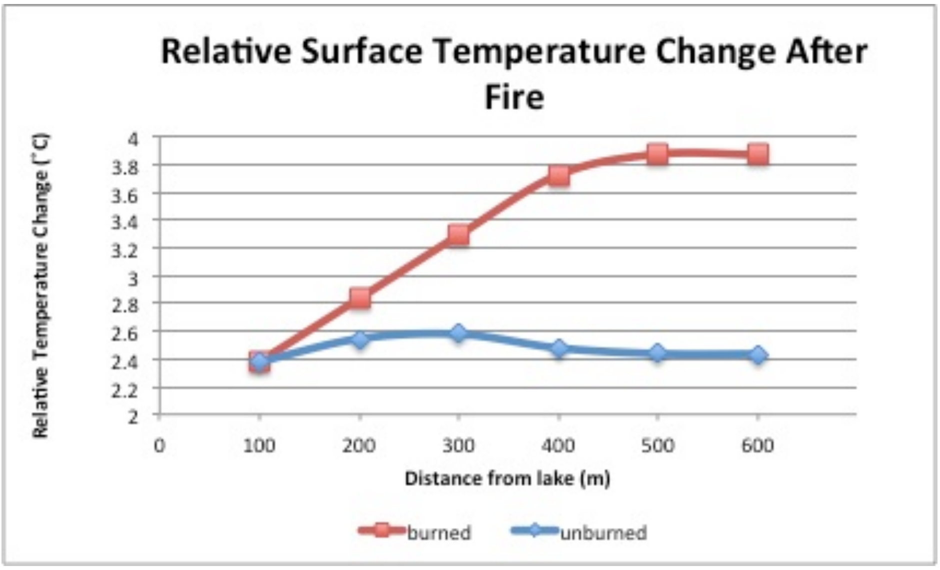


Figure 2.3 Relative surface temperature change observed one year after a fire. Radiant surface temperature values at 100-meter distance intervals from the shoreline of a burned lake and unburned lake Imagery acquisition: 19 June 1999 and 17 August 2001. Fire occurred in 2000.

2.5 Water body extraction

Water absorbs solar radiation in the near-infrared and mid-infrared spectral regions (Jenson, 1996). With a spectral range of 1.55-1.75 µm, Landsat band 5 has been widely used for successful detection of surface water features (Sethre et al., 2005; Lichvar et al., 2004; Frazier & Page, 2000; Smith et al., 2005). Each scene in our data had a unique range of band 5 DN values and no consistent threshold value could be applied for water body detection across all scenes. Therefore, we applied a density slicing method based upon histogram analysis for each band 5 image (Fig. 2.4).

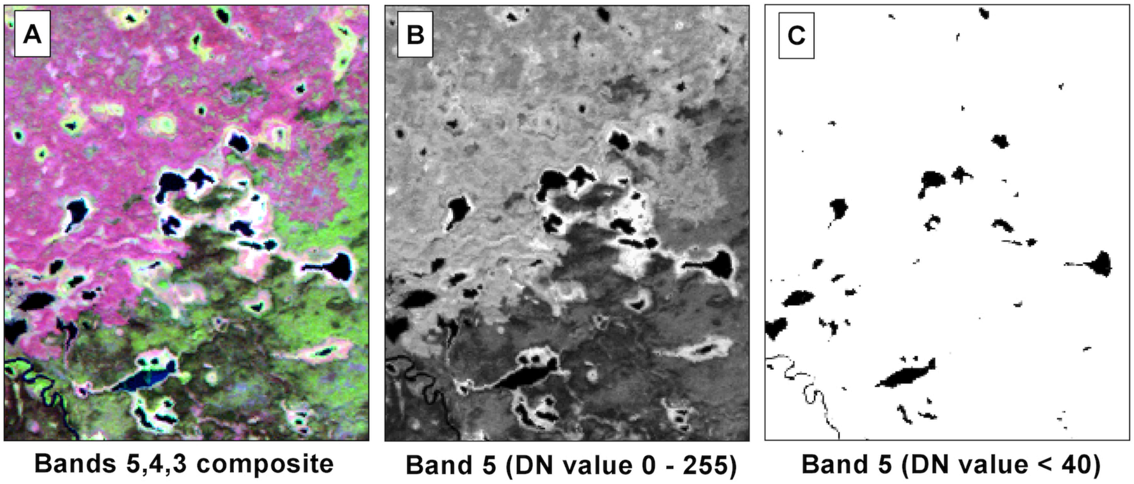


Figure 2.4 Landsat TM Bands 5, 4, 3 (near-IR, G, B) composite (A), Band 5 grey scale (B), Band 5 density slice (C).

Spectral overlapping between water, and dark pixels induced by hills, clouds, and black spruce forests, required further visual refinement. To visually verify the threshold at which overlapping between water and dark pixels (primarily dark shadows and/or black spruce forest) occurs, false color composites using bands 5 (Mid-IR), 4 (NIR), 3 (Red) were created. Composite images were visually compared with density slice results until suitable hydrologic feature extraction was attained. The delineated raster was converted into a polygon shapefile format and polygon lake areas were calculated in hectare units (ha). The shapefiles from burned and control areas were then compiled for multi-temporal analysis.

2.6 GIS Analysis

GIS analysis consisted of compiling fire history data, processing available imagery, water body extraction, and calculating area of open water.

The Alaska Fire Service maintains a large data set of all Alaska wildfires occurring from 1950 to the present (http://fire.ak.blm.gov/). Fire parameters from individual fires have been digitized both manually and more recently with the aid of satellite imagery, providing a comprehensive Alaska fire history data set (Fig. 1.2). A total of 86 individual fires occurring in our study areas during a 25-year period from 1981-2006 were identified. Individual fire sites were then selected based on the availability of lakes satisfying our criteria for lake area, and the availability of at least four reliable satellite images from different time periods. This resulted in a total of 20 individual fire sites where lake area dynamics in relation to fire were examined.

For each fire area, a 2” NED (National Elevation Data Set) digital elevation model was obtained from the USGS Seamless web server (http://seamless.usgs.gov/) to identify lowlands with minimal relief both inside (burn) and outside (control) the fire parameter. Since many sites were adjacent to hills or rivers, we chose to manually select, rather than buffer, the extent of analysis for each site. This method also facilitated a greater attainment of representative lakes in control areas, rather than applying an arbitrary distance that would have excluded lakes with similar spatial characteristics.

2.7 Lake Area Analyses

We quantified lake area change for individual lakes as the percent area change relative to the pre-fire lake area mean. The percent area change was then averaged over all lakes in burn or control groups to indicate the mean percent change for each group. We then calculated the difference in mean percent change between burn and control groups by subtracting the mean percent change of control lakes from the mean percent change of burn lakes (Fig. 2.5). A single paired t-test with an α level of 0.1 was used to compare lake area changes during the pre-fire period, and post-fire periods divided into short-term (0-5 years), mid-term (5-10 years), and long-term (10+ years) intervals.

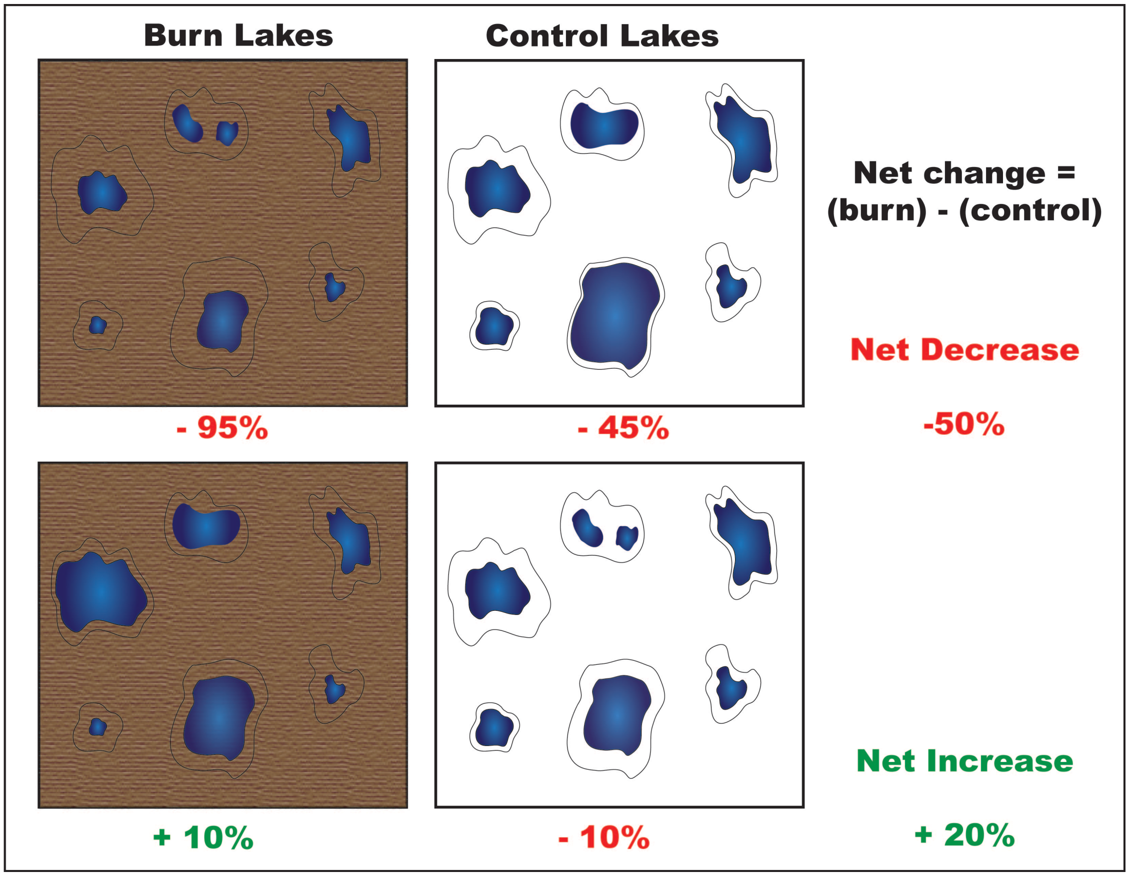


Figure 2.5 Calculating the difference in percent area change. The percent area change relative to the pre-fire lake area mean was calculated for individual lakes. The percent area change was then averaged over all lakes in burn or control groups to indicate the mean percent change for each group. The difference in mean percent change between each burn and control group was derived by subtracting the mean percent change of control lakes from the mean percent change of burn lakes.

2.8 Statistical Analyses

The effect of fire on lake areas was statistically tested using a linear regression model (Eq. 6). Since lake areas can be effected by various factors even in the absence of fire occurrence, lake areas will naturally fluctuate in response to precipitation, surface runoff, evaporation, groundwater flux, and river stage level (for lakes with channel connections to rivers). In order to detect the effect of fire on lake areas, it is imperative to know the natural variability of lakes without fire occurrence. Since the control lakes selected were adjacent to the burned region for each study site, they can be used to represent the natural variability of lake areas without the impact of fire. Our assumption is that lakes in both burned areas and control areas were adjacent or very close (<5km) so their natural variability (without fire) may be influenced or controlled by similar factors such as local water balance, topography, and permafrost distribution. Therefore, lake fluctuations in both burned and control areas should behave similarly, so that we can predict how lakes in burned area will change when we observe the change in control lakes (Fig. 2.6). Under this assumption, we account for the impacts of other factors on lake areas by including control lakes in the model, which makes it possible to more confidently detect the effect of fire.

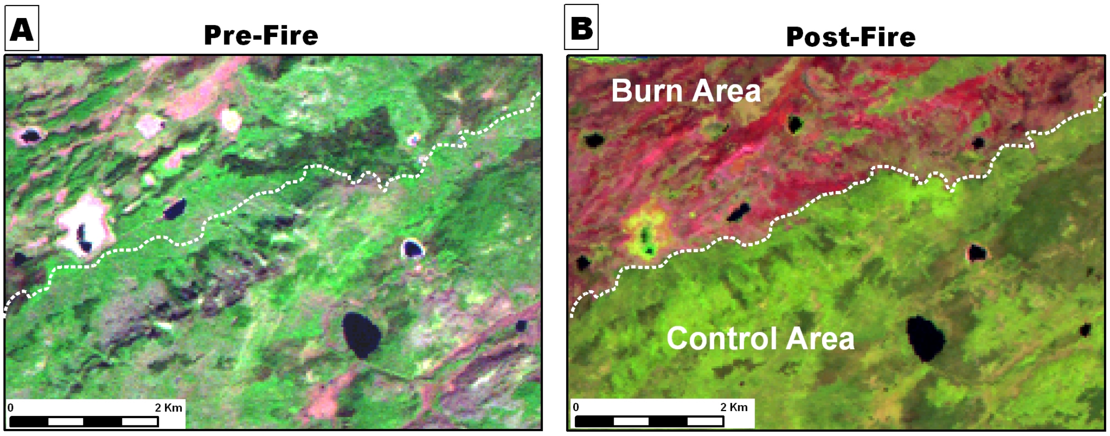


Figure 2.6 Sampled lakes used for regression analysis. Landsat Bands 5,4,3 composite images displaying pre-fire (A), and post-fire (B) burn and control areas. The total area of sampled lakes from each burn area was compared with the total area of sampled lakes in the corresponding control area.

Our linear regression model is as follows (eq. 6):

$$lake.b = a + b \bullet lake.c + c_1 f_1 + c_2 f_2 + c_3 f_3 + e$$

Where *lake.b* is the total area of sampled lakes in a particular burn area, *lake.c* is the total area of sampled lakes in the corresponding control area, $f_{1,2,3}$ are the dummy variables representing the different temporal ranges following wildfire, f_1 is the short term period (0-5 years), f_2 is the mid term period (6-10 years), and f_3 is the long term period (> 10years) following wildfire. a is the intercept, b, c_1, c_2, c_3 are the coefficients of *lake.c*, $f_{1,2,3}$ respectively, and e is the error term. The threshold for significance is 0.1. The criterion for this threshold is based on the relatively small sample size.

In some cases, there was no significant correlation between burned lakes and control lakes across all time periods, pre- and post-fire, which indicated that factors controlling the lake area might be different between burned sites and control sites, such as distribution of permafrost or connection to rivers. In those cases, control lakes could not reflect the natural variability of lakes in burned areas and were not useful to include them in the model. Instead, we performed a separate regression analysis of the burn lakes with the time of observation based on the Julian day of that year to provide a control for the natural water balance. The premise for this analysis is that lake levels will behave similarly throughout the season, with early season (May – June) lakes displaying the greatest surface area due to lake level recharge from spring runoff, and late-season (August - September) lakes exhibiting lower surface areas due to water deficits resulting from increased evaporation and less precipitation (Bowling et al., 2003). Using the Julian date, we postulate the coefficient estimate will be negative due to lake areas decreasing throughout the season.

Chapter 3 Results

3.1 Differences in mean lake areas between burn and control groups

The variability of the lake area mean differences obtained from all four study areas are plotted in figure 3.1. Each point represents the difference in mean percent change for each fire area relative to the unburned control area during the observation period. Observations throughout all time periods have both negative and positive differences, indicating the variability of lake areas was heterogeneous with no consistent trajectory in lake area change.

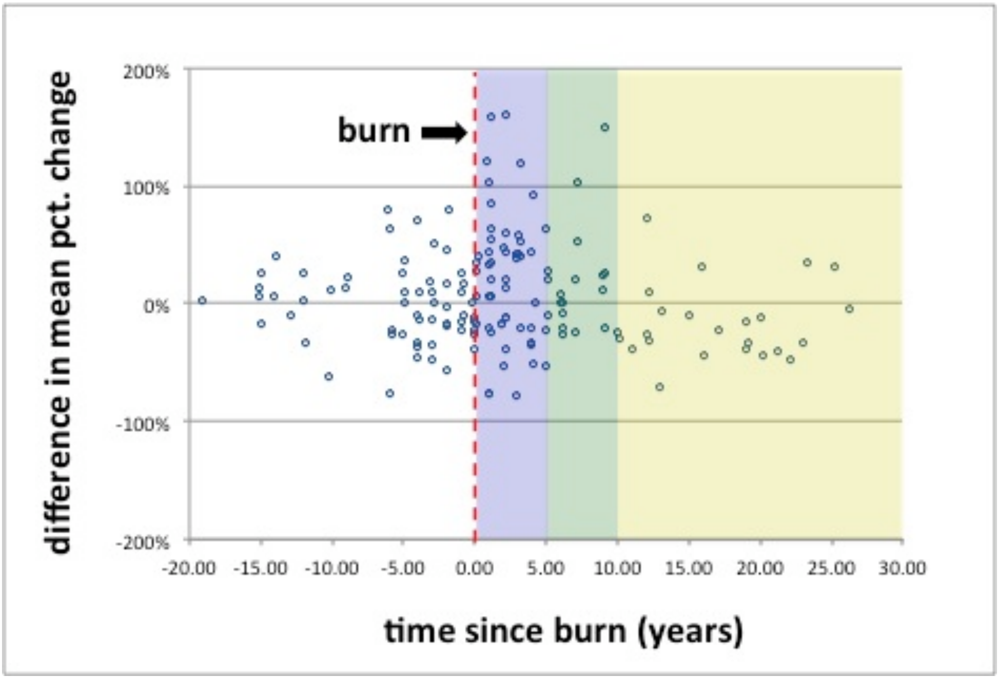


Figure 3.1 Difference in mean percent change of lake areas in burn and control groups. The x-axis represents the time of all observations in relation to fire occurrence, with the short-term (0-5 years), mid-term (5-10 years), and long term (> 10 years) periods colored as blue, green, and yellow, respectively. The Y-axis represents the difference in mean percent lake area change between burn and control groups. Natural variation before fire is ± 100%. Only in the period after fire (< 10 years) is this threshold exceeded, and consistently as the mean percent change of lakes in burn areas expanded positively as these lake areas increased in comparison to lakes in control areas.

No significant trend in time was observed ($p > 0.1$) when comparing total observations (n=152) across all pre-fire and post fire time periods (Fig. 3.1). When we divide the post-fire period into three parts, more statistically significant patterns in time emerge. In the short-term (0-5 years) period following fire, the expansion of lakes in burn areas compared to lakes in control areas is evident as the range of net percent change between burn and control lake areas is notably greater than any other period before or after fire (see fig. 3.1). A single paired t-test from this period indicates that burn lakes increased 10% and control lakes decreased -8% ($p = 0.061$). During the mid-term (5-10 year) period, there was no significant effect ($p > 0.1$) from fire. However, during the long-term (> 10 years) period, observations showed an -18% decrease in burn lakes, compared to control lakes that remained relatively stable with only a 1% increase.

3.2 Regional observations related to lake area differences between burn and control groups

Since variability and the number of observations were greatest in the short-term period following fire, we compared the short-term variability in mean percent lake area differences during in each study region (Fig. 3.2). The greatest differences in lake areas between burn and control areas occurred in the Yukon Flats and Tanana Flats region. The Innoko flats displayed mostly positive increases in lake area between burn lakes and control lakes ($\mu = 38\%$), while the Minchumina Basin showed the least variability between burn and control lakes.

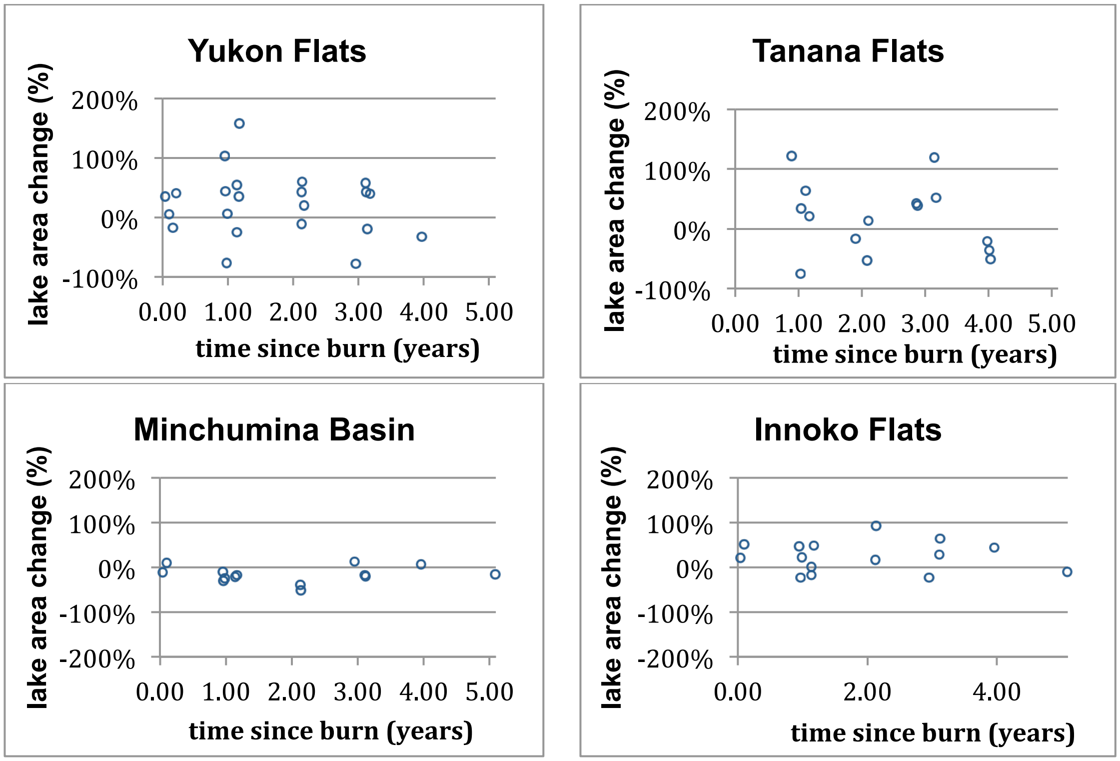


Figure 3.2 Regional variability observed during the short-term (0-5 years) period following fire. The Yukon Flats and Tanana flats displayed the largest range of lake area differences between burn and control groups. Minchumina Basin net average lake area differences displayed mostly negative values, while values in the Innoko Flats were mostly positive.

3.3 Linear regression results

Regression analysis indicates that half (50%) of the 20 fires sites displayed a significant correlation ($p > 0.1$) in the lake areas between the control and burn groups (Table 3.1). This positive correlation indicates that lakes in both control areas and burned areas behaved similarly across all time periods, indicating that control lakes may account for the natural variability resulting from all other factors beyond fire for lakes in burn areas. We therefore use these 10 reliable data sets to further examine the effect of fire on lake area using linear regression analysis.

Table 3.1 Regression analysis of fire influence on lake area for all fire sites. In the 20 data sets, half of these fires displayed strong correlations ($p < 0.1$) with the control variable, indicating that control lakes provide a reliable baseline for assessing the effect of fire on burn lakes.

Regression analysis of fire influence on lake area in each study site

Region	Fire Year	Fire Name	lake.c		short-term (<5 yrs)		mid-term (6-10 yrs)		long-term (>10 yrs)		R^2		Images		Lakes		Total lake area (Ha) in burn*
			coef. (b)	P-value	coef. (c_1)	P-value	coef. (c_2)	P-value	coef. (c_3)	P-value	multiple	adjusted	pre-fire	post-fire	burn	cntrl	
YF	2004	Lower Mouth	0.65	**0.07**	-2.69	0.49	-9.42	0.20	n/a	n/a	0.50	0.33	7	6	6	5	18.08
YF	2005	John Herberts Village	0.57	0.18	-0.68	0.42	n/a	n/a	n/a	n/a	0.53	0.37	4	5	3	2	4.09
YF	1988	832015	-0.45	0.70	-37.53	0.25	n/a	n/a	-115.03	***0.03***	0.91	0.82	1	6	6	6	95.70
YF	2005	Squirrel Creek	0.95	0.23	1.55	0.27	n/a	n/a	n/a	n/a	0.88	0.64	2	2	3	3	3.53
YF	2004	Dall River	2.66	***0.04***	-2.81	0.36	13.79	0.16	n/a	n/a	0.95	0.88	2	4	10	8	31.52
TAN	2001	Teklanika	2.57	0.25	1.46	0.73	3.31	0.57	n/a	n/a	0.29	-0.13	2	7	9	6	15.95
TAN	2001	Survey Line	1.09	0.16	-16.95	***0.05***	-18.11	***0.04***	n/a	n/a	0.73	0.57	3	6	4	4	16.22
TAN	2005	Parks Highway	11.23	***0.02***	13.02	**0.12**	n/a	n/a	n/a	n/a	0.82	0.73	4	3	11	4	26.32
TAN	1998	Carla Lake	1.19	***0.01***	7.90	***0.04***	4.60	0.29	-4.15	0.24	0.95	0.89	4	4	15	10	58.15
TAN	1995	Minto Flats	0.44	0.39	-6.43	0.48	-3.98	0.55	-2.50	0.77	0.89	0.43	2	4	7	5	6.02
TAN	1983	BIG W 17	2.35	***0.05***	n/a	n/a	-3.03	**0.07**	-3.53	***0.01***	0.77	0.66	0	10	7	3	6.59
MIN	1986	631010	2.91	***0.002***	n/a	n/a	n/a	n/a	-11.63	0.21	0.94	0.92	2	5	11	6	107.14
MIN	1990	TAL S76	-0.31	**0.10**	-4.11	**0.04**	-3.24	**0.03**	-1.86	**0.06**	0.98	0.90	2	4	4	4	14.97
MIN	1990	TAL SE 87	1.34	0.23	n/a	n/a	5.96	0.78	-19.86	0.30	0.84	0.59	2	4	9	6	58.22
MIN	2000	Foraker	0.53	*0.14*	-1.06	0.75	0.68	0.63	n/a	n/a	0.96	0.89	2	4	5	7	8.36
INN	2000	Yukon Creek	4.55	***0.02***	16.24	**0.06**	-7.96	***0.03***	n/a	n/a	0.98	0.95	3	3	9	6	33.75
INN	2004	Big Yetna	0.48	**0.04**	-0.11	0.85	n/a	n/a	n/a	n/a	0.31	-0.14	3	3	6	4	4.63
INN	2002	Yetna River	1.80	**0.07**	0.36	0.82	-1.30	0.36	n/a	n/a	0.95	0.87	3	3	7	3	11.68
INN	2004	Bonanza Creek	5.77	0.23	-19.55	0.32	n/a	n/a	n/a	n/a	0.61	0.22	3	2	10	7	49.04
INN	1997	Magitchlie Creek	1.52	0.16	-3.19	0.64	-0.87	0.84	n/a	n/a	0.97	0.88	2	3	5	3	34.15
												sum	53	88	147	102	
												total	141		249		

(lake.c =variable indicating local water balance)

* = total lake area averaged over all time periods for observed shallow lakes in burn areas

Examinations of the ten data sets with $p < 0.1$ reveal varying effects of fire on lake area lake area throughout the three temporal periods following fire.

3.4 Short-term regression results

In the short-term period, four of these fires displayed p-values < 0.1, indicating a strong effect on lake area from fire (Table 3.2). Two of these fires occurred in the Tanana Valley (Parks Highway, Carla Lake), one in the Minchumina Basin (TAL S76), and one in the Innoko Flats (Yukon Creek).

Table 3.1 Short-term (0-5 years) regression analyses. Lake areas expanded in the Parks Highway, Carla Lake, and Yukon Creek fires sites, while a decrease was observed in the TAL S76 fire site during the short-term period.

Region	Fire Year	Fire Name	lake.c		short-term (0-5 yrs)		R^2		Total lake area (Ha) in burn*
			coef. (b)	P-value	coef. (c_2)	P-value	multiple	adjusted	
TAN	2005	Parks Highway	11.23	***0.02***	13.02	**0.12**	0.82	0.73	26.32
TAN	1998	Carla Lake	1.19	***0.01***	7.90	***0.04***	0.95	0.89	58.15
MIN	1990	TAL S76	-0.31	**0.10**	-4.11	***0.04***	0.98	0.90	14.97
INN	2000	Yukon Creek	4.55	***0.02***	16.24	**0.06**	0.98	0.95	33.75

(lake.c =variable indicating local water balance)

* = total lake area averaged over all time periods for observed shallow lakes in burn areas

Based on the short-term period coefficient estimates, the TAL S76 fire displayed a negative effect (decrease) in lake surface area, while the Parks Highway, Carla Lake, and Yukon Creek fires displayed a positive effect (increase) in lake surface area. Four fires showed no significant impact in the short term and two additional fires displaying strong correlation with control lakes had no data (due to lack of available images) for this short-term period.

3.5 Mid-term regression results

Three study areas had lake areas differences significantly influenced by fire during the mid-term period (6-10 years) following fire, including the BIG W 17 fires in the Tanana Valley, the Tal S76 fire in Minchumina Basin, and the Yukon Creek fire in Innoko Flats (Table 3.3). These sites consistently had cumulative lake areas decreases during this time period.

Table 3.2 Mid-term (6-10 years) regression analyses. Lakes in the mid-term period consistently had cumulative lake area decreases as evidenced by the corresponding negative coefficient estimates.

Region	Fire Year	Fire Name	lake.c		mid-term (6-10 yrs)		R^2		Total lake area (Ha) in burn*
			coef. (b)	P-value	coef. (c_2)	P-value	multiple	adjusted	
TAN	1983	BIG W 17	2.35	***0.05***	-3.03	**0.07**	0.50	0.33	6.59
MIN	1990	TAL S76	-0.31	**0.10**	-3.24	**0.03**	0.53	0.37	14.97
INN	2000	Yukon Creek	4.55	***0.02***	-7.96	***0.03***	0.91	0.82	33.75

(lake.c =variable indicating local water balance)

* = total lake area averaged over all time periods for observed shallow lakes in burn areas

3.6 Long-term regression results

Long-term effects of fire on lake area were significant in two of the seven fires with data during this temporal period (Table 3.4). The corresponding low p-values and negative coefficient estimates indicate long-term decreases in lake areas following fires that occurred in the Tanana Valley and Minchumina Basin. No long-term observations were acquired for the Innoko Flats study region.

Table 3.3 Long-term (> 10 years) regression analyses. Lakes displayed long-term shrinking during this period, evidenced by negative coefficient values.

Region	Fire Year	Fire Name	lake.c		long-term (>10 yrs)		R^2		Total lake area (Ha) in burn*
			coef. (b)	P-value	coef. (c_2)	P-value	multiple	adjusted	
TAN	1983	BIG W 17	2.35	***0.05***	-3.53	***0.01***	0.77	0.66	6.59
MIN	1990	TAL S76	-0.31	**0.10**	-1.86	**0.06**	0.98	0.90	14.97

(lake.c =variable indicating local water balance)

* = total lake area averaged over all time periods for observed shallow lakes in burn areas

In the remaining 10 fire sites, control lake areas did not show significant correlations with burn area lakes across all time periods. This indicates that other factors such as hydrologic connectivity, topography, vegetation, or permafrost distribution may differ between the control lakes and burn lakes, thus reducing their validity as a reliable data set.

In an attempt to examine whether control lakes and burn lakes were controlled by similar factors and changed similarly without fire occurrence, we examined the correlation between burn lakes and control lakes for the pre-fire period only. These analyses yielded poor correlations ($p > 0.1$), indicating that factors controlling the area change of burn lakes were different from those for control lakes even without fire occurrence in these sites.

Fire sites 832015 and Survey Line are two aforementioned fire sites displaying a poor correlation between control and burn lakes, and also insignificant correlation between burned lake areas and Julian date. However, data shows that burned lakes in these sites did have significant effects from fire. Fire 832015 displayed a p-value of 0.03 and a negative coefficient estimate of -115.03 in the long-term (>10 years), indicating a long-term decrease in surface area can result from fire. Survey Line also displayed decreases in area through negative coefficients and respectable p-values in the mid-term and long-term periods following fire.

3.7 Post fire radiant temperature changes in burn areas

There was a consistent increase in radiant surface temperature in burn areas following fire, likely due to decreased transpiration and increased surface moisture (Fig. 3.3). The greatest radiant temperature increases occur within the first year following a burn, and subsequently decrease over time. Radiant temperature increases of 3˚-7˚ C were observed in burn sites during first snow-free season following fire, ~2˚-5˚ C in the second season, and 0.5˚-3.5˚ C three years after fire. Radiant surface temperatures increased < 1˚ C after 4 years.

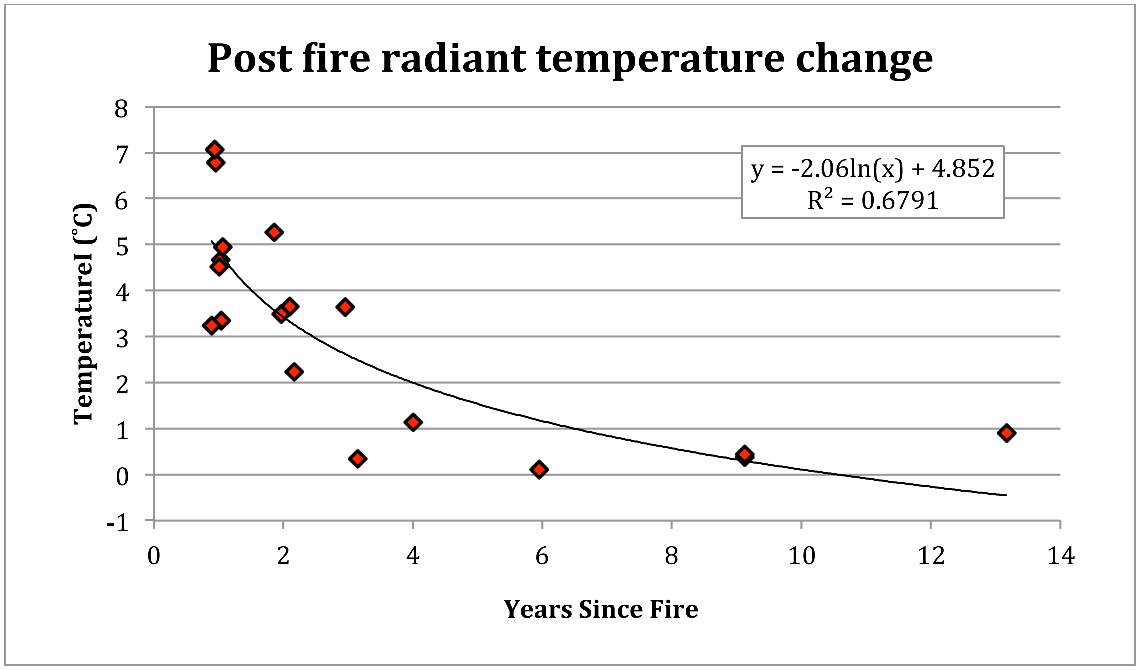


Figure 3.3 Post fire radiant temperature change after burn. Each point represents the radiant temperature change observed at different burn sites throughout Interior Alaska. The x-axis

corresponds with the image acquisition time in relation to the fire occurrence. The y-axis indicates the temperature change (˚C) observed between pre-fire and post fire imagery.

3.8 Post fire radiant temperature change and individual lake area change

Lake areas that decreased in size displayed no relationship with surrounding areas that were more severely impacted by fire. There was a significant relationship ($p = 0.03$) between increases in temperature and increases in lake area for individual lakes showing surface area changes > ± 20%.

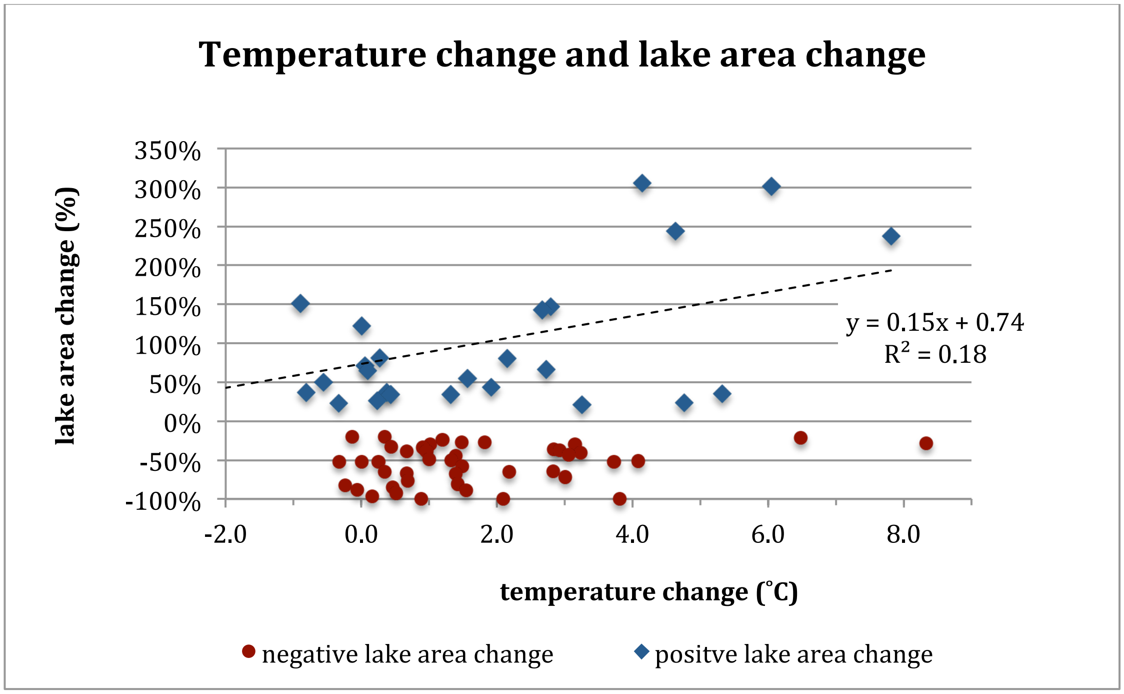


Figure 3.4 Temperature change as a function of lake area. Temperature change as a function of lake area change was evident in lakes that increased in size. Lake areas that decreased displayed no relationship with temperature change.

Chapter 4 Discussion

The surface area response to fire by individual lakes and ponds showed temporal variability. Trends in pond dynamics were most profound during the short-term (1-3 years) period. Observed short-term changes are increases in pond surface area, which may be due to decreased evapotranspiration (ET) or a decrease in the infiltration rates and water holding capacity of the peat layer following wildfire. Typical ET rates of boreal vegetation vary with respect to vegetation community. In black spruce forests, where fire occurs most frequently, ET rates are typically low (~ 1.1 – 2.4 mm/day) due to the shallow rooting and low productivity of coniferous vegetation and feather mosses (Kimball et al., 1997; Van Cleve 1993). Deciduous forests, however, have typically 50-80% higher ET rates from increased productivity (Chapin et al., 2000). As transpiration decreases or ceases, soil moisture increases and remains high throughout the year (Hinzman et al., 2003). Boreal peatlands are often characterized by sphagnum mosses, which have water-holding capacities of 30-80% by volume (15 to 23 times their dry weight (Whalen and Reeburgh, 1996; Richardson, 2000). The absence or reduction of this vegetation by fire, combined with increased soil moisture, decreased infiltration rates, and the potential increases in overland flow, are likely to facilitate the short-term increases we observed (Fig. 3.1).

Similar trends in more temperate North American ecosystems indicate that an increase in overland flow from reduced infiltration often occurs after fire. This process may help explain the short-term trend observed in our study (Neary, et al., 2005). De Bano et al. (1998) further explains:

> Watershed management studies throughout the world have demonstrated that the runoff component of the hydrologic cycle can increase following a vegetative change that reduces ET losses. . . .When burning exposes bare soil, infiltration can be reduced due to:
>
> - A collapse of the soil structure and a subsequent increase in bulk density of the soil because of the removal of the organic matter that serves as binding material
> - A consequent reduction in soil porosity
> - The impact of raindrops on the soil surface causing compaction and a further loss of soil porosity
> - The kinetic forces of raindrop impact displacing surface soil particles and causing a sealing of surface pores
> - Ash and charcoal residues clogging soil pores

Soils in boreal Alaska can develop a characteristic of water repellency following fire, which can reduce infiltration capacities by increasing the hydrophobicity of feather-moss derived organic matter (O'Donnell et al., 2009). As a consequence, water may not penetrate readily, and accelerated overland flow will result in increased stream flow and ponding. In anomalous years where we observed short-term surface area decreases in pond sizes across the landscape, we attribute inter-annual climate variability to these trends. Figure 4.1 shows mean monthly precipitation averages during the snow free period from 2000 through 2008 at Fairbanks International Airport, a representative site of Interior Alaska. While July tends to receive higher amounts of precipitation, inter-annual variability is constant. We attribute the inconsistent surface water trends observed in this study to the variability of inter-annual precipitation rates and volumes. Rainfall and snowmelt rates (mm/hr) relative to the surface infiltration capacity (mm/hr) are the keys to generating overland flow and surface ponding. In addition to changes brought about by fires, natural variability in the rates of rainfall and snowmelt can be significant from year to year, month to month, and storm to storm. However, data with this level of detail were unavailable for our study areas.

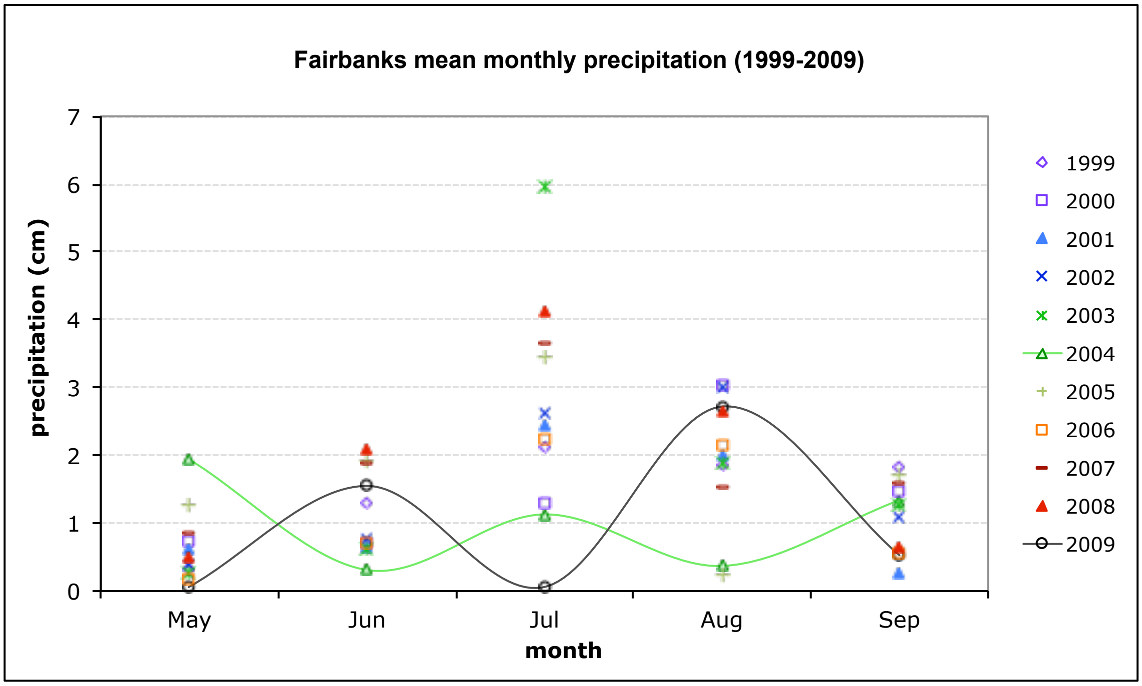


Figure 4.1 Mean Monthly precipitation variability from May through September in Fairbanks, Alaska 1998-2008. While July tends to experience the highest monthly average precipitation, intra- and inter-annual variability suggests other summer months may experience the highest experience the highest rates.

Other variables not relating to precipitation could also account for short-term lake area losses. Particularly, active layer deepening and/or thaw bulb expansion near lakes can breach permafrost, creating vertical and lateral drainage pathways through unfrozen patches of ground called taliks (Yoshikawa & Hinzman, 2003; Rowland et al., 2011).

In most cases, ponds inside and outside of wildfire perimeters had similar surface hydrology temporal patterns. This is not surprising, given the intrinsically dynamic nature of shallow lakes and ponds that tend to respond uniformly to precipitation or groundwater flux. However, there were occurrences of ponds that dried out completely and did not respond as expected to regional episodes of hydrologic recharge. We presume that talik drainage may have occurred, accelerated by warming of the dry lakebed and thus preventing permafrost from sufficiently recovering. Ponds were the most stable within active floodplain wildfires where surface water dynamics was more likely controlled by local water table variability.

Remote sensing analysis using the thermal band (B6) revealed surface temperatures in fire scars may be upwards of 7˚C warmer than surrounding unburned areas (Fig. 3.3). We presume that these changes result from the effects associated with the reduction of plant matter and peat in severely burned areas. However, a wide range of temperature differences (0˚ to 7˚ C) within the fire scars was also evident, suggesting that fire severity varies according to site-specific conditions during a fire. This may also explain why changing ponds did not occur more frequently in areas where warmer temperatures were estimated with satellite data.

Severe wildfire may also affect the insulating quality of the organic layer. Previous studies have examined the dependence of post fire thermal regime on the depth of duff consumption (Viereck, 1973; Viereck & Dryness, 1979; Yoshikawa et al., 2003). When the duff layer is reduced or removed by fire, and depending on site conditions, permafrost begins to thaw nears the surface and warm to greater depths for periods 3-5 years after fire (Fig. 4.2).

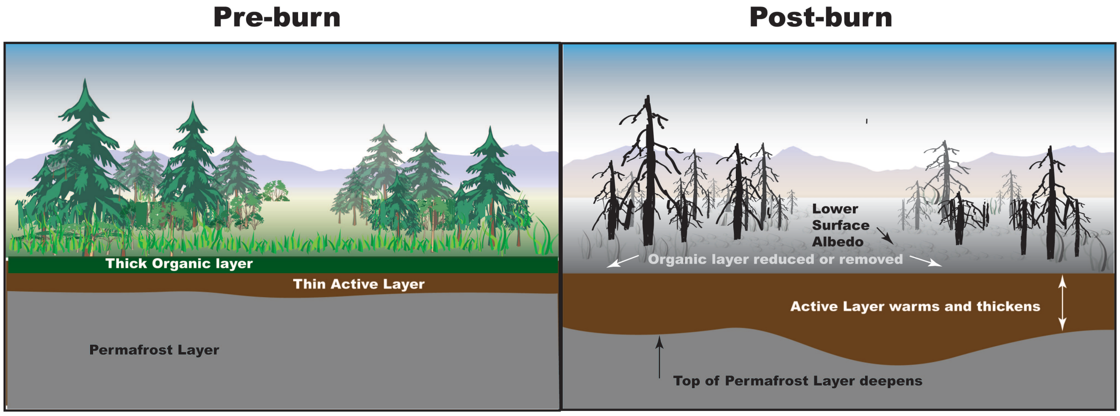


Figure 4.2 Effect of fire on insulating organic layer and active layer thickness. Short-term effects (1-2 years) include a removal of surficial vegetation and reduction or complete removal of the organic layer, lower surface albedo, reduced precipitation interception by vegetation, and an increase water repellency (hydrophobicity) of the soil surface. Long-term (3-5 years) effects will translate to an increase in thermal conductivity, and thickening of the active layer.

Yoshikawa et al, 2003 explains, “While heat conduction by fire to the permafrost is not significant, ground thermal conductivity may increase 10-fold and the surface albedo can decrease by 50% depending on the extent of burning of the surficial organic soil.” Approximately 3-5 years following severe disturbance, the active layer may increase to a thickness that does not completely refreeze the following winter (Yoshikawa et al., 2003). During longer periods (3-15 years) following severe fire, this increase in ground heat flux can deepen the seasonally thawed active layer, decrease soil moisture in near surface zones (Swanson, 1996; O'Donnell et al., 2009), breach permafrost, and promote lateral and vertical drainage via taliks (Hinzman, et al., 2003; Yoshikawa & Hinzman, 2003). Figure 4.3 illustrates the comparative effects between moderate and severe burns.

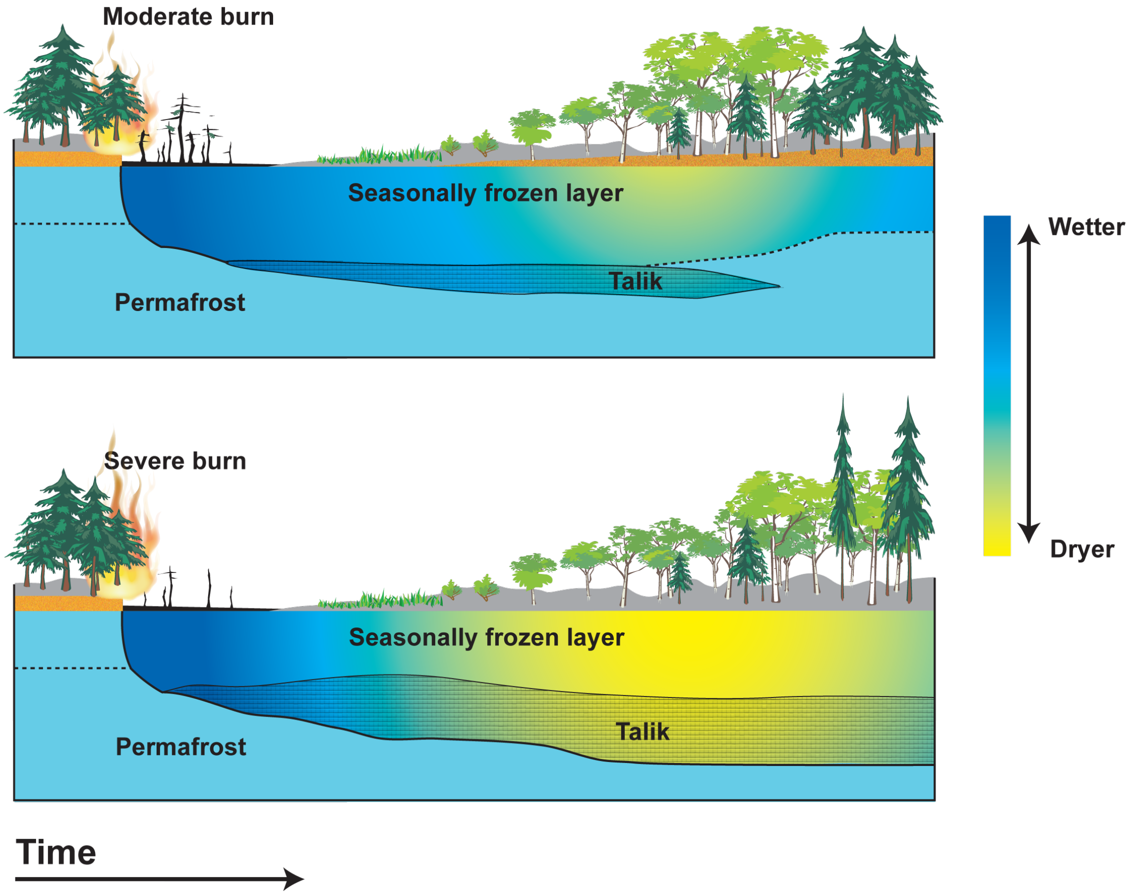


Figure 4.3 Burn severity effect on talik formation (Updated from Yoshikawa et al. *Frostfire*, 2003).

Any significant disturbance to the surface organic layer (fire, thermokarst, fluvial erosion) will increase heat flux into and heat flow through the active layer and into the permafrost. In less severe fires, the thickness of the remaining organic layer is less likely to be reduced. While a decrease in surface albedo will occur, Yoshikawa et al (2003) observed that the active layer depth does not change when the organic layer is not significantly reduced. Field measurements by O'Donnell et al. (2009) also documented negligible difference in soil temperature at five centimeters beneath the moss surface between the burned versus unburned sites two-years after fire, whereas generally wetter surface organic soil was observed in burned areas. Since wetter soil insulates less than dry soil (Yi et al., 2009), the active layer may become prone to deepening over a period > 2 years as subsurface heat conduction escalates from an increase in soil moisture. These observations coincide with the expansion of lake areas observed in our short-term observations while coinciding with our longer-term (3-15 years) findings that typically display a decrease in pond surface area, possibly due to talik drainage and an increase in ET.

Our long-term observations showing landscape-level lake drying and shrinking are consistent with other boreal Alaska lake studies that attribute these changes to a warming and drying climate (Lebrecque et al, 2009; Heglund, et al., 2009, Riordan et al., 2006; Smith et al., 2005; Klein et al., 2005). When examining this effect in burn areas, Klein et al. (2005) observed that landscape change (i.e. drying) did not depend substantially on burn history, observing that from 1950 to 1996 water areas decreased 22% in unburned areas and decreased 7% in unburned areas. While seasonal recharge events occur (Chen et al., 2013; Chen et al., 2012; Frohn et al., 2005), the variability of lake size due to seasonal recharge does not completely mask the longer term trend of less surface water due to a warming climate. These findings suggest that processes other than disturbance dominate long-term lake dynamics, and the observed trends towards a reduction in the distribution and surface area of ponds are consistent with studies attributing these changes to a warming and drying climate (Labrecque et al, 2009; Heglund, et al., 2009, Riordan et al., 2006; Smith et al., 2005; Klein et al., 2005).

Chapter 5 Conclusion

Wildfire is the primary large-scale disturbance affecting ecosystem succession in boreal forest. While several studies have examined the effect of fire on vegetation composition, soil properties, and permafrost integrity, fire also has been identified as a potential mechanism influencing lake area change (Roach et al., 2013). This study is the first to examine the role of this disturbance on boreal lake surface area dynamics on a landscape scale.

An initial review of 75 fires occurring throughout our four study regions indicated that lake areas between burn lakes and control lakes did not change significantly (> ± 25% area change) in 48 fire sites. This can be explained by either the fire intensity not burning severely enough to affect the thermal properties regulating heat flux, or because the effect of fire was not significant enough to alter hydrologic pathways influencing lake areas in these regions. Furthermore, observation time in relation to precipitation events, lake morphometry, as well as limitations in temporal coverage may also have masked the effect of fire for these lakes not displaying significant change. Of the remaining 27 fire sites, seven were excluded from analysis due to a lake size limitations and control lake availability, providing us with a data set of 20 fires for analysis.

We observed that fire had an effect on lake area changes in all four of our study regions in interior Alaska. In sites that displayed change between burn lakes and control lakes following fire, we observed more frequent rates of lake area expansion than shrinkage during the short-term (0 to 5 years) period. During this period, burn lakes displayed a net increase of 10% (range: – 61% to 33%) and control lakes decreased -8% (range: -46% to 11%). We attribute these changes to increased overland flow resulting from the removal of transpiring vegetation, hydrophobic soil properties formed during combustion processes (O'Donnell et al., 2009), and lower transpiration rates. These factors result in catchment basin infilling and overall increases in lake area.

In the midterm period (6 to 10 years), lower rates of lake area expansion and more frequent occurrences of lake stabilization were observed. Lake area stabilization is explained by the reestablishment of broad leaf vegetation, which results in higher ET rates and less deep percolation of water through the root zone. Reestablishment of broadleaf vegetation would likely increase evapotranspiration rates which might lead to an eventual decline in lakes surface water area (Jorgenson, et al., 2010). Lake area declines may have initiated in the earlier post-fire period from active layer deepening and formation of lateral and vertical drainage pathways that persisted.

Either stabilization or a decline in lake area occurred over the >10 year post fire period. Our study found, on average, a decrease in lake area of 17% (range: -42% to 78%) in burn areas over the long term, which is consistent with other lake area studies in the boreal region (Riordan et al., 2006; Roach et al., 2013; Smith et al., 2006; Rover et al., 2012; Chen et al., 2012). Long-term lake area stabilization can be attributed to vegetation reestablishment and subsequent increases in ET. Reduced lake areas may result from precipitation deficits, misinterpretation of floating vegetation encroachment, or increased drainage via taliks.

Across all time periods, both shrinking and expanding lakes were common in burned areas and their surrounding control areas. Intra- and inter-seasonal precipitation, connectivity to other hydrologic features, or site-specific conditions may be attributed to these heterogeneous changes (Chen et al., 2012; Roach et al, 2011).

Burn severity analysis displayed radiant surface temperatures increased 3-7˚C in burn areas, with the highest temperatures recorded within two years after fire. Lakes in the most severely impacted areas from fire displayed heterogeneous changes in lake area. Cases of lake shrinkage support our hypothesis that lake areas my drain due to a deepening of the active layer, resulting in both lateral and horizontal subsurface flow. Lake area increases in these areas may be attributed to limitations of our burn severity analysis, including: daily and seasonal variability due to image acquisition time. Early season (May-June) temperatures were typically lower than temperatures attained in July-August. Time of day displayed a stronger effect in early and late season images as shadowing and diurnal variability increased with lower azimuth angles.

Since increases in fire frequency and severity are becoming widely observed throughout the boreal region (Kelly et al., 2013; Kasischke, et al. 2010), it is essential to understand the effect of fire on the surface area of the numerous lakes in boreal areas. With the aid of remote sensing, this understanding will allow land management agencies to better and more efficiently predict the role of fire in riparian areas (Barrett, et al., 2013), thus facilitating more effective management of fire as both a disturbance and tool for maintaining ecosystems. Future lake area studies may be improved with more frequent and consistent observations, and further complemented with in-situ measurements of variables such as vegetation composition, organic and active layer thickness, subsurface flow, and lake basin morphology. While in-situ measurements may provide the highest accuracy, improved remote sensing detection of subsurface processes, such as those by Dafflon et al. (2013), could be applied to more efficiently assess underlying mechanisms affecting regional-scale lake area dynamics.

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Appendix A

Appendix A lists all Landsat satellite imagery used in this study. Imagery was obtained from the USGS Earth Resources Observation and Science Center (EROS), via the Gobal Visualization Viewer (http://glovis.usgs.gov/). Individual scene clips are listed by study region, fire name, satellite platform, sensor, path/row configuration, and acquisition date. Extracted and vectorized lakes are listed with their corresponding GIS shapefile, which includes the associated threshold value from density slicing listed as a '_th##' value extension to each shapefile name. Notable observations associated with each scene clippping are listed in the 'Notes' column.

For further data set inquiries, please consult the LTER data portal (https://metacat.lternet.edu/das/lter/index.jsp), or conact the author directly (<glaltmann@alaska.edu>).

Satellite data appendix

* = meterological disturbance
**= no significant hydrological change

Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
1	1	Inn	Wapoo Fire	1984	L5	TM	7615	1985jul24		
2	2	Inn	Wapoo Fire	1984	L5	TM	7615	1986jun9		
3	3	Inn	Wapoo Fire	1984	L4	TM	7615	1988july24		
4	4	Inn	Wapoo Fire	1984	L5	TM	7615	1991aug26		
5	5	Inn	Wapoo Fire	1984	L7	ETM+	7515	1999jun30		
6	6	Inn	Wapoo Fire	1984	L7	ETM+	7416	2000jun25		
7	7	Inn	Wapoo Fire	1984	L7	ETM+	7416	2002jun15		
8	8	Inn	Wapoo Fire	1984	L5	TM	7416	2008jun7		
9	9	Inn	Wapoo Fire	1984	L5	TM	7515	2009july3		
10	1	Inn	Chick Mountain	2005	L5	TM	7416	1985jun24	**	
11	2	Inn	Chick Mountain	2005	L5	TM	7616	1985july24	**	
12	3	Inn	Chick Mountain	2005	L5	TM	7416	1986may26	**	
13	4	Inn	Chick Mountain	2005	L5	TM	7616	1986july24	**	
14	5	Inn	Chick Mountain	2005	L4	TM	7616	1988aug9	**	
15	6	Inn	Chick Mountain	2005	L4	TM	7416	1989aug14	**	
16	8	Inn	Chick Mountain	2005	L5	TM	7616	1991aug26	**	
17	9	Inn	Chick Mountain	2005	L4	TM	7616	1992jun17	**	
18	10	Inn	Chick Mountain	2005	L7	ETM+	7416	2000jun25	**	
19	11	Inn	Chick Mountain	2005	L7	ETM+	7416	2000july11	**	
20	12	Inn	Chick Mountain	2005	L7	ETM+	7516	2001aug22	**	
21	13	Inn	Chick Mountain	2005	L7	ETM+	7416	2002jun15	**	
22	14	Inn	Chick Mountain	2005	L7	ETM+	7616	2002july31	**	
23	15	Inn	Chick Mountain	2005	L7	ETM+	7416	2002aug2	**	
24	16	Inn	Chick Mountain	2005	L5	TM	7616	2005jun29	**	
25	17	Inn	Chick Mountain	2005	L5	TM	7616	2005july15	**	
26	18	Inn	Chick Mountain	2005	L5	TM	7616	2005sep1	**	
27	19	Inn	Chick Mountain	2005	L5	TM	7616	2006may31	**	
28	20	Inn	Chick Mountain	2005	L5	TM	7416	2006july4	**	
29	21	Inn	Chick Mountain	2005	L5	TM	7616	2006sep4	**	
30	22	Inn	Chick Mountain	2005	L5	TM	7416	2007aug24	**	
31	23	Inn	Chick Mountain	2005	L5	TM	7416	2008jun7	**	
32	24	Inn	Chick Mountain	2005	L5	TM	7616	2008july7	**	
33	25	Inn	Chick Mountain	2005	L5	TM	7416	2008july25	**	
34	26	Inn	Chick Mountain	2005	L5	TM	7416	2009july12	**	
35	27	Inn	Chick Mountain	2005	L5	TM	7416	2009aug29	**	
36	1	Inn	Magitchlie Creek	1988	L4	TM	7615	1988aug9		
37	2	Inn	Magitchlie Creek	1988	L4	TM	7615	1988july24		
38	3	Inn	Magitchlie Creek	1988	L5	TM	7615	1991aug26	1991aug26_ponds_th41	
39	4	Inn	Magitchlie Creek	1988	L5	TM	7615	1995july20		

Satellite data appendix (continued)

* = meterological disturbance
**= no significant hydrological change

Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
40	5	Inn	Magitchlie Creek	1988	L7	ETM+	7515	1999aug17	1999aug17_ponds_th47	
41	6	Inn	Magitchlie Creek	1988	L7	ETM+	7615	1999july7		
42	7	Inn	Magitchlie Creek	1988	L7	ETM+	7515	1999jun30		
43	8	Inn	Magitchlie Creek	1988	L7	ETM+	7416	2000jun25		
44	9	Inn	Magitchlie Creek	1988	L7	ETM+	7515	2001aug6		
45	10	Inn	Magitchlie Creek	1988	L7	ETM+	7515	2006aug28	2006aug28_ponds_th19	
46	11	Inn	Magitchlie Creek	1988	L7	ETM+	7515	2009july3	2009july3_ponds_th73	
47	1	Inn	Bonanza Creek	2004	L5	TM	7515	1986july4		
48	2	Inn	Bonanza Creek	2004	L4	TM	7615	1988july24		
49	3	Inn	Bonanza Creek	2004	L5	TM	7615	1991aug26	1991aug26_ponds_th31	
50	4	Inn	Bonanza Creek	2004	L7	ETM+	7515	1999jun30		
51	5	Inn	Bonanza Creek	2004	L7	ETM+	7515	1999aug17	1999aug17_ponds_th35	
52	6	Inn	Bonanza Creek	2004	L7	ETM+	7615	1999sep9		
53	7	Inn	Bonanza Creek	2004	L7	ETM+	7515	2001aug6	2001aug6_ponds_th36	
54	8	Inn	Bonanza Creek	2004	L7	ETM+	7515	2002jun22		
55	9	Inn	Bonanza Creek	2004	L5	TM	7515	2006aug28	2006aug28_ponds_th19	
56	10	Inn	Bonanza Creek	2004	L5	TM	7515	2009july3	2009july3_ponds_th73	
57	1	Inn	Soonkakat River	1997	L5	TM	7515	1986july4		
58	2	Inn	Soonkakat River	1997	L4	TM	7615	1988july24		
59	3	Inn	Soonkakat River	1997	L5	TM	7615	1991aug26	1991aug26_ponds_th31	
60	4	Inn	Soonkakat River	1997	L7	ETM+	7515	1999jun30		
61	5	Inn	Soonkakat River	1997	L7	ETM+	7515	1999aug17	1999aug17_ponds_th35	
62	6	Inn	Soonkakat River	1997	L7	ETM+	7615	1999sep9		
63	7	Inn	Soonkakat River	1997	L7	ETM+	7515	2001aug6	2001aug6_ponds_th36	
64	8	Inn	Soonkakat River	1997	L7	ETM+	7515	2002jun22		
65	9	Inn	Soonkakat River	1997	L5	TM	7515	2006aug28	2006aug28_ponds_th19	
66	10	Inn	Soonkakat River	1997	L5	TM	7515	2009july3	2009july3_ponds_th73	
67	1	Inn	Yukon Creek	2000	L5	TM	7615	1985jun22		
68	2	Inn	Yukon Creek	2000	L5	TM	7615	1986jun9		
69	3	Inn	Yukon Creek	2000	L4	TM	7615	1988july24		
70	4	Inn	Yukon Creek	2000	L5	TM	7615	1991aug26		
71	5	Inn	Yukon Creek	2000	L7	ETM+	7515	1999jun30		
72	6	Inn	Yukon Creek	2000	L7	ETM+	7615	1999july7		
73	7	Inn	Yukon Creek	2000	L7	ETM+	7515	1999aug17	1999aug17_ponds_th57	
74	8	Inn	Yukon Creek	2000	L7	ETM+	7515	2001aug6	2001aug6_ponds_th62	
75	9	Inn	Yukon Creek	2000	L5	TM	7515	2006aug28	2006aug28_ponds_th14	
76	10	Inn	Yukon Creek	2000	L5	TM	7515	2009july3	2009july3_ponds_th70	

Satellite data appendix (continued)

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Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
77	1	Inn	Simels	1997	L5	TM	7416	1985jun24	1985jun24_ponds_th30	
78	2	Inn	Simels	1997	L5	TM	7416	1986may26		
79	3	Inn	Simels	1997	L4	TM	7416	1989aug14	1989aug14_ponds_th37	
80	4	Inn	Simels	1997	L7	ETM+	7515	1999jun30		
81	5	Inn	Simels	1997	L7	ETM+	7515	1999aug17	1999aug17_ponds_th75	
82	6	Inn	Simels	1997	L7	ETM+	7416	2000july11		
83	7	Inn	Simels	1997	L7	ETM+	7416	2002jun15		
84	8	Inn	Simels	1997	L7	ETM+	7416	2002aug2	2002aug2_ponds_th25	
85	9	Inn	Simels	1997	L5	TM	7515	2006aug28		
86	10	Inn	Simels	1997	L5	TM	7416	2007aug24		
87	11	Inn	Simels	1997	L5	TM	7416	2008jun7		
88	12	Inn	Simels	1997	L5	TM	7515	2009july3		
89	13	Inn	Simels	1997	L5	TM	7416	2009aug29	2009aug29_ponds_th34	
90	1	Inn	Dr Beaver Creek	1997	L5	TM	7416	1985jun24	1985jun24_ponds_th30	
91	2	Inn	Dr Beaver Creek	1997	L5	TM	7416	1986may26		
92	3	Inn	Dr Beaver Creek	1997	L4	TM	7416	1989aug14	1989aug14_ponds_th37	
93	4	Inn	Dr Beaver Creek	1997	L7	ETM+	7515	1999jun30		
94	5	Inn	Dr Beaver Creek	1997	L7	ETM+	7515	1999aug17	1999aug17_ponds_th75	
95	6	Inn	Dr Beaver Creek	1997	L7	ETM+	7416	2000july11		
96	7	Inn	Dr Beaver Creek	1997	L7	ETM+	7416	2002jun15		
97	8	Inn	Dr Beaver Creek	1997	L7	ETM+	7416	2002aug2	2002aug2_ponds_th25	
98	9	Inn	Dr Beaver Creek	1997	L5	TM	7515	2006aug28		
99	10	Inn	Dr Beaver Creek	1997	L5	TM	7416	2007aug24		
100	11	Inn	Dr Beaver Creek	1997	L5	TM	7416	2008jun7		
101	12	Inn	Dr Beaver Creek	1997	L5	TM	7515	2009july3		
102	13	Inn	Dr Beaver Creek	1997	L5	TM	7416	2009aug29	2009aug29_ponds_th34	
103	1	Inn	Big Yetna	2004	L7	ETM+	7416	2000july11	2000july11_ponds_th36	
104	2	Inn	Big Yetna	2004	L7	ETM+	7516	2001aug22	2001aug22_pond_th43	
105	3	Inn	Big Yetna	2004	L7	ETM+	7416	2002jun15	2002jul31_ponds_th39	
106	4	Inn	Big Yetna	2004	L7	ETM+	7616	2002july31		
107	5	Inn	Big Yetna	2004	L5	TM	7616	2005sep1		
108	6	Inn	Big Yetna	2004	L5	TM	7416	2006july4	2006july4_ponds_th12	
109	7	Inn	Big Yetna	2004	L5	TM	7616	2006sep4		
110	8	Inn	Big Yetna	2004	L5	TM	7616	2008july7		
111	9	Inn	Big Yetna	2004	L5	TM	7416	2008july25	2008july25_ponds_th35	
112	10	Inn	Big Yetna	2004	L5	TM	7416	2009july12	2009july12_ponds_th49	
113	11	Inn	Big Yetna	2004	L5	TM	7416	2009aug29		
114	1	Inn	832143	1988	L5	TM	7416	1985jun24	1985jun24_ponds_th30	

Satellite data appendix (continued)

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Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
115	2	Inn	832143	1988	L5	TM	7416	1986may26		
116	3	Inn	832143	1988	L4	TM	7416	1989aug14	1989aug14_ponds_th37	
117	4	Inn	832143	1988	L7	ETM+	7515	1999jun30		
118	5	Inn	832143	1988	L7	ETM+	7515	1999aug17	1999aug17_ponds_th75	
119	6	Inn	832143	1988	L7	ETM+	7416	2000july11		
120	7	Inn	832143	1988	L7	ETM+	7416	2002jun15		
121	8	Inn	832143	1988	L7	ETM+	7416	2002aug2	2002aug2_ponds_th25	
122	9	Inn	832143	1988	L5	TM	7515	2006aug28		
123	10	Inn	832143	1988	L5	TM	7416	2007aug24		
124	11	Inn	832143	1988	L5	TM	7416	2008jun7		
125	12	Inn	832143	1988	L5	TM	7515	2009july3		
126	13	Inn	832143	1988	L5	TM	7416	2009aug29	2009aug29_ponds_th34	
127	1	Inn	Hammer Creek #2	2005	L4	TM	7615	1988july24		
128	2	Inn	Hammer Creek #2	2005	L5	TM	7615	1991aug26		
129	3	Inn	Hammer Creek #2	2005	L7	ETM+	7416	2000july11		
130	4	Inn	Hammer Creek #2	2005	L7	ETM+	7416	2001aug6		
131	5	Inn	Hammer Creek #2	2005	L7	ETM+	7516	2001aug22	2002aug2_ponds_th21	
132	6	Inn	Hammer Creek #2	2005	L7	ETM+	7416	2002jun15		
133	7	Inn	Hammer Creek #2	2005	L7	ETM+	7416	2002aug2		
134	8	Inn	Hammer Creek #2	2005	L5	TM	7416	2006july4	2006july4_ponds_th27	
135	9	Inn	Hammer Creek #2	2005	L5	TM	7515	2006aug28		
136	10	Inn	Hammer Creek #2	2005	L5	TM	7416	2007aug24		
137	11	Inn	Hammer Creek #2	2005	L5	TM	7416	2008jun7		
138	12	Inn	Hammer Creek #2	2005	L5	TM	7416	2008july25		
139	13	Inn	Hammer Creek #2	2005	L5	TM	7416	2009july12		
140	14	Inn	Hammer Creek #2	2005	L5	TM	7416	2009aug29	2009aug29_ponds_th39	
141	1	Inn	Khotol River	2002	L5	TM	7615	1986jun9	**	
142	2	Inn	Khotol River	2002	L4	TM	7615	1988july24	**	
143	3	Inn	Khotol River	2002	L5	TM	7615	1991aug26	**	
144	4	Inn	Khotol River	2002	L7	ETM+	7515	1999jun30	**	
145	5	Inn	Khotol River	2002	L7	ETM+	7515	1999aug17	**	
146	6	Inn	Khotol River	2002	L7	ETM+	7416	2001aug6	**	
147	7	Inn	Khotol River	2002	L5	TM	7515	2006aug28	**	
148	8	Inn	Khotol River	2002	L5	TM	7515	2009july3	**	
149	1	Inn	Yetna	2005	L7	ETM+	7416	2000july11	2000july11_ponds_th36	
150	2	Inn	Yetna	2005	L7	ETM+	7516	2001aug22	2001aug22_pond_th43	
151	3	Inn	Yetna	2005	L7	ETM+	7416	2002jun15	2002jul31_ponds_th39	
152	4	Inn	Yetna	2005	L7	ETM+	7616	2002july31		

Satellite data appendix (continued)

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Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
153	5	Inn	Yetna	2005	L5	TM	7616	2005sep1		
154	6	Inn	Yetna	2005	L5	TM	7416	2006july4	2006july4_ponds_th12	
155	7	Inn	Yetna	2005	L5	TM	7616	2006sep4		
156	8	Inn	Yetna	2005	L5	TM	7616	2008july7		
157	9	Inn	Yetna	2005	L5	TM	7416	2008july25	2008july25_ponds_th35	
158	10	Inn	Yetna	2005	L5	TM	7416	2009july12	2009july12_ponds_th49	
159	11	Inn	Yetna	2005	L5	TM	7416	2009aug29		
160	1	Inn	Yetna River	2002	L7	ETM+	7416	2000july11	2000july11_ponds_th36	
161	2	Inn	Yetna River	2002	L7	ETM+	7516	2001aug22	2001aug22_pond_th43	
162	3	Inn	Yetna River	2002	L7	ETM+	7416	2002jun15	2002jul31_ponds_th39	
163	4	Inn	Yetna River	2002	L7	ETM+	7616	2002july31		
164	5	Inn	Yetna River	2002	L5	TM	7616	2005sep1		
165	6	Inn	Yetna River	2002	L5	TM	7416	2006july4	2006july4_ponds_th12	
166	7	Inn	Yetna River	2002	L5	TM	7616	2006sep4		
167	8	Inn	Yetna River	2002	L5	TM	7616	2008july7		
168	9	Inn	Yetna River	2002	L5	TM	7416	2008july25	2008july25_ponds_th35	
169	10	Inn	Yetna River	2002	L5	TM	7416	2009july12	2009july12_ponds_th49	
170	11	Inn	Yetna River	2002	L5	TM	7416	2009aug29		
171	1	Min	631010	1986	L5	TM	7115	1985july21	1985july21_ponds_th36	
172	2	Min	631010	1986	L5	TM	7215	1986jun29	1986jun29_ponds_th23	
173	3	Min	631010	1986	L4	TM	7115	1992jun14	1999aug28_ponds_th31	
174	4	Min	631010	1986	L7	ETM+	7215	1999aug28		
175	5	Min	631010	1986	L7	ETM+	7116	2001jun23	2001jun23_ponds_th34	
176	6	Min	631010	1986	L7	ETM+	7115	2002may25	2002may25_ponds_th82	
177	7	Min	631010	1986	L7	ETM+	7116	2002aug13		
178	8	Min	631010	1986	L7	ETM+	7115	2002sep14		
179	9	Min	631010	1986	L5	TM	7215	2006july22		
180	10	Min	631010	1986	L5	TM	7215	2007aug26	2007aug26_ponds_th40	
181	11	Min	631010	1986	L5	TM	7115	2008aug21		
182	12	Min	631010	1986	L5	TM	7115	2009july7	2009july7_ponds_th55	
183	1	Min	TAL S 76	1990	L5	TM	7115	1985july21	1985july21_ponds_th16	
184	2	Min	TAL S 76	1990	L5	TM	7215	1986jun13	1986jun13_ponds_th40	
185	3	Min	TAL S 76	1990	L4	TM	7115	1992jun14	1992jun14_ponds_th17	
186	4	Min	TAL S 76	1990	L5	TM	7215	1995july24	1995july24_ponds_th5	
187	5	Min	TAL S 76	1990	L7	ETM+	7215	1999aug28	1999aug28_ponds_th10	
188	6	Min	TAL S 76	1990	L7	ETM+	7115	2001jun23		
189	7	Min	TAL S 76	1990	L7	ETM+	7115	2002may25		
190	8	Min	TAL S 76	1990	L7	ETM+	7115	2002sep14		

Satellite data appendix (continued)

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Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
191	9	Min	TAL S 76	1990	L5	TM	7215	2006july22		
192	10	Min	TAL S 76	1990	L5	TM	7215	2007aug26		
193	11	Min	TAL S 76	1990	L5	TM	7115	2007sep4		
194	12	Min	TAL S 76	1990	L5	TM	7115	2008aug21		
195	13	Min	TAL S 76	1990	L5	TM	7115	2009july7	2009july7_ponds_th40	
196	1	Min	31063	1990	L5	TM	7215	1986jun13	1986jun13_ponds_th69	
197	2	Min	31063	1990	L5	TM	7215	1986jun29	1986jun29_ponds_th23	
198	3	Min	31063	1990	L4	TM	7115	1992jun14		
199	4	Min	31063	1990	L7	ETM+	7215	1999aug28	1999aug28_ponds_th31	
200	5	Min	31063	1990	L7	ETM+	7116	2001jun23		
201	6	Min	31063	1990	L7	ETM+	7115	2002may25	2002may25_ponds_th82	
202	7	Min	31063	1990	L7	ETM+	7215	2002sep21	2002sep21_ponds_th8	
203	8	Min	31063	1990	L5	TM	7215	2006july22		
204	9	Min	31063	1990	L5	TM	7215	2007aug26	2007aug26_ponds_th40	
205	10	Min	31063	1990	L5	TM	7115	2008aug21		
206	11	Min	31063	1990	L5	TM	7116	2008sep6		
207	12	Min	31063	1990	L5	TM	7116	2009july7	2009july7_ponds_th55	
208	1	Min	Foraker	2000	L5	TM	7115	1985july21	1985july21_ponds_th39	
209	2	Min	Foraker	2000	L5	TM	7215	1986jun13		
210	3	Min	Foraker	2000	L5	TM	7215	1986jun29	1986jun29_ponds_th29	
211	4	Min	Foraker	2000	L4	TM	7115	1992jun14		
212	5	Min	Foraker	2000	L5	TM	7215	1995july24		
213	6	Min	Foraker	2000	L7	ETM+	7215	1999aug28	1999aug28_ponds_th46	
214	7	Min	Foraker	2000	L7	ETM+	7115	2002sep14	2002sep14_ponds_th6	
215	8	Min	Foraker	2000	L5	TM	7215	2006july22		
216	9	Min	Foraker	2000	L5	TM	7215	2007aug26	2007aug26_ponds_th68	
217	10	Min	Foraker	2000	L5	TM	7115	2007sep4		
218	11	Min	Foraker	2000	L5	TM	7115	2008aug21		
219	12	Min	Foraker	2000	L5	TM	7115	2009july7	2009july7_ponds_th87	
220	1	Min	TAL SE 87	1990	L5	TM	7115	1985july21	1985july21_ponds_th39	
221	2	Min	TAL SE 87	1990	L5	TM	7215	1986jun13		
222	3	Min	TAL SE 87	1990	L5	TM	7215	1986jun29	1986jun29_ponds_th29	
223	4	Min	TAL SE 87	1990	L4	TM	7115	1992jun14		
224	5	Min	TAL SE 87	1990	L5	TM	7215	1995july24		
225	6	Min	TAL SE 87	1990	L7	ETM+	7215	1999aug28	1999aug28_ponds_th46	
226	7	Min	TAL SE 87	1990	L7	ETM+	7115	2002sep14	2002sep14_ponds_th6	
227	8	Min	TAL SE 87	1990	L5	TM	7215	2006july22		
228	9	Min	TAL SE 87	1990	L5	TM	7215	2007aug26	2007aug26_ponds_th68	

Satellite data appendix (continued)

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Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
229	10	Min	TAL SE 87	1990	L5	TM	7115	2007sep4		
230	11	Min	TAL SE 87	1990	L5	TM	7115	2008aug21		
231	12	Min	TAL SE 87	1990	L5	TM	7115	2009july7	2009july7_ponds_th87	
232	1	Min	MHM SE 16	1993	L5	TM	7115	1985july21	**	
233	2	Min	MHM SE 16	1993	L5	TM	7215	1986jun13	**	
234	3	Min	MHM SE 16	1993	L5	TM	7215	1986jun29	**	
235	4	Min	MHM SE 16	1993	L4	TM	7115	1992jun14	**	
236	5	Min	MHM SE 16	1993	L5	TM	7215	1995july24	**	
237	6	Min	MHM SE 16	1993	L7	ETM+	7215	1999aug28	**	
238	7	Min	MHM SE 16	1993	L7	ETM+	7115	2002sep14	**	
239	8	Min	MHM SE 16	1993	L5	TM	7215	2006july22	**	
240	9	Min	MHM SE 16	1993	L5	TM	7215	2007aug26	**	
241	10	Min	MHM SE 16	1993	L5	TM	7115	2007sep4	**	
242	11	Min	MHM SE 16	1993	L5	TM	7115	2008aug21	**	
243	12	Min	MHM SE 16	1993	L5	TM	7115	2009july7	**	
244	1	Min	Highpower Creek	2005	L5	TM	7215	1986jun29	1986jun29_ponds_th23	
245	2	Min	Highpower Creek	2005	L7	ETM+	7215	1999aug28	1999aug28_ponds_th31	
246	3	Min	Highpower Creek	2005	L7	ETM+	7116	2001jun23	2001jun23_ponds_th34	
247	4	Min	Highpower Creek	2005	L7	ETM+	7116	2002aug13	2002aug13_ponds_th22	
248	5	Min	Highpower Creek	2005	L7	ETM+	7215	2002sep21		
249	6	Min	Highpower Creek	2005	L5	TM	7215	2006july22		
250	7	Min	Highpower Creek	2005	L5	TM	7215	2007aug26	2007aug26_ponds_th40	
251	8	Min	Highpower Creek	2005	L5	TM	7116	2008sep6	2008sep6_ponds_th10	
252	9	Min	Highpower Creek	2005	L5	TM	7115	2009july7	2009july7_ponds_th55	
253	1	Min	Moose Lake	2002	L5	TM	7215	1986jun29	1986jun29_ponds_th23	
254	2	Min	Moose Lake	2002	L7	ETM+	7215	1999aug28	1999aug28_ponds_th31	
255	3	Min	Moose Lake	2002	L7	ETM+	7116	2001jun23	2001jun23_ponds_th34	
256	4	Min	Moose Lake	2002	L7	ETM+	7116	2002aug13	2002aug13_ponds_th22	
257	5	Min	Moose Lake	2002	L7	ETM+	7215	2002sep21		
258	6	Min	Moose Lake	2002	L5	TM	7215	2006july22		
259	7	Min	Moose Lake	2002	L5	TM	7215	2007aug26	2007aug26_ponds_th40	
260	8	Min	Moose Lake	2002	L5	TM	7116	2008sep6	2008sep6_ponds_th10	
261	9	Min	Moose Lake	2002	L5	TM	7115	2009july7	2009july7_ponds_th55	
262	1	Min	Herron River	2001	L5	TM	7215	1986jun29	1986jun29_ponds_th23	
263	2	Min	Herron River	2001	L7	ETM+	7215	1999aug28	1999aug28_ponds_th31	
264	3	Min	Herron River	2001	L7	ETM+	7116	2001jun23	2001jun23_ponds_th34	
265	4	Min	Herron River	2001	L7	ETM+	7116	2002aug13	2002aug13_ponds_th22	

Satellite data appendix (continued)

* = meterological disturbance
**= no significant hydrological change

Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
266	5	Min	Herron River	2001	L7	ETM+	7215	2002sep21		
267	6	Min	Herron River	2001	L5	TM	7215	2006july22		
268	7	Min	Herron River	2001	L5	TM	7215	2007aug26	2007aug26_ponds_th40	
269	8	Min	Herron River	2001	L5	TM	7116	2008sep6	2008sep6_ponds_th10	
270	9	Min	Herron River	2001	L5	TM	7115	2009july7	2009july7_ponds_th55	
271	1	Min	332663	1993	L5	TM	7215	1986jun29	1986jun29_ponds_th23	
272	2	Min	332663	1993	L7	ETM+	7215	1999aug28	1999aug28_ponds_th31	
273	3	Min	332663	1993	L7	ETM+	7116	2001jun23	2001jun23_ponds_th34	
274	4	Min	332663	1993	L7	ETM+	7116	2002aug13	2002aug13_ponds_th22	
275	5	Min	332663	1993	L7	ETM+	7215	2002sep21		
276	6	Min	332663	1993	L5	TM	7215	2006july22		
277	7	Min	332663	1993	L5	TM	7215	2007aug26	2007aug26_ponds_th40	
278	8	Min	332663	1993	L5	TM	7116	2008sep6	2008sep6_ponds_th10	
279	9	Min	332663	1993	L5	TM	7115	2009july7	2009july7_ponds_th55	
280	1	Min	31061	1990	L5	TM	7215	1986jun29	1986jun29_ponds_th23	
281	2	Min	31061	1990	L7	ETM+	7215	1999aug28	1999aug28_ponds_th31	
282	3	Min	31061	1990	L7	ETM+	7116	2001jun23	2001jun23_ponds_th34	
283	4	MIn	31061	1990	L7	ETM+	7116	2002aug13	2002aug13_ponds_th22	
284	5	Min	31061	1990	L7	ETM+	7215	2002sep21		
285	6	MIn	31061	1990	L5	TM	7215	2006july22		
286	7	Min	31061	1990	L5	TM	7215	2007aug26	2007aug26_ponds_th40	
287	8	MIn	31061	1990	L5	TM	7116	2008sep6	2008sep6_ponds_th10	
288	9	Min	31061	1990	L5	TM	7115	2009july7	2009july7_ponds_th55	
289	1	Min	MHM S 28	1986	L5	TM	7215	1986jun29	1986jun29_ponds_th23	
290	2	Min	MHM S 28	1986	L7	ETM+	7215	1999aug28	1999aug28_ponds_th31	
291	3	Min	MHM S 28	1986	L7	ETM+	7116	2001jun23	2001jun23_ponds_th34	
292	4	Min	MHM S 28	1986	L7	ETM+	7116	2002aug13	2002aug13_ponds_th22	
293	5	Min	MHM S 28	1986	L7	ETM+	7215	2002sep21		
294	6	Min	MHM S 28	1986	L5	TM	7215	2006july22		
295	7	Min	MHM S 28	1986	L5	TM	7215	2007aug26	2007aug26_ponds_th40	
296	8	Min	MHM S 28	1986	L5	TM	7116	2008sep6	2008sep6_ponds_th10	
297	9	Min	MHM S 28	1986	L5	TM	7115	2009july7	2009july7_ponds_th55	
298	1	Min	Herron River	2005	L5	TM	7215	1986jun29	1986jun29_ponds_th23	
299	2	Min	Herron River	2005	L7	ETM+	7215	1999aug28	1999aug28_ponds_th31	
300	3	Min	Herron River	2005	L7	ETM+	7116	2001jun23	2001jun23_ponds_th34	
301	4	Min	Herron River	2005	L7	ETM+	7116	2002aug13	2002aug13_ponds_th22	
302	5	Min	Herron River	2005	L7	ETM+	7215	2002sep21		

Satellite data appendix (continued)

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Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
303	6	Min	Herron River	2005	L5	TM	7215	2006july22		
304	7	Min	Herron River	2005	L5	TM	7215	2007aug26	2007aug26_ponds_th40	
305	8	Min	Herron River	2005	L5	TM	7116	2008sep6	2008sep6_ponds_th10	
306	9	Min	Herron River	2005	L5	TM	7115	2009july7	2009july7_ponds_th55	
307	1	Tan	Dune Lake	1981	L5	TM	7115	1985july21	1985july21_ponds_th28	
308	2	Tan	Dune Lake	1981	L5	TM	7115	1992jun14	1992JUN14_ponds_th16	
309	3	Tan	Dune Lake	1981	L5	TM	7115	1999jun26	1999jun26_ponds_th18	
310	4	Tan	Dune Lake	1981	L7	ETM+	7115	2001jun23	2001jun23_ponds_th50	
311	5	Tan	Dune Lake	1981	L7	ETM+	7115	2002may25	2002may25_th55	
312	6	Tan	Dune Lake	1981	L7	ETM+	7015	2002july21	2002july21_ponds_th29	
313	7	Tan	Dune Lake	1981	L5	TM	7015	2006sep10	2006sep10_ponds_th31	
314	8	Tan	Dune Lake	1981	L5	TM	7015	2008may10	2008may10_ponds_th27	
315	9	Tan	Dune Lake	1981	L5	TM	7115	2009july7	2009july7_ponds_th61	
316	1	Tan	Parks Highway	2006	L5	TM	6815	1984july13	**	
317	2	Tan	Parks Highway	2006	L5	TM	7015	1986jun15	1986jun15_ponds_th30	
318	3	Tan	Parks Highway	2006	L5	TM	7014	1987aug21	**	
319	4	Tan	Parks Highway	2006	L4	TM	7014	1988jun12	**	
320	5	Tan	Parks Highway	2006	L4	TM	7014	1988july14	**	
321	6	Tan	Parks Highway	2006	L4	TM	7014	1988july30	**	
322	7	Tan	Parks Highway	2006	L5	TM	7115	1992jun14	**	
323	8	Tan	Parks Highway	2006	L4	TM	7014	1992july25	**	
324	9	Tan	Parks Highway	2006	L4	TM	6915	1992aug19	**	
325	10	Tan	Parks Highway	2006	L5	TM	7014	1994jun5	**	
326	11	Tan	Parks Highway	2006	L5	TM	7014	1994aug8	**	
327	12	Tan	Parks Highway	2006	L5	TM	7014	1994sep9	**	
328	13	Tan	Parks Highway	2006	L5	TM	6915	1998may24	**	
329	14	Tan	Parks Highway	2006	L5	TM	7115	1999jun26	**	
330	15	Tan	Parks Highway	2006	L5	TM	6915	1999july14	**	
331	16	Tan	Parks Highway	2006	L7	ETM+	6915	1999sep8	**	
332	17	Tan	Parks Highway	2006	L7	ETM+	6915	2000jun6	**	
333	18	Tan	Parks Highway	2006	L7	ETM+	6815	2001jun2	**	
334	19	Tan	Parks Highway	2006	L7	ETM+	7015	2001jun16	2001jun16_ponds_th35	
335	20	Tan	Parks Highway	2006	L7	ETM+	7115	2001jun23	**	
336	21	Tan	Parks Highway	2006	L7	ETM+	6815	2001jun18	**	
337	22	Tan	Parks Highway	2006	L7	ETM+	6915	2001jun25	**	
338	23	Tan	Parks Highway	2006	L7	ETM+	6915	2001sep29	**	
339	24	Tan	Parks Highway	2006	L7	ETM+	7115	2002may25	**	
340	25	Tan	Parks Highway	2006	L7	ETM+	6915	2002may27	**	
341	26	Tan	Parks Highway	2006	L7	ETM+	7015	2002july21	2002july21_ponds_th17	

Satellite data appendix (continued)

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Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
342	27	Tan	Parks Highway	2006	L7	ETM+	6915	2002july30	**	
343	28	Tan	Parks Highway	2006	L7	ETM+	6915	2002aug15	**	
344	29	Tan	Parks Highway	2006	L7	ETM+	6915	2003may30	**	
345	30	Tan	Parks Highway	2006	L5	TM	6915	2003aug10	2003aug10_ponds_th36	
346	31	Tan	Parks Highway	2006	L5	TM	6815	2004sep6	**	
347	32	Tan	Parks Highway	2006	L5	TM	6915	2005jun28	**	
348	33	Tan	Parks Highway	2006	L5	TM	6915	2005july14	**	
349	34	Tan	Parks Highway	2006	L5	TM	7015	2006jun22	**	
350	35	Tan	Parks Highway	2006	L5	TM	7015	2006aug9	**	
351	36	Tan	Parks Highway	2006	L5	TM	6915	2006sep3	2006sep3_ponds_th19	
352	37	Tan	Parks Highway	2006	L5	TM	7015	2006sep10	**	
353	38	Tan	Parks Highway	2006	L5	TM	6915	2007aug21	**	
354	39	Tan	Parks Highway	2006	L5	TM	7015	2007aug28	**	
355	40	Tan	Parks Highway	2006	L5	TM	6915	2008may10	2008may10_ponds_th30	
356	41	Tan	Parks Highway	2006	L5	TM	6915	2008aug23	2008aug23_ponds_th18	
357	42	Tan	Parks Highway	2006	L5	TM	7015	2008aug30	**	
358	43	Tan	Parks Highway	2006	L5	TM	7115	2009july7	**	
359	1	Tan	Bolio Lake RX	2007	L5	TM	6815	1986aug4	1986aug4_ponds_th5	
360	2	Tan	Bolio Lake RX	2007	L4	TM	6815	1993july14	1993july14_ponds_th40	
361	3	Tan	Bolio Lake RX	2007	L5	TM	6815	1995july28	1995july28_ponds_th14	
362	4	Tan	Bolio Lake RX	2007	L7	ETM+	6815	2001jun2	2001jun2_ponds_th38	
363	5	Tan	Bolio Lake RX	2007	L5	TM	6815	2004aug21	2004aug21_ponds_th42	
364	6	Tan	Bolio Lake RX	2007	L5	TM	6815	2009aug3	2009aug3_ponds_th23	
365	1	Tan	Teklanika	2001	L5	TM	6915	1991jun22	1991jun26_ponds_th26	
366	2	Tan	Teklanika	2001	L7	ETM+	7015	2001jun16	2001jun16_ponds_th27	
367	3	Tan	Teklanika	2001	L7	ETM+	6915	2002may27	2002may27_ponds_th20	
368	4	Tan	Teklanika	2001	L7	ETM+	6915	2002july30		
369	5	Tan	Teklanika	2001	L7	ETM+	6915	2002aug15	2002aug15_ponds_th32	
370	6	Tan	Teklanika	2001	L7	ETM+	6915	2003may30	2003may30_ponds_th28	
371	7	Tan	Teklanika	2001	L5	TM	6915	2003aug10	2003aug10_ponds_th36	
372	8	Tan	Teklanika	2001	L5	TM	6915	2005jun28	2005jun28_ponds_th40	
373	9	Tan	Teklanika	2001	L5	TM	6915	2006sep3	2006sep3_ponds_th22	
374	10	Tan	Teklanika	2001	L5	TM	6915	2008aug23		
375	11	Tan	Teklanika	2001	L5	TM	7015	2008aug30	2008aug30_ponds_th7	
376	1	Tan	Survey Line	2001	L5	TM	7015	1986jun15	1986jun15_ponds_th17	
377	2	Tan	Survey Line	2001	L5	TM	6915	1999july14	1999july14_ponds_th29	
378	3	Tan	Survey Line	2001	L7	ETM+	7015	2001jun16	2001jun16_ponds_th27	
379	4	Tan	Survey Line	2001	L7	ETM+	6915	2001jun25		

Satellite data appendix (continued)

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Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
380	5	Tan	Survey Line	2001	L7	ETM+	7015	2002july21	2002july21_ponds_th9	
381	6	Tan	Survey Line	2001	L5	TM	6915	2003aug10	2003aug10_ponds_th30	
382	7	Tan	Survey Line	2001	L5	TM	6915	2005jun28		
383	8	Tan	Survey Line	2001	L5	TM	6915	2005july14	2005july14_ponds_th10	
384	9	Tan	Survey Line	2001	L5	TM	7015	2006aug9	2006aug9_ponds_th4	
385	10	Tan	Survey Line	2001	L5	TM	6915	2006sep3		
386	11	Tan	Survey Line	2001	L5	TM	7015	2007aug28	2007aug28_ponds_th14	
387	12	Tan	Survey Line	2001	L5	TM	6915	2008aug23	2008aug23_ponds_th17	
388	1	Tan	Willow Creek	2004	L5	TM	7015	1986jun15	1986jun15_ponds_th17	
389	2	Tan	Willow Creek	2004	L5	TM	6915	1999july14	1999july14_ponds_th29	
390	3	Tan	Willow Creek	2004	L7	ETM+	7015	2001jun16	2001jun16_ponds_th27	
391	4	Tan	Willow Creek	2004	L7	ETM+	6915	2001jun25		
392	5	Tan	Willow Creek	2004	L7	ETM+	7015	2002july21	2002july21_ponds_th9	
393	6	Tan	Willow Creek	2004	L5	TM	6915	2003aug10	2003aug10_ponds_th30	
394	7	Tan	Willow Creek	2004	L5	TM	6915	2005jun28		
395	8	Tan	Willow Creek	2004	L5	TM	6915	2005july14	2005july14_ponds_th10	
396	9	Tan	Willow Creek	2004	L5	TM	7015	2006aug9	2006aug9_ponds_th4	
397	10	Tan	Willow Creek	2004	L5	TM	6915	2006sep3		
398	11	Tan	Willow Creek	2004	L5	TM	7015	2007aug28	2007aug28_ponds_th14	
399	12	Tan	Willow Creek	2004	L5	TM	6915	2008aug23	2008aug23_ponds_th17	
400	1	Tan	Wood River	2004	L5	TM	7015	1986jun15	1986jun15_ponds_th17	
401	2	Tan	Wood River	2004	L5	TM	6915	1999july14	1999july14_ponds_th29	
402	3	Tan	Wood River	2004	L7	ETM+	7015	2001jun16	2001jun16_ponds_th27	
403	4	Tan	Wood River	2004	L7	ETM+	6915	2001jun25		
404	5	Tan	Wood River	2004	L7	ETM+	7015	2002july21	2002july21_ponds_th9	
405	6	Tan	Wood River	2004	L5	TM	6915	2003aug10	2003aug10_ponds_th30	
406	7	Tan	Wood River	2004	L5	TM	6915	2005jun28		
407	8	Tan	Wood River	2004	L5	TM	6915	2005july14	2005july14_ponds_th10	
408	9	Tan	Wood River	2004	L5	TM	7015	2006aug9	2006aug9_ponds_th4	
409	10	Tan	Wood River	2004	L5	TM	6915	2006sep3		
410	11	Tan	Wood River	2004	L5	TM	7015	2007aug28	2007aug28_ponds_th14	
411	12	Tan	Wood River	2004	L5	TM	6915	2008aug23	2008aug23_ponds_th17	
412	1	Tan	Observation Post	1998	L5	TM	6815	1984july13	1984july13_ponds_th15	recharge
413	2	Tan	Observation Post	1998	L4	TM	6815	1993july14	1993july14_ponds_th43	
414	3	Tan	Observation Post	1998	L5	TM	6815	1994aug10	1994aug10_ponds_th16	
415	4	Tan	Observation Post	1998	L7	ETM+	6815	1999july31	1999july31_ponds_th31	
416	5	Tan	Observation Post	1998	L7	ETM+	6815	2001jun2	2001jun2_ponds_th38high	
417	6	Tan	Observation Post	1998	L5	TM	6815	2004aug21	2004aug21_ponds_th42	

Satellite data appendix (continued)

Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	* = meterological disturbance **= no significant hydrological change Shapefile	Notes
418	7	Tan	Observation Post	1998	L5	TM	6815	2009aug3	2009aug3_ponds_th23	
419	1	Tan	Crooked	1998	L5	TM	7015	1986jun15	1986jun15_ponds_th17	
420	2	Tan	Crooked	1998	L5	TM	6915	1999july14	1999july14_ponds_th29	
421	3	Tan	Crooked	1998	L7	ETM+	7015	2001jun16	2001jun16_ponds_th27	
422	4	Tan	Crooked	1998	L7	ETM+	6915	2001jun25		
423	5	Tan	Crooked	1998	L7	ETM+	7015	2002july21	2002july21_ponds_th9	
424	6	Tan	Crooked	1998	L5	TM	6915	2003aug10	2003aug10_ponds_th30	
425	7	Tan	Crooked	1998	L5	TM	6915	2005jun28		
426	8	Tan	Crooked	1998	L5	TM	6915	2005july14	2005july14_ponds_th10	
427	9	Tan	Crooked	1998	L5	TM	7015	2006aug9	2006aug9_ponds_th4	
428	10	Tan	Crooked	1998	L5	TM	6915	2006sep3		
429	11	Tan	Crooked	1998	L5	TM	7015	2007aug28	2007aug28_ponds_th14	
430	12	Tan	Crooked	1998	L5	TM	6915	2008aug23	2008aug23_ponds_th17	
431	1	Tan	832002	1988	L5	TM	6815	1984july13	1984july13_ponds_th24	
432	2	Tan	832002	1988	L5	TM	7015	1986jun15	1986jun15_ponds_th34	
433	3	Tan	832002	1988	L5	TM	6915	1991jun22	1991jun22_ponds_th34	
434	4	Tan	832002	1988	L4	TM	6915	1992aug19	*	
435	5	Tan	832002	1988	L4	TM	6915	1992sep4	*	
436	6	Tan	832002	1988	L5	TM	7014	1994jun5	1994jun5_ponds_th17	
437	7	Tan	832002	1988	L5	TM	7014	1994sep9	**	
438	8	Tan	832002	1988	L5	TM	6915	1999july14	**	
439	9	Tan	832002	1988	L7	ETM+	6915	1999sep8	**	
440	10	Tan	832002	1988	L7	ETM+	7014	2001jun16	2001jun16_ponds_th47	
441	11	Tan	832002	1988	L7	ETM+	6915	2001jun25	**	
442	12	Tan	832002	1988	L7	ETM+	6915	2002july30	2002july30_ponds_th19	
443	13	Tan	832002	1988	L5	TM	6915	2003aug10	**	
444	14	Tan	832002	1988	L5	TM	6915	2005july14	**	
445	15	Tan	832002	1988	L5	TM	7015	2006aug9	**	
446	16	Tan	832002	1988	L5	TM	6915	2006sep3	**	
447	17	Tan	832002	1988	L5	TM	7015	2007aug28	**	
448	18	Tan	832002	1988	L5	TM	7015	2008aug30	**	
449	19	Tan	832002	1988	L5	TM	6815	2009july2	2009july2_ponds_th24	
450	1	Tan	Minto Flats	1995	L5	TM	7015	1986jun15	1986jun15_ponds_th40	
451	2	Tan	Minto Flats	1995	L5	TM	6915	1991jun22	**	
452	3	Tan	Minto Flats	1995	L4	TM	7115	1992jun14	**	
453	4	Tan	Minto Flats	1995	L4	TM	7114	1992july16	1992july16_ponds_th12	
454	5	Tan	Minto Flats	1995	L5	TM	7115	1999jun26	**	
455	6	Tan	Minto Flats	1995	L5	TM	6915	1999july14	1999july14_ponds_th44	

Satellite data appendix (continued)

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**= no significant hydrological change

Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
456	7	Tan	Minto Flats	1995	L7	ETM+	6915	1999sep8	**	
457	8	Tan	Minto Flats	1995	L7	ETM+	6915	2000jun6	**	
458	9	Tan	Minto Flats	1995	L7	ETM+	7115	2001jun23	2001jun23_ponds_th30	
459	10	Tan	Minto Flats	1995	L7	ETM+	7115	2002may25	**	
460	11	Tan	Minto Flats	1995	L7	ETM+	6915	2002may27	**	
461	12	Tan	Minto Flats	1995	L7	ETM+	6915	2002july30	**	
462	13	Tan	Minto Flats	1995	L7	ETM+	6915	2003may30	**	
463	14	Tan	Minto Flats	1995	L5	TM	6915	2003aug10	**	
464	15	Tan	Minto Flats	1995	L5	TM	7114	2005jun26	2005jun26_ponds_th17	
465	16	Tan	Minto Flats	1995	L5	TM	6915	2005jun28	**	
466	17	Tan	Minto Flats	1995	L5	TM	6915	2005july14	**	
467	18	Tan	Minto Flats	1995	L5	TM	7015	2006jun22	**	
468	19	Tan	Minto Flats	1995	L5	TM	7015	2006aug9	**	
469	20	Tan	Minto Flats	1995	L5	TM	6915	2006sep3	**	
470	21	Tan	Minto Flats	1995	L5	TM	7015	2006sep10	**	
471	22	Tan	Minto Flats	1995	L5	TM	6915	2007aug21	**	
472	23	Tan	Minto Flats	1995	L5	TM	7015	2007aug28	2007aug28_ponds_th20	
473	24	Tan	Minto Flats	1995	L5	TM	7015	2008may10	**	
474	25	Tan	Minto Flats	1995	L5	TM	6915	2008aug23	**	
475	1	Tan	Carla Lake	1998	L5	TM	6815	1984july13	1984july13_ponds_th15	recharge
476	2	Tan	Carla Lake	1998	L5	TM	6815	1985aug1	*	
477	3	Tan	Carla Lake	1998	L5	TM	6815	1986july3	**	
478	4	Tan	Carla Lake	1998	L5	TM	6815	1986aug4	**	
479	5	Tan	Carla Lake	1998	L5	TM	6815	1987aug23	*	
480	6	Tan	Carla Lake	1998	L5	TM	6915	1991jun22	*	
481	7	Tan	Carla Lake	1998	L4	TM	6915	1992aug19	**	
482	8	Tan	Carla Lake	1998	L4	TM	6915	1992sep4	**	
483	9	Tan	Carla Lake	1998	L4	TM	6815	1993july14	1993july14_ponds_th43	
484	10	Tan	Carla Lake	1998	L5	TM	6815	1994aug10	1994aug10_ponds_th16	
485	11	Tan	Carla Lake	1998	L5	TM	6815	1995july28	**	
486	12	Tan	Carla Lake	1998	L5	TM	6915	1998may24	**	
487	13	Tan	Carla Lake	1998	L5	TM	6915	1999july14	**	
488	14	Tan	Carla Lake	1998	L7	ETM+	6815	1999july31	1999july31_ponds_th31	
489	15	Tan	Carla Lake	1998	L7	ETM+	6915	1999sep8	**	
490	16	Tan	Carla Lake	1998	L7	ETM+	6915	2000jun6	**	
491	17	Tan	Carla Lake	1998	L7	ETM+	6815	2001jun2	2001jun2_ponds_th38high	
492	18	Tan	Carla Lake	1998	L7	ETM+	6815	2001jun18	**	
493	19	Tan	Carla Lake	1998	L7	ETM+	6915	2001jun25	**	
494	20	Tan	Carla Lake	1998	L7	ETM+	6915	2001sep29	**	
495	21	Tan	Carla Lake	1998	L7	ETM+	6915	2002may27	**	

Satellite data appendix (continued)

Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	* = meterological disturbance **= no significant hydrological change Shapefile	Notes
496	22	Tan	Carla Lake	1998	L7	ETM+	6915	2002july30	**	
497	23	Tan	Carla Lake	1998	L7	ETM+	6915	2002aug15	**	
498	24	Tan	Carla Lake	1998	L7	ETM+	6915	2003may30	**	
499	25	Tan	Carla Lake	1998	L5	TM	6915	2003aug10	**	
500	26	Tan	Carla Lake	1998	L5	TM	6815	2004aug21	2004aug21_ponds_th42	
501	27	Tan	Carla Lake	1998	L5	TM	6815	2004sep6	**	
502	28	Tan	Carla Lake	1998	L5	TM	6915	2005jun28	**	
503	29	Tan	Carla Lake	1998	L5	TM	6915	2005july14	**	
504	30	Tan	Carla Lake	1998	L5	TM	6915	2006sep3	**	
505	31	Tan	Carla Lake	1998	L5	TM	6915	2008aug23	**	
506	32	Tan	Carla Lake	1998	L5	TM	6815	2009july2	**	
507	33	Tan	Carla Lake	1998	L5	TM	6815	2009aug3	2009aug3_ponds_th23	
508	1	Tan	Bolio	1981	L5	TM	6815	1986july3	*	
509	2	Tan	Bolio	1981	L5	TM	6815	1986aug4	1986aug4_ponds_th5	recharge
510	3	Tan	Bolio	1981	L5	TM	6815	1987aug23	*	smoke
511	4	Tan	Bolio	1981	L4	TM	6815	1993july14	1993july14_ponds_th40	
512	5	Tan	Bolio	1981	L5	TM	6815	1994aug10	**	
513	6	Tan	Bolio	1981	L5	TM	6815	1995july28	1995july28_ponds_th14	
514	7	Tan	Bolio	1981	L7	ETM+	6815	1999july31	*	heavy clouds
515	8	Tan	Bolio	1981	L7	ETM+	6815	2001jun2	2001jun2_ponds_th38	
516	9	Tan	Bolio	1981	L7	ETM+	6815	2001jun18	*	clouds
517	10	Tan	Bolio	1981	L5	TM	6815	2004aug21	2004aug21_ponds_th42	
518	11	Tan	Bolio	1981	L5	TM	6815	2004sep6	*	small cloud
519	12	Tan	Bolio	1981	L5	TM	6815	2009july2	**	
520	13	Tan	Bolio	1981	L5	TM	6815	2009aug3	2009aug3_ponds_th23	
521	1	Tan	Winter Ridge	2001	L5	TM	6815	1986aug4	1986aug4_ponds_th5	recharge
522	2	Tan	Winter Ridge	2001	L4	TM	6815	1993july14	1993july14_ponds_th40	
523	3	Tan	Winter Ridge	2001	L5	TM	6815	1995july28	1995july28_ponds_th14	
524	4	Tan	Winter Ridge	2001	L7	ETM+	6815	2001jun2	2001jun2_ponds_th38	
525	5	Tan	Winter Ridge	2001	L5	TM	6815	2004aug21	2004aug21_ponds_th42	
526	6	Tan	Winter Ridge	2001	L5	TM	6815	2009aug3	2009aug3_ponds_th23	
527	1	Tan	BIG W 17	1983	L5	TM	6815	1984july13	1984july13_ponds_th25	small cloud
528	2	Tan	BIG W 17	1983	L5	TM	6815	1985aug1	*	
529	3	Tan	BIG W 17	1983	L5	TM	6815	1986july3	*	
530	4	Tan	BIG W 17	1983	L5	TM	6815	1986aug4	1986aug4_ponds_th26	small cloud
531	5	Tan	BIG W 17	1983	L5	TM	6815	1987aug23	*	heavy smoke
532	6	Tan	BIG W 17	1983	L5	TM	6915	1991jun22	*	
533	7	Tan	BIG W 17	1983	L4	TM	6915	1992aug19	*	

Satellite data appendix (continued)

* = meterological disturbance
**= no significant hydrological change

Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
534	8	Tan	BIG W 17	1983	L4	TM	6915	1992sep4	**	
535	9	Tan	BIG W 17	1983	L4	TM	6815	1993july14	1993july14_ponds_th75	
536	10	Tan	BIG W 17	1983	L5	TM	6915	1999july14	1999july14_ponds_th60	minimal smoke
537	11	Tan	BIG W 17	1983	L7	ETM+	6815	1999july31	**	
538	12	Tan	BIG W 17	1983	L7	ETM+	6915	1999sep8	*	
539	13	Tan	BIG W 17	1983	L7	ETM+	6915	2000jun6	*	
540	14	Tan	BIG W 17	1983	L7	ETM+	6815	2001jun2	**	
541	15	Tan	BIG W 17	1983	L7	ETM+	6815	2001jun18	*	
542	16	Tan	BIG W 17	1983	L7	ETM+	6915	2001jun25	*	
543	17	Tan	BIG W 17	1983	L7	ETM+	6915	2001sep29	**	
544	18	Tan	BIG W 17	1983	L7	ETM+	6915	2002may27	*	
545	19	Tan	BIG W 17	1983	L7	ETM+	6915	2002july30	*	
546	20	Tan	BIG W 17	1983	L7	ETM+	6915	2002aug15	2002aug15_ponds_th37	
547	21	Tan	BIG W 17	1983	L7	ETM+	6915	2003may30		
548	22	Tan	BIG W 17	1983	L7	ETM+	6915	2003aug10	2003aug10_ponds_th60	
549	23	Tan	BIG W 17	1983	L5	TM	6815	2004aug21	*	haze
550	24	Tan	BIG W 17	1983	L5	TM	6815	2004sep6	*	haze
551	25	Tan	BIG W 17	1983	L5	TM	6915	2005jun28	2005jun28_ponds_th65	*
552	26	Tan	BIG W 17	1983	L5	TM	6915	2005july14	*	heavy smoke
553	27	Tan	BIG W 17	1983	L5	TM	6915	2006sep3	2006sep3_ponds_th41	small cloud
554	28	Tan	BIG W 17	1983	L5	TM	6915	2008aug23	2008aug23_ponds_th44	
555	29	Tan	BIG W 17	1983	L5	TM	6815	2009july2	**	small cloud
556	30	Tan	BIG W 17	1983	L5	TM	6815	2009aug3	2009aug3_ponds_th89	smoke
557	1	Tan	100 Mile Creek	1996	L5	TM	6815	1984july13	1984july13_ponds_th25	small cloud
558	2	Tan	100 Mile Creek	1996	L5	TM	6815	1986aug4	1986aug4_ponds_th26	small cloud
559	3	Tan	100 Mile Creek	1996	L4	TM	6815	1993july14	1993july14_ponds_th75	
560	4	Tan	100 Mile Creek	1996	L5	TM	6915	1999july14	1999july14_ponds_th60	minimal smoke
561	5	Tan	100 Mile Creek	1996	L7	ETM+	6915	2002aug15	2002aug15_ponds_th37	
562	6	Tan	100 Mile Creek	1996	L7	ETM+	6915	2003aug10	2003aug10_ponds_th60	
563	7	Tan	100 Mile Creek	1996	L5	TM	6915	2005jun28	2005jun28_ponds_th65	haze
564	8	Tan	100 Mile Creek	1996	L5	TM	6915	2006sep3	2006sep3_ponds_th41	
565	9	Tan	100 Mile Creek	1996	L5	TM	6915	2008aug23	2008aug23_ponds_th44	
566	10	Tan	100 Mile Creek	1996	L5	TM	6815	2009aug3	2009aug3_ponds_th89	smoke
567	1	Tan	Spurs	1996	L5	TM	6815	1984july13	1984july13_ponds_th25	small cloud
568	2	Tan	Spurs	1996	L5	TM	6815	1986aug4	1986aug4_ponds_th26	small cloud
569	3	Tan	Spurs	1996	L4	TM	6815	1993july14	1993july14_ponds_th75	
570	4	Tan	Spurs	1996	L5	TM	6915	1999july14	1999july14_ponds_th60	minimal smoke
571	5	Tan	Spurs	1996	L7	ETM+	6915	2002aug15	2002aug15_ponds_th37	
572	6	Tan	Spurs	1996	L7	ETM+	6915	2003aug10	2003aug10_ponds_th60	

Satellite data appendix (continued)

Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	* = meterological disturbance **= no significant hydrological change Shapefile	Notes
573	7	Tan	Spurs	1996	L5	TM	6915	2005jun28	2005jun28_ponds_th65	haze
574	8	Tan	Spurs	1996	L5	TM	6915	2006sep3	2006sep3_ponds_th41	
575	9	Tan	Spurs	1996	L5	TM	6915	2008aug23	2008aug23_ponds_th44	
576	10	Tan	Spurs	1996	L5	TM	6815	2009aug3	2009aug3_ponds_th89	smoke
577	1	Tan	Military # 7	1990	L5	TM	6815	1984july13	1984july13_ponds_th25	small cloud
578	2	Tan	Military # 8	1990	L5	TM	6815	1986aug4	1986aug4_ponds_th26	small cloud
579	3	Tan	Military # 9	1990	L4	TM	6815	1993july14	1993july14_ponds_th75	
580	4	Tan	Military # 10	1990	L5	TM	6915	1999july14	1999july14_ponds_th60	minimal smoke
581	5	Tan	Military # 11	1990	L7	ETM+	6915	2002aug15	2002aug15_ponds_th37	
582	6	Tan	Military # 12	1990	L7	ETM+	6915	2003aug10	2003aug10_ponds_th60	
583	7	Tan	Military # 13	1990	L5	TM	6915	2005jun28	2005jun28_ponds_th65	haze
584	8	Tan	Military # 14	1990	L5	TM	6915	2006sep3	2006sep3_ponds_th41	
585	9	Tan	Military # 15	1990	L5	TM	6915	2008aug23	2008aug23_ponds_th44	
586	10	Tan	Military # 16	1990	L5	TM	6815	2009aug3	2009aug3_ponds_th89	smoke
587	1	Tan	Donnely Flats	1999	L5	TM	6815	1986aug4	1986aug4_ponds_th5	
588	2	Tan	Donnely Flats	1999	L4	TM	6815	1993july14	1993july14_ponds_th40	
589	3	Tan	Donnely Flats	1999	L5	TM	6815	1995july28	1995july28_ponds_th14	
590	4	Tan	Donnely Flats	1999	L7	ETM+	6815	2001jun2	2001jun2_ponds_th38	
591	5	Tan	Donnely Flats	1999	L5	TM	6815	2004aug21	2004aug21_ponds_th42	
592	6	Tan	Donnely Flats	1999	L5	TM	6815	2009aug3	2009aug3_ponds_th23	
593	1	Tan	Oklahoma Range RX	2007	L7	ETM+	6915	2003aug10	2003aug10_ponds_th60	
594	2	Tan	Oklahoma Range RX	2007	L5	TM	6915	2005jun28	2005jun28_ponds_th65	haze
595	3	Tan	Oklahoma Range RX	2007	L5	TM	6915	2006sep3	2006sep3_ponds_th41	
596	4	Tan	Oklahoma Range RX	2007	L5	TM	6915	2008aug23	2008aug23_ponds_th44	
597	5	Tan	Oklahoma Range RX	2007	L5	TM	6815	2009aug3	2009aug3_ponds_th89	smoke
598	1	YF	Lower Mouth	2004	L5	TM	6814	1985aug1	*	W clouds
599	2	YF	Lower Mouth	2004	L5	TM	7013	1986july17	1986july17_ponds_th27	
600	3	YF	Lower Mouth	2004	L4	TM	6913	1989july10	1989july10_ponds_th49	
601	4	YF	Lower Mouth	2004	L5	TM	6913	1994may13	1994may13_ponds_th13	SE clouds
602	5	YF	Lower Mouth	2004	L5	TM	6913	1999july14	1999july1_ponds_th48	
603	6	YF	Lower Mouth	2004	L7	ETM+	7014	2000aug16	2000aug16_ponds_th39	
604	7	YF	Lower Mouth	2004	L7	ETM+	7013	2001jun16	2001jun16_ponds_th59	
605	8	YF	Lower Mouth	2004	L5	TM	6913	2003sep27	2003sep27_ponds_th7	
606	9	YF	Lower Mouth	2004	L5	TM	6814	2004aug21	2004aug21_ponds_th2	active fire
607	10	YF	Lower Mouth	2004	L5	TM	6913	2005jun28	2005jun28_ponds_th17	
608	11	YF	Lower Mouth	2004	L5	TM	6913	2005sep16	2005sep16_ponds_th3	*
609	12	YF	Lower Mouth	2004	L5	TM	6814	2006jun24	**	seasonal variability

Satellite data appendix (continued)

* = meterological disturbance
**= no significant hydrological change

Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
610	13	YF	Lower Mouth	2004	L5	TM	6814	2006july26	*	haze/small clouds
611	14	YF	Lower Mouth	2004	L5	TM	6913	2006sep3	2006sep3_ponds_th23	
612	15	YF	Lower Mouth	2004	L5	TM	7013	2007aug28	2007aug28_ponds_th39	
613	16	YF	Lower Mouth	2004	L5	TM	6814	2009july2	**	
614	17	YF	Lower Mouth	2004	L5	TM	7013	2009aug17	2009aug17_ponds_th29	
615	1	YF	Hat Tie Lakes	2004	L5	TM	6814	1985aug1	**	
616	2	YF	Hat Tie Lakes	2004	L5	TM	6913	1999july14	1999july14_ponds_th53	
617	3	YF	Hat Tie Lakes	2004	L7	ETM+	6913	2001jun25	2001jun25_ponds_th49	
618	4	YF	Hat Tie Lakes	2004	L7	ETM+	6913	2003may30	**	
619	5	YF	Hat Tie Lakes	2004	L5	TM	6814	2003july18	2003july18_ponds_th19	
620	6	YF	Hat Tie Lakes	2004	L5	TM	7013	2004july2	*	smoke/haze
621	7	YF	Hat Tie Lakes	2004	L5	TM	6814	2004sep6	**	active fire
622	8	YF	Hat Tie Lakes	2004	L5	TM	6814	2005jun21	2005jun21_ponds_th24	
623	9	YF	Hat Tie Lakes	2004	L5	TM	6913	2005sep16	2005sep16_ponds_th8	
624	10	YF	Hat Tie Lakes	2004	L5	TM	6913	2006sep3	2006sep3_ponds_th27	
625	11	YF	Hat Tie Lakes	2004	L5	TM	6814	2007aug30	2007aug30_ponds_th27	
626	12	YF	Hat Tie Lakes	2004	L5	TM	6913	2008aug23	**	
627	13	YF	Hat Tie Lakes	2004	L5	TM	6814	2008sep1	2008sep1_ponds_th28	
628	1	YF	John Herbert's Village	2005	L5	TM	6913	1999jun28	**	smoke/haze
629	2	YF	John Herbert's Village	2005	L7	ETM+	6913	2003may30	**	smoke/haze
630	3	YF	John Herbert's Village	2005	L5	TM	6813	2003july18	2003july18_ponds_th27	
631	4	YF	John Herbert's Village	2005	L5	TM	6713	2003sep13?	**	
632	5	YF	John Herbert's Village	2005	L5	TM	6913	2003sep27	**	
633	6	YF	John Herbert's Village	2005	L5	TM	6813	2004aug21	2004aug21_ponds_th4	
634	7	YF	John Herbert's Village	2005	L5	TM	6913	2005jun28	2005jun28_ponds_th24	
635	8	YF	John Herbert's Village	2005	L5	TM	6713	2006july3	2006july3_ponds_th21	
636	9	YF	John Herbert's Village	2005	L5	TM	6913	2006jun15		smoke/haze
637	10	YF	John Herbert's Village	2005	L5	TM	6913	2006sep3	2006sep3_ponds_th12	
638	11	YF	John Herbert's Village	2005	L5	TM	6813	2007aug30	2007aug30_ponds_th3	
639	12	YF	John Herbert's Village	2005	L5	TM	6913	2008aug23	2008aug23_ponds_th38	
640	13	YF	John Herbert's Village	2005	L5	TM	6813	2009july2	2009july2_ponds_th31	
641	1	YF	Middle Birch Creek	2004	L5	TM	6814	1985aug1	1985aug1_ponds_th23	
642	2	YF	Middle Birch Creek	2004	L5	TM	6914	1991jun22	1991jun22_ponds_th42	
643	3	YF	Middle Birch Creek	2004	L5	TM	6813	2003july18	2003jul18_ponds_th13	
644	4	YF	Middle Birch Creek	2004	L5	TM	6914	2005jun28	2005jun28_ponds_th30	
645	5	YF	Middle Birch Creek	2004	L5	TM	6914	2006sep3	2006sep3_ponds_th22	
646	6	YF	Middle Birch Creek	2004	L5	TM	6814	2007aug30	**	
647	7	YF	Middle Birch Creek	2004	L5	TM	6814	2008sep1	2008sep1_ponds_th26	

Satellite data appendix (continued)

* = meterological disturbance
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Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
648	8	YF	Middle Birch Creek	2004	L5	TM	6814	2009july2	2009july2_ponds_th23	
649	1	YF	Preacher Creek	2004	L5	TM	6814	1985aug1	1985aug1_ponds_th23	
650	2	YF	Preacher Creek	2004	L5	TM	6914	1991jun22	1991jun22_ponds_th42	
651	3	YF	Preacher Creek	2004	L4	TM	6914	1992sep4		
652	4	YF	Preacher Creek	2004	L5	TM	6913	1999jul14		
653	5	YF	Preacher Creek	2004	L7	ETM+	6913	2000jun6		
654	6	YF	Preacher Creek	2004	L7	ETM+	6913	2003may30		
655	7	YF	Preacher Creek	2004	L5	TM	6813	2003july18		
656	8	YF	Preacher Creek	2004	L5	TM	6814	2004aug21		
657	1	YF	FYU S 39	1987	L5	TM	6814	1985aug1	1985aug1_ponds_th35	
658	2	YF	FYU S 39	1987	L5	TM	6914	1986may23	**	
659	3	YF	FYU S 39	1987	L5	TM	6914	1986july10	*	
660	4	YF	FYU S 39	1987	L5	TM	6913	1986aug11	1986aug11_ponds_th25	
661	5	YF	FYU S 39	1987	L4	TM	6914	1989july10	1989july10_ponds_th23	
662	6	YF	FYU S 39	1987	L5	TM	6914	1991jun22	1991jun22_ponds_th47	
663	7	YF	FYU S 39	1987	L4	TM	6914	1992sep4	1992sep4_ponds_th47	
664	8	YF	FYU S 39	1987	L5	TM	6913	1999jun28	1999jun28_ponds_th99	
665	9	YF	FYU S 39	1987	L7	ETM+	6913	2000jun6	**	
666	10	YF	FYU S 39	1987	L5	TM	6814	2003jul18	2003july18_ponds_th48	
667	11	YF	FYU S 39	1987	L5	TM	6914	2005jun28	**	smoke/haze
668	12	YF	FYU S 39	1987	L5	TM	6914	2006sep3	**	
669	13	YF	FYU S 39	1987	L5	TM	6814	2007aug30	**	
670	14	YF	FYU S 39	1987	L5	TM	6914	2008aug23	**	
671	15	YF	FYU S 39	1987	L5	TM	6914	2008sep1	**	
672	16	YF	FYU S 39	1987	L5	TM	6814	2009july2	**	
673	1	YF	32018	1990	L5	TM	7013	1985july30	*	smoke/haze/shadows
674	2	YF	32018	1990	L5	TM	6913	1985july7	*	smoke/haze/shadows
675	3	YF	32018	1990	L5	TM	7013	1985sep16	**	haze
676	4	YF	32018	1990	L5	TM	6913	1985sep25	**	
677	5	YF	32018	1990	L5	TM	6913	1986may23	1986may23_ponds_th21	
678	6	YF	32018	1990	L5	TM	7013	1986july17	1986july17_ponds_b543	
679	7	YF	32018	1990	L5	TM	6913	1986aug11	**	perimeter clouds
680	8	YF	32018	1990	L4	TM	7013	1988jun12	1988jun12_ponds_th14	
681	9	YF	32018	1990	L4	TM	6913	1989july10	1989july10_ponds_th46wet	
682	10	YF	32018	1990	L5	TM	7013	1991aug16	1991aug16_th13	clouds*
683	11	YF	32018	1990	L5	TM	6913	1994may13	1994may13_ponds_th28	
684	12	YF	32018	1990	L5	TM	7013	1995aug27	1995aug27_ponds_th8	
685	13	YF	32018	1990	L5	TM	6913	1999jul14	1999july14_ponds_th29	

Satellite data appendix (continued)

* = meterological disturbance
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Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
686	14	YF	32018	1990	L7	ETM+	7013	2000jun13	2000jun13_ponds_th29_wet	
687	15	YF	32018	1990	L7	ETM+	7013	2000july15	2000july15_ponds_th18	
688	16	YF	32018	1990	L7	ETM+	7013	2000aug16	2000aug16_ponds_th39	
689	17	YF	32018	1990	L7	ETM+	7013	2001jun16	2001jun16_ponds_th60_wet	
690	18	YF	32018	1990	L7	ETM+	7013	2001july2	2001july2_ponds_th28	
691	19	YF	32018	1990	L7	ETM+	7013	2002aug6	2002aug6_ponds_th16	
692	20	YF	32018	1990	L7	ETM+	6913	2003may30	2003may30_ponds_th48	
693	21	YF	32018	1990	L5	TM	6913	2003sep27	2003sep27_ponds_th3	
694	22	YF	32018	1990	L5	TM	7013	2004july2	2004july2_ponds_th54	smoke/haze
695	23	YF	32018	1990	L5	TM	6913	2005jun28	2005jun28_ponds_th37	
696	24	YF	32018	1990	L5	TM	6913	2006sep3	2006sep3_ponds_th23	
697	25	YF	32018	1990	L5	TM	6913	2008aug23	2008aug23_ponds_th52	
698	26	YF	32018	1990	L5	TM	7013	2009july16	2009july16_ponds_th59	
699	1	YF	Deadman Island	1996	L5	TM	7013	1985july30	*	smoke/haze/shadows
700	2	YF	Deadman Island	1996	L5	TM	6913	1985july7	*	smoke/haze/shadows
701	3	YF	Deadman Island	1996	L5	TM	7013	1985sep16	**	haze
702	4	YF	Deadman Island	1996	L5	TM	6913	1985sep25	**	
703	5	YF	Deadman Island	1996	L5	TM	6913	1986may23	1986may23_ponds_th21	
704	6	YF	Deadman Island	1996	L5	TM	7013	1986july17	1986july17_ponds_b543	
705	7	YF	Deadman Island	1996	L5	TM	6913	1986aug11	**	perimeter clouds
706	8	YF	Deadman Island	1996	L4	TM	7013	1988jun12	1988jun12_ponds_th14	
707	9	YF	Deadman Island	1996	L4	TM	6913	1989july10	1989july10_ponds_th46wet	
708	10	YF	Deadman Island	1996	L5	TM	7013	1991aug16	*	clouds*
709	11	YF	Deadman Island	1996	L5	TM	6913	1994may13	1994may13_ponds_th28	
710	12	YF	Deadman Island	1996	L5	TM	7013	1995aug27	1995aug27_ponds_th8	
711	13	YF	Deadman Island	1996	L5	TM	6913	1999jul14	1999july14_ponds_th29	
712	14	YF	Deadman Island	1996	L7	ETM+	7013	2000jun13	2000jun13_ponds_th29_wet	
713	15	YF	Deadman Island	1996	L7	ETM+	7013	2000july15	2000july15_ponds_th18	
714	16	YF	Deadman Island	1996	L7	ETM+	7013	2000aug16	2000aug16_ponds_th39	
715	17	YF	Deadman Island	1996	L7	ETM+	7013	2001jun16	2001jun16_ponds_th60_wet	
716	18	YF	Deadman Island	1996	L7	ETM+	7013	2001july2	2001july2_ponds_th28	
717	19	YF	Deadman Island	1996	L7	ETM+	7013	2002aug6	2002aug6_ponds_th16	
718	20	YF	Deadman Island	1996	L7	ETM+	6913	2003may30	2003may30_ponds_th48	
719	21	YF	Deadman Island	1996	L5	TM	6913	2003sep27	2003sep27_ponds_th3	
720	22	YF	Deadman Island	1996	L5	TM	7013	2004july2	2004july2_ponds_th54	smoke/haze
721	23	YF	Deadman Island	1996	L5	TM	6913	2005jun28	2005jun28_ponds_th37	
722	24	YF	Deadman Island	1996	L5	TM	6913	2006sep3	2006sep3_ponds_th23	
723	25	YF	Deadman Island	1996	L5	TM	6913	2008aug23	2008aug23_ponds_th52	
724	26	YF	Deadman Island	1996	L5	TM	7013	2009july16	2009july16_ponds_th59	

Satellite data appendix (continued)

* = meterological disturbance
**= no significant hydrological change

Id no.	Count	Region	Fire Name	Fire Year	Satellite	Sensor	Path/Row	Acquisition	Shapefile	Notes
725	1	YF	Squirrel Creek	2005	L4	TM	6913	19992sep4	**	
726	2	YF	Squirrel Creek	2005	L5	TM	6913	1999jun28	**	smoke/haze
727	3	YF	Squirrel Creek	2005	L5	TM	6913	1999jul14	1999july14_ponds_th43	
728	4	YF	Squirrel Creek	2005	L7	ETM+	6913	2003may30	**	
729	5	YF	Squirrel Creek	2005	L5	TM	6814	2003july18	2003july18_ponds_th47	
730	6	YF	Squirrel Creek	2005	L5	TM	6814	2003sep20	*	cloud shadow
731	7	YF	Squirrel Creek	2005	L5	TM	6814	2004sep6	**	smoke/haze
732	8	YF	Squirrel Creek	2005	L5	TM	6913	2005jun28	**	
733	9	YF	Squirrel Creek	2005	L5	TM	6913	2006sep3	2006sep3_ponds_th37	
734	10	YF	Squirrel Creek	2005	L5	TM	6813	2007aug30	**	
735	11	YF	Squirrel Creek	2005	L5	TM	6913	2008aug23	**	
736	12	YF	Squirrel Creek	2005	L5	TM	6814	2008sep1	2008sep1_ponds_th29	