3.1 Physical Characteristics

3.1.1 Terrestrial Environment

By R. Dugan and Golder Associates

TAPS crosses widely varying terrain including the broad Arctic Coastal Plain, three major mountain ranges, hilly uplands, hundreds of small steams, and several major rivers. The different topographic regimes are a result of the pipeline's general orientation perpendicular to the major mountain ranges. These regimes include extensive broad plains with little relief, rugged mountain passes, linear U-shaped valleys, rolling hills, and steep canyons.

More than half of the terrain has been intensely glaciated, often resulting in steep sideslopes in the mountains where the glaciers originated, and broad irregular surfaces in the lowlands where the glacially excavated materials were deposited. The highest elevation along the route occurs at Atigun Pass in the Brooks Range at 4,739 feet. Other major high points occur at Isabel Pass (3,420 feet) in the Alaska Range and at Thompson Pass (2,812 feet) in the Chugach Mountains.

3.1.1.1 Physiography and Geology

The pipeline traverses seven major physiographic units, as shown in Figure 3.1-1. These units are regions of similar geologic structure and climate and have had a unified geomorphic history (Wahrhaftig, 1965). Geomorphic processes have modified the landscape to its present configuration and character through erosion, deposition, and mass wasting by the actions of glaciers, flowing water, wind, and gravity. In general, unconsolidated surficial materials eroded from bedrock have been transported to lower elevations and deposited. The texture, moisture content, drainage characteristics, and thermal state of these unconsolidated materials affect their engineering properties. Permafrost — or perennially frozen ground — is encountered along most of the route. Each physiographic unit is described below, and Table 3.1-1 presents a summary of the principal characteristics of each unit.

North Slope

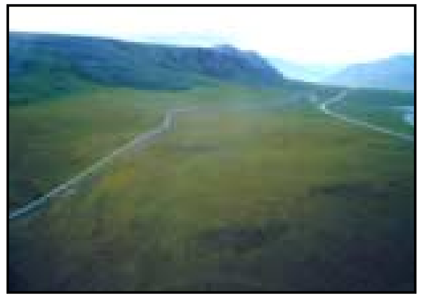
The North Slope physiographic unit includes the Arctic Coastal Plain and Arctic Foothills of the Brooks Range provinces, extending from pipeline MP 0 to MP 140. This unit is bounded to the north by the Beaufort Sea and to the south by the Brooks Range. Elevation ranges from sea level at Prudhoe Bay to approximately 3,100 feet at the northern limit of the Brooks Range. The tundra-covered coastal plain extends south from Prudhoe Bay for about 60 miles. Other than riverbanks and scattered pingos (small ice-cored hills), there is little relief. The smooth plain is poorly drained and rises gently to the south with an average gradient of about 10 feet per mile. Elongated, wind-oriented thaw-lakes and marshy thaw-lake basins cover 25 to 30 percent of the landscape. The depths of these lakes are generally limited to a few feet, and many of them are geologically short-lived features (Rawlinson, 1993).

The pipeline closely follows the northward-flowing Sagavanirktok River across a wedge of perennially frozen Quaternary sediments which become progressively thinner to the north. The Sagavanirktok is the dominant drainage in the region, with a wide, braided, and coarse-grained floodplain. Aufeis, or sheet ice from successive overflows, develops on portions of the floodplain in winter. The underlying bedrock consists of northward-dipping Tertiary and Cretaceous sedimentary rocks. The Barrow Arch, a major structural feature of uplifted lower Paleozoic rocks, underlies about 12,000 feet of post-Devonian sedimentary rocks. The Prudhoe Bay oil field is located on the crest of the arch and is a combination structural and stratigraphic trap (Mull and Adams, 1989).

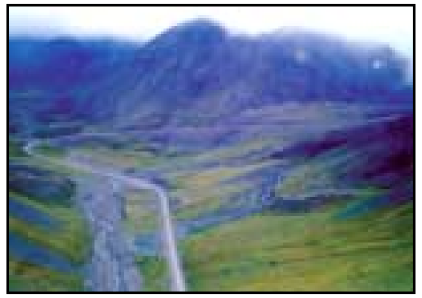
South of the coastal plain, the pipeline passes between low, treeless foothills of tilted Tertiary and Cretaceous sedimentary rocks mantled with river terrace and glacial moraine deposits. This segment is characterized by broad uplands and east-west trending ridges.

The arctic coastal maritime climate is cold and dry, with the mean temperature ranging from 9° to 21°Fahrenheit (°F) and annual precipitation averaging 5.5 inches (Haugen,

North Slope: Elevated pipeline over ice-rich permafrost on the Arctic Coastal Plain near Prudhoe Bay (MP 4)



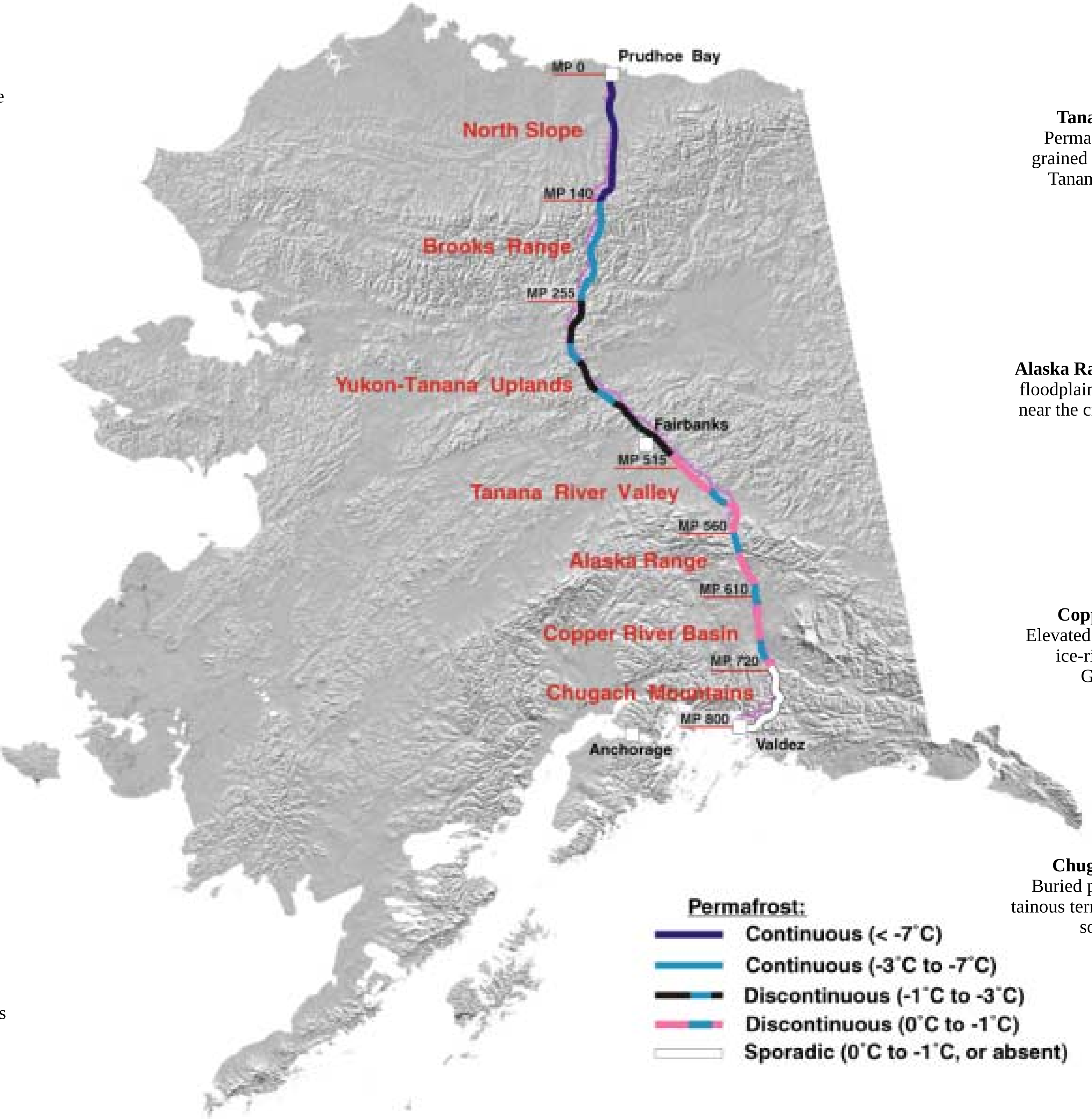
North Slope: Elevated pipeline in the broad uplands in the Arctic Foothills between the Sagavanirktok and Atigun river valleys (MP 136)



Brooks Range: Buried pipeline below the north side of Atigun Pass (MP 165)

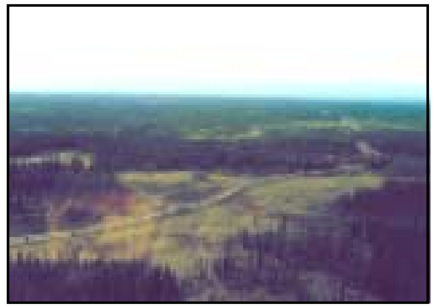
Brooks Range: Elevated pipeline adjacent to the Koyukuk River in a U-shaped valley (MP 200)

Yukon-Tanana Uplands: Pipeline in permafrost soils in hilly terrain south of the Yukon River (MP 400)



Tanana River Valley: Permafrost soils in fine-grained alluvium near the Tanana River (MP 520)

Alaska Range: Delta River floodplain and steep ridges near the crest of the Alaska Range (MP 593)



Copper River Basin: Elevated pipeline in broad ice-rich lowlands near Gulkana (MP 677)

Chugach Mountains: Buried pipeline in mountainous terrain near Thompson Pass (MP 763)

Sources: After Wahrhaftig (1965) and Brown et al. (1997).

Figure 3.1-1.
Physiographic units along the Trans Alaska Pipeline System

Table 3.1-1. *Physiographic units along the Trans Alaska Pipeline System.*

Physiographic Unit (MP Range)	Pipeline Elevation Range (ft)	Terrain	Glaciated Terrain	General Geology	Permafrost Distribution (Temp. Range)
North Slope (0 to 140)	40 to 3,100	Level plain and gentle hills	Southern portion only	Alluvial and glacial sediments overlying sedimentary bedrock	Continuous (<-7°C)
Brooks Range (140 to 255)	950 to 4,739	Steep mountain pass and U-shaped valleys	Yes	Colluvial, alluvial, and glacial sediments overlying sedimentary and metamorphic bedrock	Mostly continuous (-3°C to -7°C)
Yukon-Tanana Uplands (255 to 515)	325 to 2,300	Broad hills	No	Silt-covered metamorphic bedrock	Discontinuous (-1°C to -3°C)
Tanana River Valley (515 to 560)	900 to 2,700	Lowlands	No	Deep alluvial and glacial sediments	Discontinuous (0°C to -1°C)
Alaska Range (560 to 610)	1,900 to 3,420	Mountainous	Yes	Glacial and alluvial sediments overlying metamorphic bedrock	Discontinuous (0°C to -1°C)
Copper River Basin (610 to 720)	3,575 to 925	Gentle uplands and lowlands with deeply incised river valleys	Partially	Former lake basin filled with deep, mostly fine-grained sediments which overlie sedimentary and metamorphic bedrock	Discontinuous (0°C to -1°C)
Chugach Mountains (720 to 800)	10 to 2,812	Mountainous	Yes	Glacial and colluvial sediments overlying intensely glaciated metamorphic bedrock	Sporadic or absent (0°C to -1°C)

1982). The climate has resulted in the province being underlain by continuous, relatively cold permafrost [<-7°Centigrade (°C)] (Brown et al., 1997) that typically extends from within a few feet of the ground surface to a maximum depth of about 2,000 feet.

Brooks Range

The Brooks Range physiographic unit ranges from MP 140 to MP 255. It is bounded to the north by the mesa-like Slope Mountain and to the south by hills of the Yukon-Tanana Uplands. The Brooks Range is rugged and rises abruptly from the Arctic Foothills to elevations reaching 8,000 feet. The range trends east-west and forms the continental divide, with major drainages flowing north or south in broad valleys carved by repeated Pleistocene glaciations. Northeast-trending belts of Mesozoic and Paleozoic marine sedimentary, metamorphic, and volcanic rocks are composed primarily of limestone, shale, siltstone, schist, slate, quartzite, and basalt (Mull and Adams, 1989). The structural fabric is dominated by numerous low-angle faults resulting from northward thrusting in the Late Cretaceous and early Tertiary time (Wahrhaftig, 1965).

The pipeline crosses the continental divide at Atigun Pass, the highest point on the route (MP 166). North of the pass, the route follows the Atigun River valley, a broad, treeless, U-shaped valley with steep sideslopes rising 2,000 to 3,000 feet above the river. Bedrock is exposed in the upper slopes. Lower elevations are mantled with deep colluvial accumulations and coarse-grained floodplain deposits. Recent avalanche and slush flow deposits mantle portions of the slopes. Permafrost is continuous.

On the south side of the pass, the route descends steeply losing 1,200 feet in elevation, traverses the head of a broad valley at the head of the Chandalar River basin, and then descends abruptly another 700 feet to the headwaters of the Dietrich-Koyukuk river system. The upper Dietrich River valley is narrow, with a steep gradient and steep, coalescing fans on the sideslopes. In the middle and lower reaches, the valley widens and becomes distinctly U-shaped, and the floodplain becomes wide and braided. Permafrost is continuous. Frozen till and fan deposits blanket the valley sideslopes. Frozen alluvium and lake deposits predominate in the valley bottom (Brown and Kreig, 1983).

Yukon-Tanana Uplands

The Yukon-Tanana Uplands physiographic unit extends from MP 255 to MP 515 and encompasses the Kokrine-Hodzana Highlands, Rampart Trough, and Yukon-Tanana Uplands provinces. The elevation of the pipeline ranges from 325 to 2,300 feet.

The northernmost province is the Kokrine-Hodzana Highlands, which consists of even-topped, rounded ridges and hills reaching elevations of 2,000 to 4,000 feet. The valleys have alluviated floors to within a few miles of their heads (Wahrhaftig, 1965). This province extends from the South Fork of the Koyukuk River (MP 255) to near Hess

Creek (MP 375) and includes the irregular drainage divide between the Yukon and Koyukuk rivers. These highlands are generally underlain at depth by northeast-trending Paleozoic and Precambrian schist and gneiss. The bedrock is commonly exposed on small tors on the ridge tops. The only known mineral resource is a 4- to 5-foot coal seam which is exposed near the pipeline on a tributary to Dall Creek (Barnes, 1967).

The terrain has not been glaciated except for the very northern margin. Unconsolidated deposits generally consist of frozen colluvial silts, sands, and rock fragments; glacial sand and gravel; windblown silts; lake sediments; and stream sediments. Ice wedges, ice lenses, and ice-rich sediments occur locally, and permafrost is discontinuous but very widespread.

The Yukon River crossing is included in this unit. The Yukon is the largest river in Alaska and carries a substantial load of suspended glacial sediment during the summer. The river flows in entrenched meanders in the vicinity of the crossing, having eroded into mafic rocks of the Tozitna terrain (Mull and Adams, 1989).

The Rampart Trough province is a narrow, mostly lowland area south of the Yukon River. It has gently rolling topography 500 to 1,500 feet in elevation and extends from the north side of Hess Creek (MP 375) to the south side of Erickson Creek (MP 390). The trough was eroded into a tightly folded belt of soft continental coal-bearing rocks of Tertiary age (Wahrhaftig, 1965). The permafrost is discontinuous. The lowlands are underlain by ice-rich silt and fine-grained alluvium, while uplands are mantled with colluvium and windblown silt which overlies bedrock.

The Yukon-Tanana Uplands province, MP 390 to MP 515, is a hilly area of broad undulating divides and flat-topped spurs characterized by even-topped ridges with gentle sideslopes. The pipeline generally follows the ridge crests between the major east-west trending valleys. A belt of highly deformed Paleozoic sedimentary and volcanic rocks containing limestone units extends along the north side of the upland. The rest of the upland is underlain by Precambrian schist and gneiss with granitic intrusions. The bedrock is mineralized. Placer and lode deposits of gold and other metals have been mined for nearly a century. Windblown silt mantles the slopes. Reworked windblown silt and ice-rich organic silt cover deep stream gravels in the lowland areas. Permafrost is discontinuous.

Tanana River Valley

The Tanana River Valley physiographic unit extends from the Shaw Creek floodplain (MP 515) to Donnelly Dome (MP 560). It is a broad, lowland depression filled with sediments from the Alaska Range and drained by the Tanana River system. The elevation along the pipeline ranges from 900 to 2,700 feet. Outwash materials from the Alaska Range have pushed the Tanana River against the base of hills to the north. Most of the northern part of this region is underlain by shallow permafrost.

South of the Tanana River, permafrost is discontinuous. The terrain gently rises to the south and is mostly underlain by glacial outwash and till deposits (APSC, 1974a). Scattered low hills of granite, ultramafic rocks, and schist rise above the sediments (Wahrhaftig, 1965).

Alaska Range

The Alaska Range physiographic unit encompasses the Northern Foothills province as well as the Alaska Range mountains. It extends from Donnelly Dome (MP 560) to Isabel Pass (MP 610). The pipeline route is in or adjacent to the floodplains of the Delta River and Phelan Creek as it progresses into the mountains, reaching a maximum elevation of 3,420 feet. The crest of the range consists of rugged glaciated ridges 6,000 to 9,000 feet in elevation that trend east-west.

The Northern Foothills are underlain by Paleozoic to Precambrian schist and granitic intrusions mantled with glacial moraine. On the north side of the Alaska Range up to the Denali Fault (MP 589), the route is underlain by schist. South of the Denali Fault, bedrock consists principally of late Paleozoic marine sedimentary and volcaniclastic rocks (Péwé and Reger, 1983). No metallic minerals have been produced from lode deposits in this unit, but occurrences of copper, lead, zinc, nickel, chromium, gold, silver, asbestos, and antimony have been reported. Less than 1,000 ounces of fine placer gold have been mined from the Delta River drainage (Cobb, 1973).

Large valley glaciers radiate from the higher mountains, and some of these glaciers terminate within a mile or two of the pipeline. The Black Rapids Glacier (MP 579) made a rapid advance of about 4 miles in 1937. A 300-foot ice cliff formed at the terminus, less than a mile from the pipeline route. The glacier has since stagnated. The Castner Glacier (MP 587) has made similar advances during the Holocene epoch. Breakouts from meltwater lakes dammed by the Castner Glacier have produced brief floods on the outwash fan (Péwé and Reger, 1983).

Great longitudinal faults trend parallel to the axis of the range. The most significant fault is the Denali Fault, an active fault that is one of the longest crustal breaks in Alaska. This right-lateral, strike-slip fault is topographically expressed as an arcuate trough that can be traced without interruption from the southwestern Alaska Range through the

crest of the range into the Yukon Territory and perhaps into Chatham Strait in Southeast Alaska. Geologic evidence indicates that average rates of displacement along the Denali Fault vary from 0.04 to 1.38 inches per year. In the last 10,000 years, offsets of glacial deposits indicate that 17 to 200 feet of right-lateral movement and 20 to 33 feet of vertical movement have occurred (Péwé and Reger, 1983). Other smaller active faults include the Donnelly Dome and McGinnis faults.

A variety of glacial and glacial fluvial deposits cover most of the terrain where the slopes are not too steep. The Delta River and Phelan Creek have wide, braided floodplains and relatively steep gradients. Steep side-creeks to these streams have developed outwash fans of coarse sediments which are periodically truncated by the shifting channels of the larger streams. Talus and coarse colluvium have accumulated at the base of steep slopes. Terraces along the streams are composed of sand and gravel. Silt blown from the broad floodplain of the Delta River system has been deposited as a surficial blanket on the north flank of the range and beyond. Permafrost is discontinuous.

Copper River Basin

The Copper River Basin physiographic unit encompasses the Gulkana Uplands and the Copper River Lowlands provinces, and extends from Isabel Pass (MP 610) to Tonsina (MP 720). This intermontane basin is rimmed by 4,500- to 16,500-foot peaks of the Alaska Range and the Talkeetna, Chugach, and Wrangell mountains.

The Gulkana Uplands consist of rounded east-trending ridges separated by lowlands 2 to 10 miles wide extending from Isabel Pass to the south end of Paxson Lake (MP 635). The ridge crests — 3,500 to 5,000 feet in elevation — are 4 to 15 miles apart and have been eroded by glaciers and glacial meltwater. The lower elevations are covered by glacial deposits and esker systems. Long narrow lakes such as Summit and Paxson lakes occupy the basins. The region is underlain by Paleozoic and Mesozoic greenstone and sedimentary rocks with local granitic intrusions. No significant mineral deposits have been reported. Bedrock is mantled with glacial till and ice-contact deposits.

The Copper River Lowlands is a broad plain 1,000 to 2,500 feet in elevation that is incised by the Copper River and its tributaries. It is underlain by Paleozoic and Mesozoic metamorphic volcanic rocks to the north, and to the south by erodible Mesozoic sandstone and shale. The pipeline is several miles west of, and generally parallels, the Copper River and crosses several large tributaries including the Gulkana, Tazlina, and Klutina rivers. These rivers originate in glaciers in the surrounding mountains and generally have braided floodplains.

Ice advances in the late Pleistocene glaciations filled the lower reaches of the Copper River to form an extensive glacially dammed lake. Glaciers and streams discharging into the lake created a complex interfingering of glacial and lake deposits locally more than 500 feet thick. Following retreat of the glaciers about 9,000 years ago, permafrost began to form in the lake and glacial deposits as the streams began downcutting to their present incised valleys (Péwé and Reger, 1983). Discontinuous permafrost persists over much of the unit.

Chugach Mountains

The Chugach Mountains physiographic unit is a spectacular coastal range of intensely glaciated and rugged peaks along the Gulf of Alaska between MP 720 and the Valdez Marine Terminal (VMT) at MP 800. The higher peaks in this unit range from 7,000 to 13,000 feet, although along the pipeline route, the highest peaks are 6,000 to 7,000 feet high. The topography is characterized by U-shaped valleys, knife-edged ridges, horns, hanging glaciers, and slot canyons. The prominent drainages along the pipeline route are the Tiekel, Tsaina, and Lowe rivers, which are short, swift, and glacially fed.

The pipeline route follows the U-shaped valleys of the Little Tonsina, Tiekel, and Tsaina rivers, gradually ascending to Thompson Pass at an elevation of 2,812 feet. South of the pass, the route descends 2,000 feet in one mile and then traverses steep bedrock sideslopes parallel to the Lowe River for the remaining 20 miles to the VMT.

The area is underlain by complexly folded and faulted Cretaceous graywacke, phyllite, and greenstone. Bedrock is exposed or close to the surface over much of the route. Although no large mines have been developed near the route, gold has been mined from a few lode deposits near Port Valdez (Cobb, 1973).

Unconsolidated materials include glacial moraine and colluvium on the slopes. The terraces and floodplains along the valley bottoms typically consist of coarse sands and gravels. The steep slopes are locally subject to avalanches. The Worthington Glacier, which has been retreating for many years, terminates about half a mile from the pipeline immediately north of Thompson Pass. Permafrost is sporadic north of Thompson Pass and generally absent south of the pass.

3.1.1.2 Paleontological Resources

Considerable portions of the pipeline route are underlain by sedimentary rocks or prehistoric soils. As a result,

the corridor contains a wide array of plant and animal fossils. The North Slope and portions of the Brooks Range are underlain by several kilometers of sedimentary rocks. Most of the limestone, sandstone, siltstone, and shale is marine in origin. The earliest fossils are found in Middle Devonian rocks about 380 million years old. Most subsequent rock formations exhibit some form of fossil record (Mull and Adams, 1989).

Common fossils in these rocks include brachiopods, cephalopods, gastropods, pelecypods, sponges, bryozoans, corals, and crinoids. The first terrestrial plant fossils are found in rocks from the middle part of the Jurassic Period, roughly 160 million years ago. This is an indication of at least temporary retreat of the ancient seas that previously covered most of the region. Following this, the seas repeatedly advanced and retreated over most or all of the North Slope (Lindsey, 1986).

Late Cretaceous vertebrate fossils dating to about 70 million years ago and Tertiary fossils represented primarily by invertebrates are also common. Dinosaur fossils have been discovered recently along the Colville River several miles west of the TAPS ROW.

South of the Brooks Range, the older metamorphic, igneous, or rapidly deposited sedimentary rocks predominate, and pre-Quaternary fossils are either absent or less common.

Pleistocene fossils are present in many locations along the pipeline and are generally preserved in gravel or retransported silt. Fossil land mollusks are abundant in the Copper River Basin. Freshwater mollusks, insects, and vertebrates are common in the Fairbanks area. Large extinct mammals including mammoth, mastodon, bison, Siberian steppe antelope, horse, muskox, and others have also been found in placer mining operations in the Fairbanks vicinity. Pleistocene birds have been found on the Arctic Coastal Plain and near Fairbanks (Péwé, 1975).

Discoveries of paleontological resources are reported to the Alaska Department of Natural Resources (ADNR). During construction of TAPS, Pleistocene vertebrate remains were uncovered in gravel deposits north of the Yukon River. These typically consisted of isolated bones or tusks. No major bone beds have been encountered. Since construction, there have been no significant discoveries or impacts to paleontological resources on the TAPS ROW (Kunz, 2000, pers. comm.).

3.1.1.3 Soils and Permafrost

Permafrost is the primary factor influencing the pipeline's construction modes and distinguishing it from conventional pipelines. Permafrost is widespread in Alaska and is present along most of the route (Figure 3.1-1). Major engineering problems can arise where warming of permafrost occurs in poorly drained, fine-grained sediments. These materials generally contain large amounts of ice, which takes the form of coatings, lenses, wedges, and veins that may vary in thickness from fractions of an inch to several feet. If this material thaws, significant consolidation and loss of pipeline support could occur. Thawing of permafrost in well-drained, granular soils or in bedrock is not a technical problem, because loss of support would not normally occur.

The "active layer" is a thin, seasonally-thawed layer overlying the permafrost. It begins at the ground surface and ranges to a depth of one to approximately 15 feet depending on the climate, organic surface cover, soil moisture content, depth of snow cover, and other factors (Shur, 1997). This layer freezes in winter and thaws in summer. The thickness of the active layer can change dramatically when the surface is disturbed, thus affecting the thermal condition of the underlying soils. In the continuous permafrost zone north of Atigun Pass and in portions of the discontinuous zone throughout Alaska's Interior, the active layer annually freezes to the top of permafrost. In the more southerly portions, particularly south of the Klutina River (MP 697) and in the areas affected by previous development in the discontinuous permafrost zone, the top of permafrost is fairly deep — as much as 25 feet below the surface. Seasonal freezing does not reach the permafrost table, leaving a continuously thawed zone above the top of the permafrost. The thickness of the permafrost layer is controlled by the mean annual air temperature and the geothermal gradient (Péwé, 1982), as shown in Figure 3.1-2. The base of the permafrost is stable when the heat lost to the atmosphere is equal to geothermal heating from the earth's interior.

Permafrost Characteristics of Physiographic Units

The permafrost on Alaska's North Slope is relatively cold (<-7°C), continuous, and typically encountered within a couple feet of the ground surface in disturbed areas (Brown et al., 1997). The permafrost is up to 2,000 feet thick, while the active layer is generally less than 1.5 feet thick. Unfrozen zones are shallow and usually limited to deep river channels and the deeper lakes (Rawlinson, 1993). Massive ground ice is widespread and occurs as vertical ice wedges, films, lenses, pore-fillings, and other small segregated masses. Most basin floors display the polygonal pattern of cellular ice-wedge networks. The polygons are bordered by sod dikes, and in the more poorly-

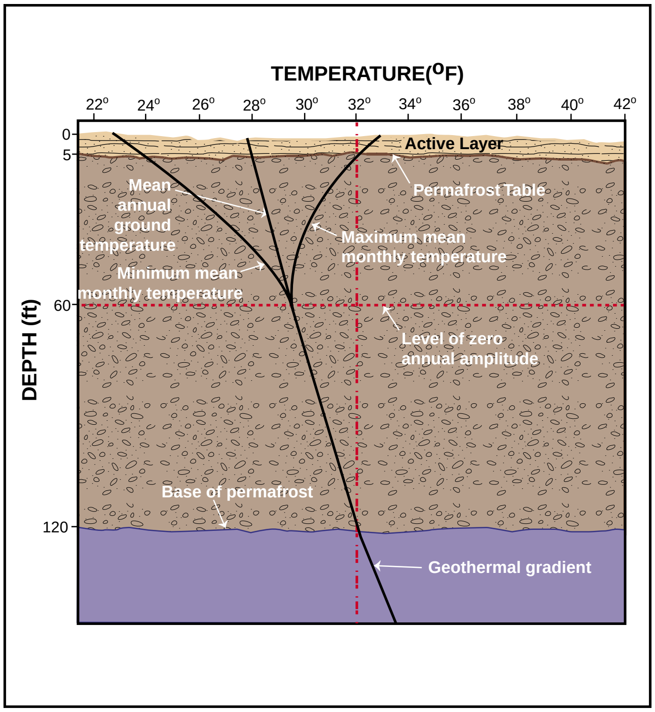


Figure 3.1-2. *Hypothetical example of typical temperature profile and thickness of permafrost in central Alaska (after Péwé, 1982)*

drained areas, they have shallow, saturated depressions in the center. The sod dikes overlie ice wedges. Shallow troughs along the crests of the dikes indicate actively growing ice wedges (Brown and Kreig, 1983). Surficial soils typically consist of several feet of ice-rich organic silt overlying coarse sands and gravels. Ice wedges are the most sensitive to disturbance because, once disturbed, the ice can rapidly melt causing significant settlement.

Permafrost in the Brooks Range is relatively cold (-3 to -7°C), mostly continuous, and up to several hundred feet thick (Brown et al., 1997). Segregated ice is present in a variety of landforms including talus cones and bedrock fractures. Permafrost transitions from continuous to discontinuous south of Atigun Pass, and the amount of ground ice is widely variable. Solifluction — the slow, downslope flow of shallow, unfrozen earth materials on a frozen substrate — is evident on many slopes due to the high silt and moisture content in the near-surface soils (Brown and Kreig, 1983).

In the Yukon-Tanana Uplands, the permafrost is discontinuous and relatively warm (-1°C to -3°C) (Brown et al., 1997). It is widespread north of Fairbanks and can be more than 175 feet thick. Massive ice in the form of wedges and lenses several feet thick occurs in lowlands (Péwé, 1982). South of Fairbanks, the ground is warmer and generally thawed, but permafrost is locally present. The permafrost is susceptible to thawing if the surface is disturbed. Permafrost in the Tanana Valley is discontinuous and warm (0°C to -1°C) (Brown et al., 1997). Interstitial ice includes massive lenses in the silts that typically overlie deep deposits of coarse alluvial sands and gravels.

Permafrost in the Alaska Range and Copper River Basin is discontinuous, relatively warm (0°C to -1°C) (Brown et al., 1997), and locally ice-rich. The Copper River Basin locally contains ice wedges (Péwé and Reger, 1983). Most of the pipeline route is underlain by hundreds of feet of glacial-lacustrine clay, silt, and sand. Fluvial silt, sand, gravel, colluvium, and swamp deposits underlie a small portion. Permafrost is commonly within 5 feet of the ground surface and may be as thick as 250 feet (Nichols, 1956). The ground ice is typically segregated in veins and veinlets in the mostly fine-grained soil matrix.

Permafrost is sporadic and warm (0°C to -1°C) in the Chugach Mountains and occurs mostly in the very northern portion of the unit in the Tonsina River valley. It is generally absent south of the upper Tiekel River, except under glaciers, because of the influence of the maritime climate.

3.1.1.4 Sand, Gravel, and Rock

Alyeska has contracts to purchase granular materials from 69 sites on public land along the ROW (Table C-1 in Appendix C). These materials consist of sand and gravel, or bedrock used to build and maintain TAPS earthwork structures. The sand and gravel sites are typically situated on alluvial fan and floodplain deposits near the ROW. Bedrock sites are located at bedrock outcrops. The size of the sites varies from a few acres to more than 40 acres.

Most of the sites were established during TAPS construction. Many are still used jointly with the Alaska Department of Transportation and Public Facilities for highway maintenance (Table C-1).

3.1.1.5 Hazardous Materials

Hazardous materials include chemicals, explosives, corrosives, and wastes that could cause harm to human health or the environment. TAPS was originally routed to avoid areas such as landfills, gunnery ranges, or contaminated sites that might contain potentially hazardous materials.

Currently, there are 58 contaminated sites on the TAPS ROW that are under the jurisdiction of the Alaska Department of Environmental Conservation. All of the sites have been contaminated by spills or leaks of petroleum hydrocarbons. The status of the sites and the number of sites in each category is as follows (Willson, 2000, pers. comm.):

- Closed (no further action required): 14 sites.

- Active (actively being either investigated, monitored, or remediated): 19 sites.
- Pending closure (application submitted for closure): 16 sites.
- Inactive (investigations and interim cleanups have been performed but concerns for safety or damage to existing structures currently prevent complete remediation): 9 sites.

A special program has been carried out since 1990 to examine and address 31 sites along the pipeline that were contaminated, or had the potential to be contaminated, by past spills. These sites had been considered clean under regulations previously in place but were re-examined in light of new public uses and current cleanup standards. Five of the sites were found to contain contamination and are included in the list of 58 contaminated sites described above (Willson, 2000, pers. comm.).

3.1.1.6 Hydrology/River Characteristics

By W. Veldman

Overview of Crossings

The pipeline crosses more than 800 identified creeks and rivers ranging in size from the Yukon River to creeks only several feet wide. In addition to the river crossings, extensive sections of the pipeline are located within or parallel and proximate to the active channels or floodplains of the Sagavanirktok, Atigun, Chandalar, Dietrich, Middle Fork Koyukuk, and Delta rivers and Phelan Creek.

Table C-2 in Appendix C provides a summary of the major and minor river and creek crossings and instream and floodplain segments for which detailed design drawings were prepared. These constitute about 12.4 percent of the total length of the pipeline.

River Types and Characteristics

The primary river and creek types crossed are:

- **Braided:** Wide, steep, high-bedload, multi-channeled systems such as the Sagavanirktok and Delta rivers and Phelan Creek (Figures 3.1-3, 3.1-4).
- **Split channels:** such as the lower parts of the Middle Fork Koyukuk (Figure 3.1-5).
- **Single channels with wide floodplains:** South Fork Koyukuk, Chena, and Salcha rivers, and Moose Creek — or deeply incised channels with no floodplain — Sulphide Gulch (Figure 3.1-6).
- **Alluvial fans:** the majority of the creeks that flow into the Delta River in the Pump Station 10 area and Sheep, Brown, and Unnamed creeks flowing into the Lowe River (Figure 3.1-7).

The behavior of the rivers and creeks is a function of the river type, magnitude of flow and size of crossing, and presence or absence of debris, permafrost, and aufeis.

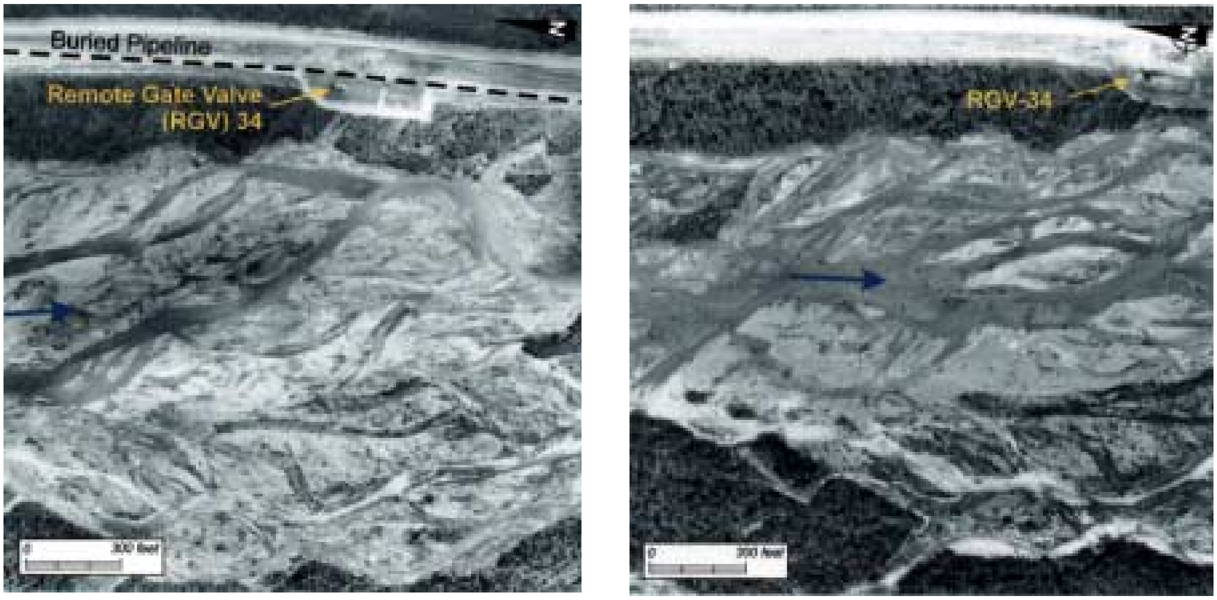
Flow Characteristics

The hydrologic characteristics along the pipeline route are varied, and stream flows are highly variable with time of year. For the purposes of a regional flood-frequency analysis, a recent report by the U.S. Geological Survey (Jones and Fahl, 1994) essentially used one hydrologic region for the entire pipeline route. (Large regions are required to generate regional relationships because smaller hydrologically unique regions — the Atigun River valley, for example — do not have sufficient flow-data measurement locations to generate a regional relationship of flow versus drainage area. The adequacy of the flow data is addressed in Section 4.) For purposes of describing hydrologic characteristics for this report, five hydrologic regions are identified:

North of the Brooks Range in the Sagavanirktok and Atigun Rivers: Winter flows are minimal to nil. For example, during the mainline replacement of the 8-mile-long Atigun River pipeline section in 1991, there was no surficial flow in the Atigun River south of about MP 160. Low winter flows in the Sagavanirktok River result in significant accumulations of groundfast ice or aufeis. The flows in the winter may occur either as surface or subsurface flow from place to place or from time to time. Breakup on the Sagavanirktok River is triggered by warm temperatures and snowmelt runoff from the Atigun River and the Brooks Range. Breakup flows are over the groundfast ice resulting generally in maximum water levels. High flows on the Atigun and Sagavanirktok rivers (August 1992, for example) are usually triggered by heavy sustained rains in the Brooks Range. Flows increase and decrease rapidly in response to rainfall magnitude because the Brooks Range and permafrost conditions of the slope have a low capacity for retaining precipitation.

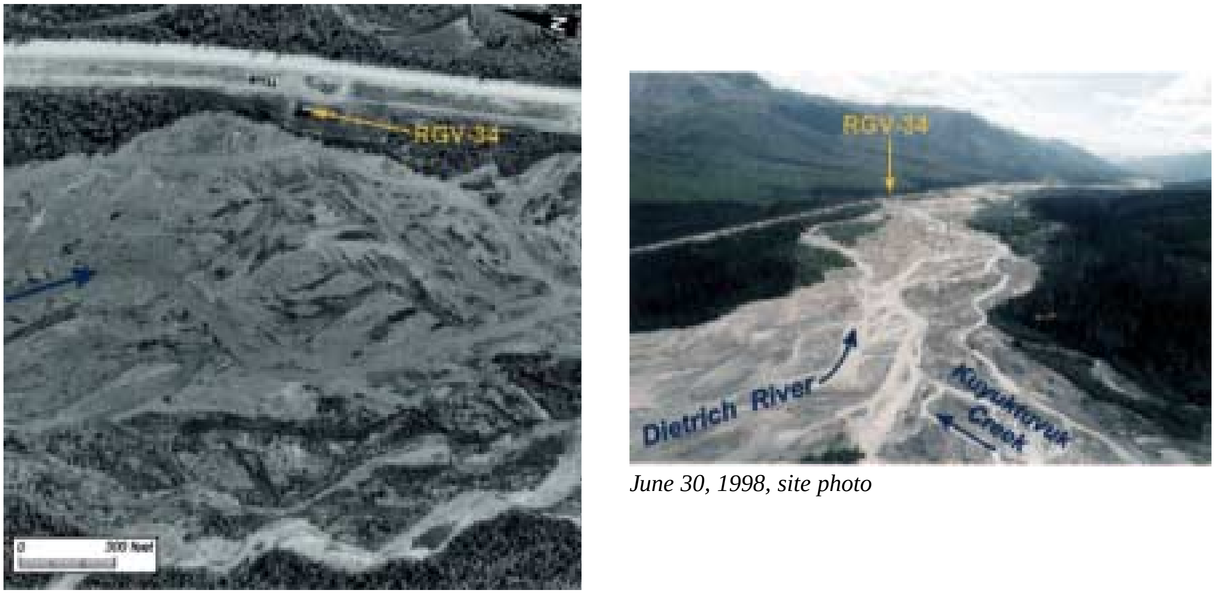
South Side of the Brooks Range: The Dietrich River is also characterized by severe winter aufeis formations, especially from MP 195 to 200, where small tributaries from the west supply the flow to generate the ice on the wide Dietrich River. The Middle Fork Koyukuk River has less aufeis buildup because its deeper channels result in less formation of groundfast ice. As on the north side of the Brooks Range, maximum flows are usually triggered by intense rain. One such event occurred in August 1994.

Interior: Flows in the Interior from the Jim River to the Yukon River to Big Delta are highly variable and depend largely on watershed and thus runoff characteristics.



1982 air photo

1989 air photo



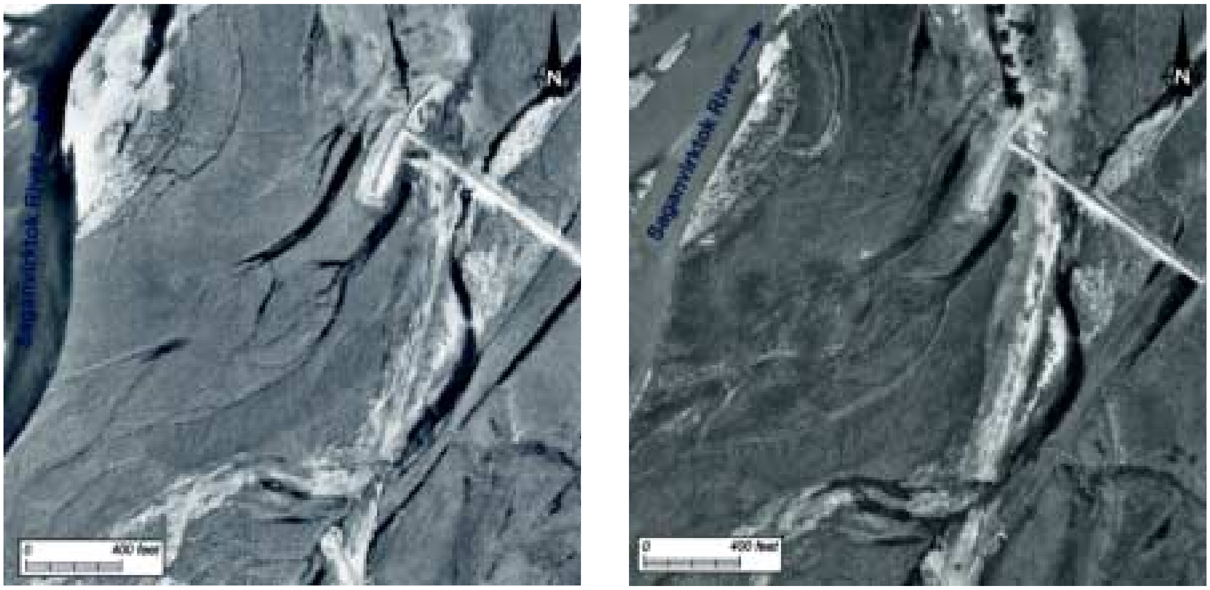
June 30, 1998, site photo

1996 air photo

Braided rivers have multiple channels that are highly mobile, especially during high flows. Their mobility is caused by the deposition or erosion of bedload and gravel bars. The magnitude and location of bank erosion are difficult to predict because sudden channel changes may cause the flow to deflect away from the riverbank or cause it to attack the riverbank.

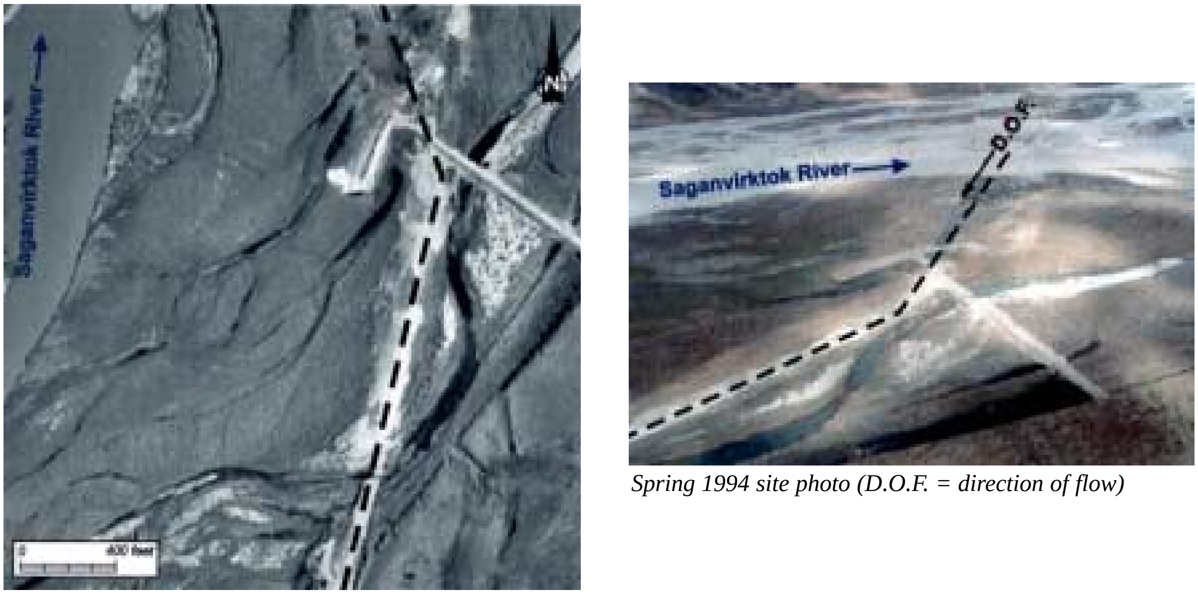
Note the numerous subchannels within the active width of the river. Erosion of the main vegetated banks can be significant during a flood.

Figure 3.1-3. *Braided river — Dietrich River, MP 185.8. Characteristics and changes over time.*



1980 air photo

1989 air photo

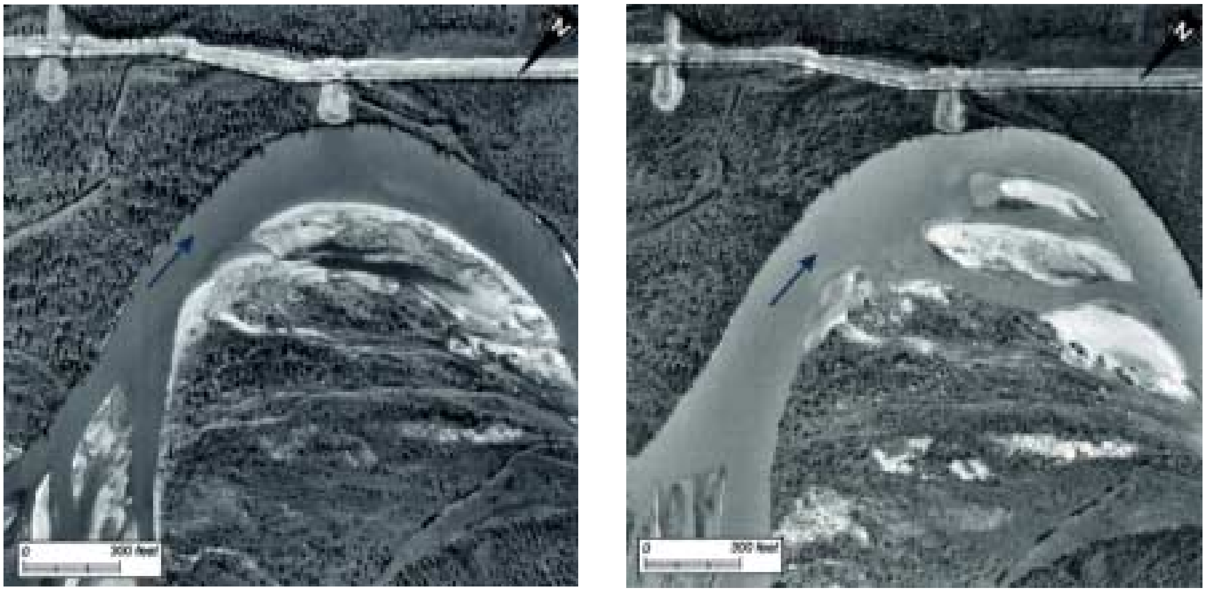


1996 air photo

Spring 1994 site photo (D.O.F. = direction of flow)

Extensive floodplain overflow occurs during spring breakup as a result of flow over groundfast icings. With the floodplain and its subchannels frozen during breakup, the overflow causes little if any change in the channels. Late summer floods, such as occurred in 1992, can cause channels to enlarge or deepen or new channels to form.

Figure 3.1-4. *Floodplain in a braided North Slope river — Sagavanirktok River, MP 63.0. Characteristics and changes over time.*



1983 air photo

1989 air photo

1996 air photo

June 30, 1998, site photo

The future behavior of sharp bends in rivers such as the example shown are relatively easy to predict (at least compared to braided rivers as shown on Figure 3.1-4). Whereas the precise location of maximum velocities and thus potential bank erosion can change depending on flow patterns upstream, the bend is a constant area of bank erosion unless a cutoff channel forms across the bend. If the cutoff (1996 photo) were to form, velocities and the potential for bank erosion at the pipeline would be significantly reduced.

Figure 3.1-5. *Split channel and sharp bend — Middle Fork Koyukuk River, MP 218.5. Characteristics and changes over time.*

1974 air photo (before construction)

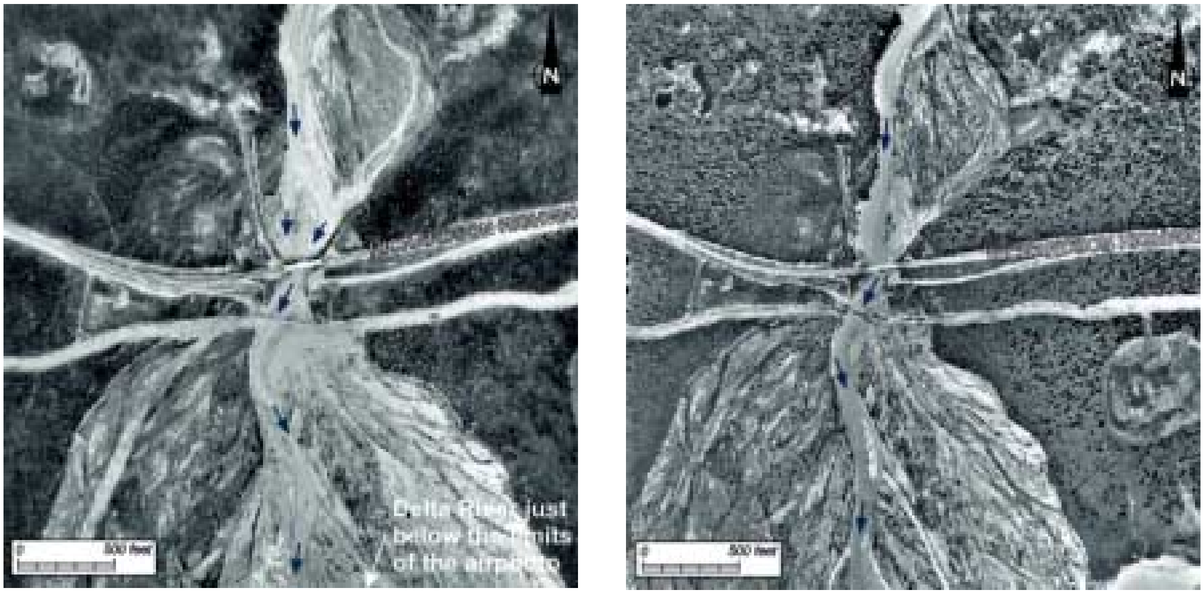
1985 air photo

1996 air photo

May 1998 site photo

River changes (depth of channel and bank erosion) are the least in straight channels with high banks that do not overtop, even during extreme floods. However, minor changes upstream, like the formation of the bar on the south bank upstream of the crossing (A in the 1996 photo), can result in a change in the direction of flow into the opposite bank (B in the 1996 photo) and erosion, as shown on the site photo.

Figure 3.1-6. *Single incised channel — Tazlina River, MP 687.0. Characteristics and changes over time.*



1982 air photo

1989 air photo

September 1999 site photo

Alluvial fans, by their very nature, are zones of sediment deposition and rapid channel changes during high flows. Generally, the channels move within the width of the active fan, as illustrated by the photos. At times, the flow may attack the vegetated borders of the fan, thus widening the active part of the fan. Depending on the movement of the receiving stream (the Delta River in this case), fans may experience general deposition or downcutting. If the stream erodes into the nose of the fan, the channel's slope and scour depth on the fan increase, resulting generally in less bank erosion. On the other hand, if the receiving stream moves away from the mouth of the alluvial fan, the slope of the fan decreases, scour depth decreases, and bank erosion increases. (Brown Creek at MP 784 has undergone several cycles of changes.)

The Richardson Highway bridge located immediately upstream tends to restrict or limit the movement of the creek at the elevated pipeline crossing. However, even minor works constructed at the highway bridge, such as the addition of riprap to protect its abutments, can affect bank erosion and/or bed scour at the pipeline.

Figure 3.1-7. *Alluvial fan — Miller Creek, MP 599.6. Characteristics and changes over time.*

Breakup in the region can produce significant flows due to the snowfall accumulations and rapid temperature increases in the spring in this area.

Alaska Range: The Delta River and Phelan Creek are characterized by low winter flows and significant aufeis development in their wide, braided systems. Summer flows on the glacier-fed streams are dependent on temperatures and rainfall. Intense rainfall produces high flows, particularly if concurrent with a high snowmelt/glacier-induced flow. Glacier-dammed lakes occur in the Miller Creek area near Pump Station 10. When they release, very high flows can be produced.

Glennallen to Valdez: Maximum flows on the Tazlina River, Tsina River, and Sheep Creek are generally triggered by releases from glacier-dammed lakes. These releases, which occur when the head built up in the lakes is sufficient to burst through the glacier via a tunnel, can be relatively regular (e.g., the Tsina River) to less regular (e.g., the Tazlina) to infrequent (e.g., Sheep Creek). In 1997, heavy and prolonged rains following a summer snowmelt period resulted in record flows on the Tazlina River (at least for the period of recorded flow) as the lakes upstream burst simultaneously. In the Valdez area, heavy rains can produce high flows on the Lowe River and particularly on its major tributaries such as Brown Creek.

Flow Data

Peak annual flows for streams crossed by TAPS are summarized on Table 3.1-2, which highlights the maximum recorded flows both before and after pipeline startup. The relative magnitude of recent high flows along the pipeline (such as the 1992 Sagavanirktok River flood, the 1994 Middle Fork Koyukuk River flood and the 1997 flows on the Tazlina River) are observable from this listing. The relative magnitude of flows during operation of the pipeline is important in assessing its potential impact and integrity (discussed in Section 4.3.1).

Figure 3.1-8 shows the mean, maximum and minimum monthly flows for a representative number of rivers or creeks crossed by the pipeline. The dramatic breakup and summer flows compared to the low winter flows are well illustrated on this graphic. It should be noted that for systems such as the Sagavanirktok and Atigun, winter flows are estimated from late-fall flow measurements and are not based on actual field data. Therefore, they may not be representative of the actual flows at a specific time at a specific location. Because of aufeis formations, flows at a specific time and location may vary dramatically from one location to the next as flow is “lost” to ice formation or “gained” by the inflow of a local tributary. Flow at times may go subsurface at one location and then surface again downstream.

Figure 3.1-9 illustrates the maximum flows for a number of representative stations since TAPS startup. The figure shows the rapid rise in flow that can occur even in the larger watersheds. The steep terrain of the Brooks Range, little or no vegetation, and frozen ground conditions are all factors leading to minimal rainfall retention and thus high runoff coefficients and rapid increases and decreases in flow as a result of a high rainfall event.

Bed Scour and Bank Erosion

The potential for riverbed scour and bank erosion depends on the magnitude, duration, and time of the flow, as well as the bedload material transported. The majority of scour and erosion occurs during high-flow-magnitude runoff events, which may range in duration from several days to several weeks for small and large watersheds, respectively. River characteristics such as size, slope and bed material also have a significant influence on potential stream changes, as illustrated on Figures 3.1-3 to 3.1-7. The river and hydrologic characteristics that influence bed scour and bank erosion are described below.

Floodplain overflow during spring breakup, when the ground is still frozen, results in few channel changes or the formation of new channels. For example, frequent and almost annual overflows occur along and across the Dalton Highway in certain sections along the Sagavanirktok River, with little impact on the floodplain. On the other hand, dramatic scour, bank erosion, enlargement of subchannels, and development of new channels can occur if the ground is thawed during major late-summer floods — such as the record floods on the Sagavanirktok River in August 1992 and the very high summer flows on the Dietrich/Middle Fork Koyukuk River systems in 1994.

Melt from glaciers during long warm periods can result in relatively high, sustained flow that can produce bed and bank scour and erosion. The sudden release of multiple glacier-dammed lakes, as occurred on the Tazlina River in 1997, in combination with antecedent high rains, can produce extremely high flows and dramatic river changes necessitating remedial measures. Other streams with single glacier-dammed lakes, such as the Tsina River, release the stored water more frequently and almost regularly, with resultant annual moderately high flows.

Alluvial fans are areas of high potential bedload deposition, bank erosion, and development of new channels as a result of high flows. The location of the pipeline on the fan greatly determines the nature and magnitude of potential channel changes. At the upstream end, or apex, of the fan, changes will be less than at the mouth of the fan.

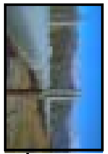
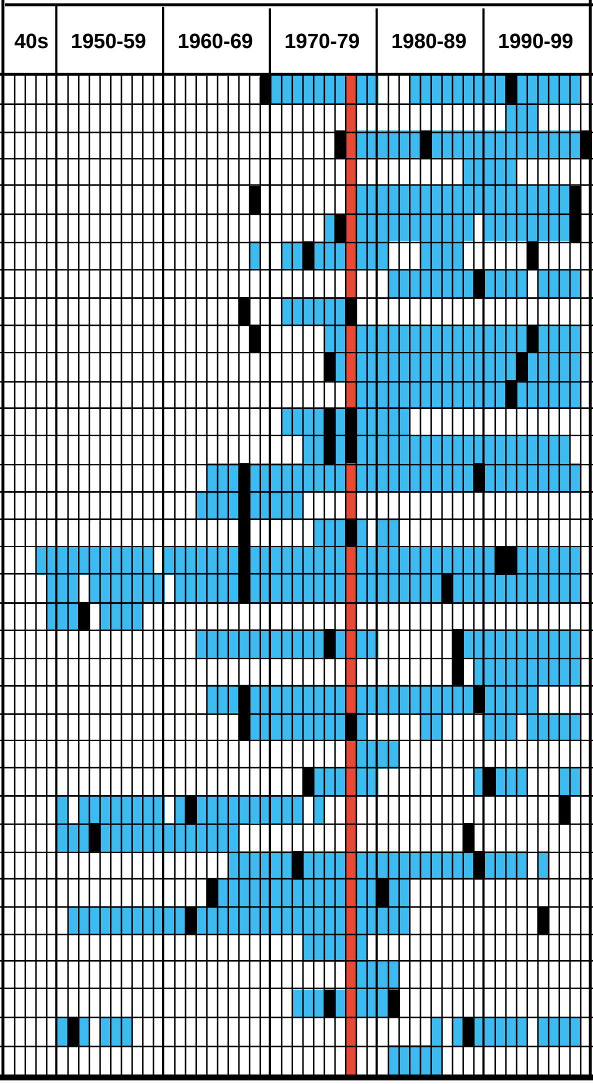


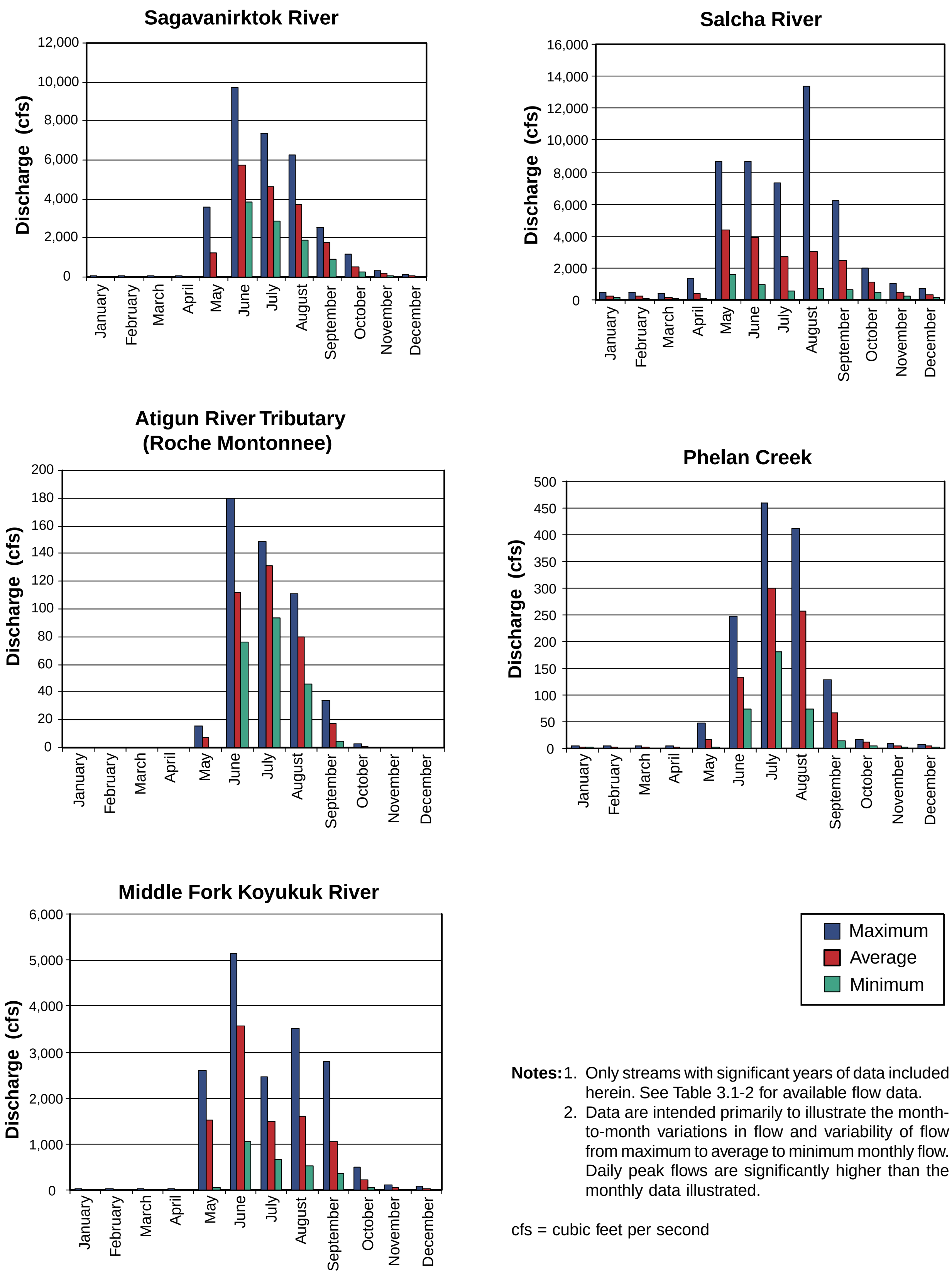
Table 3.1-2. *Flow data record for streams crossed by the pipeline.*



USGS Flow Station		Drainage Area (mi^2)	Peak Annual Flow in cfs		
Name	**Number**		**Pre-Pipeline Operation**	**Post Pipeline Operation**	**Average over Period of Record**
Sagavanirktok River near Sagwon/Pump Station 3	15910000/15908000	2208/1860	34900	42900	19300
Atigun River near Pump Station 4	15904800	48.7			
Atigun River Tributary near Pump Station 4	15904900	32.6	1000	1650	642
Nutirwik Creek near Wiseman	15564866	29.2			
Snowden Creek near Wiseman	15564868	16.7	1200	600	405
Nugget Creek near Wiseman	15564872	9.47	132	540	193
Middle Fork Koyukuk River near Wiseman	15564875	1200	17100	42700	14400
Slate Creek at Coldfoot	15564879	73.4		3900	1530
Jim River near Bettles	15564885	465	21000	12800	10100
Prospect Creek near Prospect Camp	15564884	110	6800	4500	1920
Bonanza Ck. Tributary near Prospect Camp	15564887	11.7	220	290	164
Yukon River near Stevens Village	15453500	196300		827000	476000
Hess Creek near Livengood	15457800	662	10000	6480	5310
Erickson Creek near Livengood	15457700	26.3	660	860	315
Globe Creek near Livengood	15541600	23	1240	1230	379
Washington Creek near Fox	15541800	46.7			
Goldstream Creek near Nenana	15540070	41.8	1490	483	335
Chena River at Fairbanks	15514000	1995	74400	11400	10300
Salcha River near Salchaket	15484000	2170	97000	37100	18800
Tanana River at Big Delta	15478000	13500			
Ruby Creek near Donnelly/above Richardson Hwy	15478500/15478499	5.32/4.89	250	1660	274
Suzy Q Creek near Pump Station 10	15478093	1.29		1070	227
Boulder Creek near Central	15439800	31.3	1150	1460	368
Phelan Creek near Paxson	15478040	12.2	2320	1560	998
Fish Creek near Cantwell	15516010	18.2			
Gulkana River at Sourdough	15200280	1770	8840	12700	7830
Tazlina River near Glennallen	15202000	2670	60700	120400	33500
Klutina River at Copper Center	15206000	880	9040	8600	7080
Rock Creek near Tonsina	15208200	14.3	110	225	68
Squirrel Creek at Tonsina	15208100	70.5	1200	460	371
Tonsina River at Tonsina	15208000	420	8490	7000	4860
Little Tonsina River at Tonsina	15207800	22.7			
Tiekel River neart Tiekel	15212600	115			
Stuart Creek near Tiekel	15213400	37.4	1800	2690	1260
Solomon Gulch near Valdez	15226000	19.7	2420	2270	1550
Allison Creek above mouth near Valdez	15225945	7.5			

1. According to annual "Water Resources Data, Alaska" reports published by the U.S. Geological Survey, Department of the Interior, in cooperation with the State of Alaska. 1999 status (whether or not the stations are still operating) according to the USGS Internet site and/or personal communication with USGS staff in Alaska.
2. 1999 Atigun River Tributary data are preliminary. 1997 Tazlina River data are estimated by Alyeska.

🟦 Years for which data are available 🟥 Pipeline startup ⬛ Data available and peak flows recorded

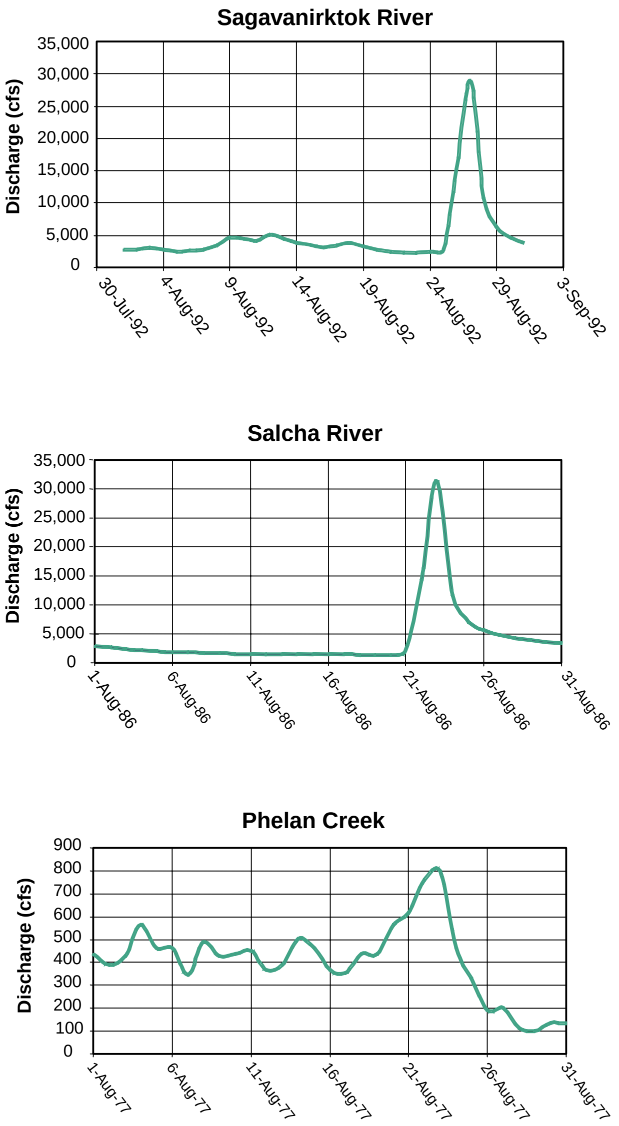


Notes: 1. Only streams with significant years of data included herein. See Table 3.1-2 for available flow data.

2. Data are intended primarily to illustrate the month-to-month variations in flow and variability of flow from maximum to average to minimum monthly flow. Daily peak flows are significantly higher than the monthly data illustrated.

cfs = cubic feet per second

Figure 3.1-8. *Monthly flow data for streams crossed by the trans-Alaska pipeline.*



Hydrographs illustrate the rate of rise and fall of flow during high flood events. Even for large watersheds such as the Sagavanirktok River, the total duration of the flood flows is less than a week — an important consideration in regard to the duration of high flows that could affect crossings, floodplains, or instream pipe alignments.

Figure 3.1-9. *Peak flow hydrographs for representative streams crossed by the pipeline.*

Changes in the stream that the fan empties into may also have a significant influence on the behavior of the fan. For example Brown Creek, which empties into the Lowe River, has alternated between scour with little bank erosion and deposition with bank erosion as changes in the Lowe River respectively shortened and lengthened the alluvial fan.

Debris accumulations in small streams can result in dramatic local bank erosion or bed scour. Even in large river systems such as the Dietrich River or Middle Fork Koyukuk River, debris can produce significant changes in flow patterns. Major rivers north of the Brooks Range, such as the Atigun and Sagavanirktok, have no trees and thus are not affected by debris. However, as evidenced by the 1992 and 1999 rainfall-induced floods on the Sagavanirktok and Atigun rivers, respectively, high runoff rates from the steep permafrost watersheds can produce sudden and dramatic increases in flow, with resultant channel changes.

Channel Icings (Aufeis)

In wide, braided streams which have low winter flow, development of groundfast ice or aufeis is common. If the streambed is also frozen, the flow is forced to surface and freezes as a succession of shallow overflows. The location of overflows — and thus icings — varies spatially and temporally.

In some locations, such as the Dietrich River, most of the aufeis appears to be generated from inflow from the western tributaries. When the inflow freezes as it empties from the west into the wide Dietrich River, the resultant ice can have a significant slope from the west down to the east side of the river. Consequently, the initial breakup flow is concentrated along the lower east side of the river where the pipeline is located. MP 194 to 198 is one such area where dikes were added during TAPS construction to reduce the potential for overflows across the pad and VSMs.

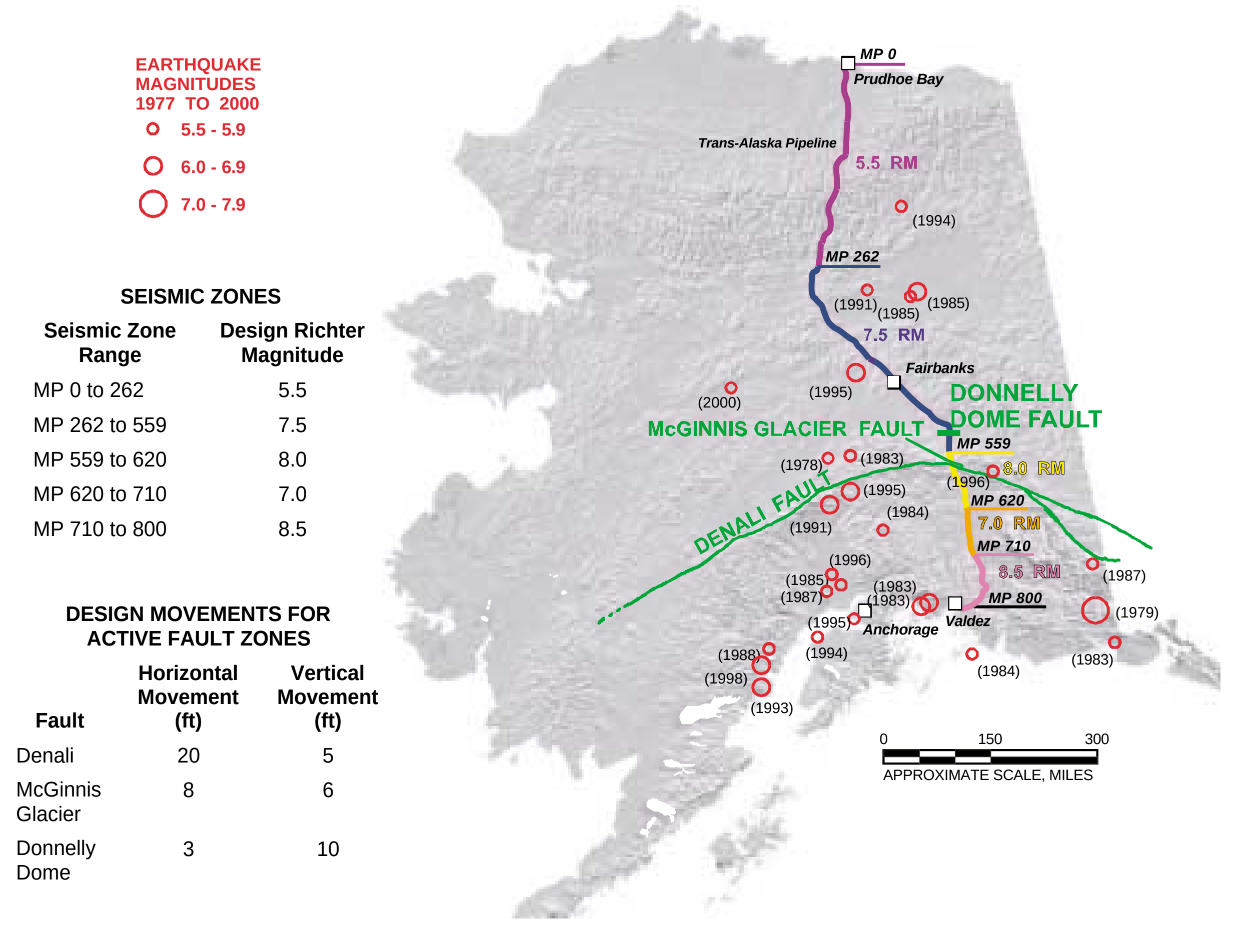
Maximum water levels are often generated by the initial spring breakup flow over the aufeis. After several days to a week of overflow, the aufeis deteriorates, lifts, and moves downstream or becomes stranded on bars and islands.

Aufeis was a significant consideration in the design of river training structures, bridges, and elevated pipeline sections.

3.1.1.7 Seismicity

By D. Nyman

The pipeline route begins in a region of low seismicity on the North Slope and terminates in one of the most seismically active regions in the world. Locations of large earthquakes and major faults are shown in Figure 3.1-10



SEISMIC ZONES

Seismic Zone Range	Design Richter Magnitude
MP 0 to 262	5.5
MP 262 to 559	7.5
MP 559 to 620	8.0
MP 620 to 710	7.0
MP 710 to 800	8.5

DESIGN MOVEMENTS FOR ACTIVE FAULT ZONES

Fault	Horizontal Movement (ft)	Vertical Movement (ft)
Denali	20	5
McGinnis Glacier	8	6
Donnelly Dome	3	10

Sources: Haeussler and Plafker (1995), Alaska Earthquake Information Center (2000), Federal Grant

Figure 3.1-10. *Map showing seismic zones and fault crossings along TAPS and earthquakes greater than magnitude 5.5 that have occurred near TAPS since startup.*

(Haeussler and Plafker, 1995).

The northern part of the TAPS route has low seismic activity. Seventy-six earthquakes greater than Richter magnitude 4.0 were recorded between the Arctic Coast and the Brooks Range from Point Barrow to the Canadian border between 1898 and 1999. Most of these earthquakes were located in the Camden Bay region approximately 80 miles east of Prudhoe Bay. Magnitudes ranged up to 5.3 on the Richter Scale (Alaska Earthquake Information Center, 2000). No known damage has resulted from these events. Earthquake activity is also low in the Brooks Range and the uplands north of the Yukon River.

The southern two-thirds of the pipeline route is seismically active and has experienced large earthquakes. Three earthquakes of magnitude 7 or greater have occurred within 50 miles of Fairbanks in the last 90 years — all before construction of TAPS. Strong shaking caused minor damage in the Fairbanks area, but there were no fault ruptures at the ground surface.

The most significant fault crossed by the pipeline is the Denali Fault, which runs along the Alaska Range for hundreds of miles. This fault is considered active and appears to have moved at least 20 feet in the past 10,000 years, although it has not moved in historical times. An earthquake of magnitude 7 has been recorded in the Alaska Range (Péwé, 1982).

The seismicity of the Chugach Mountains is very high. The epicenter of the 1964 earthquake, which had a moment magnitude of 9.2 (Richter magnitude 8.4), was about 40 miles west of the Valdez Marine Terminal. The primary tectonic displacement occurred on a subduction zone fault. The city of Valdez and associated harbor facilities, located at that time at the eastern end of Valdez Arm, were severely damaged by wave run-up caused by a massive submarine landslide. After the 1964 earthquake, the city was relocated to a site on the north shore of Valdez Arm that offers natural protection against a similar occurrence. The Valdez Marine Terminal is located on high ground on the south shore

of Valdez Arm. The site is naturally protected by bedrock ridges at Jackson Point and Saw Island, and all onshore facilities (except the small boat dock) are located at elevations higher than the estimated 30-foot run-up that occurred during the 1964 Alaska earthquake (Marine Advisers, Inc., 1969; Plafker and Mayo, 1965).

Since construction, there have been no large earthquakes in the TAPS vicinity and no reports of earthquake damage to TAPS facilities (Simmons, 2000, pers. comm.). The epicentral locations of earthquakes greater than moment magnitude 5.5 occurring in general proximity to TAPS are shown in Figure 3.1-10. The largest earthquake within 50 miles of the TAPS ROW was a magnitude 6.4 event in 1983 west of Valdez.

3.1.2 Water Resources

By B. Jokela, V. Gates, and D. Gryder-Boutet

3.1.2.1 Fresh Water Quality

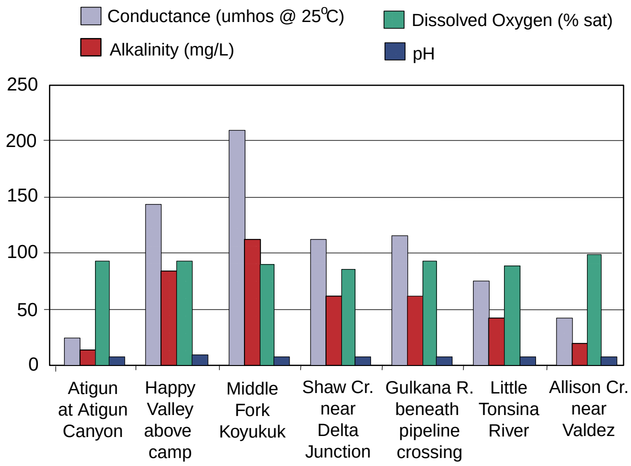
Water quality data for the pipeline route are sparse. State of Alaska Water Quality Standards (18 AAC 70) describe 13 categories of water quality criteria and four major categories of uses for which to apply the criteria. Few data exist which allow comparison to water quality standards. Existing data do not provide adequate documentation of variability through the seasons of the year, nor over the course of time. Data are not sufficient to identify differences in background water quality between watersheds nor differences subject to hydrologic influence, (e.g., high versus low flow levels in streams).

Although a database of current water-quality conditions does not exist, few concerns have been expressed about water quality along TAPS. According to the Alaska Department of Fish and Game, “The planning effort prior to construction of the TAPS really shows. There have not been many fish and game habitat ‘problems,’ only ‘incidents,’ and these have been resolved quickly” (Webber-Scannell, 2000, pers. comm.). Furthermore, of nearly 800 stream crossings, only Goldstream Creek (TAPS MP 448) and the Chena River (MP 460), both near Fairbanks, are listed as impaired waters by the Alaska Department of Environmental Conservation, which maintains a list of impaired waters in accordance with Section 303(d) of the Clean Water Act. Neither of these waterbodies is impaired due to TAPS operations. Placer mining is reported to be a cause of turbidity increases in Goldstream Creek, while runoff from urban and military lands may be introducing sediment and petroleum compounds into the Chena River.

Several partnerships among stakeholders have developed in watersheds where interested parties support monitoring and management efforts for maintenance of pristine conditions in specific waterways. These groups include the Yukon River Intertribal Watershed Council, the Copper River Watershed Council, and the Tanacross Village Watershed Council. These groups are non-profit corporations and are receiving grants from EPA for certain activities envisioned as promoting watershed health. While these groups are relatively new, none has identified any specific degradation of water quality or habitat that is attributable to TAPS operations (Kellogg, 2000, pers. comm.).

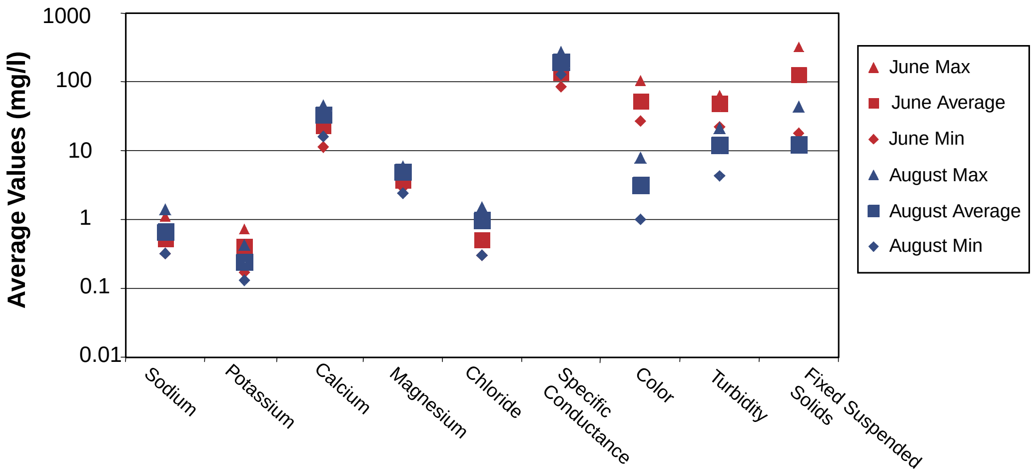
Some field surveys were performed by state and federal agency staff before pipeline construction (Childers, 1975; Childers et al., 1978). Nauman and Kernodle (1973) measured and reported water-quality characteristics at 69 stations along the pipeline from 1970 to 1972. Representative data from this study are presented in Figure 3.1-11. No comprehensive follow-up has been done for comparison to current conditions.

A 1969 study focusing on North Slope streams provided a series of comparable measurements along the length of the Sagavanirktok River from high in the Brooks Range to the delta near Prudhoe Bay (Figure 3.1-12). Water sampling was performed in June and August of that year. Mineral data — particularly principal cation data — show strong similarities between June and August sampling for the watershed. Turbidity, color, and fixed suspended solids values, however, were significantly higher in June than in August, reflecting the change in principal runoff source from snow-



Source: Nauman and Kernodle (1973)

Figure 3.1-11. *Field water-quality data from selected TAPS route locations (May-September 1972).*



Source: DOI (1970)

mg/l = milligrams per liter

Figure 3.1-12. *Water quality in Sagavanirktok River basin, average values along watercourse, June and August 1969.*

melt to rainfall runoff and discharge from active-layer meltwater.

Although few water-quality data exist from the TAPS corridor, some general trends may be extrapolated from literature on water resources in cold regions (e.g., Jokela, 1990). Such generalizations include:

- Glacial streams have high turbidity in summer, with productivity often limited by light penetration rather than nutrient loading.
- Ice cover on streams and lakes can prevent or retard reaeration, leading to hypoxic or anoxic conditions in the water underneath the ice. This is particularly true in shallow lakes and tundra ponds with high sediment oxygen demand.
- Breakup stream flows tend to be relatively low in dissolved solids because of the high proportion of snowmelt compared to the groundwater contribution of stream flows.
- Groundwater-fed streams tend to have higher dissolved-solids and nutrient concentrations than glacial streams.

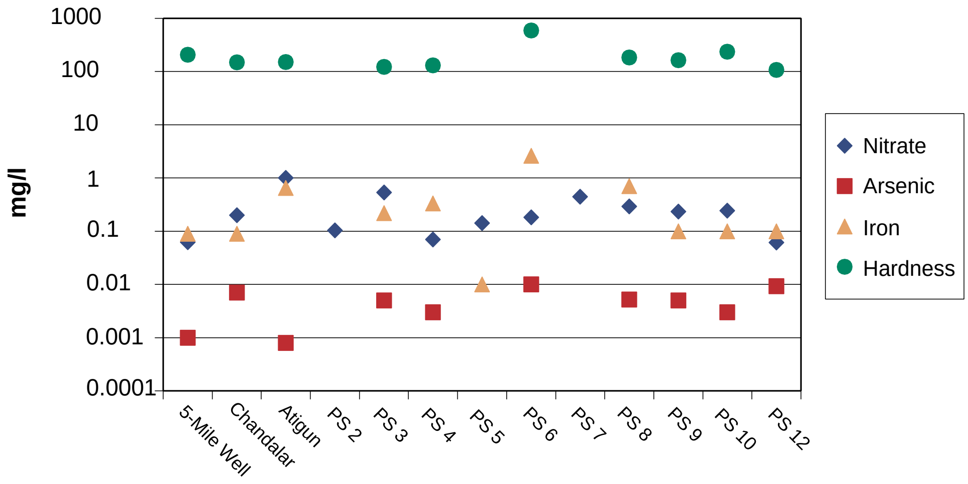
Groundwater resources are limited in permafrost areas. Near flowing water or large bodies of surface water, a thaw bulb is created by continuous heat input from the water body to the surrounding soils. The pipeline can also create a thaw bulb. DenBeste and McCart (1984a) reported “irregularities” in records of stream temperatures in several Brooks Range province streams. They suggested that the irregularities are the result of warming of the river bed by the buried pipeline. Their findings are not known to have been corroborated by subsequent research.

Water wells provide much of the potable water used by the pipeline facilities. Regular water-quality monitoring is required for public water-supply systems, such as at each pump station. Groundwater quality values from water supply monitoring at Alyeska facilities are shown in Figure 3.1-13. Nitrate data shown are from the 1990s and represent annual monitoring in accordance with state regulations (18 AAC 80). Other data are limited and may reflect only a few samples. Hardness data, for example, date back to the 1970s.

3.1.2.2 Port Valdez Marine Waters

The Valdez Marine Terminal is on Port Valdez, a fjord approximately 5 kilometers (km) wide by 18 km long, with a mean depth of 180 meters (m). It is separated from Valdez Arm of Prince William Sound by Valdez Narrows, where the minimum depth is approximately 138 m. The east-west trending Port Valdez has steep sideslopes and a relatively flat bottom, with a typical depth of 240 m over three-quarters of its length. The fjord bottom is composed principally of silts and clay-sized minerals derived from glacial river sediment loads (Naidu and Klein, 1988). Typical organic carbon content of the bottom averages 4.7 milligrams per gram (mg/g).

Surface temperature of Port Valdez ranges from -1.2°C in winter to a typical maximum of 16°C in the summer. There is a large seasonal variation in runoff from snowfields and glaciers into Port Valdez. As a result, density stratification due to temperature differences and freshwater inflow is quite strong in the summer. This stratification



Source: Alyeska Drinking Water Database

mg/l = milligrams per liter

Figure 3.1-13. *Groundwater quality at Alyeska Pipeline Service Company facilities.*

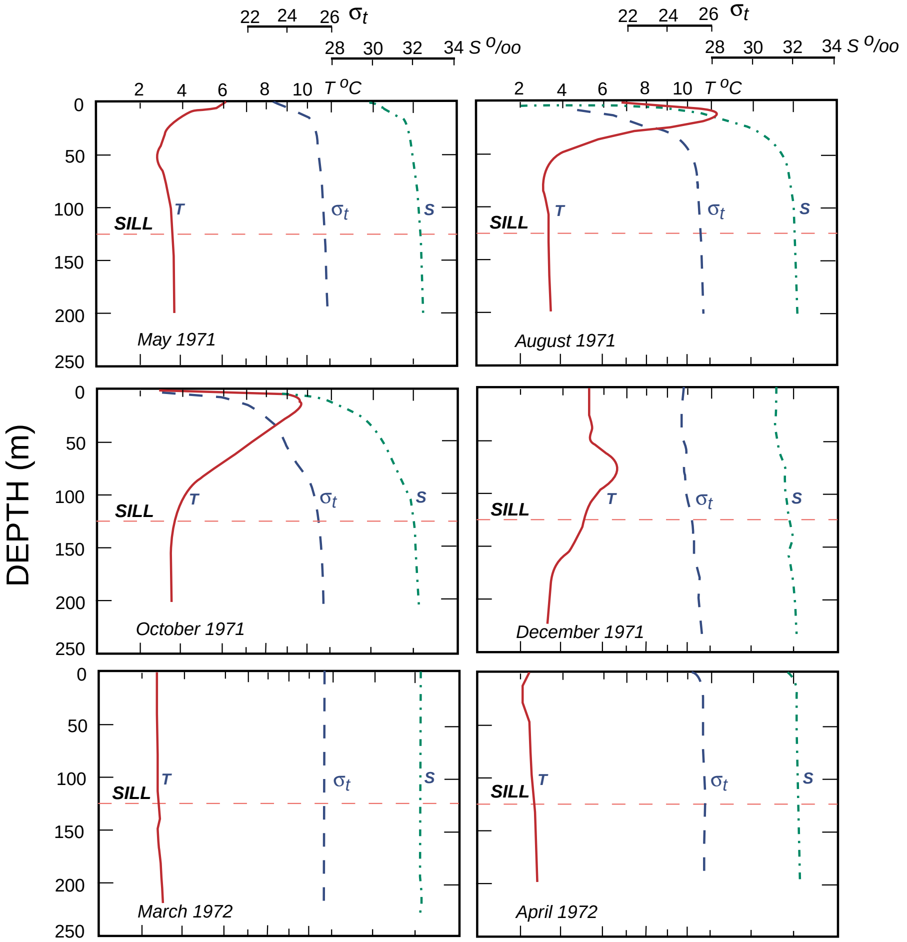
gives way to nearly complete mixing of the water column during the winter. Seasonal changes in density structure are illustrated in Figure 3.1-14.

The mean amplitude of tides in Port Valdez is about 3 meters; thus, the tidal prism corresponds to about 1.6 percent of the total volume of water contained in Port Valdez. During well-mixed winter conditions, this provides for refreshment of half the volume of Port Valdez about every 22 days. In the summer and early autumn, cold, dense marine water from the continental shelf pours into Prince William Sound and Port Valdez. This water is subsequently mixed with surface waters and ongoing inflow to provide for a hydraulic residence time for these deep waters of approximately 40 days.

During certain weather conditions, however, large volumes of surface water are introduced into Port Valdez from Prince William Sound, displacing much of the deeper waters of the fjord relatively quickly. Current measurements in the Valdez Narrows by Colonell (1980) suggest that residence times for deep waters during passage of weather systems could be reduced to a few days. Thus, climatological influence may be more important in promoting deep-water exchange than either tides or mixing with surface waters.

Hydrocarbons and trace metals were measured in the water column in Port Valdez between 1976 and 1978. Before VMT operation began, hydrocarbons included pristane, heptadecane, alkane chains, and squalene. In 1978, following initiation of ballast water treatment and disposal, samples from the area near the diffuser showed additional hydrocarbons, including xylenes, alkyl benzenes, naphthalenes, and phytane in addition to the pristane and alkanes previously documented. Total hydrocarbon concentration was in the range of 44 to 104 nanograms/gram. At sampling locations as close as 700 m to the discharge point, this array of hydrocarbons was undetectable, indicating a dilution of at least 100-fold (Colonell, 1980, p. 328).

Eight elements (aluminum, arsenic, chromium, cadmium, copper, mercury, nickel, and selenium) were surveyed in Port Valdez between 1976 and 1978. Researchers found concentrations of these elements to be typically in the normal range for clean systems. Exceptions were found in 1978, including aluminum and copper concentrations in ballast water treatment effluent from an unknown source (Gosink, 1980). Plant operations were modified to address aluminum discharges, while the occurrence of copper is considered an isolated event (Gosink, 1980). None of the trace elements mentioned is considered a pollutant of concern today. Regulatory requirements for wastewater discharges from the VMT do not include effluent limitations or water quality monitoring for these trace metals (EPA, 1997). No further water-quality data have been collected for comparison to pre-pipeline conditions, although various monitoring efforts have been designed and implemented to ensure that the most likely occurrences of water quality degradation are identified and resolved. See Section 4.2.2.2 for a discussion of monitoring efforts.



Source: After Muench and Nebert (1973)

Figure 3.1-14. *Vertical distribution of temperature (T), salinity (S), and density (σ) in Port Valdez.*

3.1.3 Atmospheric Environment

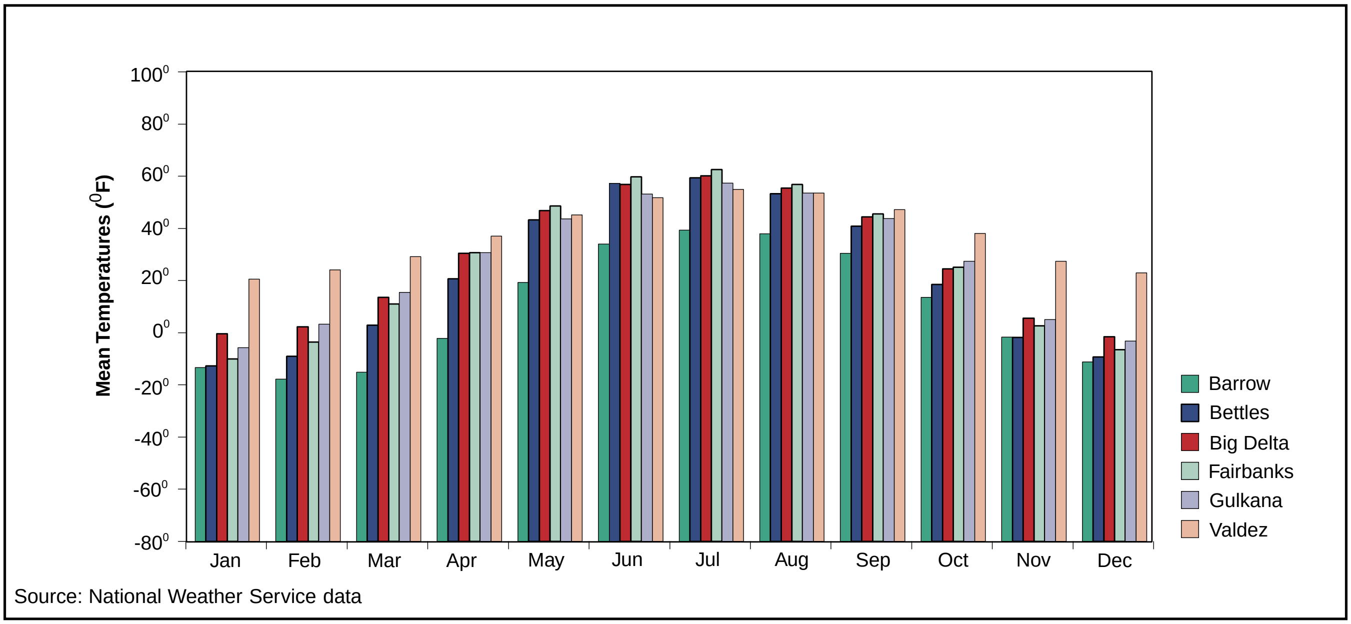
By E. Haas

TAPS spans all three major climate zones of Alaska: the Arctic Region north of the Brooks Range, the Subarctic Region south of the Brooks Range to the northern slope of the Alaska Range, and the climatically milder Maritime Region south of the Alaska Range including Prince William Sound and the Gulf of Alaska.

The climate recordings from six National Weather Service (NWS) stations were used to describe the three climatic regions. The following discussions include representative monthly average climatological data for these stations, including ambient temperature normals, precipitation, snowfall, number of clear days, and the average number of daylight hours (Figures 3.1-15 through 3.1-19). Wind roses for four stations and Prudhoe Bay are provided (Figure 3.1-20).

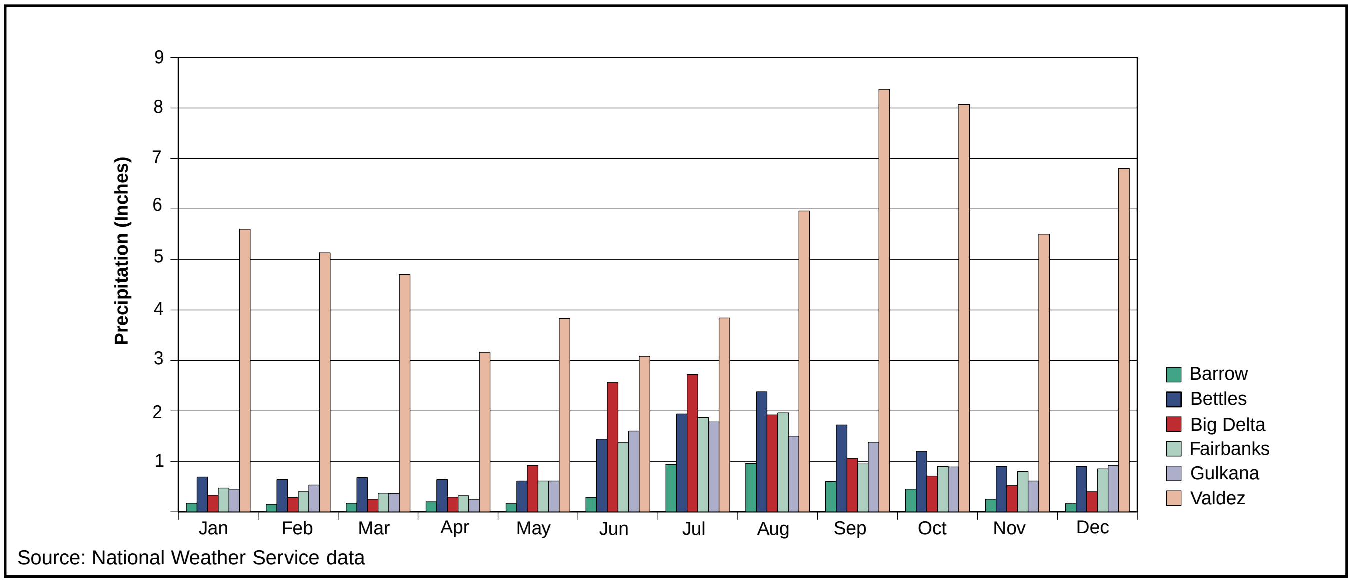
3.1.3.1 North of Brooks Range

Data from the Point Barrow NWS station approximately 200 miles west of Prudhoe Bay are representative of the region north of the Brooks Range. While far from Prudhoe Bay, Point Barrow is in the same climate zone, and because of the absence of physical terrain obstructions, the data from Barrow can be considered representative of Prudhoe. Meteorological data also have been collected at several monitoring sites in the North Slope exploration and production areas (SECOR, 1995). A wind-rose data summary was prepared from the data collected at the Prudhoe Bay Pad A station from 1987 to 1992 (Figure 3.1-20). A comparison of



Source: National Weather Service data

Figure 3.1-15. *Mean temperature for six weather stations.*

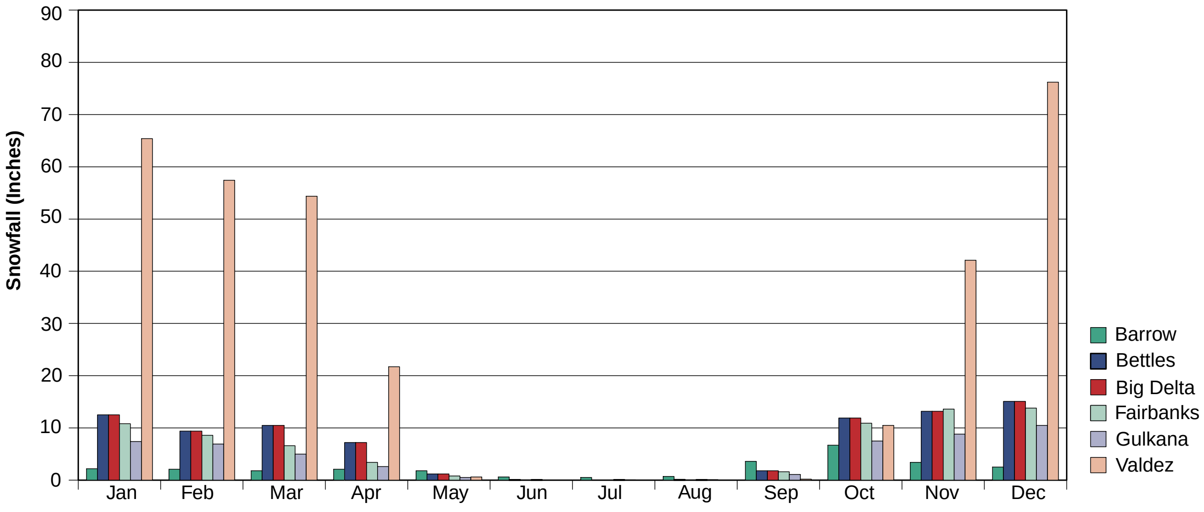


Source: National Weather Service data

Figure 3.1-16. *Normal monthly accumulation of precipitation for six weather stations.*

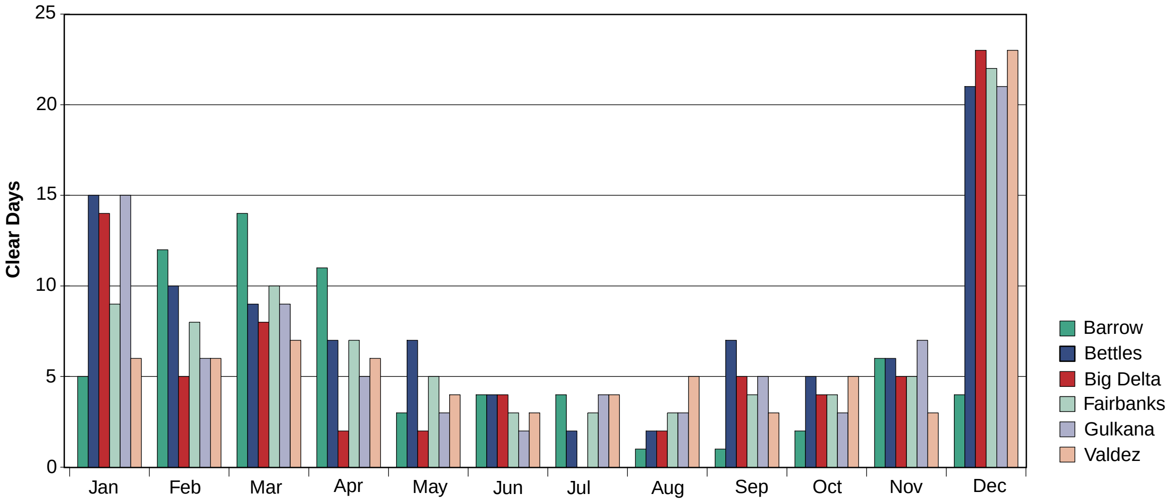
the Prudhoe Bay and Barrow wind roses shows a strong similarity in wind speed and direction.

In winter, the Barrow station generally records one of the lowest mean temperatures for the state, even though the lowest temperatures do not occur there (WRRC, 1999). The Arctic Ocean to the north and level tundra stretching 100+ miles to the south create a persistent wind regime that reduces cooling by radiation and prevents cool air from pooling in low-lying areas. The temperatures in this region remain below freezing through most of the year, with the daily maximum reaching higher than 32°F only 109 days a year on average. Freezing temperatures have been observed every month of the year. January, February, and March are generally the coldest months. In April, temperatures begin to warm, and May is the transitional period from winter to summer. July and August are the warmest months, even though the possibility still exists that temperature lows may drop below freezing. During late July or early August, the Arctic Ocean is usually ice-free near shore. The end of the short summer is reached in September, and in November about half of the daily mean temperatures are zero or below. The variation of wind speeds during the year is small, with the fall months the windiest. Consequently, temperature inversions in the lower levels of the atmosphere are not



Source: National Weather Service data

Figure 3.1-17. *Average monthly snowfall for six weather stations.*



Source: National Weather Service data

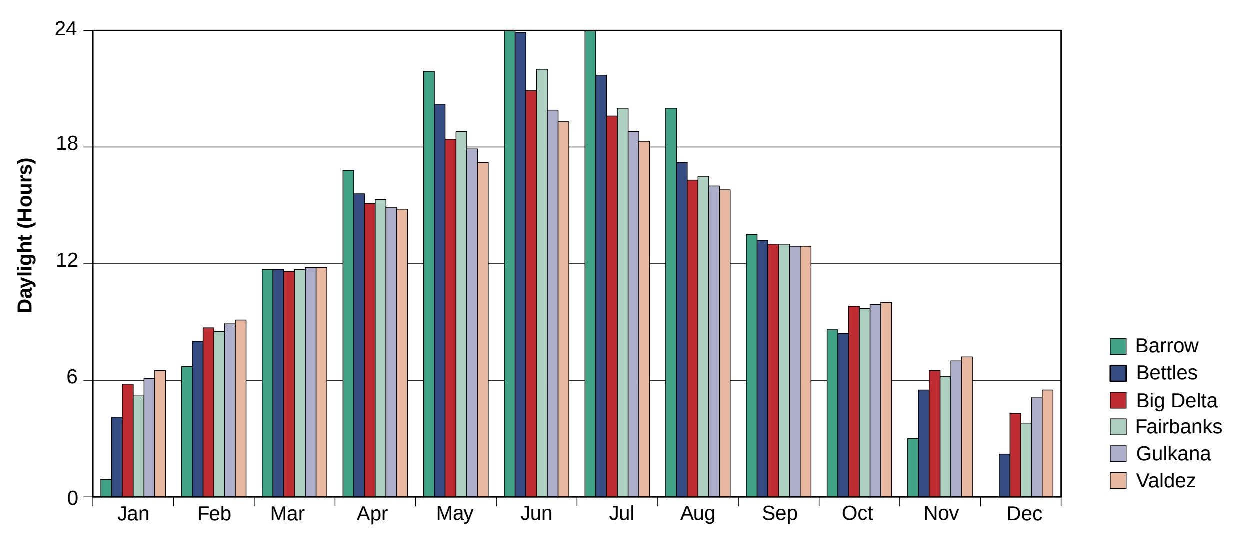
Figure 3.1-18. *Mean number of clear days for six weather stations.*

as marked as those observed at stations in the central Interior. All of the above effects reduce the likelihood of extreme winter lows; however, periodic high winds create extremely low wind chills.

At Barrow, the sun dips below the horizon at 12:50 p.m. on November 18 and does not reappear until January 24. By that time, the amount of daylight increases by at least 9 minutes per day until May 10, when daylight reaches 24 hours per day. The sun does not set from that time to August 2, when it again sets for 1 hour and 25 minutes. The decrease in hours of daylight is as rapid as the increase. The level of cloudiness, precipitation, and coastal fog tracks closely with the number of daylight hours. All three build to a maximum along with the hours of daylight. Maximum cloudiness continues into the fall. Since accurate cloud observations can be made only during daylight, records of cloudiness are not available for winter. The annual average precipitation is less than 8 inches [200 millimeters (mm)]. The layer of snow covering the tundra during the winter months is usually thin.

3.1.3.2 South of Brooks Range to North of Alaska Range

This region covering all of central Alaska can be best described with observations from the Bettles and Fairbanks



Source: National Weather Service data

Figure 3.1-19. *Average hours of daylight for six weather stations.*

stations. Bettles airport is located on the south side of the Koyukuk River and is one of four NWS stations north of the Arctic Circle. The climate in this zone is typical of a continental regime. Temperatures in this region during the long summer days are mild, with maximums mostly in the high 60s and low 70s, and occasionally in the 80s and even 90s for Fairbanks (WRRC, 1999).

In Bettles the sun does not set from June 2 to July 9. The freeze-free period averages 89 days, from May to late August. Minimum temperatures average below zero from November through March. The average January temperature is about -9°F, and lows can reach -60°F or colder. Cold winter temperatures are often amplified by terrain-induced temperature inversions in the lower atmosphere.

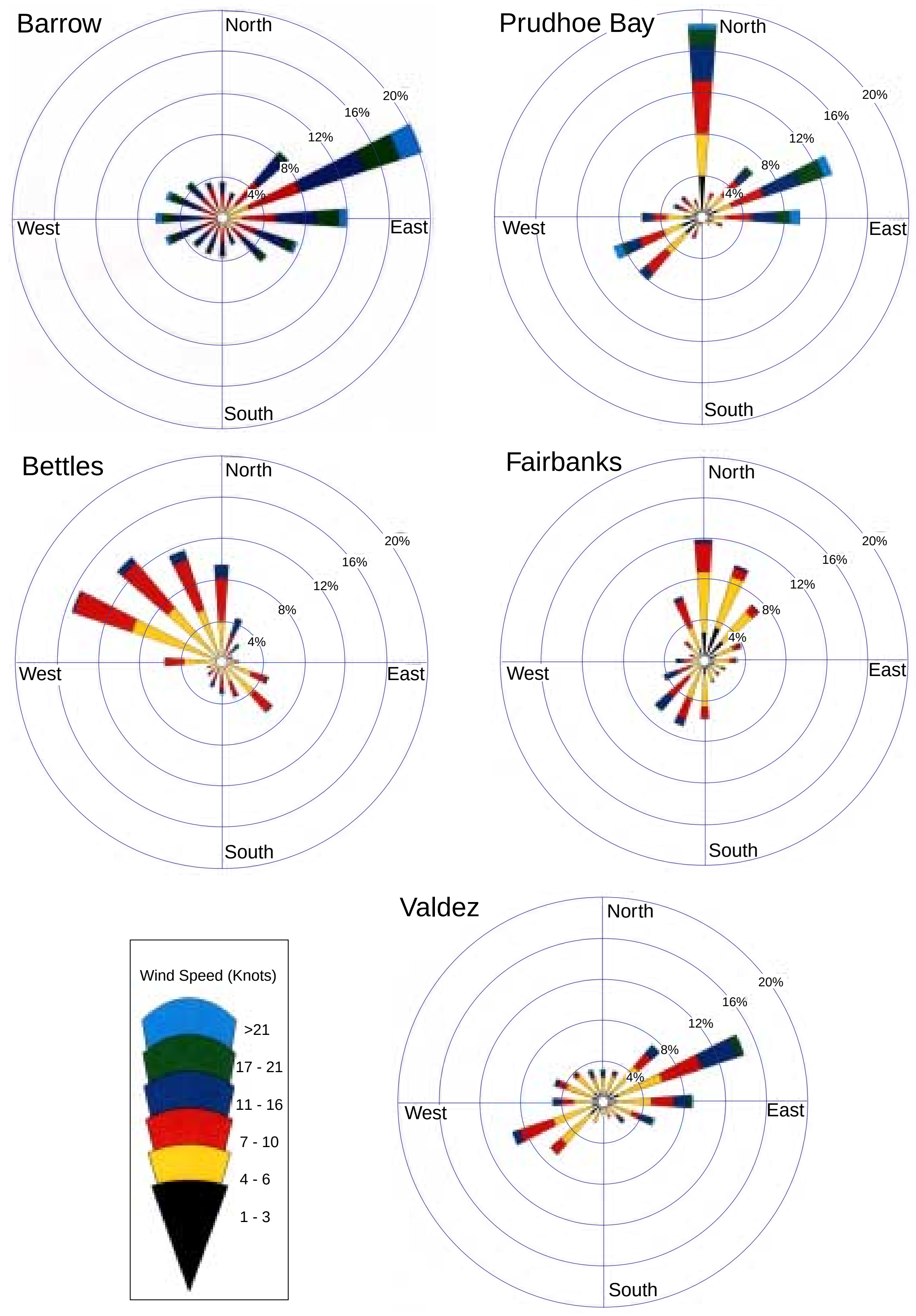
Fairbanks, located in the Tanana Valley, is surrounded by rolling hills reaching elevations up to 2,000 feet to the north and east of the city. Frequently during winter, a pool of cold air settles into the valley, while the uplands are often warmer by more than 10 degrees. Low-lying areas nearby, such as the community of North Pole, are often noticeably colder than Fairbanks. For most of the Interior, the transitions from summer to winter and vice versa are rapid, resulting in short spring and fall seasons. For Fairbanks the temperature range is larger in the winter, from about -65° to +45°F. This large range reflects the great difference between frigid weather associated with dry northerly air flow from the Arctic and mild temperatures associated with southerly air flow from the Gulf of Alaska, accompanied by chinook winds off the Alaska Range, 80 miles to the south.

Annual precipitation amounts in this region fall well within what is expected for a continental climate. They also follow the pattern of nearly all Alaskan stations, with precipitation amounts building up to a maximum during late summer and fall. The average annual precipitation is about 24 inches. During summer, thunderstorms are frequent but generally without damaging hail or winds. Snow has occurred during all months except July. The total seasonal snowfall has ranged from less than 40 inches to more than 130 inches. From October through April, the ground is covered with powdery snow that accumulates to depths of several feet. Snowfalls of 4 inches or more in a day are common; however, blizzard conditions are almost never seen.

Surface winds in this region are seldom strong during any season of the year, nor do they show much seasonal variation. Wind directions prevail from the north 10 months of the year. Winds in Fairbanks are above 20 miles an hour less than 1 percent of the time.

Water vapor generated by domestic combustion sources in urban areas frequently forms dense ice fog during winter at temperatures of -20°F or colder. In Fairbanks, cold snaps accompanied by ice fog generally last from about a week up to three weeks. The fog is usually about 300 feet deep, so that the surrounding uplands are usually in the clear, with warmer temperatures. Visibility in the ice fog is sometimes quite low, and this can hinder aircraft operations for as much as several days in severe cases.

Freezing of local rivers normally begins in the first week



Source: National Weather Service data, except Secor (1995) for Prudhoe Bay

Figure 3.1-20. *Windroses for five weather stations.*

of October. By the end of October, the ice will normally support a person's weight. Breakup of the river ice usually occurs in the first week of May. The growing season is very short and limited to the warm summer months. Hardy vegetables and grains can be grown mainly in the southern parts of this region.

3.1.3.3 South of the Alaska Range

The Alaska Range arches from the Lake Iliamna area northward through Denali National Park and Preserve, and then eastward to Tok and the Wrangell-St. Elias Mountains. Given the general wind pattern that brings moist maritime air from the Gulf of Alaska north toward the Interior, the Alaska Range creates a formidable climatic barrier. The coastal region south of the range includes the Panhandle and the coast of the Gulf of Alaska. This area is greatly affected by the relatively warm Japan Current and by the proximity of the Gulf of Alaska. Cloudy skies, successive wet days, dampness, fogginess, and occasional gale winds are typical. Annual precipitation is heavy in most of the area and varies from 20 inches at Cook Inlet to as much as 200+ inches at some areas in the Panhandle (WRRC, 1999). The abundant snowfall feeds the many glaciers. Summers are cool here, and winters, relatively mild.

NWS stations are located at Gulkana and Valdez. Gulkana is in the Copper River Basin approximately 150 air miles northeast of Anchorage and about 75 miles south of the Alaska Range. The Gulkana weather station represents nearly 100 miles of the pipeline in the Copper River drainage from the south slope of Isabel Pass in the Alaska Range to the foot of Thompson Pass in the Chugach Mountains. Even though Gulkana is south of the Alaska Range, its climate clearly cannot be classified as coastal. The mountains surrounding the Gulkana area capture a large portion of the moisture that might otherwise reach the valley, particularly from the Gulf of Alaska. Sixty inches or more are deposited each year on the windward slopes of the Chugach Mountains (WRRC, 1999). The average length of the growing season is 78 days. The heaviest precipitation occurs during the summer, and maximum cloudiness occurs during these months. Prevailing surface wind directions are from the southeast during spring, summer, and early fall, and from the north during late fall and winter.

The terrain surrounding Valdez exerts a pronounced influence on practically all aspects of the local weather and climate. The sheltering and channeling effects of the surrounding mountains produce two distinct wind regimes. From October through April, the prevailing direction is from the northeast, and from May through September the prevailing direction is from the southwest (WRRC, 1999). During winter, high pressure in the Interior and low pressure in the Gulf of Alaska occasionally cause east to north winds of about 100 knots to flow out of passes and river canyons. The high mountain ridges to the north provide a considerable barrier to the flow of cold continental air from the Interior, and temperatures rarely dip below zero. However, there is a definite offsetting factor with the downslope drainage of colder air from higher elevations, snowfields and glaciers on the southern slopes of these mountains. The coldest temperatures at Valdez appear to be related to this phenomenon. Valdez has average daily minimum temperatures below 15°F in December, January, and February (WRRC, 1999). The extreme minimum recorded between 1909 and 1967 was -28°F in February 1947. The nearby snowfields and icefields, combined with the ocean areas, provide a moderating effect on the summer high temperatures, which have seldom reached the middle 80s. Considerable variations occur in practically all weather elements within relatively short distances.

Precipitation is abundant in Valdez year-round, but builds up noticeably during late summer and fall. The heaviest precipitation usually occurs in September and October, when almost one-third of the total annual rainfall of 64 inches occurs. Snowfall during winter is very heavy, averaging about 250 inches a year. There is considerable cloudiness during the entire year. Cloudy conditions (eight-tenths cloud cover or more) occur between 60 and 70 percent of the time.

The growing season in Valdez averages slightly over 100 days, extending from May 26 to September 12. In addition, the glacial nature of the plain, the ruggedness of other surrounding terrain, and the cold water runoff from glacier melt tend to keep most available agricultural soil at temperatures too cool for desirable vegetation development during the growing season.