TANADA LAKE TRAIL INTEGRATED TERRAIN UNIT MAPPING AND PERMAFROST SURVEYS, WRANGELL-ST. ELIAS NATIONAL PARK AND PRESERVE, ALASKA, 2012

FINAL REPORT

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INTRODUCTION

Wrangell-St. Elias National Park and Preserve (WRST) is located in the Copper River Basin in southcentral Alaska and is the largest park in the National Park Service (NPS) system (Figure 1). WRST encompasses a diverse array of ecosystems ranging from coastal meadows and tidal marshes in the southern maritime region, to alpine tundra above treeline, and boreal forest and bogs in the northwest (Jorgenson et al. 2008a). Permafrost is discontinuous in the boreal region of WRST where ice-rich permafrost (>50% ice content) has formed in eolian silt, clay-rich lacustrine deposits from prehistoric Lake Ahtna (Ferrians 1989) and in organic bog deposits. Permafrost is defined as soil materials that remain at or below 0 °C for at least two consecutive years (SSS 2010). Permafrost fundamentally influences landscape patterns and processes, including vegetation composition and distribution (Chapin et al. 2006), nutrient dynamics (Petrone et al. 2006), carbon cycling (O'Donnell et al. 2011), and hydrology (Luoto 2007). The Copper River Basin occurs in the zone of discontinuous permafrost where it is estimated that permafrost occurs across 50–90% of the land surface (Jorgenson et al. 2008b).

Traditional land uses in the boreal region of WRST include subsistence and the use of off-highway vehicles (OHVs) to access subsistence resources and land inholdings (Happe et al. 1998). These traditional uses have been preserved as part of the Alaska National Interest Lands Conservation Act (ANILCA) and OHV use has continued on traditional trail systems in WRST. However, six traditional trails were recently closed to non-subsistence users on a seasonal basis (Jensen 2009) due to resource damage, several due to damage in permafrost environments. The Nabesna Off-Road Vehicle Management Plan Final Environmental Impact Statement (EIS) for WRST (NPS 2011) was prepared in part to address these issues with the goal of providing "appropriate and reasonable access to wilderness and backcountry recreational activities, that also accommodates subsistence use and access to inholdings, while protecting scenic quality, fish and wildlife habitat, and other park resource values." Six alternatives were provided in the WRST EIS, including a no action alternative. Under alternative 6, the NPS preferred alternative, all trails would be improved to a maintainable standard. Additionally, a recent study assessed the impacts of OHVs on watershed processes along the Tanada Lake Trail (TLT), one of the trails closed due to resource damage (Figures 2 and 3) and recently reopened (Arp and Simmons

2012). The study documented changes in drainage channel morphology, soil temperature, and active layer depth on the TLT. The present study is designed 1) to provide resource managers with data and mapping products to aid in decision making pursuant with the NPS preferred alternative, and 2) to supplement the work of Arp and Simmons (2012) using an Integrated Terrain Unit (ITU) approach to characterize and map the vegetation-soil-permafrost relationships along the TLT.

Jorgenson et al. (2008a) provide an ecological land survey and landcover map of WRST. Although ELS provides a robust classification and mapping, it is not without limitations. The map series produced as part of the ELS provides a landscape-scale (thousands to hundreds of thousands of square kilometers) view of ecosystem components with a minimum pixel size of 30 meters. While this scale of mapping is appropriate for large, remote areas like WRST, it does limit the usefulness for some applications. For instance, the Jorgenson et al. (2008a) map is appropriate for landscape-scale analyses of ecological components (e.g., terrain suitability, wildlife habitat), broad-scale management and planning, and development of stratified sampling designs for landscape scale inventory and monitoring studies. However, an Integrated Terrain Unit (ITU) approach (Jorgenson et al. 2003) to mapping ecosystem components is better suited for finer-scale (tens to hundreds of square kilometers), site specific management and planning, monitoring, and study design. ITU mapping is a type of integrated data management. It is the process of adjusting mapped boundaries delineated by hand on high-resolution (≤1 m) satellite or aerial imagery, resulting in increased coincidence between the boundaries and occurrences of interdependent terrain variables such as geology, physiography, soil, and vegetation units. ITU mapping can and should be designed to complement available landscape-scale ELS mapping, a task made easier because the Jorgenson et al. (2008a) mapping was created with GIS modeling, allowing implementation of a simplified ITU approach. Therefore, a primary objective of this study was to design the ITU mapping of the TLT study area to dovetail with the Jorgenson et al. (2008a) ELS. Given the limited timeframe and funding available for this project it has been designed as a pilot study to illustrate the utility of the ITU approach for classification, mapping, and analysis of landscape components, and to collect baseline data for potential future broader scale mapping and monitoring in the vicinity of the TLT. Specific objectives include:

- Characterize and describe landscape relationships in the ecosystems traversed by the first several kilometers of the TLT;
- Map vegetation, soils, geomorphology, and disturbance along the initial 2.5–3.0 km of the TLT using an Integrated Terrain Unit (ITU) approach (Jorgenson et al. 2003);
- Use field data and the ITU classification to map ecotypes (local-scale ecosystems) and landscape sensitivities; and
- Use field data and observations to develop recommendations for potential future broader-scale mapping, rehabilitation, and monitoring of the TLT.

STUDY AREA

The study area is located in northwestern WRST, south of the Mentasta Mountains and north of the Wrangell Mountains (Figure 1). The TLT trailhead is located on the south side of the Nabesna Road at approximately 39 km (24 mi) from the intersection with the Tok Cutoff. The study area encompasses 438.7 ha (1,084.2 acres) and includes the first ~2.7 km (1.7 mi) of the TLT. The study area is characterized by intermountain lowlands dominated by black spruce forest, low shrub birch-tussock tundra and bogs, and sedge fens; and uplands and subalpine areas dominated by white spruce forests and woodlands and birch-willow low shrub (Jorgenson et al. 2008a).

METHODS

Field surveys were conducted 23–24 August 2012. Transect locations were stratified across the landscape using a gradient-directed sampling scheme (Austin and Heyligers 1989) to gather the range of ecological conditions and to provide the spatially-related data needed to interpret ecosystem development. Data were collected at 16 plots along 2 transects (toposequences) (Figure 1). Along each transect, 5–10 ELS plots (approximately 10 m radius) were typically sampled, each in a distinct vegetation type or spectral signature identifiable on aerial or satellite imagery. Sample plot locations were selected subjectively by the field crew leader, choosing homogenous patches of vegetation (~½ to ¾ ha, minimum area) and avoiding ecotones. Plots were spaced so as to cover the entire length of each transect and to avoid "pseudoreplication" (i.e., sampling the same or very similar vegetation and soils in more than one plot on a transect).

Coordinates (including approximate elevations) were obtained with Garmin eTrex Legend HCx Global Positioning System (GPS) receivers (accuracy ±5 m). Given the short time frame, we used rapid verification plots to describe a reduced set of variables designed for mapping verification and ecosystem characterization. Variables included physiography, geomorphic unit, surface form, dominant vascular plant species (and estimated cover values), water table and thaw depth, soil electrical conductivity (EC) and pH, generalized soil texture, surface organic thickness, depth to >15% rock fragments, Viereck Level IV vegetation class, and vegetation structure class. Digital photos were taken at each plot location, including landscape and ground cover view, and photos of the soil pit face.

We collected one soil sample in a lowland glaciolacustrine deposit for verification of soil texture. The soil sample was sent for particle size analysis to the Palmer Research Center at the University of Alaska Fairbanks Center for Sustainable Living in Palmer, AK (Laurie Wilson). Dominant vascular species that could not be identified with confidence in the field were sent for verification to Carolyn Parker, University of Alaska Museum of the North Herbarium (ALA), Fairbanks.

Thaw depth surveys were conducted along 100–200 m transects placed perpendicular to the TLT using a thaw probe (0.25-inch diameter steel rod). The thaw depth transects were placed 1) such that either the beginning or end was co-located with the center of a vegetation/soil plot, and 2) such that they began in undisturbed terrain and traversed across the TLT (Figure 1). Minimum depth (cm) to frozen ground, rock fragments, or unknown (in cases of uncertainty) were recorded every meter. Permanent magnetic markers (SurvKap®) were buried at approximately 20 cm depth at the start (0 meters) and end of each transect. Although surface elevation, measured concurrent with thaw depth measurements, would have provided a more complete dataset for use in future monitoring and in understanding the impacts of the TLT on thaw depth and surface hydrology, surface elevation measurements were beyond the scope of this study.

CLASSIFICATION

We classified ecosystems in the study area at two levels. First, individual ecological components were classified and coded using standard classification systems developed for Alaska (Table 1). Second, we used the ecological type classification (i.e., Key to Ecotypes) for

WRST developed by Jorgenson et al. (2008a) to assign ecotypes to each field plot and combination of ITU components.

ECOLOGICAL COMPONENTS

The ecological component classification follows the general methods developed by Jorgenson et al. (1997, 2003, 2004, 2008a, 2009) and Roth et al. (2007, 2009) for work throughout Alaska.

Physiography characterizes the dominant tectonic and geomorphic processes controlling the landscape and was classified following Jorgenson et al. (2008a) for WRST. Geomorphic units were classified according to a system based on landform–soil characteristics for Alaska developed originally by Kreig and Reger (1982) and ADGGS (1983), with modification based on the recent works mentioned above. We focused on soil characteristics near the surface (<1 m) because they have the greatest influence on ecological processes. Surface forms (macrotopography) were classified according to a system modified from that of Schoeneberger et al. (1998). Microtopography was classified according to the periglacial system of Washburn (1973).

Generalized soil texture was classified using 1) the USDA, NRCS (2010) guidelines for differentiating mineral (<20 cm organic material) and organic (20 to >40 cm organic material) soils, and 2) the guidelines provided by Soil Survey Staff (1993) for differentiating coarse, rocky (≥15% rock fragments) and fine-textured (<15% rock fragments) mineral soils. Rocky soils were further differentiated by the degree of roundness or angularity of rocks, characteristics indicative of different types of landscape processes and depositional setting (e.g., rounded = fluvial, angular = colluvial or glacial). Fine-textured soil classes were classified by aggregating similar soil textures from the soil texture triangle (Schoeneberger et al. 2002). Table 1 provides the soil texture classification, including a summary of soils data by geomorphic unit.

Vegetation was classified using the Alaska Vegetation Classification (AVC) developed by Viereck et al. (1992). Disturbance was classified based on a system developed by ABR, Inc., for use on the Arctic Coastal Plain and modified where appropriate for this project.

ITU MAPPING

Individual ecological components were mapped simultaneously as compound codes called Integrated Terrain Units (ITUs). ITUs were mapped by assigning a five-parameter code to each polygon describing physiography, geomorphology, generalized soil texture, vegetation, and disturbance (e.g., L/Gll/LO/Slott/Htsnw) (Table 2). Delineation was completed on-screen using a Digital CIR orthophoto mosaic by GeoEye from geometrically corrected 1-meter IKONOS-2, 2004–2006. Mapping was completed at 1:3,000 to 1:5,000 scale and the minimum mapping size for polygons (a 'polygon' is defined here as an area delineated on the map as a single unit; it does not refer to polygons in the sense of polygonized landforms) was 0.10 ha. Two complex surface vegetation classes were used to map highly heterogeneous areas associated with dynamic geomorphic processes or anthropogenic disturbance. The complexes were used for polygons where at least three vegetation classes were present, the dominant cover type occupied <65% of the polygon, and inclusions were below the minimum size for mapping. Individual maps were produced for each of the ecological components used to create the ITUs: physiography, geomorphology, general soil texture, vegetation, and disturbance. We aggregated unique ITU combinations into ecotypes based on the concepts of an integrated-terrain-unit (ITU) classification that originally was developed by ABR, Inc., for the Arctic Coastal Plain of Alaska (Jorgenson et al. 1997, 2003, 2004, 2008a, 2009; Roth et al. 2007, 2009; Wells et al. 2012) and modified for the TLT study area. The ITU map classes were assigned ecotypes based on a cross-walk between mapped physiography and vegetation, and the ecotype classification of Jorgenson et al. (2008a) for WRST. The ecotype map was then developed by recoding the ITU map based on the ecotype cross-walk.

EVALUATION

We used the ITU mapping to evaluate land sensitivity in the TLT study area. First, ecotypes were assigned permafrost and summer traffic sensitivity classes (high, moderate, low, negligible) based on vegetation-soil-landscape relationships developed from field surveys, and by summarizing a reduced set of field variables (surface organic thickness, thaw depth, and depth to >15% rock fragments, dominant soil texture) by ecotype (Table 3). Next, the landscape sensitivity classification was created by combining the permafrost and summer traffic sensitivity rankings by ecotype. The ITU map was recoded to create a map of landscape sensitivity. Lastly, to assess the effectiveness of the landscape sensitivity classification, we overlaid the trails layer from the NPS Permanent Dataset (PDS) and calculated the total distance of four trail type and disturbance rating classes assigned to the TLT from the NPS trails layer (Track Type, Track Width, Impact Rating, and Mud-Muck).

RESULTS AND DISCUSSION

LANDSCAPE RELATIONSHIPS

TOPOSEQUENCES

The classification and mapping of ecological components (physiography, geomorphology, soils, and vegetation) and ecotypes, and the evaluation of landscape sensitivites was based on the field survey along toposequences designed to assess vegetation-soil-landscape relationships. Toposequences display two-dimensional views of the ecological components that were used as the basis for classification and mapping (Figures 4 and 5). Vegetation classes follow the AVC (Viereck et al. 1992). Two toposequences representing distinct ecosystems within the study area are described below and summarize ecological relationships in subalpine-lowland and lowland-upland-lacustrine environments.

On a subalpine-lowland toposequence the geomorphology was dominated by younger till on low kames and moraines in subalpine areas, and glaciolacustrine deposits in lowlands (Figure 4). Soil pH was typically circumneutral (5.5 ≤ 7.3) across all geomorphic units. Acidic (pH < 5.5) soils were occasionally encountered on older landforms under coniferous and/or ericaceous vegetation. Soils formed in younger till were very gravelly/cobbly loamy sands to sandy loams in the upper 40 cm and featured thin (typically <15 cm) surface organics. Depth to frozen ground is unknown in younger till deposits as it was never encountered in the shallow (typically 40 cm deep) soil pits used to describe soils in this study. However, it is likely that frozen ground is at least several meters deep and may be entirely absent in these coarse-textured soils on well drained surfaces. Soils formed in glaciolacustrine deposits were silt loams to silty clay loams with moderately thick (typically 20–30 cm) surface organics, thaw depths were shallow (<50 cm), and rock fragments were rarely encountered in the upper 50 cm of the soil profile. Vegetation in subalpine areas included white spruce woodland and low open birch-willow shrub.

In lowland areas, vegetation was open low shrub-tussock tundra and mixed white and black spruce woodlands and forests. The TLT typically occurred in lowland areas in the study area where it often featured “braided” trail morphology. A complex of several different vegetation types occurred in these braided areas, including open low shrub-tussock tundra on small undisturbed areas between braids, wet sedge meadow tundra and freshwater sedge marsh in low-lying areas and thermokarst depressions, and barrens/partially vegetated areas in recently disturbed tire ruts and “muck” holes. Thaw depths typically ranged from 50 to 100 cm in braided trail areas.

On a lowland-upland-lacustrine toposequence (Figure 5) the geomorphology was dominated by glaciolacustrine and organic fen deposits in lowlands, glaciofluvial deposits in uplands, and ice-poor drained lake deposits in lacustrine environments. Soil pH was typically circumneutral ($5.5 \leq 7.3$) across all geomorphic units. Acidic ($pH < 5.5$) soils were occasionally encountered on older landforms under coniferous and/or ericaceous vegetation. Soils formed in glaciolacustrine deposits were silt loams to silty clay loams with moderately thick (typically 20–30 cm) surface organics, thaw depths were shallow (<50 cm), and rock fragments were rarely encountered in the upper 50 cm of the soil profile. Soils in organic fen deposits featured thick (>40 cm) organic material, a shallow water table (<50 cm), and moderate thaw depths (50–100 cm). Soils formed in glaciofluvial deposits typically featured a thin (typically <15 cm) surface organic horizon, over a series of thin silt-rich loess layers interbedded with buried organic, overlying very gravelly/cobbly loamy sands to sandy loams. Depth to frozen ground is unknown in glaciofluvial deposits as it was never encountered in the shallow (typically 40 cm deep) soil pits used to describe soils in this study. However, it is likely that frozen ground is at least several meters deep and may be entirely absent in these coarse-textured soils on well drained surfaces. Soil in the ice-poor drained basin featured a thin surface organic horizon over a moderately thick (50–100 cm) layer of silty clay loam with abundant low chroma mottles indicative of prolonged saturation. However, the water table was not encountered in the upper 40 cm. A layer of rocky glaciofluvial deposits occurred at depth. A small area of standing water occurred at the center of the drained basin; a remnant of the once larger and deeper kettle lake that formerly filled this basin. Vegetation in lowland areas included tussock tundra and open low shrub-tussock tundra on glaciolacustrine deposits and wet sedge meadow tundra on fen deposits. In uplands, vegetation was predominantly mixed white and black spruce woodlands and forests. Lacustrine environments featured a mixture of moist and wet sedge meadow tundra.

THAW DEPTH SURVEYS

Thaw transects WRST-PF2, WRST-PF3, and WRST-PF4 are displayed graphically in Figures 6–8, showing depths in centimeters to frozen ground, >15% rock fragments, or unknown features at each meter, and approximate boundaries of trails and braided trail sections ("braid") relative to ecotypes encountered along each transect. Thaw depth transects WRST-PF1 and WRST-PF5 are not displayed for the sake of brevity. All thaw transect data is provided in the M.S. Access field database accompanying this report. Mean thaw depths in undisturbed lowland ecotypes, including Boreal Lowland Tussock-Shrub Bog and Boreal Lowland Black Spruce Forest were shallower and less variable than in areas of Lowland Disturbance Complex that were disturbed by the Tanada Lake Trail, where thaw was deep and variability was high (Table 4). Rock fragments were encountered frequently in Boreal Subalpine Willow-Birch and Boreal Riverine White Spruce Forest, while in lowland ecotypes rock fragments were encountered only sporadically. Frozen ground was rarely encountered in subalpine and riverine ecotypes.

ECOLOGICAL COMPONENTS

PHYSIOGRAPHY

Physiographic units are broad areas on the landscape that are characterized by similar geomorphic processes, topographic relief, and geologic substrate. Six physiography classes were mapped in the study area, including lowland (62.8% of total area), subalpine (20.7%), upland (13.0%), riverine (2.1%), lacustrine (0.8%), and human-altered (0.6%) (Figure 9, Tables 5 and 6). Lowland was the most common physiography class in the study area and was dominated by organic, organic-rich, and fine-textured permafrost affected soils. Subalpine was the second most common physiography class in the study area and was dominated by rocky, well-drained soils and permafrost either very deep or absent. Environmental gradients separating physiographic areas in the vicinity of the TLT are abrupt, occurring over relatively short distances both horizontally and vertically. For instance, the elevation difference between subalpine and lowland was often not more than a few meters. However, the difference between vegetation and soils in those few meters was disproportionately important in the types of vegetation and soils occurring in these two environments.

GEOMORPHIC UNIT

Twelve geomorphic units were mapped in the study area (Figure 10, Table 7). The most common included Lowland Glaciolacustrine Deposit (46.2% of total area), Younger Till (18.9%), Glaciofluvial Outwash (12.6%), Upland Glaciolacustrine Deposit (10.6%), and Organic Fen (4.1%) (Table 5). Geomorphic units represent geological materials associated with distinct erosional and depositional settings and processes. The types and composition of geomorphic units in an area reflect the regional geologic framework and history. In the TLT study area, glacial processes have shaped the types and spatial distribution of geomorphic units, including glacial till and outwash deposits overlying thick layers of silt- and clay-rich glaciolacustrine deposits resulting from a series of prehistoric pro-glacial lakes. In modern times, drainage systems have formed, creating narrow floodplains, and kettle lakes have periodically flooded and drained, resulting in the formation of lacustrine deposits.

GENERALIZED SOIL TEXTURE

A generalized soil texture map was developed using an ITU approach (Figure 11, Table 8). Soil textures included Loamy-Organic (57.8% of total area), Rubbly (19.7%), Gravelly (14.0%), Organic (5.5%), and Loamy (1.8%) (Table 5). Geomorphic units were aggregated into generalized soil textures based on field data (Table 1), including dominant soil textures in the upper 40 cm, depth to >15% rock fragments, an understanding of soil-landscape relationships (Figures 4 and 5); and thaw depth surveys (Figures 6–8) along the TLT. Generally, rocky soil textures (rubbly, gravelly) were assigned to geomorphic units with surface organic thickness <20 cm, rock depth <40 cm, and soils with gravelly or rubbly dominant soil textures. Loamy soil texture was assigned to geomorphic units with loamy (i.e., silt loam to clay loam) soils and thaw depths greater than rock depths. A single soil sample from a loamy lowland soil was sent for laboratory analysis and had the following particle size: 15% sand, 57% silt, and 28% clay, and a texture of silty clay loam. Organic soil texture was assigned to geomorphic units with >40 cm surface organics; while loamy-organic was assigned to those units with 20-40 cm surface organic overlying silt loam and silty clay loam mineral soils, and shallow thaw depths (ca. 40–60 cm).

Five geomorphic units were mapped but did not have field data (Table 1). For three of these it was straightforward to assign generalized texture without field data, including 1) the Nabesna Road, which was mapped as Gravel Fill and assigned a general soil texture of “Fill”, 2) Deep Isolated Thaw Lake, which was assigned a general soil texture of “Water”, and 3) Bogs, which was assigned a general soil texture of organic. The remaining two, Hillside Colluvium and Old Alluvial Fan, were assigned generalized textures of rubbly and gravelly (respectively) based on the processes by which these types of geomorphic units are formed (colluvial and fluvial mass movements) and the associated vegetation (as indicated in the imagery), including white spruce forest and woodland, which indicate rocky, well-drained soils.

Permafrost soils typically feature an “active layer” that thaws each summer and refreezes over the winter and occurs above the permanently frozen soils. Two types of permafrost are differentiated depending on the ice content of the soil, ice-rich (≥50% ice by volume) and ice-poor (Williams and Smith 1991). Soil texture is strongly related to the ice content of permafrost (Jorgenson and Osterkamp 2005). For instance, coarse, rubbly, and gravelly soils are well-drained and often free of permafrost or support low ice content, while fine loamy and organic-rich soils are more poorly drained and often support higher ice content. Hence, thermokarst (Jorgenson and Osterkamp 2005, Osterkamp et al. 2000, Osterkamp et al. 2009) is generally less severe or absent in coarser soils than in finer soils due to the lower grain size to pore space ratio in coarser soils.

VEGETATION

Thirteen vegetation types were mapped in the study area (Figure 12, Table 9). The most common included Open Mixed Low Shrub–Sedge Tussock Tundra (41.2% of total area), Open Low Shrub Birch–Willow (18.9%), White Spruce Woodland (9.9%), Black Spruce–White Spruce Woodland (9.2%), Open White Spruce Forest (5.2%), and Tussock Tundra (5.2%) (Table 5). The type and distribution of vegetation in an area reflects a combination of the available species pool, broad-scale climatic, and fine-scale topo-edaphic factors. For instance, the TLT study area is located in the subarctic in boreal forest, a broad vegetation zone close to the upper elevation limit of trees in this area (~1,000 m). Hence, black and white spruce forests and woodlands, low shrub birch–willow stands, and tussock tundra types are common. At the site-scale, the distribution of vegetation in a given location is determined by fine-scale (1 to several meters) topographic and soil variability. This is expressed in the study area as Open Mixed Low Shrub–Sedge Tussock Tundra, Tussock Tundra, and Black Spruce–White Spruce Woodland occurring on frozen soils on flat and gently sloping surfaces in lowland areas; White Spruce Forest and Woodland, and Open Low Shrub Birch–Willow occurring on rocky, unfrozen soils on convex surfaces in subalpine, upland, and riverine areas; and Wet Sedge Meadow tundra occurring in depressions on wet, organic soils in lowland areas.

DISTURBANCE

Four disturbance classes were mapped in the study area (Figure 13). The majority of the study area (97.3%) was undisturbed (Table 5). Wheeled Vehicle Summer trail accounted for the largest disturbed area (1.4%) and corresponded to braided areas of the TLT. Braided sections of the TLT were most common when the trail passed over large sections of Open Mixed Low Shrub–Sedge Tussock Tundra vegetation on frozen Lowland Glaciolacustrine Deposits. Lacustrine (drainage) was the second most common disturbance class (0.7%). This type of disturbance corresponds with several small kettle lakes have recently drained. Review of color infrared imagery of the study area from 7 August 1981 and field observations from 2012 revealed that these lakes have drained and flooded periodically over the past several decades. In some cases we visited lakes in the study area that had recently drained as evidenced in the 2004–2006 orthophoto mosaic, while in other cases lakes that appeared to be drained in the orthophoto mosaic were filled with water during 2012 field surveys (Figure 14). Drainage channels were not obvious in the field or on imagery. We hypothesize that in some cases, lakes drain out the bottom due to thawing permafrost, filling again once permafrost has reestablished in the lake bottom. In other cases, such as that depicted in Figure 14, the process is less clear. The Nabesna Road was mapped as Gravel Road disturbance, the least common disturbance in the study area (0.6%).

ECOTYPE

Fourteen ecotypes were mapped in the study area (Figure 15) including 11 classified and described in Jorgenson et al. (2008a) and four not previously described for WRST, including Boreal Lacustrine Drained Lake Complex, Boreal Lowland Disturbance Complex, Boreal Riverine Wet Sedge Meadow, and Human Modified. Table 10 provides descriptions of the ecotypes not previously described in WRST, for all other ecotypes, refer to Jorgenson et al. (2008a) for descriptions. One ecotype (Boreal Lowland White Spruce Forest) was sampled in the field but was not mapped because it was rare, and four ecotypes were mapped but did not have field data associated with them, including Boreal Lacustrine Drained Lake Complex, Boreal Lowland Disturbance Complex, Boreal Riverine Wet Sedge Meadow, and Human Modified. Figure 16 shows representative photographs of vegetation and soils from nine common ecotypes in the TLT study area.

The most common ecotypes included Boreal Lowland Tussock–Shrub Bog (46.4% of total area), Boreal Subalpine Willow–Birch Shrub (17.7%), Boreal Upland White Spruce Forest (13.0%), Boreal Lowland Black Spruce Forest (9.2%), and Boreal Lowland Sedge–Shrub Fen (4.1%) (Table 11). Ecotypes combine climate, geology, soils, hydrology, and vegetation into a comprehensive classification of local-scale ecosystems that is more effective at partitioning the landscape than a vegetation or soils classification alone. For instance, Open Low Shrub Birch–Willow was mapped throughout the study area in both subalpine environments with well-drained, rocky soils, and in lowlands with fine-textured, poorly drained frozen soils. In the vegetation map, Open Low Shrub Birch–Willow on the two different soil types is not differentiated. The ecotype classification allows for differentiation of this vegetation type in the very different soil types associated with lowland and subalpine environments. The ecotype classification and ITU mapping approach is well suited for a landscape modeling and analysis. In the next section we provide an example of the utility of the approach by modeling and mapping landscape sensitivity in the study area.

EVALUATION

LANDSCAPE SENSITIVITY

Landscape sensitivity represents a combination of permafrost and summer traffic sensitivity developed by assessing vegetation-soil-landscape relationships (see above) based on field surveys, and by summarizing a reduced set of variables (surface organic thickness, thaw depth, and depth to >15% rock fragments, dominant soil texture) by ecotype (Table 3). Surface organic thickness is important because thick organic soils are less resistant to summer traffic than soils with thinner surface organic horizons. Thaw depth is important because it is related to ground ice and the potential for thermokarst following disturbance. Depth to >15% rock fragments and dominant soil texture are important because coarse, rocky and sandy soils are typically better drained, drier, and more resistant to summer traffic than finer-textured soils which tend to be wetter and have lower shear strength. In general, ecotypes with thinner organic horizons, deeper thaw depths, shallower depths to rock fragments, and coarse soil textures were assigned lower sensitivity, while those ecotypes with thicker organic horizons, shallower thaw depths, deeper coarse fragments, and finer/organic-rich soils were assigned higher sensitivities. A cross-walk was developed between the landscape sensitivity model and ecotype classification, and the ITU map was recoded to create a map of landscape sensitivity (Table 3).

The model indicates that the ecotypes most sensitive to thawing permafrost and damage by summer OHV traffic comprise 62.6% of the study area and include all the lowland ecotypes: Boreal Lowland Black Spruce Forest, Boreal Lowland Disturbance Complex, Boreal Lowland Low Birch–Willow Shrub, Boreal Lowland Sedge–Shrub Fen, Boreal Lowland Tussock–Shrub Bog, and one riverine ecotype, Boreal Riverine Wet Sedge Meadow (Figure 17, Table 11). These ecotypes had the shallowest thaw depths; and wet, organic-rich and/or fine-textured mineral soil (Table 3). Moderate sensitivities (2.6%) were assigned to the lacustrine ecotypes, Boreal Lacustrine Drained Lake Complex and Boreal Lacustrine Sedge Meadow, and the remaining riverine ecotype, Boreal Riverine White Spruce Forest. These ecotypes had moderately thick surface organic horizons and fine-textured mineral soil. Actual thaw depths were unknown, but are at a minimum greater than 80 to 100 cm (Table 3). Low sensitivity (33.7%) was assigned to upland and subalpine ecotypes, including Boreal Subalpine Spruce Woodland, Boreal Subalpine Willow–Birch Shrub, and Boreal Upland White Spruce Forest. These ecotypes had the shallowest depth to >15% rock fragments and coarse, rocky soils (Table 3). Negligible sensitivity (1.2%) was assigned to the ecotypes Lowland Lake and Human Modified.

TANADA LAKE TRAIL AND SENSITIVITY

We assessed the effectiveness of the landscape sensitivity classification by clipping the NPS Trails layer from the PDS to the study area and overlaying this layer over the landscape sensitivity map. We then calculated the total distance across the sensitivity classes of four trail type classes and disturbance ratings assigned to the TLT from the NPS trails layer, including

Track Type, Track Width, Impact Rating, and Mud-Muck (Table 12). Overall, the results indicate that the majority of the TLT crosses areas on the landscape classified as highly sensitive (84.3% of the total distance), followed by low (13.2%), moderate (2.3%), and negligible (0.1%) sensitivity classes.

Multi-braided track types were the most common track type in highly sensitive areas (Table 12), including Multi-braided >10 (15.6% of total distance), Multi-braided 5–10 (31.7%), and Multi-braided 2–4 (32.0%). Double Wheel Track (5.7%) and Multi-Braided 5–10 (4.9%) were the most common areas classified as low sensitivity.

Track widths greater than 20 feet were most common in highly sensitive areas, including 20–40 feet (31.7% of total distance), 40–80 feet (31.7%), and 160–320 feet (11.7%), while trail widths of 3–6 feet (6.2% and 1.4%, respectively) were most common in low and moderate sensitivity areas (Table 12). Trail widths 40–80 feet (4.9%) and 6–20 feet (2.1%) were the second and third most common trail widths in moderate sensitivity areas.

Impact ratings of 9–16 inches (22.9% of total distance) and 17–32 inches (29.7%) were most common in areas classified as highly sensitive. In areas classified as low sensitivity, the impact rating <2 inches (5.7%) was the most common, followed by 32–60 inches (3.5%). The impact rating 2–8 inches was most common in moderately sensitivity areas.

Multi Muck Holes was the most common mud-muck class in areas classified as highly sensitive (54.7% of total area), followed by the Muddy class (12.1%, Table 12). In areas classified at low sensitivity, None and Multi Muck Holes were the most common (5.7% and 5.8%, respectively). Extremely Muddy was the most common mud-muck class in areas classified as moderately sensitive (1.1%).

Overall, the results indicate that the landscape sensitivity classification is reasonably robust. Trail type classes (multi-braided, >20 feet) and impact ratings (2–32 inches, multi-muck holes) indicative of greater damage occurred most often in areas classified as high sensitivity, while trail type classes (Multi Wheel Track, 3–6 feet) and impact ratings (<2 inches, none) indicative of less damage occurred most often in areas classified as low and moderate sensitivity. In a few cases the landscape sensitivity classification was less robust. For instance, 40–80 feet track width, Multi-Braided 5–10 track type, 32–60 inch Impact Rating, and Multi-Muck Holes mud-muck rating, all ratings indicative of greater damage, accounted for a relatively large amount of area classified as low sensitivity (Table 12). A close inspection of these areas relative to the NPS trails layer and ITU mapping revealed that in most cases either 1) the resolution of these ITU map (0.10 ha minimum map delineation) was insufficient to capture the variability in the landscape along the TLT in a few small areas, or 2) minor errors in the location of the TLT in the NPS trails layer relative to the IKONOS. Additionally, an impact rating of <2 inches, indicating lower damage, accounted for a relatively high amount of area classified as highly sensitivity (Table 12). These areas were primarily associated with the ecotype Lowland Sedge–Shrub Fen in the general location of field plot WRST_V02_07_2012. Observations in the field indicate that while the species composition, including *Trichophorum caespitosum*, *Eleocharis quinqueflora*, and *Triglochin maritimum*, in this area was indicative of a wet meadow; soils data indicated recent drying. Also, the dominate species *T. caespitosum* and *E. quinqueflora* both appeared (based on casual observations) to be relatively resilient to ORV traffic in the study area. Hence, the combination of drying soils and resilient dominant species may help explain the low impact rating in these areas classified as highly sensitive. Also, this may represent a situation where more field data would help better define the landscape sensitivity rating of the ecotype Lowland Sedge-Shrub Fen.

RECOMMENDATIONS

Recommendations for additional studies to inform future management decisions, and to rehabilitate and monitor the Tanada Lake Trail are provided below:

1. Conduct a landscape-scale sensitivity analysis in the general vicinity of the TLT using the Jorgenson et al. (2008a) ecotype map as a base. The analysis would serve to aid in selection of broad areas on the landscape as potential suitable locations for a re-route of the TLT. These areas would then be used to define a study area boundary for a more extensive ITU mapping and analysis effort similar to that presented in the present study.
2. Additional field work in the study area selected in step 1 to (i) refine the TLT ITU classification, and (ii) support an expanded ITU mapping and landscape sensitivity

analysis in the vicinity of the TLT. The ITU mapping and analysis would be used to aid in the selection of detailed alternative routes for the TLT.

3. Select an alternative route for the TLT using the ITU mapping as an aid in decision making. Once a new route is chosen and constructed, designate the original TLT as a winter-only trail (closed to summer traffic, ~1 May 1–31 October).

4. Begin rehabilitation efforts upon summer closure of the original TLT. Specific recommendations for rehabilitation are as follows:

    - Physical barriers may be needed during initial rehabilitation efforts when establishing vegetation is susceptible to physical damage
    - Identify sections where vegetation recovery is likely to occur once the trail is closed to summer traffic. These sections would not be treated and be allowed to recover naturally (i.e., unassisted natural recovery)
    - Apply plant cultivation techniques where growing conditions are suitable. Flooded sections with deep water would not be treated, nor would areas that the sensitivity analysis indicate that thermokarst is likely to occur allowing flooded conditions to develop too rapidly for plants to establish.
    - Rehabilitation efforts will focus on plant cultivation techniques that use plant materials from populations within the immediate vicinity of the trail, and may include transplanting small plugs of intact soil and vegetation (15×15 cm) collected from moist or wet meadows and contain plants that appear to be resilient to ORV traffic (e.g., *T. caespitosum* and *E. quinqueflora)*, sowing seed of trees, saplings, graminoids, or forbs, and transplanting cuttings of willows or seedlings of white spruce or other tree species.
    - Backfilling may be needed for vegetation recovery to be possible at some areas; however finding a suitable source of material is unlikely because of the stringent requirements used by the NPS. At a minimum, the volume of backfill needed at specific sites would be calculated and the feasibility of transporting sufficient fill to a particular site determined.

5. Design and implement a long-term monitoring program to i) assess the rehabilitation efforts and overall response of the original TLT to management, and ii) assess the new TLT to ensure resilience through time and to aid in decision making regarding when and where mitigation efforts may be warranted. A long-term monitoring program could include:
    - Unmanned Aerial Vehicles (UAVs) to collect repeat (every 5 years) hyper high-resolution (~10 cm) aerial imagery of the original TLT
    - Thaw and surface elevation transects perpendicular to the trails
    - Soil temperature monitoring
    - Vegetation plots along original the TLT to assess vegetation recovery and the success of transplanted and seeded areas.
    - Repeat ground photography

SUMMARY

An Integrated Terrain Unit (ITU) approach to mapping ecosystem components is well suited for fine-scale (tens to hundreds of square kilometers), site specific management and planning, monitoring, and study design. We initiated a pilot study, including field surveys, to illustrate the utility of the Integrated Terrain Unit approach for classification, mapping, and analysis of landscape sensitivities, and to collect baseline data for potential future broader scale mapping and monitoring in the vicinity of the Tanada Lake Trail in Wrangell-St. Elias National Park and Preserve (WRST). We used the Ecological Land Survey of Jorgenson et al. (2008a) to classify and map ecotypes, which we used in conjunction with field data to evaluate land sensitivity in the TLT study area. The majority of the study area occurs in lowland, upland, and subalpine physiography where glaciolacustrine (lowlands) and younger till and glacial outwash deposits (subalpine and upland) predominated. Geomorphic units were aggregated into six generalized soil texture classes for mapping, including Gravelly, Fill, Loamy, Loamy-Organic, Rubbly, and Water. Thirteen vegetation types were mapped in the study area; the most common included Open Mixed Low Shrub–Sedge Tussock Tundra, Open Low Shrub Birch–Willow, White Spruce Woodland, Black Spruce–White Spruce Woodland, Open White Spruce Forest, and Tussock

Tundra. Four disturbance classes were mapped in the study area, the greater portion of which was undisturbed. Wheeled Vehicle Summer trail accounted for the largest disturbed area and corresponded to braided areas of the TLT. Lacustrine (drainage) was the second most common disturbance class and corresponded with several small kettle lakes in the study area that have recently drained. Fourteen ecotypes were mapped in the study area including 11 classified and described in Jorgenson et al. (2008a) and four not previously described for WRST. The most common ecotypes included Boreal Lowland Tussock–Shrub Bog, Boreal Subalpine Willow–Birch Shrub, Boreal Upland White Spruce Forest, Boreal Lowland Black Spruce Forest, and Boreal Lowland Sedge–Shrub Fen. Landscape sensitivity represents a combination of permafrost and summer traffic sensitivity developed by assessing vegetation-soil-landscape relationships based on field surveys, and by summarizing a reduced set of variables (surface organic thickness, thaw depth, and depth to >15% rock fragments, dominant soil texture) by ecotype. The landscape sensitivity model classified the majority of the study area as highly sensitive, which include lowland and riverine areas with organic-rich, fine-textured, and frozen soils. Upland and subalpine areas with rocky soils were classified as low sensitivity, the second most common sensitivity class in the study area. Lacustrine and riverine areas with loamy soils were classified as moderately sensitivity. We assessed the effectiveness of the landscape sensitivity classification overlaying the NPS Trails layer over the landscape sensitivity map and calculating the distance across each of four trail type classes and disturbance ratings. Trail type classes and impact ratings indicative of greater damage occurred most often in areas classified as high sensitivity, while those indicative of less damage occurred most often in areas classified as low and moderate sensitivity. Despite a few minor inconsistencies, these results indicate that the landscape sensitivity classification is reasonably robust. Lastly, we provided recommendations for additional studies to inform future management decisions, and to rehabilitate and monitor the Tanada Lake Trail into the future.

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Table 1. Geomorphic units, dominant soil texture(s) in upper 40 cm, mean surface organic thickness, depth to >15% rock fragments, thaw depth, and assigned generalized soil texture for each of 12 geomorphic units mapped in the Tanada Lake Trail study area, Wrangell-St. Elias National Park and Preserve, Alaska, 2012.

Geomorphic Unit (n)	Dominant Soil Textures (0–40 cm)	Mean (SD) Surface Organic Thickness (cm)	Mean (SD) Depth to > 15% Rock Fragments (cm)	Mean (SD) Thaw Depth (cm)	Generalized Texture Class
Bogs (0)	NFD[a]	NA	NA	NA	Organic
Deep Isolated Thaw Lake (0)	NFD	NA	NA	NA	Water
Drained Lake Basin, Ice-poor Undifferentiated (1)	loamy	9 (--)	81 (--)	unknown[b]	Loamy
Glaciofluvial Outwash (3)	gravelly, organic, loamy, rubbly	17.3 (10.6)	28.0 (10.5)	unknown	Gravelly
Gravel Fill (0)	NFD	NA	NA	NA	Fill
Hillside Colluvium (0)	NFD	NA	NA	NA	Rubbly
Lowland Glaciolacustrine Deposit (5)	loamy, organic	25.6 (5.5)	unknown[c]	50. (8.6)	Loamy-Organic
Lowland Headwater Floodplain (1)	organic, loamy	30 (--)	201 (--)	unknown	Loamy
Old Alluvial Fan (0)	NFD	NA	NA	NA	Gravelly
Organic Fen (1)	organic-rich, peaty	40 (--)	unknown	86 (--)	Organic
Upland Glaciolacustrine Deposit (2)	loamy, organic	22 (11.3)	unknown	45.5 (2.1)	Loamy-Organic
Younger Till (3)	gravelly, loamy, rubbly, sandy	6.7 (3.2)	21.3 (10.1)	unknown	Rubbly

[a] NFD = no field data. Geomorphic unit was mapped, but no field data were collected.
[b] Unknown that depth indicates that frozen ground was not encountered within the maximum depth sampled, typically 40–100 cm.
[c] Unknown depth to >15% rock fragments indicates that rock fragments were not encountered within the maximum depth sampled, typically the depth to frozen ground.

Table 2. Coding system for classifying and mapping geomorphic units, surface forms, and vegetation in the Tanada Lake Trail study area, Wrangell-St. Elias National Park and Preserve, Alaska, 2012.

Code	Class
SURFACE GEOMORPHIC UNITS	
Ch	Hillside Colluvium
Ffo	Old Alluvial Fan
Fhl	Lowland Headwater Floodplain
Gfo	Glaciofluvial Outwash
Gll	Lowland Glaciolacustrine Deposit
Glu	Upland Glaciolacustrine Deposit
Gty	Younger Till
Hfg	Gravel Fill
Ldnu	Drained Lake Basin, Ice-poor Undifferentiated
Ob	Bogs
Of	Organic Fen
Wldit	Deep Isolated Thaw Lake
PHYSIOLOGY	
H	Human-altered
L	Lowland
P	Lacustrine
R	Riverine
S	Subalpine
U	Upland
SOIL TEXTURE	
F	Fill
G	Gravelly
L	Loamy
LO	Loamy-Organic
O	Organic
R	Rubbly
W	Water
VEGETATION CLASS	
Bb	Barrens
DC	Disturbance Complex
Fnobw	Open Black Spruce–White Spruce
Fnows	Open White Spruce Forest
Fnwbw	Black Spruce–White Spruce Woodland
Fnwws	White Spruce Woodland
Hgmst	Moist Sedge Meadow Tundra
Hgmt	Tussock Tundra
Hgwst	Wet Sedge Meadow Tundra
Sobw	Open Low Shrub Birch-Willow
Slott	Open Mixed Low Shrub–Sedge Tussock Tundra
Wf	Fresh Water
Xby	Young Basin Wetland Complex
DISTURBANCE	
Hfgr	Gravel Road
Htsnw	Wheeled Vehicle Summer trail
Ngld	Lacustrine (drainage)
(blank)	Absent (undisturbed)

Table 3. Summary of thaw depth, depth to >15% rock fragments, and surface organic thickness by ecotype used to assign permafrost (pf_sens), summer traffic (st_sens), and landscape (pf_sens × st_sens) sensitivity classes for 14 ecotypes mapped in the Tanada Lake Trail study area, Wrangell-St. Elias National Park and Preserve, Alaska, 2012.

Ecotype (n)	Permafrost Sensitivity Class	Summer Traffic Sensitivity Class	Landscape Sensitivity	Mean (SD) Thaw Depth (cm)	Mean (SD) Depth to >15% Rock Fragments (cm)	Mean (SD) Surface Organic Thickness (cm)
Boreal Lacustrine Sedge Meadow (1)	low	high	high	unknown[a]	81 (--)	9 (--)
Boreal Lacustrine Drained Lake Complex (0)	low	high	high	NFD[b]	NFD	NFD
Boreal Lowland Black Spruce Forest (1)	high	high	high	50 (--)	unknown[c]	17 (--)
Boreal Lowland Disturbance Complex (0)	high	high	high	NFD	NFD	NFD
Boreal Lowland Low Birch–Willow Shrub (1)	high	high	high	44 (--)	unknown	14 (--)
Boreal Lowland Sedge–Shrub Fen (2)	moderate	high	high	>29 to 86	29 to >86	34 (8)
Boreal Lowland Tussock–Shrub Bog (3)	high	high	high	50 (11)	unknown	28 (3)
Boreal Lowland White Spruce Forest[d] (1)	high	high	high	47 (--)	unknown	30 (--)
Boreal Riverine Wet Sedge Meadow (0)	low	high	high	NFD	NFD	NFD
Boreal Riverine White Spruce Forest (1)	low	moderate	moderate	unknown	201 (--)	30 (--)
Boreal Subalpine Spruce Woodland (1)	low	low	low	unknown	32 (--)	8 (--)
Boreal Subalpine Willow–Birch Shrub (2)	low	low	low	unknown	16 (6)	6 (4)
Boreal Upland White Spruce Forest (2)	low	low	low	unknown	28 (15)	12 (5)
Human Modified (0)	negligible	negligible	negligible	NFD	NFD	NFD
Lowland Lake (0)	negligible	negligible	negligible	NFD	NFD	NFD

[a] Unknown thaw depth indicates frozen ground was not encountered within the maximum depth sampled, typically 40–100 cm.
[b] NFD = no field data. Ecotype was mapped, but no field data were collected for this ecotype.
[c] Unknown mean depth to >15% rock fragments indicates that rock fragments were not encountered within the maximum depth sampled, typically the depth to frozen ground
[d] Ecotype sampled in field but not mapped.

Table 4. Mean thaw depth and depth to rock fragments by ecotype along three thaw transects, Tanada Lake Trail, Wrangell-St. Elias National Park and Preserve, 2012.

Transect	Distance (m)	Ecotype	Mean (SD) Thaw Depth (cm)	Mean (SD) Depth to Rock Fragments (cm)
WRST_PF2	0–12, 95–100	Boreal Lowland Tussock–Shrub Bog	–45.4 (5.0)	unknown
	13–94	Lowland Disturbance Complex	–62.6 (11.8)	unknown
WRST_PF3	0–24	Boreal Riverine White Spruce Forest	unknown	–144 (33.8)
	25–65, 79–95	Boreal Lowland Black Spruce Forest	–61.8 (12.2)	unknown
	66–78	Boreal Lowland Black Spruce Forest	unknown	–49.5 (5.9)
	96–150	Lowland Disturbance Complex	–76.7 (20.7)	unknown
WRST_PF4	0–72	Boreal Subalpine Willow–Birch Shrub	unknown	–58.6 (13.9)
	73–95	Boreal Lowland Tussock–Shrub Bog	–54.3 (6.7)	unknown
	96–105	Boreal Lowland Black Spruce Forest	–53.0 (8.1)	unknown
	106–160	Lowland Disturbance Complex	–71.4 (24.3)	–77.1 (16.2)

Table 5. Areal extent of individual components of Integrated Terrain Unit (ITU) mapping in the Tanada Lake Trail study area, Wrangell-St. Elias National Park and Preserve, Alaska, 2012.

ITU components	Acres	Hectares	%
SURFACE GEMORPHIC UNITS			
Bogs	14.5	5.9	1.3
Deep Isolated Thaw Lake	6.2	2.5	0.6
Drained Lake Basin, Ice-poor Undifferentiated	8.6	3.5	0.8
Glaciofluvial Outwash	137.0	55.4	12.6
Gravel Fill	6.4	2.6	0.6
Hillside Colluvium	8.5	3.5	0.8
Lowland Glaciolacustrine Deposit	500.5	202.6	46.2
Lowland Headwater Floodplain	23.0	9.3	2.1
Old Alluvial Fan	14.3	5.8	1.3
Organic Fen	44.8	18.1	4.1
Upland Glaciolacustrine Deposit	115.1	46.6	10.6
Younger Till	205.3	83.1	18.9
TOTAL	1,084.2	438.7	100.0
PHYSIOLOGY			
Human-altered	6.4	2.6	0.6
Lacustrine	8.6	3.5	0.8
Lowland	681.0	275.6	62.8
Riverine	23.0	9.3	2.1
Subalpine	223.9	90.6	20.7
Upland	141.2	57.2	13.0
TOTAL	1,084.2	438.7	100.0
SOIL TEXTURE			
Fill	6.4	2.6	0.6
Gravelly	151.3	61.2	1.4
Loamy	19.2	7.8	1.8
Loamy-Organic	628.0	254.1	57.8
Organic	59.2	24.0	5.5
Rubbly	213.8	86.5	19.7
Water	6.2	2.5	0.6
TOTAL	1,084.2	438.7	100.0
VEGETATION CLASSES			
Barrens	6.4	2.6	0.6
Black Spruce–White Spruce Woodland	100.0	40.5	9.2
Disturbance Complex	13.6	5.5	1.3
Fresh Water	6.2	2.5	0.6
Moist Sedge Meadow Tundra	0.8	0.3	0.1
Open Black Spruce–White Spruce	28.5	11.5	2.6

Table 5. Continued.

ITU components	Acres	Hectares	%
Open Low Shrub Birch-Willow	204.8	82.9	18.9
Open Mixed Low Shrub–Sedge Tussock Tundra	446.9	180.8	41.2
Open White Spruce Forest	56.3	22.8	5.2
Tussock Tundra	56.5	22.9	5.2
Wet Sedge Meadow Tundra	52.5	21.2	4.8
White Spruce Woodland	107.8	43.6	9.9
Young Basin Wetland Complex	3.9	1.6	0.4
TOTAL	1,084.2	438.7	100.0
DISTURBANCE			
Gravel Road	6.4	2.6	0.6
Lacustrine (drainage)	7.9	3.2	0.7
Wheeled Vehicle Summer trail	15.0	6.1	1.4
Absent (undisturbed)	1054.8	426.9	97.3
TOTAL	1,084.2	438.7	100.0

Table 6. Classification and description of physiography classes in the Tanada Lake Trail study area, Wrangell-St. Elias National Park and Preserve, Alaska, 2012.

Physiography Class	Description
Human-altered	Areas on the landscape that have modified by human activities.
Lacustrine	Recently (<1 to 10 years) drained lake basins and flooded lake margins.
Lowland	Flat to gently sloping and concave areas of the landscape at elevations below subalpine.
Riverine	Areas of the landscape subject to regular (<5 to 25 yrs) to irregular (25–100 yrs) channel and overbank flooding by rivers or streams.
Subalpine	Transition zone near the altitudinal limit of forested vegetation characterized in boreal regions of Alaska by abundant spruce woodland and low birch–willow shrub.
Upland	Moderate to steeply sloping and convex areas of the landscape at elevations below subalpine.

Table 7. Classification and description of geomorphic units in the Tanada Lake Trail study area, Wrangell-St. Elias National Park and Preserve, Alaska, 2012.

Geomorphic Unit	Description
Bogs	Thick peat deposits (>40 cm) with soils that are acidic (pH < 5.5) and low in nutrients.
Deep Isolated Thaw Lake	A lake formed due to melting permafrost and subsidence of the land surface.
Drained Lake Basin, Ice-poor Undifferentiated	Recently drained (<1 to 10 years) lake basins with little to no ground ice.
Glaciofluvial Outwash	Sediments transported by glacial meltwater streams that flow within of beyond the terminal margin of an ice-sheet or glacier.
Gravel Fill	Non-native, gravelly soil deposits used to construct roads (i.e., Nabesna Road).
Hillside Colluvium	Sediments derived by the downward movement, under the force of gravity, of soil materials from higher on a hill slope or mountainside.
Lowland Glaciolacustrine Deposit	Fine-textured (silt- and clay-rich) soil materials deposited on the bottom of prehistoric glacial lakes and dominated by tussock tundra.
Lowland Headwater Floodplain	Fine-textured mineral and organic-rich deposits along narrow (2–4 m) floodplains bordering low gradient (<3°) headwater streams.
Old Alluvial Fan	Coarse-textured, rocky mineral soils deposited in a fan-shape by the mass movement of water during a historic period (several decades to centuries ago).
Organic Fen	Thick organic deposits with soils that are circumneutral (pH 5.5–7.3) and high in nutrients.
Upland Glaciolacustrine Deposit	Fine-textured (silt- and clay-rich) soil materials deposited on the bottom of prehistoric glacial lakes and dominated spruce woodlands and low birch–willow shrub.
Younger Till	Till and glacial drift deposited within the last ten thousand years.

Table 8. Classification and description of generalized soil texture classes in the Tanada Lake Trail study area, Wrangell-St. Elias National Park and Preserve, Alaska, 2012.

Generalized Soil Texture	Description
Gravelly	Soils with 15% rock fragments (>2 mm) totaling at least 10 cm thick in the upper 50 cm of the soil profile, and total organic soil horizons (including buried) are typically less than 20 cm thick. Rock fragments are rounded.
Fill	Coarse sandy and gravelly deposits used to build roads (i.e., Nabesna Road).
Loamy	Soils with dominant mineral soil textures (in upper 50 cm) of silt-loam to clay loam, and total organic soil horizons (including buried) are less than 20 cm thick. Frozen ground absent or occurring below 50 cm.
Loamy-Organic	Soils with dominant mineral soil textures (in upper 50 cm) of silt-loam to clay loam, and total organic soil horizons (including buried) are greater than 20 cm thick. Frozen ground in the upper 50 cm of the soil profile.
Rubbly	Soils with ≥15% rock fragments (>2 mm) totaling at least 10 cm thick in the upper 50 cm of the soil profile and total organic soil horizons (including buried) are typically less than 20 cm thick. Rock fragments are angular
Water	Permanent waterbodies, including lakes and rivers. Water is fresh.

Table 9. Classification and description of vegetation classes in the Tanada Lake Trail study area, Wrangell-St. Elias National Park and Preserve, Alaska, 2012.

Vegetation Class	Description
Barrens	Vascular plant cover is less than 25%. This vegetation type includes human modified areas such as roads and trails, and recently drained lake bottoms where vegetation has yet to establish.
Black Spruce–White Spruce Woodland	Black (*Picea mariana*) and white (*P. glauca*) spruce co-dominate these stands where total conifer cover ranges from 10–25%. Common associated species include *Betula glandulosa, Salix lanata, Ledum decumbens, Vaccinium vitis-idaea*, and *Carex bigelowii*.
Disturbance Complex	This vegetation type along braided sections of the Tanada Lake Trail and includes several distinct vegetation communities in stands too small to map separately..
Fresh Water	Lake water.
Moist Sedge Meadow Tundra	The vegetation is dominated by sedges, including *Carex saxatilis, Trichophorum caespitosum,* and/or *Eleocharis quinqueflora*. Soils may be saturated in the upper (20–40 cm) soil profile for short periods in the spring and early summer, however, saturation is not continuous throughout the growing season.
Open Black Spruce–White Spruce	Black (*Picea mariana*) and white (*P. glauca*) spruce co-dominate these stands where total conifer cover ranges from 25–75%. Common associated species include *Betula glandulosa, Salix glauca, Vaccinium uliginosum,* and *Festuca altaica*.
Open Low Shrub Birch–Willow	Vegetation is dominated by low shrubs (0.20–1.5 m), including *Betula glandulosa, B. nana*, and *Salix glauca*. Common associated species include *Empetrum nigrum, Ledum decumbens, Dryas integrifolia,* and *Hierocloe alpina*.
Open Mixed Low Shrub–Sedge Tussock Tundra	Vegetation is co-dominated by *Betula nana* and the tussock-forming sedge *Eriophorum vaginatum*. Common associated species include *Salix pulchra. Ledum decumbens, Rubus chamaemorus,* and *Carex bigelowii*.
Open White Spruce Forest	White spruce (*P. glauca*) dominates these stands where total conifer cover ranges from 25–75%. Common associated species include *Salix glauca* and *S. lanata*.
Tussock Tundra	Vegetation is dominated by the tussock-forming sedge *Eriophorum vaginatum* and low shrub cover is less than 25%. Commonly associated species include *Ledum decumbens, Vaccinium vitis-idaea,* and *Carex bigelowii.*
Wet Sedge Meadow Tundra	The vegetation is dominated by sedges, including *Carex chordorrhiza, Carex limosa, Eriophorum russeolum*, and/or *Trichophorum caespitosum*. Commonly associated species include *Scorpidium scorpioides* and *Triglochin maritimum*. Soils are saturated in the upper (20–40 cm) soil profile throughout the growing season.
White Spruce Woodland	White spruce (*P. glauca*) dominates these stands where total conifer cover ranges from 10–25%. Commonly associated species include *Betula glandulosa, Salix glauca, Empetrum nigrum*, and *Vaccinium uliginosum*.
Young Basin Wetland Complex	This vegetation type occurs in recently drained lake basins and includes several distinct vegetation communities in stands too small to map separately.

Table 10. Classification and description of ecotype classes not previously described by Jorgenson et al. (2008a), Tanada Lake Trail study area, Wrangell-St. Elias National Park and Preserve, Alaska, 2012.

Ecotype Class	Description
Boreal Lacustrine Drained Lake Complex	This ecotype occurs in recently drained lake basins and includes several distinct vegetation communities in stands too small to map separately. Vegetation types may include Barrens, Moist Sedge Meadow Tundra, and Wet Sedge Meadow Tundra. These lake basins are subject to period flooding and drainage.
Boreal Lowland Disturbance Complex	This ecotype along braided sections of the Tanada Lake Trail and includes several distinct vegetation communities in stands too small to map separately. Vegetation often includes Wet Sedge Meadow Tundra, Open Mixed Low Shrub–Sedge Tussock Tundra, Moist Sedge Meadow Tundra, and Barrens.
Boreal Riverine Wet Sedge Meadow	This ecotype includes wet sedge meadows on narrow floodplains along small headwater streams. Soils are assumed to be wet and organic-rich.
Human Modified	This ecotype includes fill along the Nabesna Road. Vegetation is Barrens.

Table 11. Areal extent of mapped ecotypes and landscape sensitivity classes in the Tanada Lake Trail study area, Wrangell-St. Elias National Park and Preserve, Alaska, 2012.

Components	Acres	Hectares	%
ECOTYPE			
Boreal Lacustrine Drained Lake Complex	3.9	1.6	0.4
Boreal Lacustrine Sedge Meadow	4.7	1.9	0.4
Boreal Lowland Black Spruce Forest	100.0	40.5	9.2
Boreal Lowland Disturbance Complex	13.6	5.5	1.3
Boreal Lowland Low Birch–Willow Shrub	13.0	5.3	1.2
Boreal Lowland Sedge–Shrub Fen	44.8	18.1	4.1
Boreal Lowland Tussock–Shrub Bog	503.4	203.7	46.4
Boreal Riverine Wet Sedge Meadow	3.8	1.5	0.3
Boreal Riverine White Spruce Forest	19.2	7.8	1.8
Boreal Subalpine Spruce Woodland	32.1	13.0	3.0
Boreal Subalpine Willow–Birch Shrub	191.7	77.6	17.7
Boreal Upland White Spruce Forest	141.2	57.2	13.0
Human Modified	6.4	2.6	0.6
Lowland Lake	6.2	2.5	0.6
TOTAL	1,084.2	438.7	100.0
LANDSCAPE SENSITIVITY			
High	678.6	274.6	62.6
Low	365.1	147.8	33.7
Moderate	27.9	11.3	2.6
Negligible	12.6	5.1	1.2
TOTAL	1,084.2	438.7	100.1

Table 12. Total distances of Tanada Lake Trail across four landscape sensitivity classes by four trail type classes and impact ratings, including Track Type, Track Width, Impact Rating, and Mud-Muck, Wrangell-St. Elias National Park and Preserve, Alaska, 2012.

Landscape Sensitivity	Class/Impact Rating	Meters	Feet	% of Total
TOTAL DISTANCE				
High		2,313.1	7,589	84.3%
Low		362.7	1,190	13.2%
Moderate		64.3	211	2.3%
Negligible		4.0	13	0.1%
TOTAL		2,744.1	9,003	100.0%
TRACK TYPE				
High	Double Wheel Track	80.8	265	2.9%
	Multi–Braided >10	428.2	1,405	15.6%
	Multi–Braided 2–4	877.5	2,879	32.0%
	Multi–Braided 5–10	871.1	2,858	31.7%
	Stripped	55.4	182	2.0%
Low	Double Wheel Track	155.4	510	5.7%
	Multi–Braided 2–4	36.0	118	1.3%
	Multi–Braided 5–10	133.8	439	4.9%
	Stripped	37.5	123	1.4%
Moderate	Multi–Braided 5–10	12.5	41	0.5%
	Stripped	51.8	170	1.9%
Negligible	Multi–Braided 5–10	4.0	13	0.1%
TOTAL		2,744.1	9,003	100.0%
TRACK WIDTH				
High	160–320 feet	321.9	1,056	11.7%
	20–40 feet	870.8	2,857	31.7%
	3–6 feet	80.8	265	2.9%
	40–80 feet	871.1	2,858	31.7%
	6–20 feet	62.2	204	2.3%
	80–160 feet	106.4	349	3.9%
Low	20–40 feet	3.1	10	0.1%
	3–6 feet	169.5	556	6.2%
	40–80 feet	133.8	439	4.9%
	6–20 feet	56.4	185	2.1%
Moderate	3–6 feet	38.8	127	1.4%
	40–80 feet	12.5	41	0.5%
	6–20 feet	13.1	43	0.5%
Negligible	40–80 feet	4.0	13	0.1%
TOTAL		2,744.1	9,003	100.0%
IMPACT RATING				
High	<2 ins. rut/sub	251.2	824	9.2%
	17–32 in rut/sub	815.9	2,677	29.7%
	2–8 in rut/sub	483.1	1,585	17.6%
	32 –60 in. rut/sub	92.7	304	3.4%
	9–16 in. rut/sub	627.6	2,059	22.9%
	Loss of Surface Veg	42.7	140	1.6%

Table 12. Continued.

Landscape Sensitivity	Class/Impact Rating	Meters	Feet	% of Total
Low	<2 ins. rut/sub	155.4	510	5.7%
	2–8 in rut/sub	50.0	164	1.8%
	32 –60 in. rut/sub	95.1	312	3.5%
	9–16 in. rut/sub	62.2	204	2.3%
Moderate	<2 ins. rut/sub	7.6	25	0.3%
	17–32 in rut/sub	12.5	41	0.5%
	2–8 in rut/sub	31.1	102	1.1%
	9–16 in. rut/sub	13.1	43	0.5%
Negligible	17–32 in rut/sub	4.0	13	0.1%
TOTAL		2,744.1	9,003	100.0%
MUD–MUCK				
High	extremely muddy	256.0	840	9.3%
	muckhole	11.6	38	0.4%
	muddy	330.7	1,085	12.1%
	multi muck holes	1,502.1	4,928	54.7%
	none	212.8	698	7.8%
Low	extremely muddy	46.9	154	1.7%
	muckhole	1.8	6	0.1%
	multi muck holes	158.5	520	5.8%
	none	155.4	510	5.7%
Moderate	extremely muddy	31.1	102	1.1%
	muckhole	25.6	84	0.9%
	muddy	7.6	25	0.3%
Negligible	muckhole	4.0	13	0.1%
TOTAL		2,744.1	9,003	100.0%

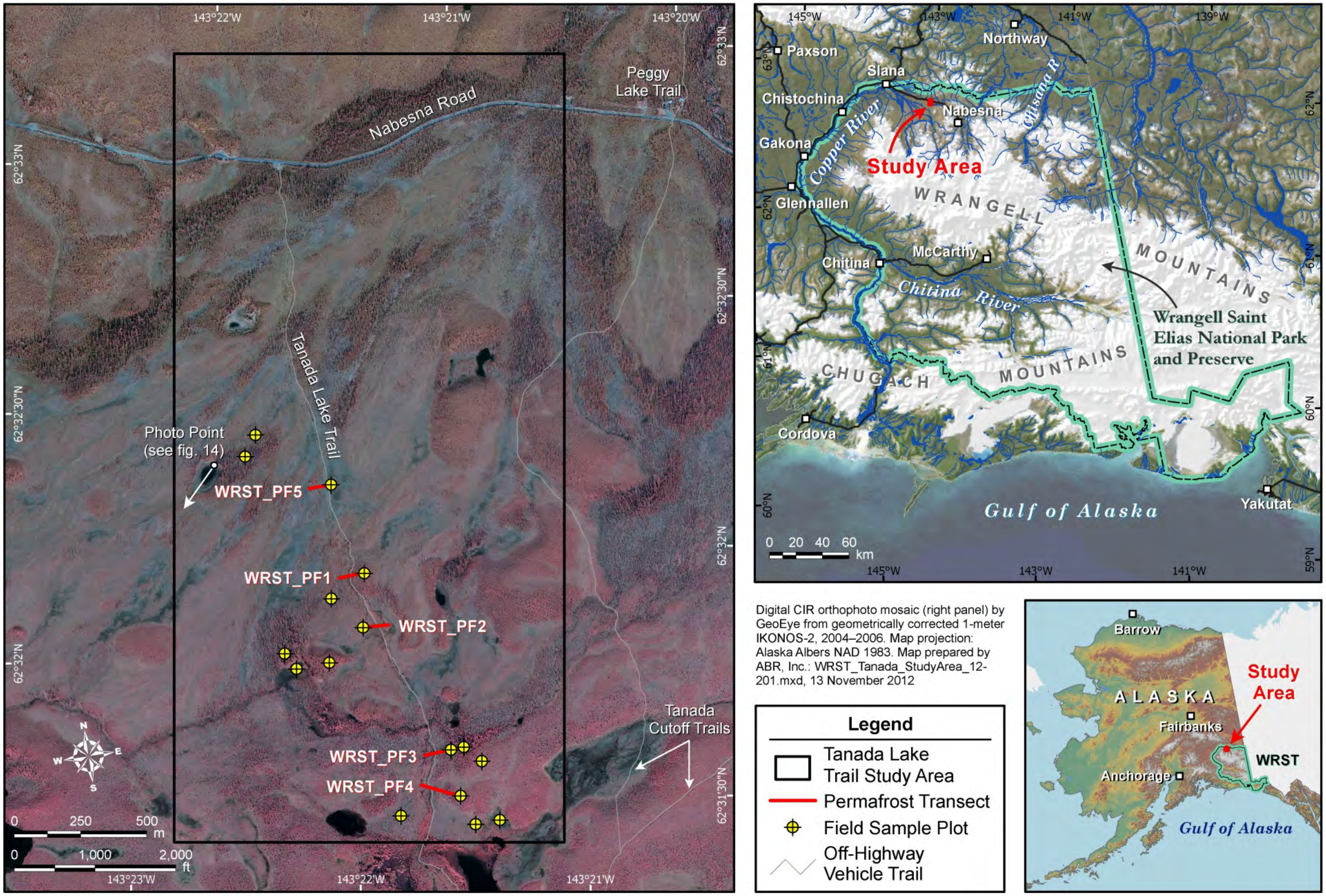


Figure 1. Overview map of Wrangell-St. Elias National Park and Preserve and location of Tanada Lake Trail study area, Copper River Basin, Alaska, 2012.

Figure 2. Off highway vehicle (OHV) being extracted from a "muck hole" along the Tanada Lake Trail (TLT), Wrangell-St. Elias National Park and Preserve, Alaska, 2012. These features are common along the TLT, forming in areas with thick organic deposits and permafrost where disturbance to the soil surface by OHVs initiates the thawing of permafrost.

Figure 3. Examples of resource damage along the Tanada Lake Trail, including A) the initiation of a trail braid to avoid a muck hole, and B) natural revegetation by cottongrass along an abandoned trail braid.

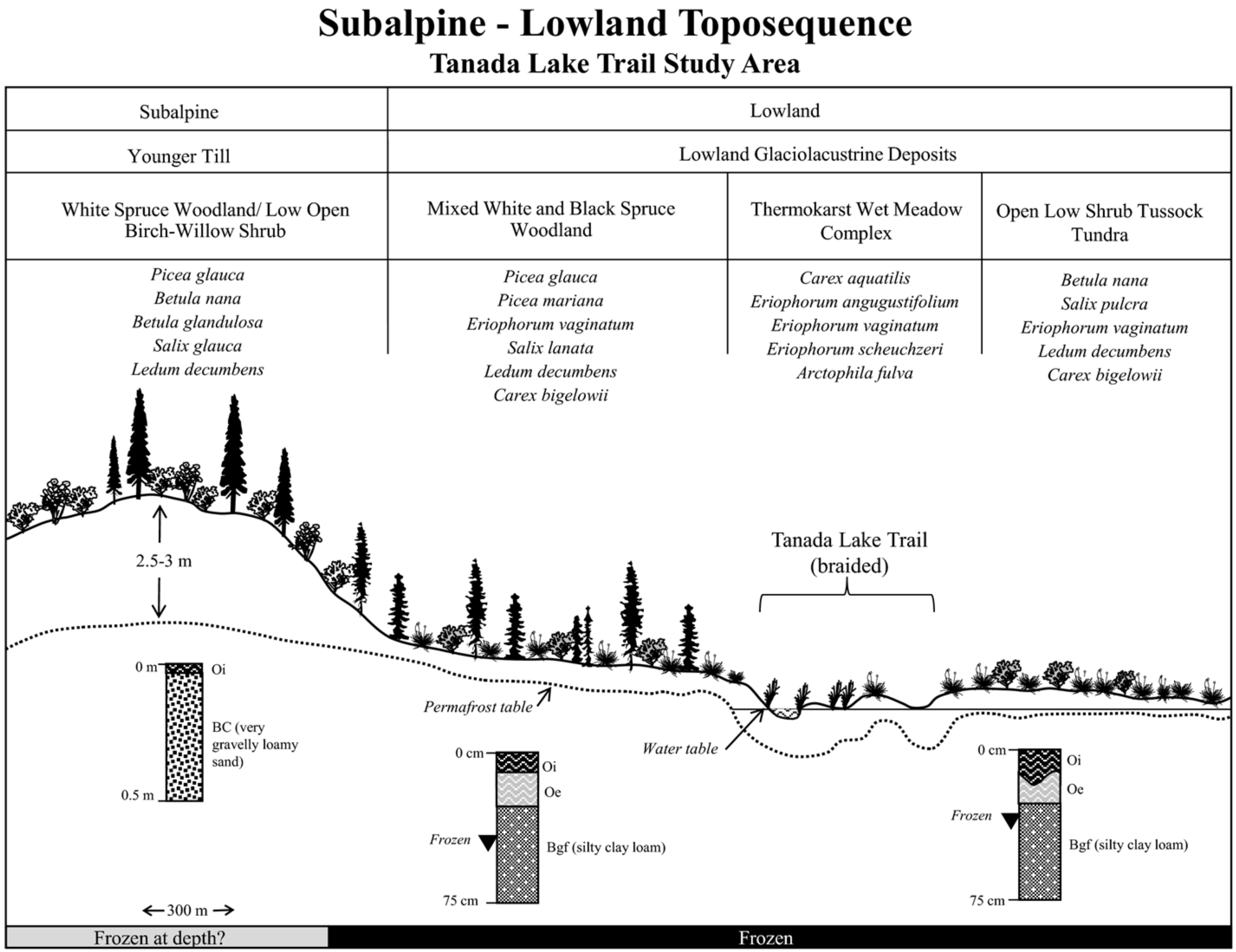


Figure 4. A generalized toposequence illustrating relationships among topography, geology, geomorphology, permafrost, soils, and vegetation along a subalpine – lowland transition, Tanada Lake Trail, Wrangell-St. Elias National Park and Preserve, 2012.

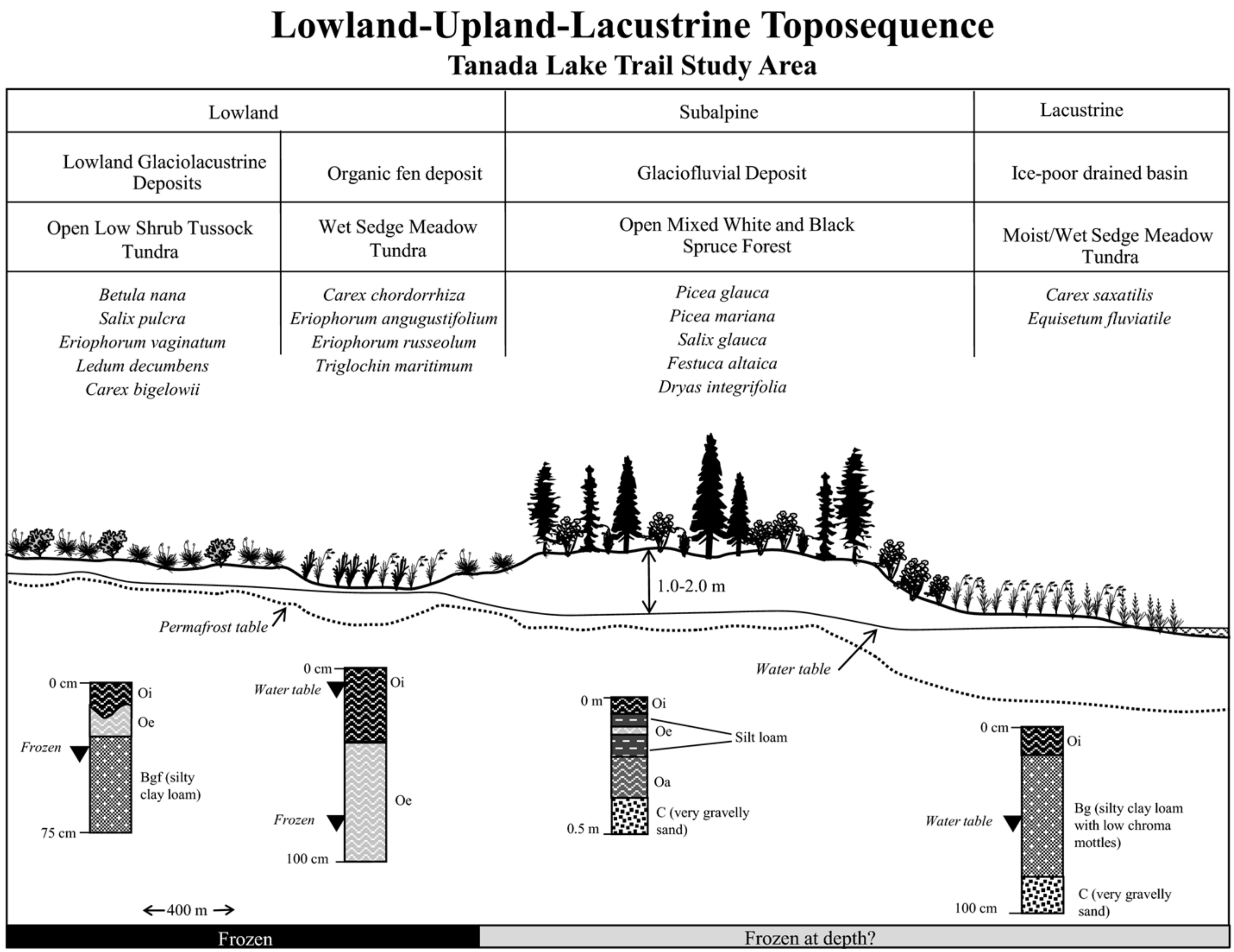


Figure 5. A generalized toposequence illustrating relationships among topography, geology, geomorphology, permafrost, soils, and vegetation along a lowland-upland-lacustrine transition, Tanada Lake Trail, Wrangell-St. Elias National Park and Preserve, 2012.

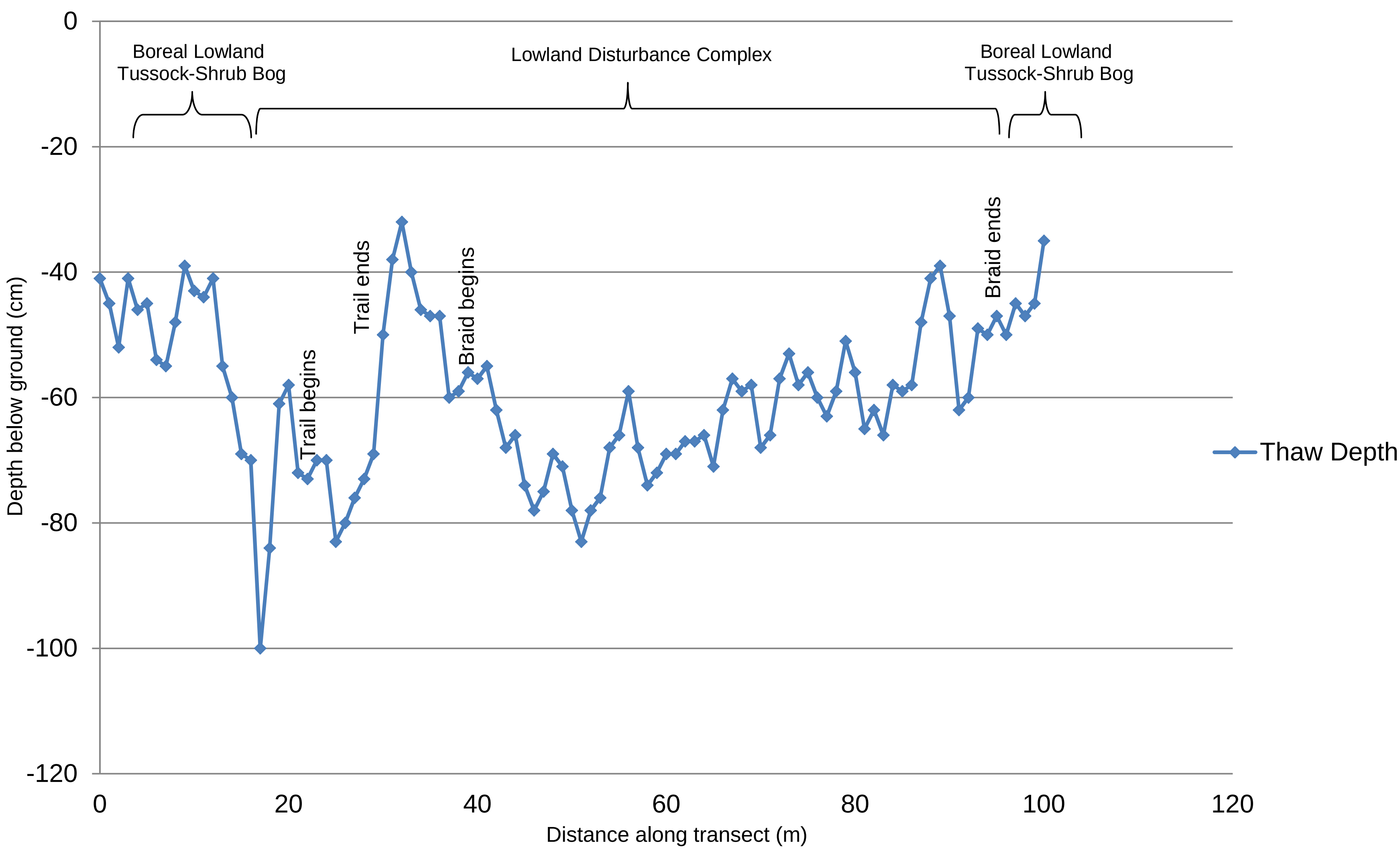


Figure 6. Thaw depth on transect WRST_PF2, Tanada Lake Trail, Wrangell-St. Elias National Park, Alaska, 2012. Approximate boundaries of ecotypes and individual trails and braided sections encountered along the transect are indicated with brackets.

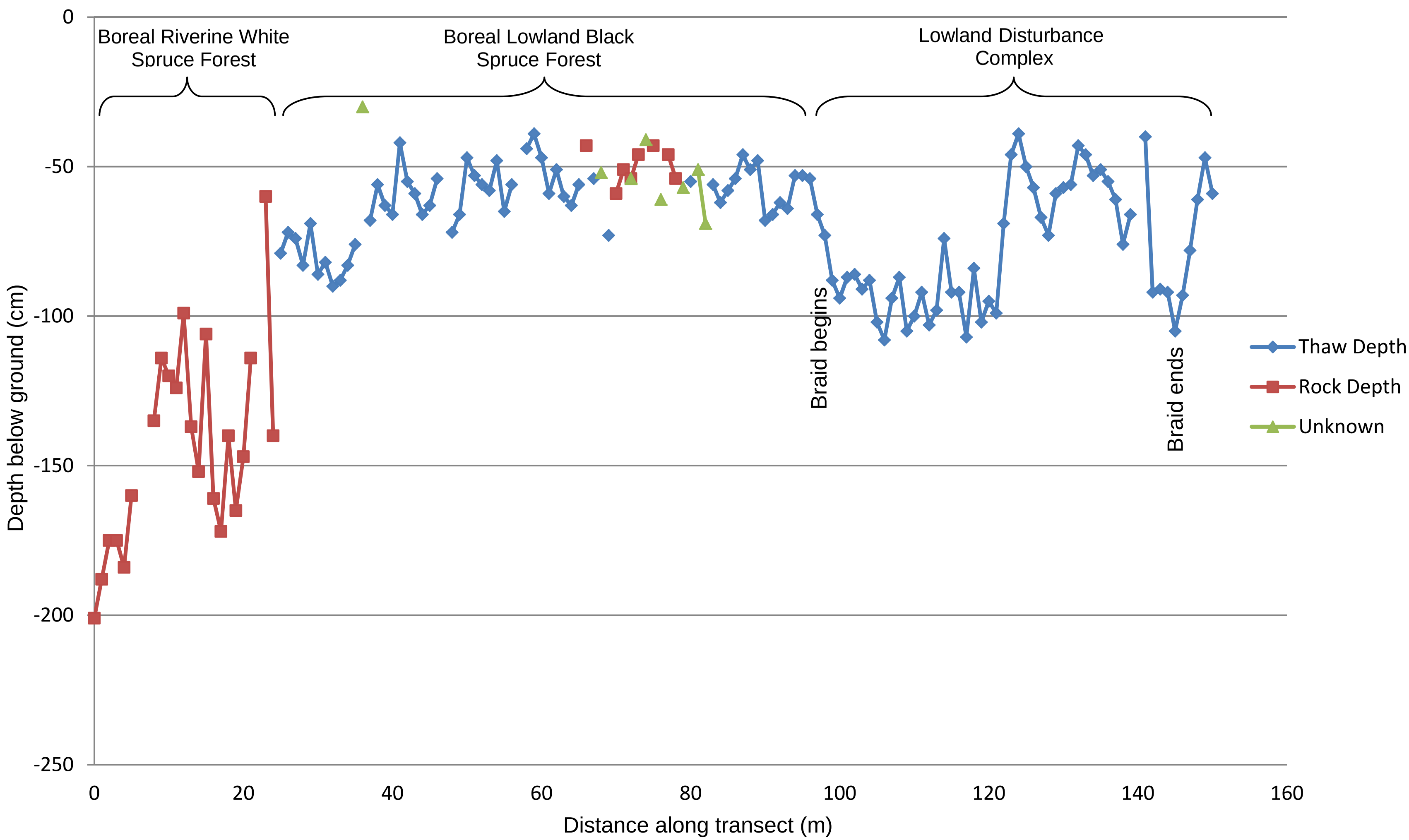


Figure 7. Thaw depth and depth to >15% rock fragments on transect WRST_PF3, Tanada Lake Trail, Wrangell-St. Elias National Park, Alaska, 2012. Approximate boundaries of ecotypes and braided sections encountered along the transect are indicated with brackets.

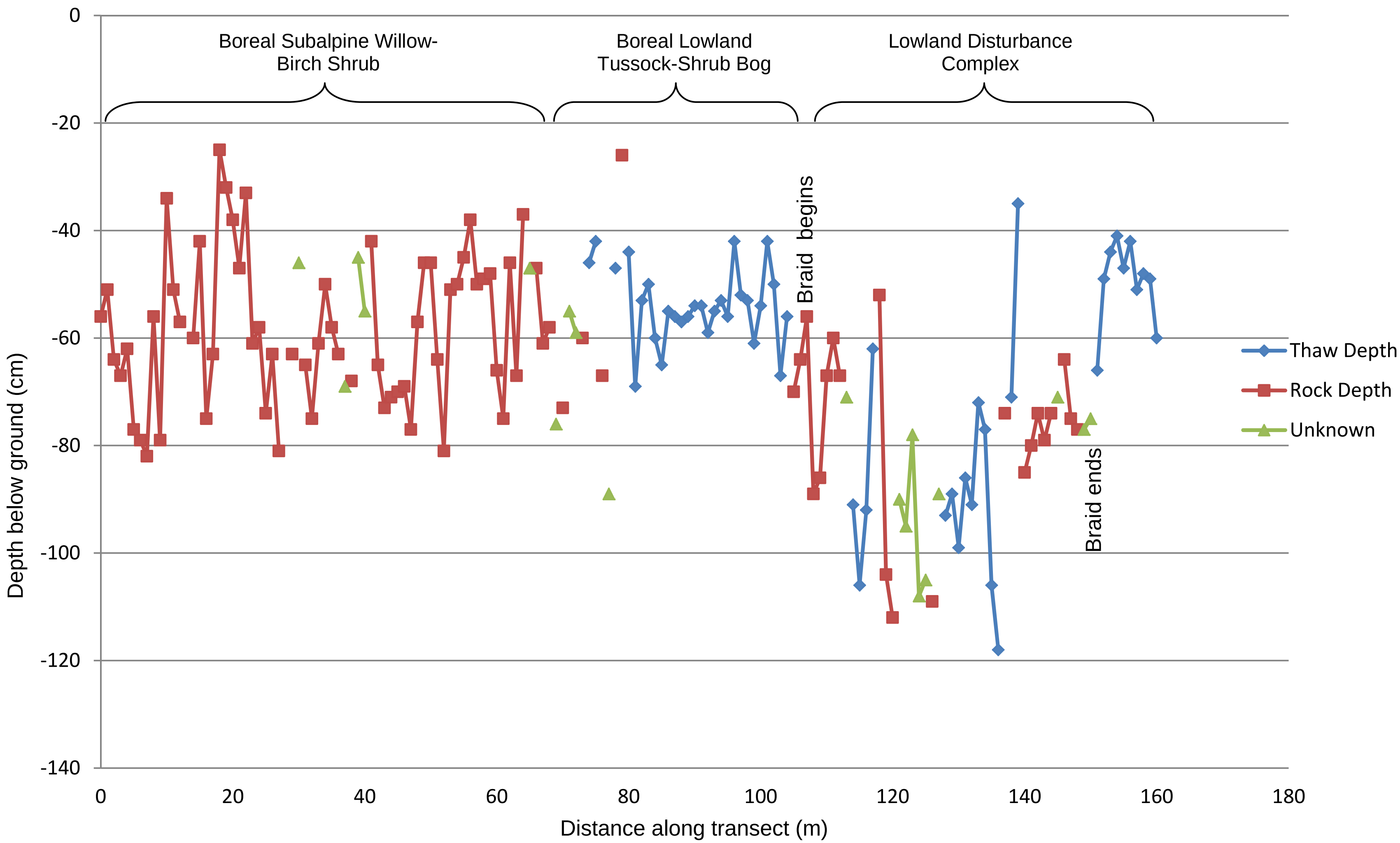
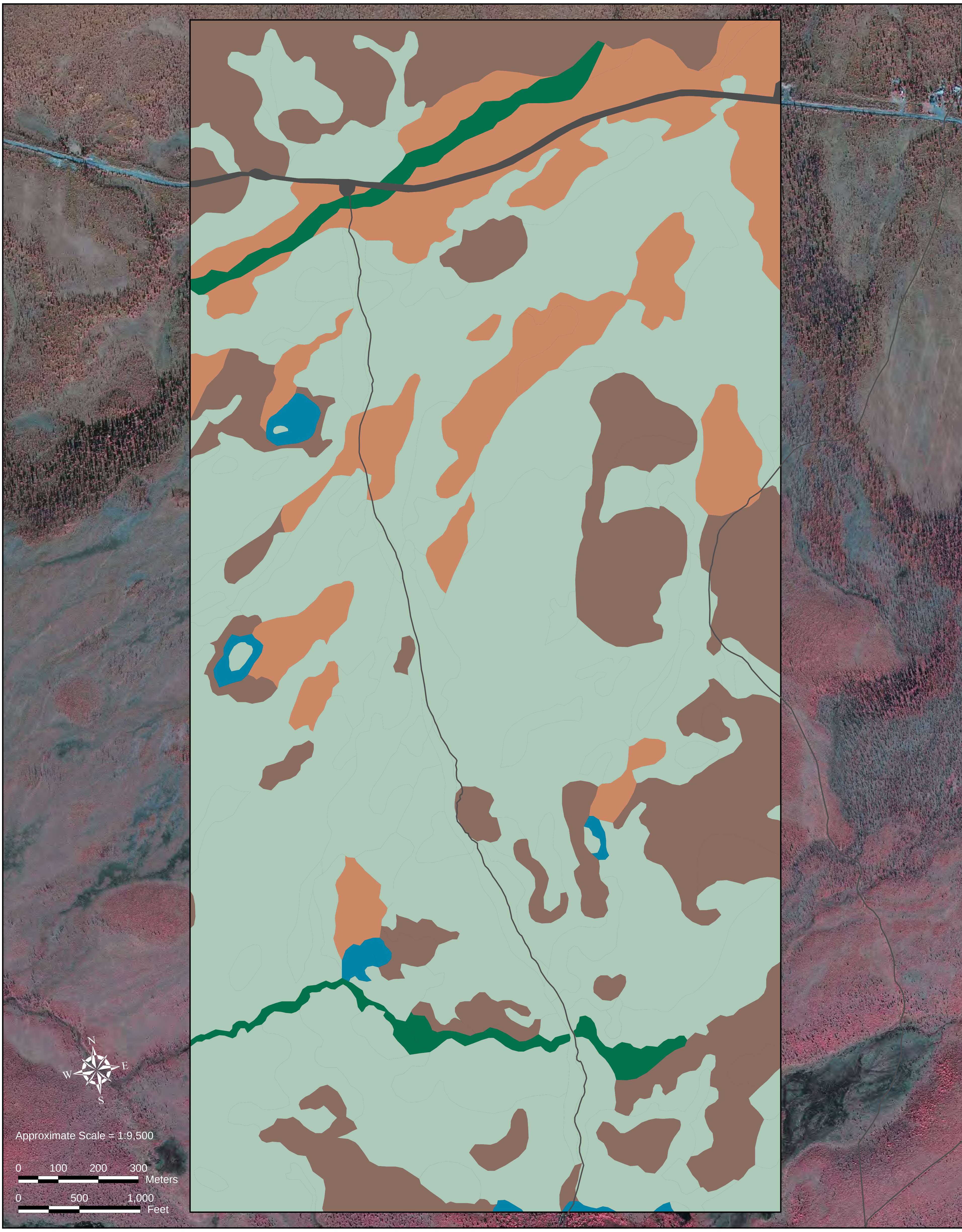


Figure 8. Thaw depth and depth to >15% rock fragments on transect WRST_PF4, Tanada Lake Trail, Wrangell-St. Elias National Park, Alaska, 2012. Approximate boundaries of ecotypes and braided trail sections encountered along the transect are indicated with brackets.



Physiographic Unit

- Subalpine
- Upland
- Lowland
- Lacustrine
- Riverine
- Human-altered

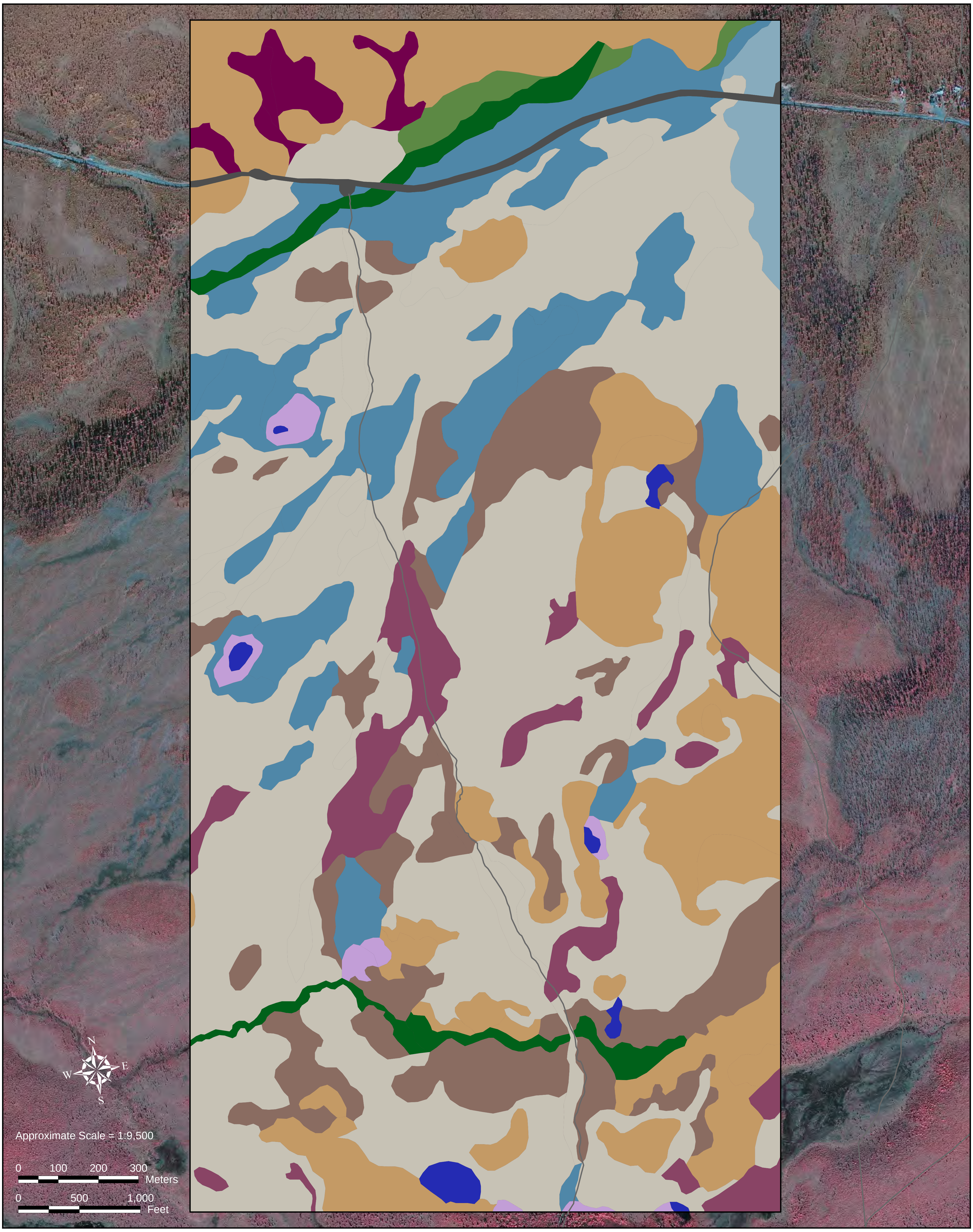
Physiographic units are broad areas on the landscape that are characterized by similar geomorphic processes, topographic relief, and geologic substrate. The classification of physiographic units for the Tanada Lake Trail in Wrangell-St. Elias National Park and Preserve follows Jorgenson et al. (2008). Photo-interpretation of physiographic units based on digital CIR orthophoto mosaic by GeoEye from geometrically corrected 1-meter IKONOS-2, 2004–2006. Map projection: Alaska Albers NAD 1983. Map prepared by ABR, Inc.: WRST_Tanada_Physiography_12-201.mxd, 13 November 2012

Physiography

Ecological Land Survey

Tanada Lake Trail

Figure 9



Geomorphic Unit

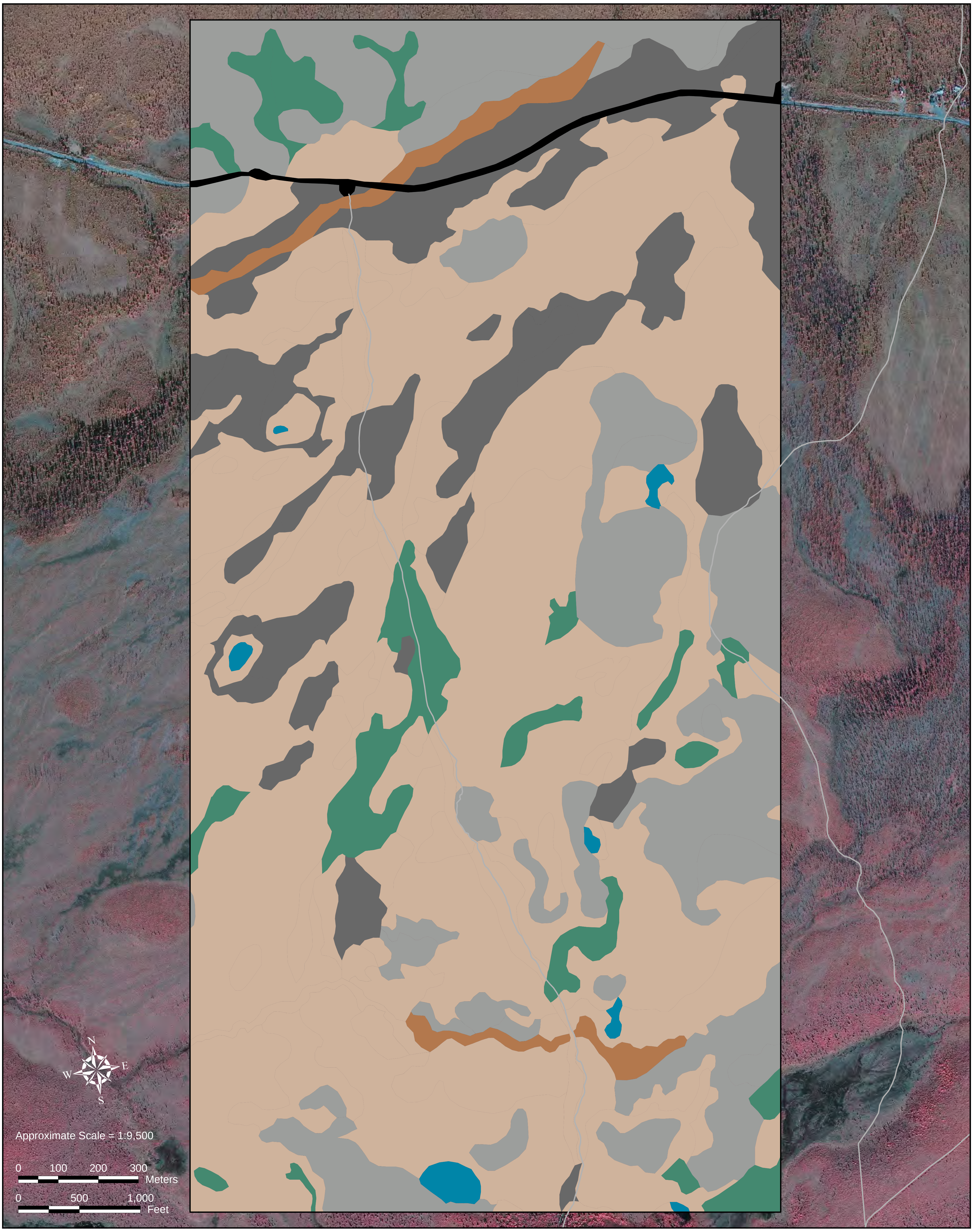
- Younger Till
- Glaciofluvial Outwash
- Old Alluvial Fan
- Hillside Colluvium
- Upland Glaciolacustrine Deposit
- Lowland Glaciolacustrine Deposit
- Organic Fen
- Bogs
- Drained Lake Basin, Ice-poor Undifferentiated
- Lowland Headwater Floodplain
- Gravel Fill
- Deep Isolated Thaw Lake

Geomorphology

Ecological Land Survey
Tanada Lake Trail

Figure 10

Geomorphic units are ecologically important because they represent areas with differing erosional and depositional characteristics and, as a result, have different types of naturally occurring disturbances, soil texture, drainage, topography, and vegetation. Geomorphic units were classified according to a system based on landform–soil characteristics for Alaska developed originally by Kreig and Reger (1982) and ADGGS (1983), with modifications for Alaska based on previous work by ABR, Inc. Digital CIR orthophoto mosaic by GeoEye from geometrically corrected 1-meter IKONOS-2, 2004–2006. Map projection: Alaska Albers NAD 1983. Map prepared by ABR, Inc.: WRST_Tanada_Geomorph_12-201.mxd, 13 November 2012



Generalized Soil Texture

- Rubbly
- Gravelly
- Loamy
- Loamy-Organic
- Organic
- Fill
- Water

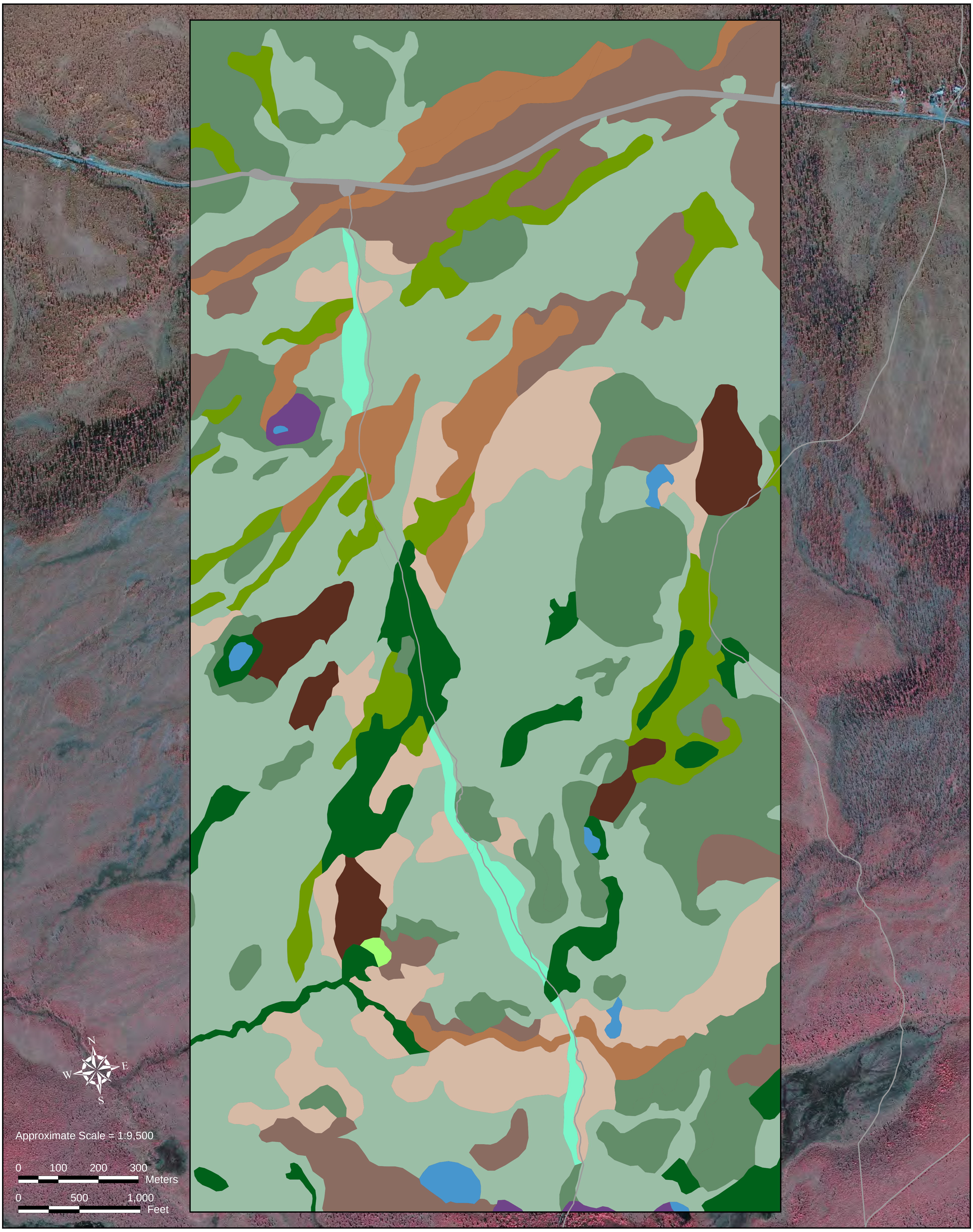
A generalized soil texture map was developed using a terrain unit approach. Geomorphic units were aggregated into generalized soil textures based on field data and an understanding of soil-landscape relationships along the Tanada Lake Trail in Wrangell-St. Elias National Park and Preserve. Digital CIR orthophoto mosaic by GeoEye from geometrically corrected 1-meter IKONOS-2, 2004–2006. Map projection: Alaska Albers NAD 1983. Map prepared by ABR, Inc.: WRST_Tanada_SoilTexture_12-201.mxd, 13 November 2012

Generalized Soil Texture

Ecological Land Survey

Tanada Lake Trail

Figure 11



Vegetation Class

- Open White Spruce Forest
- White Spruce Woodland
- Open Black Spruce–White Spruce Forest
- Black Spruce–White Spruce Woodland
- Open Low Shrub Birch-Willow
- Open Mixed Low Shrub–Sedge Tussock Tundra
- Tussock Tundra
- Moist Sedge Meadow Tundra
- Wet Sedge Meadow Tundra
- Young Basin Wetland Complex
- Disturbance Complex
- Barrens
- Fresh Water

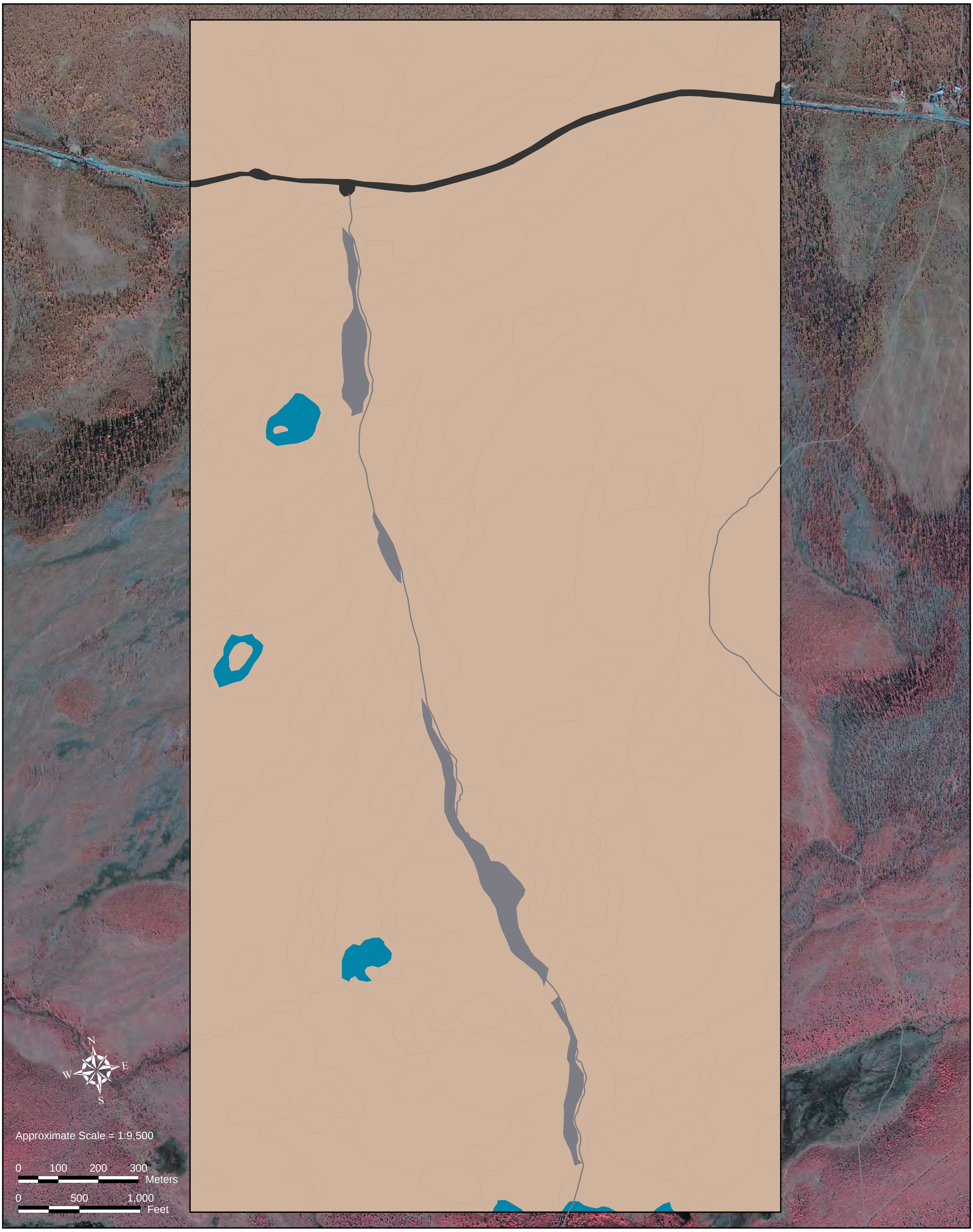
Vegetation

Ecological Land Survey

Tanada Lake Trail

Figure 12

Vegetation was classified using the Alaska Vegetation Classification (AVC) developed by Viereck et al. (1992). Photo-interpretation of vegetation classes based on digital CIR orthophoto mosaic by GeoEye from geometrically corrected 1-meter IKONOS-2, 2004–2006. Map projection: Alaska Albers NAD 1983. Map prepared by ABR, Inc.: WRST_Tanada_Vegetation_12-201.mxd, 13 November 2012



Disturbance Class

- No Disturbance
- Lacustrine (drainage)
- Wheeled Vehicle Summer Trail
- Gravel Road

Disturbance was classified based on a system developed by ABR, Inc. — Environmental Research & Services for use on the arctic coastal plain and modified where appropriate for this project. Digital CIR orthophoto mosaic by GeoEye from geometrically corrected 1-meter IKONOS-2, 2004–2006. Map projection: Alaska Albers NAD 1983. Map prepared by ABR, Inc.: WRST_Tanada_Disturbance_12-201.mxd, 13 November 2012

Disturbance

Ecological Land Survey

Tanada Lake Trail

Figure 13

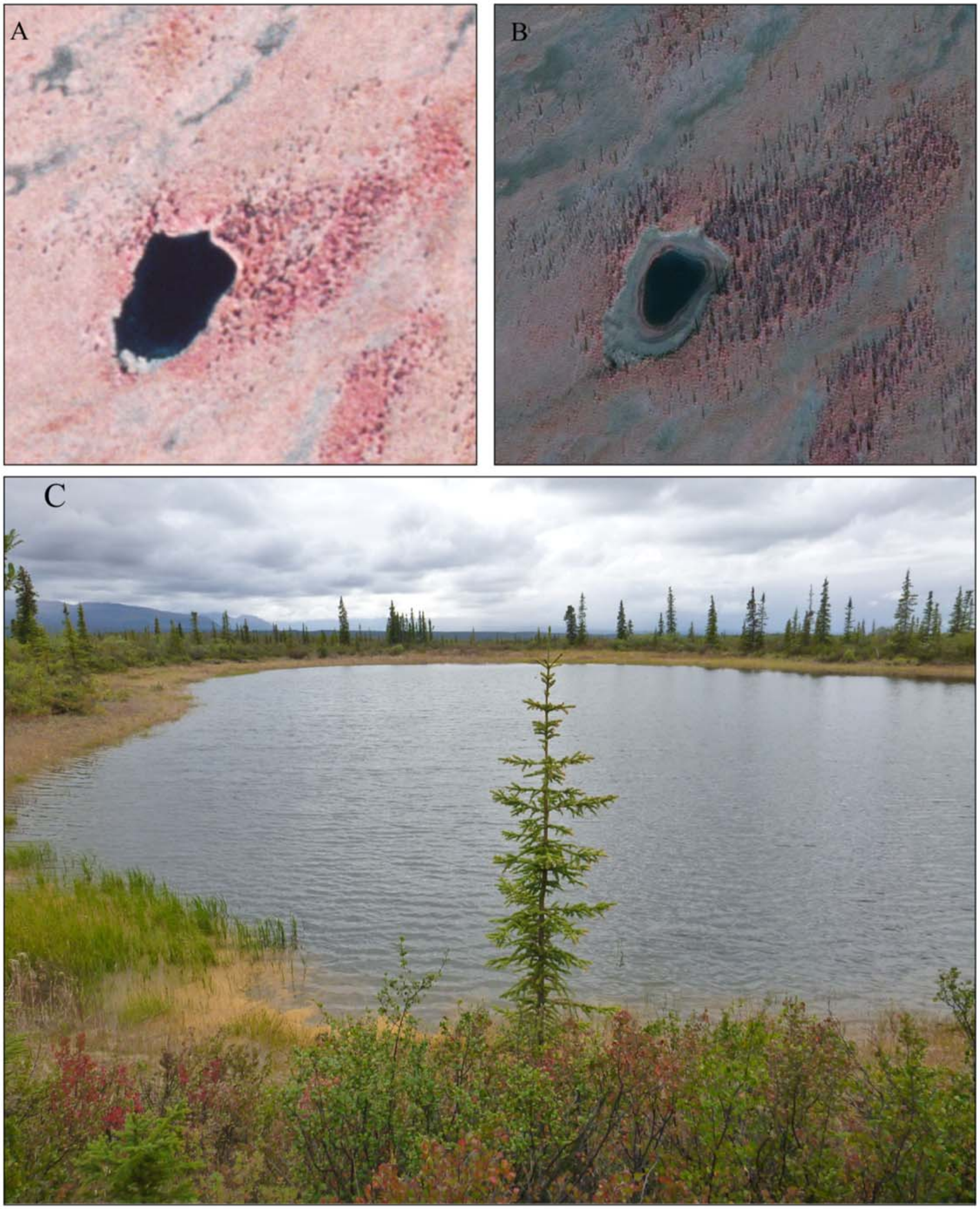
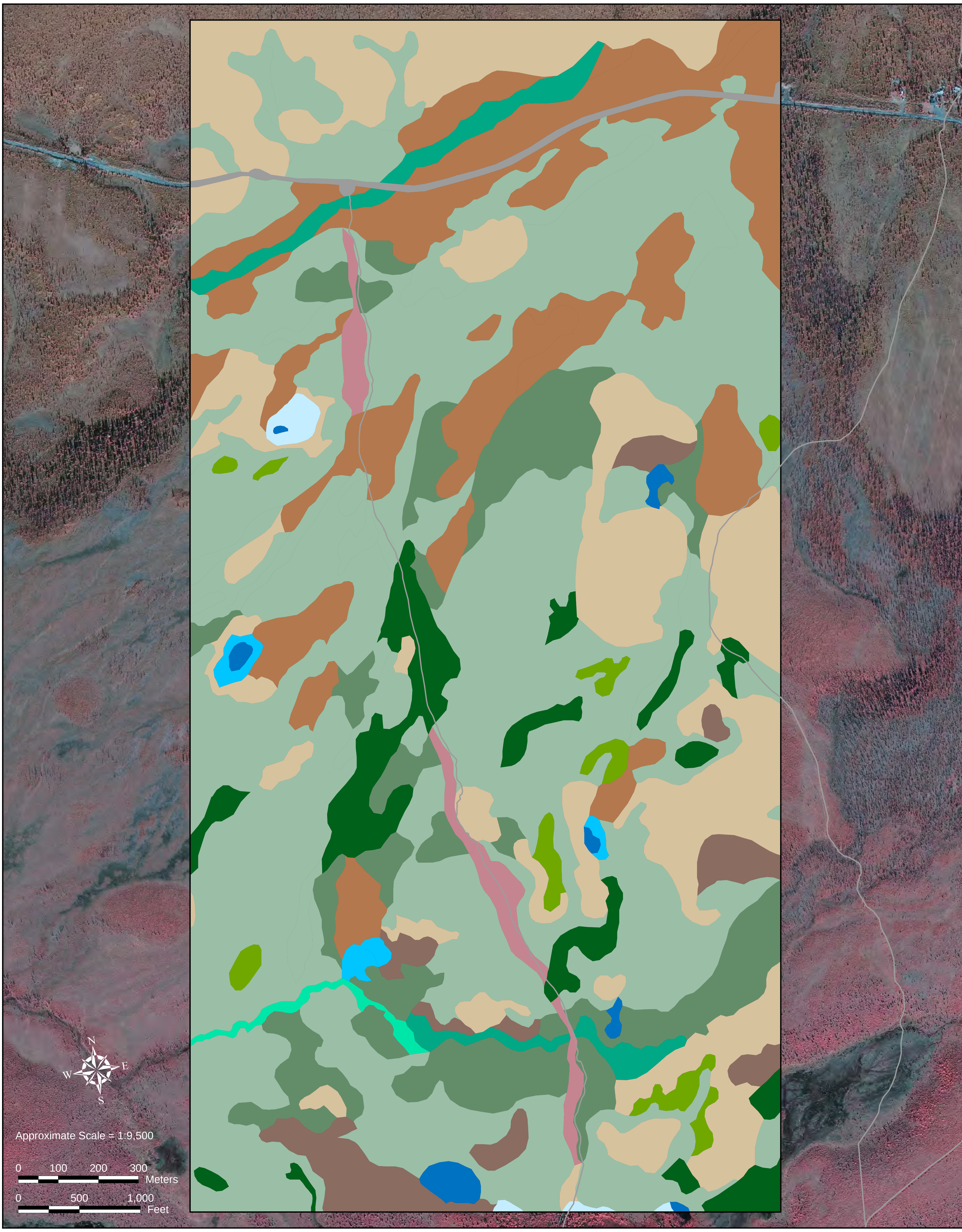


Figure 14. A series of images showing periodic flooding and drainage of a kettle lake in the Tanada Lake Trail study area, including A) color infrared imagery (CIR) from 7 August 1981 showing lake fully flooded, B) CIR 2004-2006 orthophoto mosaic showing the lake partially drained, and C) ground photo showing lake fully flooded taken in August 2012.



Ecotype

Boreal Subalpine Spruce Woodland	Boreal Lowland Disturbance Complex
Boreal Subalpine Willow–Birch Shrub	Boreal Lacustrine Sedge Meadow
Boreal Upland White Spruce Forest	Boreal Lacustrine Drained Lake Complex
Boreal Lowland Black Spruce Forest	Boreal Riverine White Spruce Forest
Boreal Lowland Low Birch–Willow Shrub	Boreal Riverine Wet Sedge Meadow
Boreal Lowland Tussock–Shrub Bog	Lowland Lake
Boreal Lowland Sedge–Shrub Fen	Human Modified

Ecotypes

Ecological Land Survey

Tanada Lake Trail

Figure 15

Ecotype classes based on recoding of integrated-terrain-unit map for Tanada Lake Trail in Wrangell-St. Elias National Park and Preserve (WRST). Ecotypes are local-scale ecosystems that represent a hierarchical organization of physical and biological variables. The advantage of this hierarchical methodology is that the combination of physiography (strongly associated with soil drainage and permafrost), geomorphic unit (strongly associated with soil), and vegetation structure yields classes that effectively differentiate both soil characteristics and vegetation composition. This approach reflects characteristics readily identifiable during mapping, where the interpreter can distinguish physiography (subalpine vs. lowlands), geomorphic units (e.g., till deposits versus glaciolacustrine deposits), and vegetation structure (e.g., low shrubs versus graminoids). Ecotypes are based on an integrated-terrain-unit (ITU) classification originally developed by ABR, Inc. for the arctic coastal plain of Alaska (Jorgenson et al. 1997, 2003, 2004, 2008a, 2009; Roth et al. 2007, 2009; Wells et al. 2012) and modified for the Tanada Lake Trail in WRST. The ITU map classes were assigned ecotypes and the ITU map recoded based on a cross-walk to the ecotype classification of Jorgenson et al. (2008) for WRST. The ITU map was delineated on digital CIR orthophoto mosaic by GeoEye from geometrically corrected 1-meter IKONOS-2, 2004–2006. Map projection: Alaska Albers NAD 1983. Map prepared by ABR, Inc.: WRST_Tanada_Ecotype_12-201.mxd, 13 November 2012

Boreal Lacustrine Sedge Meadow

Boreal Lowland Black Spruce Forest

Boreal Lowland Low Birch–Willow Shrub

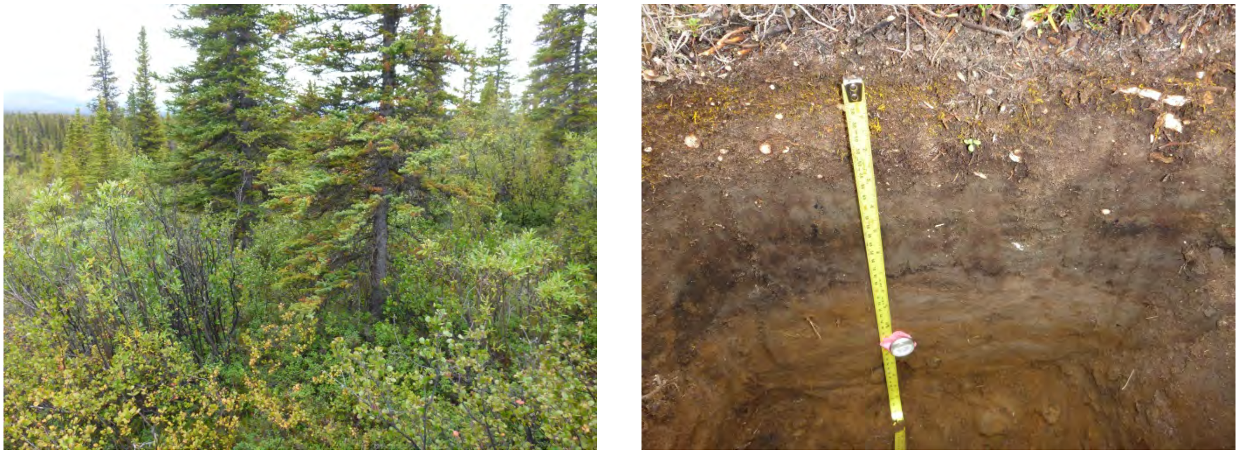
Figure 16. Representative photos of nine common ecotypes and associated soils in the Tanada Lake Trail study area, Wrangell-St. Elias National Park and Preserve, Alaska, 2012.


Boreal Lowland Sedge–Shrub Fen


Boreal Lowland Tussock–Shrub Bog


Boreal Riverine White Spruce Forest

Figure 16. Continued.

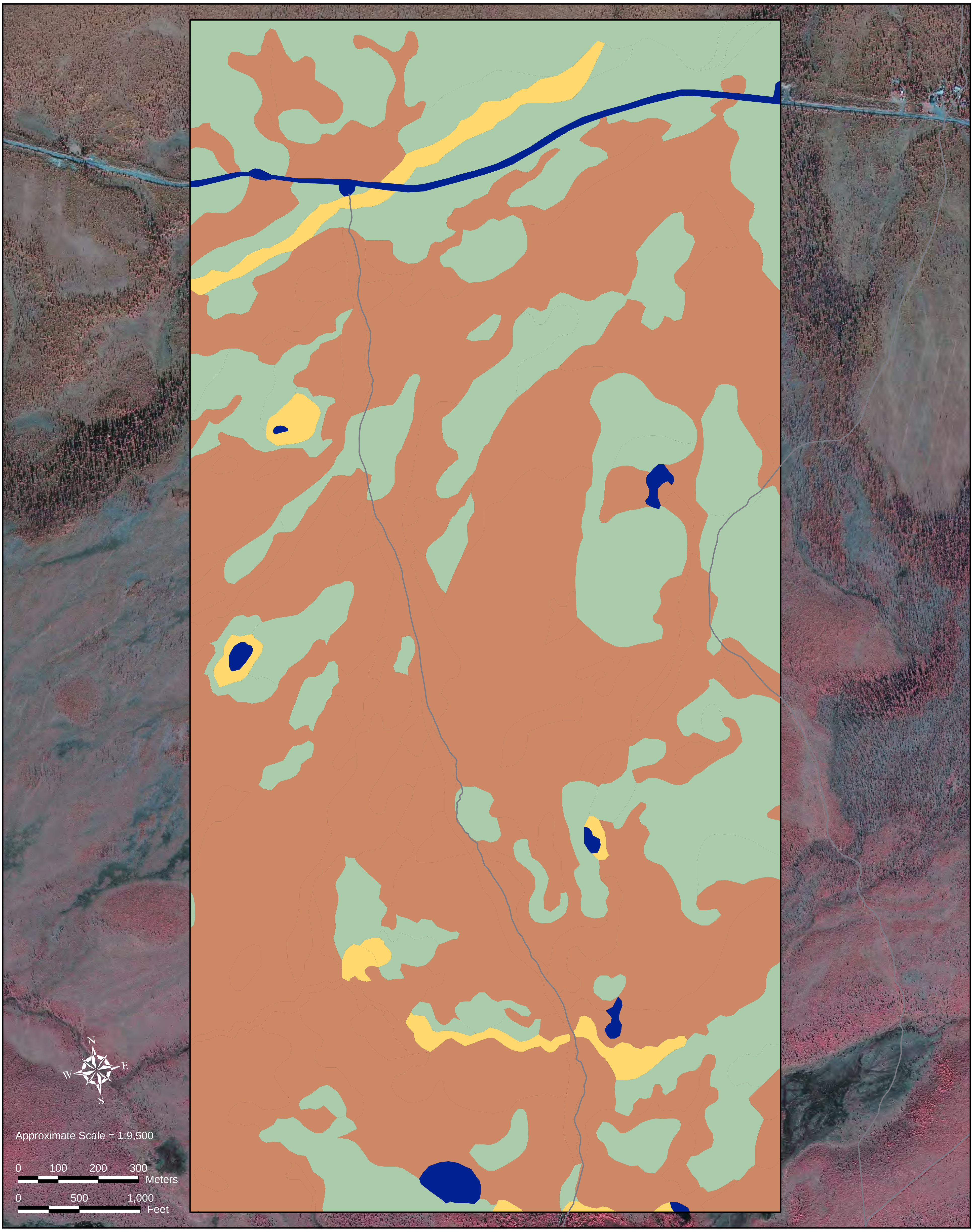


Boreal Subalpine Spruce Woodland

Boreal Subalpine Willow–Birch Shrub

Boreal Upland White Spruce Forest

Figure 16. Continued.



Landscape Sensitivity

- High
- Moderate
- Low
- Negligible

Landscape sensitivity classes based on recoding of integrated-terrain-unit map for Tanada Lake Trail in Wrangell-St. Elias National Park and Preserve. Landscape sensitivity classes represent a combination of permafrost and summer traffic sensitivity classes developed by assessing vegetation-soil-landscape relationships based on field surveys, and by summarizing a reduced set of variables (surface organic thickness, thaw depth, and depth to > 15% rock fragments, dominant soil texture) by ecotype. In general, ecotypes with thinner organic horizons, deeper thaw depths, shallower depths to rock fragments, and coarse soil textures were assigned lower sensitivity, while those ecotypes with thicker organic horizons, shallower thaw depths, deeper coarse fragments, and finer/organic-rich soils were assigned higher sensitivities. Digital CIR orthophoto mosaic by GeoEye from geometrically corrected 1-meter IKONOS-2, 2004–2006. Map projection: Alaska Albers NAD 1983. Map prepared by ABR, Inc.: WRST_Tanada_LandscSensitivity_12-201.mxd, 13 November 2012

Landscape Sensitivity

Ecological Land Survey

Tanada Lake Trail

Figure 17