

An introduction to the geomorphology, hydrology, and climate of the Copper River Delta, Alaska



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The Copper River Delta

The Copper River Delta (CRD) extends along 80 km of Gulf of Alaska coastline, adjacent to the southern piedmont of the Chugach Mountains (Figure 1). The CRD is protected as “critical habitat” for fish and wildlife and is reputed to be the largest wetland on the Pacific Rim of North America [Thilenius, 1990b; Bryant, 1992; Boggs, 2000]. The CRD supports healthy runs of coho and sockeye salmon that are critically important to the economy, culture, and ecology of the region [Christensen, 2000].

The CRD includes both marine and subaerial (above eustatic sea level) habitats. In the marine environment, the CRD is characterized by extensive tidal flats, barrier islands, and an actively prograding delta front [Reimnitz, 1966; Galloway, 1976]. The substrate is primarily sand and silt. The subaerial deltaic plain is utilized by Pacific salmon for spawning and rearing and will be the focus of this introduction.

The subaerial deltaic plain grades into the Chugach piedmont. Surficial geology in the piedmont is primarily composed of sedimentary rocks (Orca Group) with localized granodiorite intrusions [Reimnitz, 1966; Winkler *et al.*, 1992]. These layers are underlain with basalts of the late Paleocene or early Eocene age [Winkler *et al.*, 1992]. Peak elevations in the southern piedmont are around 2,300 m. The soil mantle is composed of shallow till or peat on the hillslopes. Deposits of colluvium and glaciofluvial drift are present in the valleys. The largest valleys are high-relief (1,500 m on average) and glaciated [Barclay *et al.*, 2013]. Five valley glaciers (“the proximal glaciers”) terminate on the CRD between 50 and 120 m in elevation (Table 1).

Deposition from these proximal glaciers covers much of the 1,000 km² subaerial deltaic plain, and this portion of the CRD effectively functions as a low-relief glacial foreland. The substrates are a heterogeneous mix of coarse glacial sand and gravel and fine organic materials in abundant peatlands and marshes [Reimnitz, 1966; Galloway, 1976]. Below the piedmont glacial valleys, thick layers of gravels enable phreatic storage and provide excellent spawning habitat for salmon.

The CRD is a Holocene landform, the 450 km³ deltaic pile has formed entirely during the last 10,000 years. The deltaic pile is largely composed of glaciofluvial sand and silt and has an average thickness of 180 m [Reimnitz, 1966]. It is actively prograding seaward today

[Jaeger *et al.*, 1998]. The structure and morphology of this feature are controlled by 1) the supply of glacialigenic sediments distributed by the Copper River and proximal glaciers [Reimnitz, 1966; Barclay *et al.*, 2013], 2) reworking in the high energy marine environment [Galloway, 1976], and 3) tectonic activity [Plafker, 1990].



Figure 1 Copper River Delta Study Region, Southcentral Alaska

Table 1 Geometry and terminus characteristics for the five glaciers that terminate on the CRD

Proximal Glaciers to the CRD						
Name	Geometry		Terminus Description			Type
	Length (km)	Area (km ²)	Latitude	Longitude	Elevation (m)	
Martin River	44	349	60.47	-144.25	100	Lake
Scott	24	167	60.61	-145.38	110	Land
Sheridan	24	60	60.51	-145.35	50	Lake
Sherman	13	58	60.54	-145.21	120	Land
Saddlebag	8	8	60.48	-145.1	85	Lake

Glacigenic Sediments from the Copper River

The Copper River has the second highest mean discharge ($1625 \text{ m}^3\text{s}^{-1}$) [Brabets, 1997] and the highest mean annual suspended-sediment load (70 million tons) in Alaska [Milliman and Meade, 1983; Jaeger *et al.*, 1998], despite having the state's sixth largest catchment area ($62,960 \text{ km}^2$). The Copper River distributes disproportionate quantities of meltwater and sediment due primarily to seasonal ablation and erosion associated with glacial activity [Kargel *et al.*, 2014].

The Copper River catchment is flanked by the Alaska Range and the Wrangell St. Elias, Chugach, and Talkeetna Mountains. Peak elevations exceed 4,000 m and 18% of the catchment is glaciated [Kargel *et al.*, 2014]. The combination of high-relief terrain and abundant snowfall maintains wet-based glaciers which move relatively rapidly and generate atypically large quantities of sediment [Jaeger *et al.*, 1998; Kargel *et al.*, 2014].

The sediment transported to the CRD by the Copper River is primarily fine sand and silt [Jaeger *et al.*, 1998]. These materials compose the deltaic platform, however, the surficial geology of the subaerial CRD includes coarser sand and gravel from the proximal glaciers [Barclay *et al.*, 2013] as well as finer organic materials due to vegetative growth and succession [Reimnitz, 1966].

Marine Reworking

Glacigenic sediments from the Copper River are re-distributed by tidal action, westerly longshore currents, and large storms, resulting in the CRD's long and asymmetric

(relative to the river mouth) shape [Galloway, 1976]. Tidal range in Orca Inlet (near Cordova) averages 3.5 m but can exceed 6.5 m during the highest spring tides. Westerly longshore currents are powered by prevailing winds over the Gulf of Alaska and transport Copper River sediments as far as 100 km west of the river mouth [Jaeger *et al.*, 1998]. Storms are common over the Gulf of Alaska, particularly during the fall, winter, and spring months, and are characterized by high winds and large swell that greatly impacts the CRD deltaic front [Galloway, 1976]. Marine reworking of the deltaic sediments smoothed the formerly irregular and steep coastline, enabling the proximal glacier outwashes to grade over the subaerial CRD [Reimnitz, 1966].

Tectonics

The Copper River catchment is located near the Aleutian subduction zone, a seismically active thrust fault boundary [Grantz *et al.*, 1964]. Tectonic processes at this fault is responsible for the orogenic mountain ranges present in coastal Alaska. Similar to other tectonically-active regions, these mountains have high erosion and sediment production rates [Jaeger *et al.*, 1998].

Mega-thrust earthquakes have impacted sedimentation on the CRD directly and indirectly. Direct impacts include landslides that have deposited colluvial materials in piedmont valleys and the adjacent outwash plain [Tuthill and Laird, 1966; Waller, 1966] and co-seismic tsunamis and seiches that re-distributed sediments in the marine environment [Reimnitz, 1966]. Mega-thrust earthquakes indirectly impact sedimentation on the CRD by elevating the land surface relative to sea level.

Plafker [1990] used sediment cores from the subaerial CRD to identify nine co-seismic uplift events in the last 5,600 years. Each event resulted in a 0.8 m to 2.4 m uplift with a 300-950 year recurrence interval (630 years on average). On the low-relief CRD, these sudden shifts in surface elevation greatly reduced the extent of tidal influence, resulting in major vegetation and land surface changes. The most recent event occurred in 1964 and will be introduced further in the *Hydrology* section below.

Tectonic (“crustal”) subsidence averages 7 mm yr⁻¹ between co-seismic uplift events [Plafker, 1990]. As a result, the CRD experiences net submergence over time. Buried marsh and tidal flat deposits are present 8-20 m below the surface of the subaerial CRD near the

Scott and Sheridan glacial outwashes [Reimnitz, 1966], providing record of submergence events and contributing to subsurface heterogeneity. Stumps and freshwater marsh materials were also buried in situ across the subaerial CRD [Tarr and Martin, 1914; Reimnitz, 1966; Plafker, 1990], adding further complexity to subsurface water flowpaths.

Co-seismic uplift and gradual inter-seismic subsidence greatly influence geomorphic processes on the seaward fringe of the subaerial delta while glacial processes are dominant on the foreland [Barclay *et al.*, 2013], including in the habitats where salmon spawning occurs. Here, surficial processes that govern subsurface flowpaths have been heavily influenced by the Pleistocene and Holocene advances of proximal glaciers.

Pleistocene Glaciation

The Copper River has bisected the Chugach Mountains and discharged directly into the Gulf of Alaska for approximately the last 10,000 years. During the prior 50,000 years, however, the Chugach Mountains were more heavily glaciated and the river's corridor through the Chugach range was filled with 750 m of ice [Reimnitz, 1966], effectively damming most of the Copper River's catchment and forming the 9,000 km² proglacial Lake Atna [Wiedmer *et al.*, 2010]. The present-day location of the CRD was covered with 500 m of ice [Tarr and Martin, 1914]. Eustatic sea level was over 100 m below current levels and the glaciers likely extended at least 20 km beyond the present-day barrier islands [Reimnitz, 1966].

Holocene Glaciation

Glaciers have generally retreated during the Holocene, enabling Lake Atna to drain down the Copper River's corridor through the Chugach Range; however, periodic Holocene glacial advances have been documented in the study area and globally. Barclay *et al.* [2013] documented glacial advance and retreat on the subaerial CRD during the last 2,000 years. Their reconstruction of Sheridan Glacier's late Holocene activity is one of the most complete records worldwide of glacial activity during the last 2,000 years. Sheridan Glacier has advanced four times during the late Holocene (530s to 640s, 1240s to 1280s, 1510s to 1700s and 1810s to 1860s). The last three advances were during the Little Ice Age. The last two advances were also recorded at Scott, Sherman, and Saddlebag glaciers.

The Little Ice Age advances played an important role in shaping the surficial geology of the subaerial CRD. The glaciers pushed moraines as they advanced. The moraines forced melt water to move laterally across the outwash plain, spreading glaciofluvial material (“drift”) over nearly the entire subaerial CRD [Barclay *et al.*, 2013]. Unlike the morainal tills, drift is generally well-sorted, creating layers of coarse substrates that are well-drained and layers of finer substrates that are poorly-drained. On the CRD, the poorly-drained regions promote peat-formation while the well-drained regions enable phreatic water storage.

Aggradation of glacial sediments also buried trees and other organic materials *in situ* [Barclay *et al.*, 2013], contributing to the complexity of subsurface water flowpaths. Due to the lateral movements of glacial meltwater throughout the late Holocene, glacial materials are widely distributed across the subaerial delta [Barclay *et al.*, 2013], well beyond the range of the present-day meltwater rivers, although most of the well-drained regions are likely located directly down-valley from piedmont glaciers where the drift materials are thickest [Galloway, 1976].

Driftless Area

There is a small driftless area on the CRD, between the Saddlebag and Sheridan glaciers [Tarr and Martin, 1914; Reimnitz, 1966]. Due to glacial geometry, this area remained largely unglaciated during the Pleistocene and the Holocene, as evidenced by the presence of “seastacks” (also referred to locally as “haystacks”), which are vertical rock formations that were shaped by waves, not by ice. Coarse glacial drift is absent around these seastacks, the land surface elevation is low, and tidal influence extended all the way to the piedmont before the 1964 co-seismic uplift. As a result, the surficial materials are fine-grained marine sediments that have poor hydraulic conductivity. Angular gravel is present where high energy piedmont streams intersect the CRD and coho salmon spawn in these areas, but water flowpaths are likely different than in the outwash gravels, adding further heterogeneity to present-day hydrologic processes.

Hydrology and Climate

The study region includes most of the subaerial CRD and the adjacent piedmont front and is defined as the 2950 km² area within 15 National Hydrography Dataset (NHD, www.usgs.gov) HUC 12 catchments (Table 1.2). Catchment elevations range from sea level to over 1800 m and 1200 m of relief is typical. Catchment geometries are not uniform and mean catchment elevations ranges from 18 m to over 600 m (Figure 2).

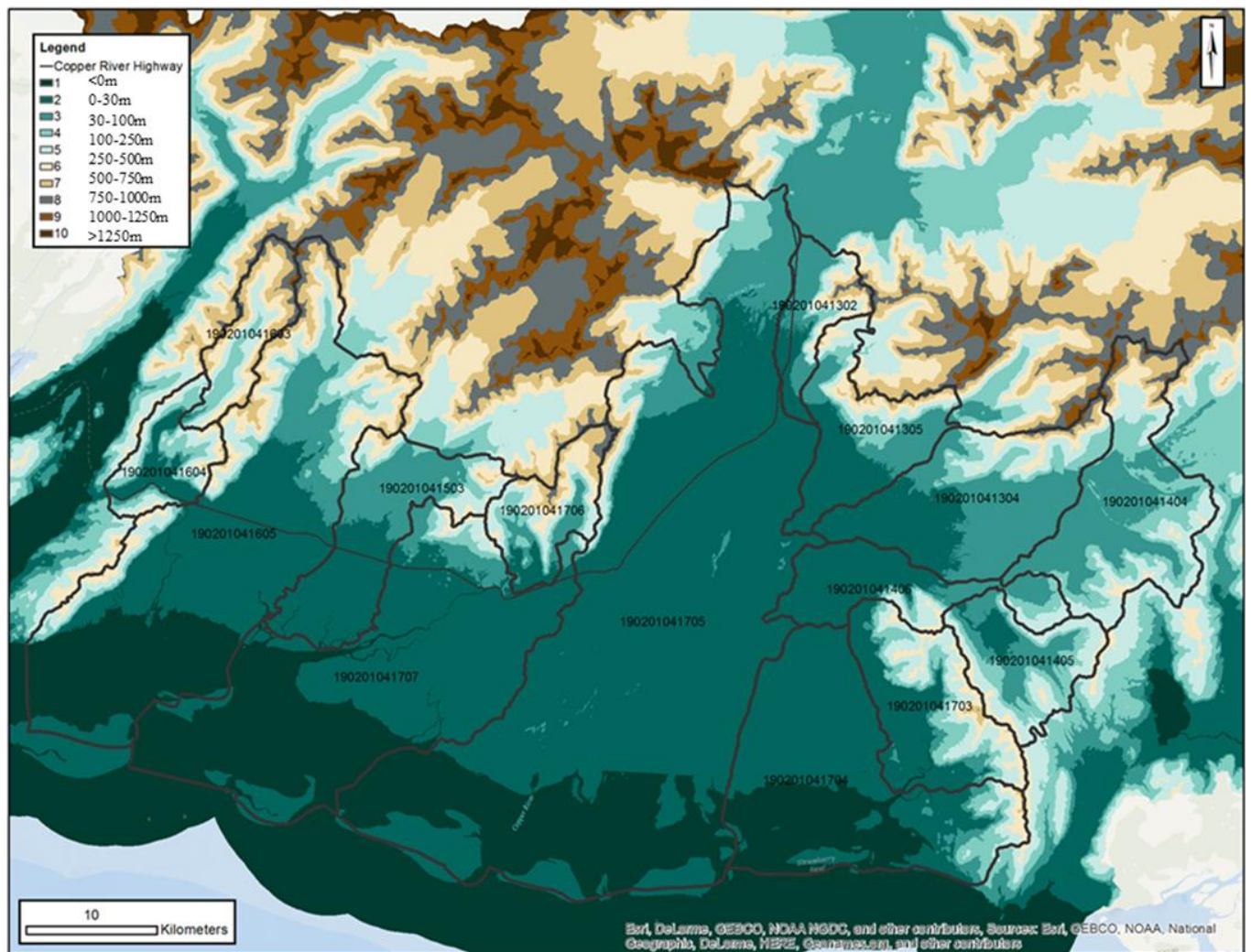


Figure 2 Map of HUC 12 units in the study area with elevation bands calculated from 5m IFSAR DEM

Land Cover

Based on NHD figures, lakes and pond coverage ranges from 0-19% and ice coverage ranges from 0 to 17% of the HUC unit land areas (Table 2). NHD stream layers are incomplete for this region, but small streams are numerous in the piedmont and on the glacial outwash. Glacial meltwater distributaries cross the CRD and discharge into tidal sloughs on the lowest reaches of the subaerial CRD.

Table 2 National Hydrography Dataset zone statistics and waterbody areas for the study region

HUC Zone Statistics								NHD Waterbody	
HUC12	NAME	km ² AREA	MIN	MAX	range RANGE	MEAN	S.D.	km ² Lake & Pond	Ice Mass
190201041707	Alaganik Slough-Frontal Gulf of Alaska	377.9	0	908	908	19	72	12.8	0.0
190201041704	Mirror Slough-Frontal Gulf of Alaska	253.2	-1	941	943	32	101	4.3	0.0
190201041703	Martin River Slough	118.9	-1	1037	1038	202	227	1.9	0.0
190201041603	Power Creek	54.1	16	1468	1452	620	314	0.0	6.4
190201041304	190201041304	159.7	10	1558	1548	145	232	0.6	1.6
190201041302	Goat Mountain	51.7	18	1329	1311	243	301	0.1	0.5
190201041503	Glacier River-Sheridan River	121.5	0	1145	1145	111	188	7.1	10.6
190201041305	Sheep Creek	97.6	8	1284	1276	194	259	0.6	0.4
190201041705	Outlet Copper River-Frontal Gulf of Alaska	847.5	0	1547	1547	36	124	8.2	16.4
190201041406	Outlet Martin River	83.9	5	787	782	94	144	4.5	0.0
190201041405	Martin Lake	80.2	27	971	945	211	186	8.3	0.0
190201041604	Eyak Lake	54.1	1	960	959	230	215	10.2	0.0
190201041605	Eyak River-Frontal Gulf of Alaska	425.7	0	1466	1466	157	270	12.9	3.0
190201041404	Headwaters Martin River	160.7	36	1702	1666	282	303	8.8	16.1
190201041706	Salmon Creek	63.6	1	1292	1291	395	335	2.8	10.7

Firn snow and glacial ice is prevalent in the large glacial valleys and is present above 1100 m elsewhere. Two general types of lakes are present in the study area 1) proglacial lakes located between glacial ice and Little Ice Age moraines and 2) clear-water lakes that form along lateral outwash margins between piedmont slopes and outwash materials. Ponds are prevalent in both the uplifted marsh region and in the driftless area. Ponds are also present on the outwash plain in locations where beavers (*Castor canadensis*) are present [Cooper, 2007].

National Land Cover (www.mrlc.gov) data indicate human developments within the study region are limited except for residential development along Eyak Lake and River, government and commercial infrastructure at the Mudhole Smith Airport ("the airport"), paved highway between the airport and Cordova, and <100 km of gravel roads elsewhere. Woody wetlands, shrub/scrub, and evergreen forests cover most land surfaces (Table 3). Barren bedrock surfaces are prevalent above 1000 m.

Table 3 Percentage of selected land surface cover types calculated from National Land Cover data

HUC12	NAME	(%) Percentage of HUC Area (%)									
		Developed intensity			Barren	Forested		Herbaceous		Wetland	
		Low	Medium	High		Deciduous	Evergreen	Shrub/ Scrub	Grassland/ Herbaceous	Woody Wetlands	Emergent Herbaceous
190201041707	Alaganik Slough-Frontal Gulf of Alaska	0.2	0.0	0.0	13.9	0.1	6.1	2.9	0.1	34.8	7.4
190201041704	Mirror Slough-Frontal Gulf of Alaska	0.0	0.0	0.0	8.5	0.1	8.5	3.8	0.0	44.3	8.4
190201041703	Martin River Slough	0.0	0.0	0.0	6.1	0.1	25.2	27.7	0.3	26.1	9.0
190201041603	Power Creek	0.2	0.0	0.0	33.1	0.0	23.1	25.7	0.4	0.3	0.0
190201041304	190201041304	0.0	0.0	0.0	3.8	0.1	23.5	19.8	0.7	32.7	12.9
190201041302	Goat Mountain	0.5	0.0	0.0	14.0	19.1	23.7	29.2	0.5	5.7	0.1
190201041503	Glacier River-Sheridan River	0.4	0.0	0.0	5.2	0.8	18.3	15.7	0.3	34.2	9.1
190201041305	Sheep Creek	0.0	0.0	0.0	7.1	0.8	19.2	31.5	1.1	31.6	2.4
190201041705	Outlet Copper River-Frontal Gulf of Alaska	0.1	0.0	0.0	18.0	0.8	2.5	8.0	0.2	13.0	3.6
190201041406	Outlet Martin River	0.0	0.0	0.0	1.2	0.0	18.7	12.1	1.1	59.1	2.6
190201041405	Martin Lake	0.0	0.0	0.0	3.7	0.3	28.2	42.1	0.9	13.2	1.1
190201041604	Eyak Lake	1.6	0.1	0.1	4.3	0.0	46.4	24.3	0.2	4.1	0.0
190201041605	Eyak River-Frontal Gulf of Alaska	0.2	0.1	0.0	19.7	0.1	12.9	15.1	0.4	21.0	7.8
190201041404	Headwaters Martin River	0.0	0.0	0.0	9.0	0.3	37.9	25.7	0.4	10.6	0.0
190201041706	Salmon Creek	0.0	0.0	0.0	14.0	0.2	33.2	23.7	0.3	4.3	0.0

Surficial geology is characterized by bedrock and till on piedmont slopes, colluvium and drift in unglaciated piedmont valleys, drift and till on the outwash plain, and marine sediments on the uplifted marsh (Table 4 and Figure 3).

Table 4 Percentages of land surface composed of selected surficial geology types as calculated from USGS data

(%) Percentage of Land Surface (%)						
HUC12	NAME	Selected Geology Types				
		Surficial deposits (Quaternary)		Bedrock (Tertiary)		
		Till, marine, & eolian sediments	Drift & colluvium	Intrusive	Sedimentary	Volcanic
190201041707	Alaganik Slough-Frontal Gulf of Alaska	20.5	54.9	3.3	4.1	0.0
190201041704	Mirror Slough-Frontal Gulf of Alaska	26.2	53.6	0.0	9.8	3.5
190201041703	Martin River Slough	22.0	18.1	0.1	27.0	30.7
190201041603	Power Creek	2.9	11.3	7.5	18.1	38.0
190201041304	190201041304	22.6	47.6	7.0	0.1	19.2
190201041302	Goat Mountain	5.7	54.9	0.0	37.1	0.5
190201041503	Glacier River-Sheridan River	6.0	60.1	11.6	8.1	0.0
190201041305	Sheep Creek	2.7	55.2	1.3	27.5	9.4
190201041705	Outlet Copper River-Frontal Gulf of Alaska	10.5	38.7	0.0	4.5	0.3
190201041406	Outlet Martin River	0.1	67.9	0.0	18.1	9.4
190201041405	Martin Lake	9.2	14.8	0.0	53.0	11.3
190201041604	Eyak Lake	0.0	8.3	0.0	57.3	15.9
190201041605	Eyak River-Frontal Gulf of Alaska	0.0	60.9	0.0	30.7	0.0
190201041404	Headwaters Martin River	22.0	27.2	4.7	32.0	1.5
190201041706	Salmon Creek	4.4	14.4	1.5	56.4	0.0

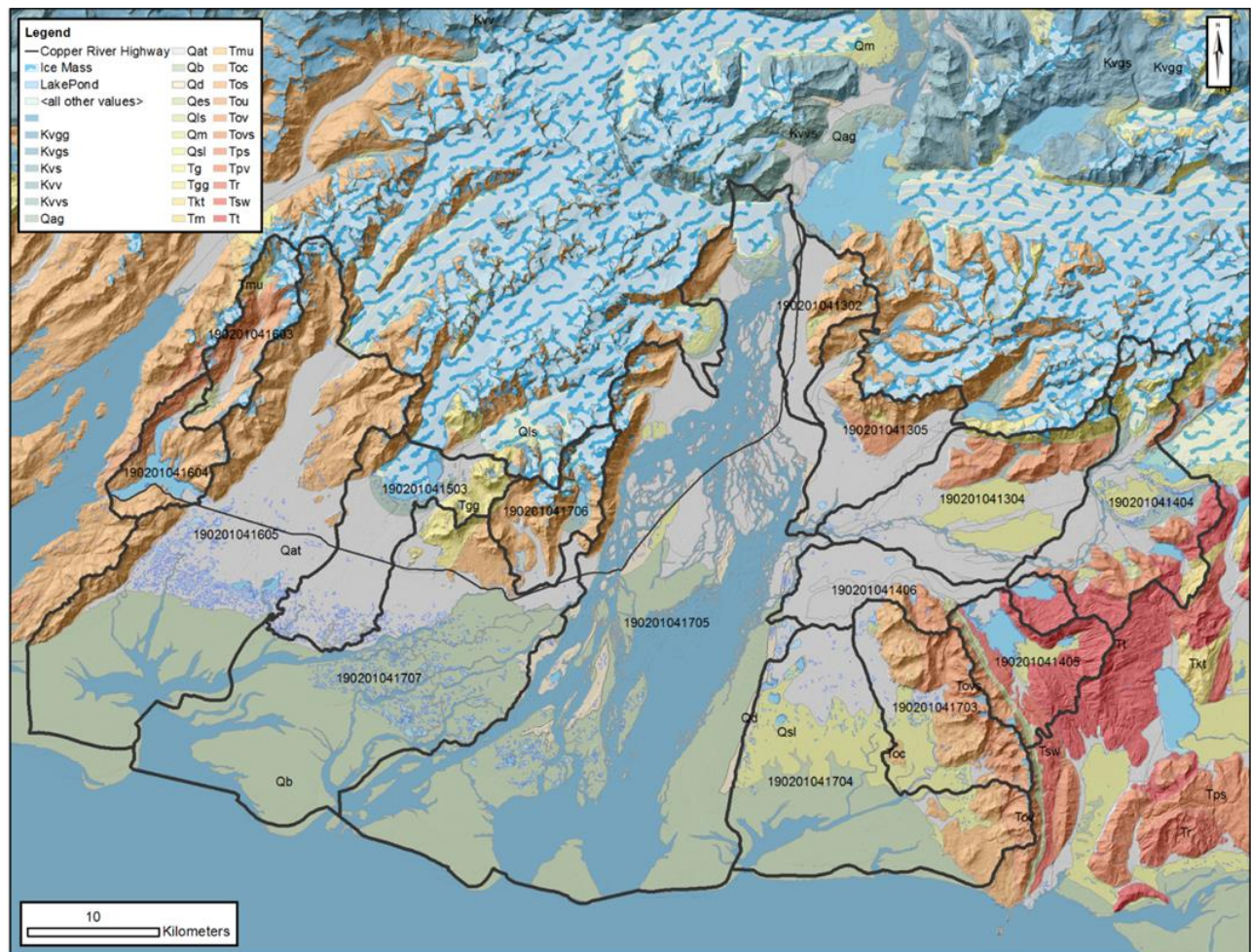


Figure 3 Surficial Geology of the study area. Glaciofluvial drift (Qat) is gray, marine sediment (Qb) are green, sedimentary rocks (Tos) are orange, granitic intrusions (Tgg) are yellow, and basaltic rocks are red (Tt).

Climate

The climate is cool and wet and is characterized as maritime. Based on 1980-2010 climate records, the monthly average maximum air temperatures ranges from 16 °C (August) to 1 °C (January) and the monthly average minimum air temperatures ranges from 8 °C (July) to -5 °C (January) (Figure 4). Measureable precipitation occurs 220 days per year. Annual precipitation averages 235 cm per year at the airport (13 m above sea level), but considerably more precipitation is likely to accumulate in localized areas and at higher elevations. Monthly precipitation at the airport ranges from 13 cm (June) to 34 cm

(September) (Figure 5) and precipitation may fall as rain any day of the year. Snowfall is also common from October until May (Figure 1.6) and normal snowfall exceeds 250 cm per year. A shallow (<30 cm) snowpack is usually present at sea level from November until May [Reimnitz, 1966] while deeper snowpacks (>3m) accumulate in the mountains and persist throughout the summer months [Kargel *et al.*, 2014].

Cold and dry continental air masses periodically influence the study area during the late fall, winter, and early spring months. Temperatures below -20 °C have been recorded most days between early November and late March (Figure 4). These influences are particularly pronounced down valley from the Copper River Canyon, where a local gap wind transports cold interior air onto the CRD due to gravity- and pressure gradient-induced air flows [Reimnitz, 1966]. The pressure difference is due to prevailing high pressure north of the Chugach Mountains and low pressure over the Gulf of Alaska. Along the Copper River, winds in excess of 150 km hr⁻¹ have been recorded during the fall, winter, and spring months [Reimnitz, 1966]. In addition to transporting cool interior air, these winds redistribute snow and sand and have created a large dunes where the Copper River bisects the CRD, adding further complexity to the region's geomorphology [Reimnitz, 1966; Galloway, 1976].

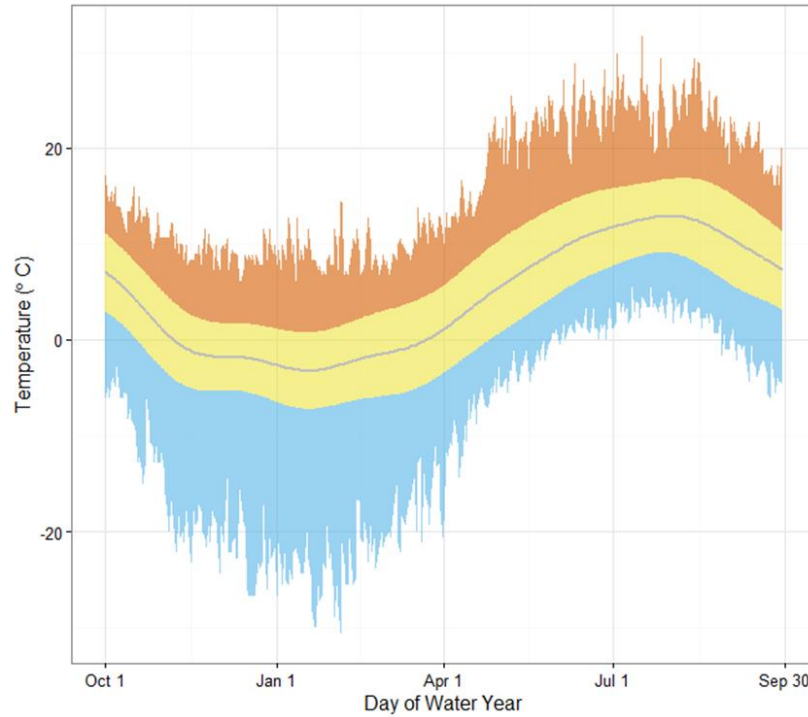


Figure 4 Mean (gray line), Normal (yellow band), and extreme (orange and blue bands) surface air temperatures based on 31 years of record (1980-2010) at the M.H. Smith Airport within the study area

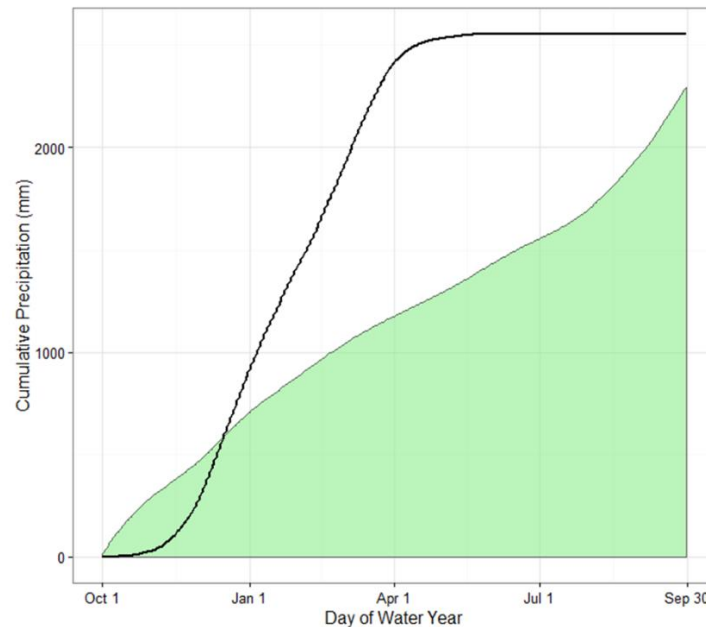


Figure 5 Cumulative mean daily precipitation (green ribbon) and cumulative mean daily snowfall (black line) based on 31 years of record (1980-2010) at the M.H. Smith Airport within the study area.

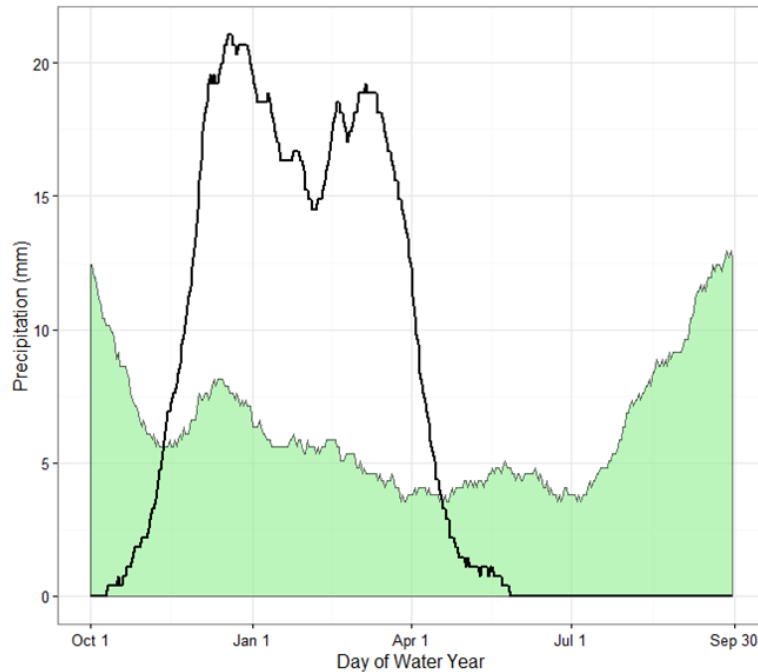


Figure 6 Climatological mean daily precipitation (green ribbon) and snowfall (black line) accumulation in millimeters based on 31 years of record (1980-2010) at the M.H. Smith Airport within the study area.

Streamflow

The US Geological Survey (USGS) maintains two gage sites on the CRD, Copper River at Million Dollar Bridge (station ID 15214000) and Glacier River Tributary (station ID 15215900). Data are also available for two inactive USGS sites, Middle Arm Eyak Lake (station ID 15216003) and Power Creek (station ID 15216000). This section will not incorporate Copper River discharges but will introduce data from the three other sites that are more representative of the study streams (Table 5). Middle Arm Eyak Lake and Power Creek are both salmon spawning areas that are used as study sites in this project. Glacier River Tributary is a piedmont catchment adjacent to Sheridan Glacier. Although this site is not heavily utilized by spawning salmon, the hydrograph is likely comparable to nearby piedmont streams that do provide spawning habitat.

Annual discharge increases exponentially with catchment area due to the positive correlation between catchment area, elevation, and total precipitation. Stream discharge is

lowest in the late winter and early spring (JFM) in all three streams. The seasonality of maximum discharges varies with watershed size and elevation.

Power Creek has the largest and highest elevation catchment with rain, snow, and glacier melt water sources. The mean annual specific discharge was 0.49 mm hr^{-1} during the period of record. Mean monthly discharge ranges from $1.36 \text{ m}^3\text{s}^{-1}$ (March) to $15.0 \text{ m}^3\text{s}^{-1}$ (July). Snow and ice ablation contribute to high late summer discharge rates. Peak discharges occur when early autumn storms coincide with snow and ice ablation (September and October). Peak discharges exceeded $28 \text{ m}^3 \text{ s}^{-1}$ each year of record and a maximum peak runoff of over $170 \text{ m}^3 \text{ s}^{-1}$ (11.55 mm hr^{-1}) was recorded in September, 1993.

Middle Arm Eyak Lake is a steep piedmont catchment with rain and snow melt water sources. The gage record is short (2 years), but indicates monthly discharge ranges from $0.27 \text{ m}^3 \text{ s}^{-1}$ (January) to $2.4 \text{ m}^3 \text{ s}^{-1}$ (August). Mean annual specific discharge was 0.56 mm hr^{-1} during the period of record. Peak discharge was recorded in August 1993 and exceeded $28 \text{ m}^3 \text{ s}^{-1}$ (13.44 mm hr^{-1}).

Glacier River Tributary is also a piedmont catchment with rain and snow melt water sources. After 4 years of record, mean discharge ranges from $0.11 \text{ m}^3 \text{ s}^{-1}$ (March) to $1.0 \text{ m}^3 \text{ s}^{-1}$ (September) and mean annual specific discharge is 0.31 mm hr^{-1} . Peak daily discharge occurred on September 16, 2012 and exceeded $6.3 \text{ m}^3 \text{ s}^{-1}$ (4.00 mm hr^{-1}). USGS also monitors water temperatures at this site. Mean monthly water temperatures are lowest in March (0.7°C) and highest in August (7.5°C).

Table 5 Locations and statistics for U.S. Geological Survey streamgages located within the study area

Station Name	ID	NAD 27		Active (?)	Years of record	Catchment Area (km^2)	Specific Discharge (mm hr^{-1})	
		Latitude	Longitude				Mean	Peak
Glacier River Tributary	15215900	$60^\circ 32'00''$	$145^\circ 22'43''$	Yes	4	5.7	0.31	4
Middle Arm Eyak Lake	15216003	$60^\circ 33'29''$	$145^\circ 37'44''$	No	2	7.5	0.56	13.44
Power Creek	15216000	$60^\circ 35'14''$	$145^\circ 37'05''$	No	48	53	0.49	11.55

Groundwater

A 52 m deep well at the airport provides a glimpse into subsurface layering within the outwash gravels between Sheridan and Sherman Glaciers. Drill log records indicate interbedded silt, sand, gravel, and organic material between 3 and 20 m below the surface [Dorava and Sokup, 1994], suggesting heterogeneous hydraulic conductivity.

Alaska Department of Highways (ADOT) performed test borings on the CRD in 1963-1964, near the location of the present day Copper River Highway [Reimnitz, 1966]. Test borings were also performed in 1914 during railroad construction. These borings indicate that glaciofluvial gravels are prevalent in the upper layers of the subaerial CRD. Isolated logs indicate previous forest cover. Reimnitz [1966] reported ADOT borehole samples (n=30) had an average water content of 29.4%. The relatively low water content may be due to co-seismic compaction. Grain densities are 2.7 to 2.8 g cm⁻³ [Reimnitz, 1966].

Borings also indicate a widespread layer of dense silty sand between 8 and 17 m below present-day sea level. This layer is likely an old tidal flat and extends from Lake Eyak to the Copper River along the mountain front [Reimnitz, 1966]. Thus, this elevation is likely the basement of unconfined aquifers on the subaerial CRD.

Impacts of the 1964 Earthquake

The magnitude 9.2 “Good Friday” earthquake occurred on March 27, 1964 [Grantz *et al.*, 1964]. Co-seismic uplift on the CRD was measured between 1.8 and 3.4 m relative to tide line, but changes to the tidal prism likely add uncertainty to these measurements [Reimnitz, 1966; Plafker, 1990]. The uplift elevated the lowest reaches of the subaerial CRD above tidal influence (“the uplifted marsh”). The formerly *carex*-dominated salt marshes are now freshwater wetlands [Thilenius, 1990a]. Particle sizes are small and hydraulic conductivity is low due to the organic marsh deposits [Bryant, 1992]. While the uplifted marsh is important habitat for birds and other wildlife, it is not suitable for spawning salmon.

Groundwater within the glacial foreland were affected by the earthquake. Co-seismic settling reduced pore space, forcing groundwater laden with sand and silt to flow to the surface [Reimnitz, 1966], but the extent of these impacts is unknown. The City of Cordova reported no noticeable effects to four city water supply wells in a 43 m thick deposit of glacial drift between Eyak Lake and Orca Inlet [Waller, 1966]. Eyak Lake, which recharges the aquifer, was uplifted 3 m, preventing saltwater intrusion. Artesian pressure in the aquifer fluctuates with the tides. Post-earthquake measurements (1964) indicated the tide and groundwater level were out of sync by 6 hours (e.g. groundwater pressure was low when the tide was high) [Waller, 1966].

The earthquake triggered widespread avalanching, rockfalls, and rockslides which transferred colluvium to piedmont valleys and the glacial foreland [Reimnitz, 1966; Waller, 1966]. One well-documented landslide during the 1964 earthquake deposited 78×10^6 tons of rock onto the ablation zone of Sherman Glacier [Tuthill and Laird, 1966]. These materials are likely still reducing ablation rates today.

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