3. Affected Environment

3.1 TAPS Background

3.1.1 History

On October 28, 1968, eight months after oil was discovered at Prudhoe Bay, three oil firms active in North Slope oil exploration – ARCO, British Petroleum, and Humble (renamed Exxon in 1972) – formed an organization called the Trans-Alaska Pipeline System to pipe North Slope crude to market. On June 6, 1969, this organization applied for a ROW to build and operate a pipeline from Prudhoe Bay to Valdez Harbor (Mead 1978; Coates 1993). Secretary of the Interior Hickel formed the Alaska Field Group to develop protective stipulations to be attached to any Federal Grant of ROW. This interdepartmental team, along with representatives from the state of Alaska and from other federal agencies, developed a set of stipulations that was approved by the Secretary on September 29, 1969.[1]

On December 11, 1969, the Senate Interior Committee cleared the way for the Secretary to issue a road permit (Naske and Slotnick 1979; Coates 1993). The DOI issued an eight-page environmental statement to address the impacts of a road from the Yukon River to the North Slope on March 20, 1970, less than three months after NEPA had become effective.

However, previously, on March 9, the Alaska Native villages of Allakaket, Bettles, Minto, Rampart, and Stevens Village had filed suit to stop construction, arguing that the likely pipeline route would pass over lands claimed by them. A little more than two weeks later, environmental groups brought a separate suit, arguing that the TAPS proposal violated the width-of-ROW provisions of the MLA and that the DOI's environmental statement inadequately addressed the requirements of NEPA. In April, U.S. District Court Judge George Hart first halted any TAPS activities on lands claimed by Stevens Village, and then, agreeing with the environmental groups' arguments, he imposed a preliminary injunction against the entire project (Coates 1993).

The TAPS Owners and APSC realized that the pipeline could be built only if Alaska Native land claims were resolved. During much of 1970 and 1971, the oil industry worked with Alaska Natives toward the passage of the Alaska Native Claims Settlement Act (ANCSA) (Coates 1993; Naske and Slotnick 1979). ANCSA, which passed in 1971, provided lands to Alaska Natives and gave the Secretary of the Interior the authority to withdraw land for the pipeline from state and Native land claims, which he did in Public Land Order 5150. APSC was also able to gain dismissal of the Native villagers' suit, which thwarted construction, by agreeing to hire and train Alaska Native village residents (APSC 1972).

The DOI released a Draft EIS (DEIS) for the TAPS in January 1971. The Final EIS (FEIS), issued in March 1972, contained nine volumes, including three on economic and security aspects of the project. The FEIS responded to the large number of comments received on the DEIS. It extensively analyzed a no-action alternative as well as alternative methods of delivering North Slope oil to market. It included a substantial rewrite of the stipulations and more extensive discussions of potential impacts.

In August 1972, Judge Hart removed his injunction against TAPS construction, ruling that

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1 See two BLM documents "Chronology of Events," Record Group 49, Box 225 22/01/01(5), and "Stipulations for the Trans Alaska Pipeline System," Record Group 49, Box 19 17/08/08(3), in the National Archives-Pacific Region, Anchorage, Alaska.

the FEIS met the requirements of NEPA and that the ROW proposed by the applicant would not violate the width provisions of the MLA. The environmentalist plaintiffs took the case to the U.S. District Court of Appeals in Washington, D.C., where they won a partial victory in February 1973. The appeals court was silent on NEPA, but it ruled unanimously that Section 28 of the MLA did not allow the pipeline builders to have a construction ROW of more than 50 ft plus the width of the pipe. In April, the Supreme Court announced that it would not hear an appeal of the case (Coates 1993; Berry 1975).

In November 1973, Congress enacted TAPAA and amendments to the MLA to address the legal challenges impeding TAPS (Coates 1993). On January 16, 1974, Judge Hart dissolved the injunction against TAPS construction. A week later, on January 23, Secretary of Interior Morton signed the Federal Grant, which gave the TAPS Owners the ROW for constructing TAPS. Included in this Federal Grant were a set of stipulations and 41 sections setting out additional terms and agreements.

At the time the DOI issued the Federal Grant for the TAPS ROW, approximately 200 mi of the TAPS route was expected to be on state-owned land. Thus, a State Lease from the ADNR was required. The pipeline was also expected to cross scores of small private parcels. The TAPS Owners were able to accommodate private parties through perpetual ROW agreements. To receive permission to cross state-owned land, the TAPS Owners applied to the ADNR for a ROW on March 7, 1974. ADNR issued the State Lease pursuant to Alaska Statute (AS) 38.35.100 on May 3, 1974. Because state representatives had been working with the federal team to develop stipulations for the TAPS since 1969, the State Lease adopted much of the Federal Grant language. The State Lease was intended to apply to the ROW on then-current state lands as well as on future land acquired from the state. Today, the State Lease applies to approximately 344 mi of the pipeline and includes four pump stations (Map 1-2).[2]

To oversee construction of the TAPS, in January 1974, the DOI designated an Authorized Officer (AO), and the ADNR appointed a State Pipeline Coordinator (SPC) (Mead 1978). Federal and state engineers on the AO's and SPC's staffs and a joint state/federal fish and wildlife advisory team (established to provide guidance to minimize impacts to fish, wildlife, and their habitats) reviewed the design plans. On the basis of this review and required revisions, the BLM and ADNR issued hundreds of Notices to Proceed to APSC (Mead 1978).

The DOT certified the pipeline on June 16, 1977. On June 19, the AO gave APSC permission to operate the pipeline. Oil reached the Valdez Marine Terminal on July 28, 1977 (Mead 1978).

In the years immediately after construction, both the federal and state governments reduced their oversight of the TAPS. The state disbanded the SPC's office entirely in 1977, returning permitting activities to individual line agencies (Simenson 1999). In 1979, the DOI delegated its pipeline oversight role to the BLM's Alaska State Office, which placed responsibility for TAPS oversight in its Office of Special Projects. By 1984, the BLM had assigned six individuals to the office (renamed the Branch of Pipeline Monitoring), and during the second half of the 1980s, the BLM had two TAPS field inspectors (General Accounting Office [GAO] 1991).

APSC's announcement in February 1989 that an improved corrosion detection program had revealed serious problems along sections of the pipeline, followed in March by the Exxon Valdez oil spill, heightened the public's concern about the pipeline. The result was a government reevaluation and reformation of TAPS oversight. By March 1990, the BLM and ADNR had formed the core of the JPO to more efficiently and effectively oversee pipeline operations (BLM 1990). By the spring of 1991, the JPO had expanded to include four agencies and 38 employees.

In its first years of existence, the JPO primarily addressed ongoing problems and issues. Major projects included monitoring the rerouting of 8.5 mi of pipeline at Atigun Pass to resolve corrosion problems and reviewing two revisions to the APSC's oil spill response plan. However, a GAO report (GAO 1991) charged the JPO with faulty oversight. In subsequent months, workers and

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2 All maps referred to in this document are presented in Volume 7.

citizens complained to Congress about the TAPS, alleging serious safety problems, employee harassment, and concerns about pipeline integrity. Congressional hearings in 1993 motivated APSC and the JPO to reexamine operations and oversight.

In 1994, the JPO developed additional technical engineering, design, and quality process expertise; began evaluating specific National Electric Code questions; assessed pipeline integrity and safety; and conducted an organizational study of JPO staffing needs. In addition, unresolved findings from seven audits that had been conducted since 1990 resulted in the identification of 4,920 unresolved findings regarding the TAPS. APSC developed a database on these findings or deficiencies, and the JPO began monitoring the pipeline operator’s response to each of these “audit action items.” The JPO approved the operator’s fixes to all but about 100 audit action items by the end of 1996 (Brna et al. 1997). All of these items have subsequently been closed (Reimer 2002).

One deficiency that was apparent in the mid-1990s was APSC’s failure to live up to commitments to hire Alaska Natives to fulfill Section 29 of the Federal Grant. In an agreement pursuant to the Federal Grant, the pipeline operator had committed to train and employ Alaska Natives in a proportion equivalent to their proportion in Alaska’s population in the mid-1970s. That percentage was estimated to be 20%. By 1994, employment of Alaska Natives for the TAPS had slipped to less than 5%. In October 1995, APSC and the DOI signed an agreement requiring the operator and its contractors to take specific actions to increase employment of Alaska Natives (Brna et al. 1997). DOI and APSC renewed and revised the agreement in 1998 and 2001. APSC committed itself and its contractors to recruit, train, and employ Alaska Natives at all levels; the target was for Alaska Natives to make up 20% of TAPS employees by 2004. APSC receives credit toward that employment goal for Alaska Natives enrolled in its Alaska Native training and scholarship programs. At the end of 2001, employment of Alaska Natives for the TAPS, adjusted for training and scholarship credits, was 19.8%.

In the mid-1990s, in response to Congressional direction to provide comprehensive oversight of the TAPS, the JPO began its comprehensive monitoring program. This program fundamentally shifted the emphasis of JPO oversight from response to prevention. The JPO identified major functional elements of the TAPS for which it had oversight responsibility (e.g., project design, QA, maintenance, safety, the employee concerns program). It also developed systematic plans to assess APSC’s performance in each element. Depending on the topic, the assessment process (which continues today) involves the examination of APSC records, engineering designs, and other documents and site visits by JPO staff to examine TAPS facilities. The GAO favorably cited JPO’s initiation of the comprehensive monitoring program process (GAO 1995). More recently, the JPO has enhanced its efforts to ensure pipeline integrity and safety through an RCM program.

3.1.2 Existing Infrastructure

This section describes the various auxiliary infrastructures supporting the operation of the TAPS, including those on the North Slope, at the Valdez Marine Terminal, and in Prince William Sound. The description of the pipeline itself and its main components is given in Section 1.3; a summary of the main components of the TAPS is provided in Table 3.1-1. More detailed information on design features that directly support existing mitigation measures is presented in Section 4.1. The supporting infrastructures discussed in this section are grouped into two main categories: infrastructures directly along the TAPS ROW and infrastructures supporting other components of the North Slope Production and Transportation System (NSPTS).

As mentioned in Section 1.3, the TAPS is a 48-in. single pipeline system that stretches from Prudhoe Bay in the north to the Valdez Marine Terminal in the south. The pipeline traverses a total distance of 800 mi, about half of which is aboveground; the remaining half is belowground. Of the 11 pump stations originally constructed for the TAPS, only 7 are currently operating. PS 1, 3, 4, 7, 9, and 12 provide pumping action, while PS 5 serves as a relief station (pressure control). The TAPS crosses more than 30 major rivers, about 800 smaller streams, and three mountain ranges. A total of 13 bridges support the pipeline system.

TABLE 3.1-1 Summary of Major Features of the Trans Alaska Pipeline System

Component	Type	Data
Area covered by the TAPS	NA[a]	16.3 square mi (includes Valdez Marine Terminal)
Length of pipeline	NA	800 mi
Design mode	Aboveground Conventional belowground Refrigerated belowground	420 mi 376 mi 4 mi
Typical ROW width	Federal lands, buried pipe Federal lands, elevated pipe State lands Private lands	54 ft 64 ft 100 ft 54 to 300 ft
Vertical support members	Number Types Diameter Number with heat pipes Depth embedded	78,000 16 for different soil and permafrost conditions 18 in. 61,000 15 to 70 ft
Animal crossings	Elevated Buried Buried (refrigerated)	554 23 2 (MP 645 and 649)
Bridges	Orthotropic box girder Plate girder Suspension Tied arch	1 (Yukon River, shared with Alaska Department of Transportation) 9 (Atigun, Dietrich, Koyukuk [south and middle forks], Hammond, and Tatalina Rivers; Unnamed, Hess, and Shaw Creeks) 2 (Tanana and Tazlina Rivers) 1 (Gulkana River)
Pump stations	Operating (1999) Stand-by Relief	PS 1, PS 3, PS 4, PS 7, PS 9, PS 12 PS 2, PS 6, PS 8, PS 10 PS 5
Pipeline valves	Check valves Gate valves Ball valves	81 95 (including pump station isolation valves) 1
Fuel gas line	Buried natural gas pipeline	From PS 1 to PS 3 and PS 4; 8 to 10 in. diameter; approximately 144 mi long
Access roads		Approximately 284 secondary roads (from 120 ft to 7.5 mi long) linking state roads with pipeline, pump stations, material sites, disposal sites, and airfields
Valdez Marine Terminal	Total area Crude oil storage Tanker berths	1,000 acres 9.18 million bbl total in 18 tanks (510,000 bbl each) 4 (1 floating, 3 fixed platform)
Ship Escort/Response Vessel System (SERVS)	Tugs Other vessels Skimmers Containment boom Response centers	2 enhanced tractor tugs, 3 prevention/ response tugs, 4 other 10 workboats, 7 response barges, 48 mini-barges More than 70 More than 42 mi 5 (Valdez, Cordova, Whittier, Chenega Bay, Tatitlek)
Communications sites	Microwave stations Satellite earth stations VHF repeaters	42 (operated by AT&T) 7 (operated by AT&T) 22

[a] NA = not applicable.

Source: Modified from TAPS Owners (2001a, Table 2.1-1).

Typical ROW width specifications for the TAPS are as follows: buried segments on federal lands, 54 ft; elevated segments on federal lands, 64 ft; segments on state lands, 104 ft; and segments on private lands, 54 to 300 ft (TAPS Owners 2001a).

3.1.2.1 Infrastructures Directly along the TAPS ROW

The TAPS infrastructure support systems under this category include (1) electrical; (2) fuel; (3) water; (4) road; (5) communication and control; (6) site safety and emergency response; (7) other support systems, which include airstrips, operations material sites, and disposal sites; and (8) the Valdez Marine Terminal.

3.1.2.1.1 Electrical System. Power sources that make up the TAPS electrical system include on-site generator units for the pump stations, propane-fueled generators, batteries for remotely controlled gate valves (RGVs), and commercially available power from nearby grids or utilities to supplement on-site generator output (TAPS Owners 2001a; Technica, Inc. 1991; APSC 2001a).

All pump stations along the TAPS ROW (i.e., PS 1 through 12) have at least one on-site electric generating unit powered by either natural gas or diesel fuel. Generator units at PS 1 through 4 are gas-fueled (a natural gas line serves PS 1 to 4), while generator units at PS 5 through 12 are diesel-fueled (diesel or liquid turbine fuel is trucked from commercial vendors) (Technica, Inc. 1991). PS 8, 9, and 10 have commercially available power in addition to their diesel-fueled generating units. The size of the power units ranges from 400 to 800 kW, and the number of generator sets varies at the stations depending on the required power. The installed size ranges from 1.3 MW at PS 12 to 4.7 MW at PS 6. The size of the power units depends on the availability of commercial power and vapor recovery systems. (Crude oil topping units are located at PS 6, 8, and 10. The topping units have been placed on standby since 1997 because economics pointed to the use of commercially available fuel.)

In general, electric power is used for lighting, heating, ventilation, and air-conditioning of offices and living quarters at the pump stations (PS 1, 8, and 9 do not have permanent living quarters). Electric power also supports the TAPS instrumentation, communication and control systems, and other vital station functions.

Smaller-sized propane-fired generators are used to provide charging power to batteries supporting RGVs and remote cathodic protection installations. RGVs are placed at major river crossings and other locations where quick closure would be necessary in an emergency. Each RGV is powered by batteries that are kept charged by two propane-fired generators or by commercial electrical utilities where available. Remote cathodic protection installations are also electrically powered by gas-fired generators. Where the generator sets are in close proximity to the fuel gas line, they are fueled by natural gas (methane). In other areas, buried propane tanks supply the liquefied gas for fuel. Where commercial electricity is available, the local commercial power system is used (TAPS Owners 2001a).

3.1.2.1.2 Fuel Systems. Moving crude oil from PS 1 to Valdez requires a well-designed fuel delivery system to energize the pump stations along the pipeline, to support operations of the Valdez Marine Terminal, and to fuel other miscellaneous functions (e.g., lighting, heat, air-conditioning, and other machinery). Two major energy sources are used for the TAPS: natural gas and liquid turbine fuel (TAPS Owners 2001a; Technica, Inc. 1991).

Fuel Gas and Gas Pipeline. The fuel gas line supporting the TAPS generally parallels the main line crude oil pipeline, from Prudhoe Bay to PS 4, traversing a total distance of 149 mi. (Natural gas is produced with the crude oil on the North Slope. Processing facilities separate the gas, and APSC purchases a portion of the gas to use as fuel.) The fuel gas line is under ground throughout most of its length. Its main function is to carry natural gas from North Slope fields to fuel turbines at pump stations north of the Brooks Range (i.e., PS 1 through 4). Turbines at stations south of the Brooks Range are fueled by liquid turbine fuel (Technica, Inc. 1991; TAPS Owners 2001b).

The gas pipeline segment from PS 1 to TAPS Milepost[3] (MP) 34 is 10 in. in diameter; the segment from MP 34 to PS 4 is 115 mi long with a diameter of 8 in. The gas pipeline has a design pressure of 1,335 pounds per square inch gauge (psig) and a nominal operating pressure of 1,090 psig. Two 1,200-hp gas turbine compressors at PS 1 boost gas pressure from approximately 600 to 1,100 psig. (Gas is delivered to PS 1 by Prudhoe Bay Natural Gas at about 600 psig.) Maximum gas temperature at the PS 1 suction end is 30°F (APSC 2001a). If there is an interruption of natural gas supply, the turbines at PS 1, 3, and 4 can be converted to operate on turbine fuel (TAPS Owners 2001a). Pig launching and receiving facilities for the gas line are located at PS 1, MP 34, and PS 4 (APSC 2001a). The fuel gas pipeline is maintained and operated in compliance with federal regulations for cross-country gas pipelines. It is pigged periodically and is the focus of a corrosion-monitoring program, much like the crude oil pipeline (TAPS Owners 2001b).

Pigs

Pigs are cylindrical objects inserted into the pipeline periodically that are propelled by the moving oil or gas and used for cleaning. Sometimes the pigs are instrumented (hence their name smart pigs) to detect corrosion, deformation, wall-thinning, or curvature changes in the pipe.

Liquid Turbine Fuel and Topping Units. Liquid turbine fuel is used to fuel pump stations (including electric generators) south of the Brooks Range (i.e., PS 5 to 12) and at various places in the system (e.g., Valdez Marine Terminal). The liquid turbine fuel is purchased from commercial fuel vendors and delivered in tank trucks (TAPS Owners 2001a). Prior to 1997, crude oil topping units located at PS 6, 8, and 10 produced turbine fuel and naphtha to support pump station operations (Technica, Inc. 1991). (A small amount of commercial electric power is purchased at PS 8, 9, and 12.)

In 1999, APSC used 7.776 billion standard cubic feet (SCF) of fuel gas and purchased 46 million gal of turbine fuel (TAPS Owners 2001a). Annual consumption of diesel fuel is approximately 1,116,000 gal (about 95,000 gal per month).

3.1.2.1.3 Water Systems. Operation of the TAPS requires the availability of freshwater for domestic (i.e., manned facilities) and industrial uses (e.g., equipment washing, dust abatement on roadways and pads, and hydrostatic testing). The use of Alaska's water resources and the issuance of permits for temporary or long-term water appropriations are regulated by the ADNR (TAPS Owners 2001a). APSC has certificates of appropriation for water use at permanent facilities, including each pump station except PS 1 and 6. Water used at PS 1 is purchased from the North Slope Borough's Service Area 10 water utility. A well at 5-Mile Camp is used as a water source for PS 6, for which water is trucked across the Yukon River Bridge. Each active pump station typically consumes between 4,500 and 7,500 gal/d, mostly for domestic uses. Volumes of water use (domestic and industrial) at various facilities are illustrated in Figure 3.1-1. Table 3.1-2 gives the characteristics of the water wells located along the TAPS ROW.

Additional temporary water-use permits are maintained by APSC for facilities such as mobile contingency camp facilities (MCCFs) and for special projects. Volumes of water for temporary use vary significantly. The largest single project for which temporary-water-use permitting was necessary occurred in 1997, when 7.4 million gal was withdrawn from East Lake, near MP 0, for tank cleaning and testing at PS 1 (TAPS Owners 2001a).

Potable Water Use. Typical potable water consumption (i.e., drinking water, food preparation, and personal hygiene) at the TAPS living quarters is about 100 gal per person per day. At the pump stations and camps, potable water is generally supplied by local wells maintained by APSC for that purpose. Living quarters for workers are not maintained at PS 1,

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3 To provide locational references, the length of the TAPS is marked by mileposts (MPs), beginning at its origin in the North Slope (MP 0) and ending at its terminus in the Port of Valdez (MP 800).

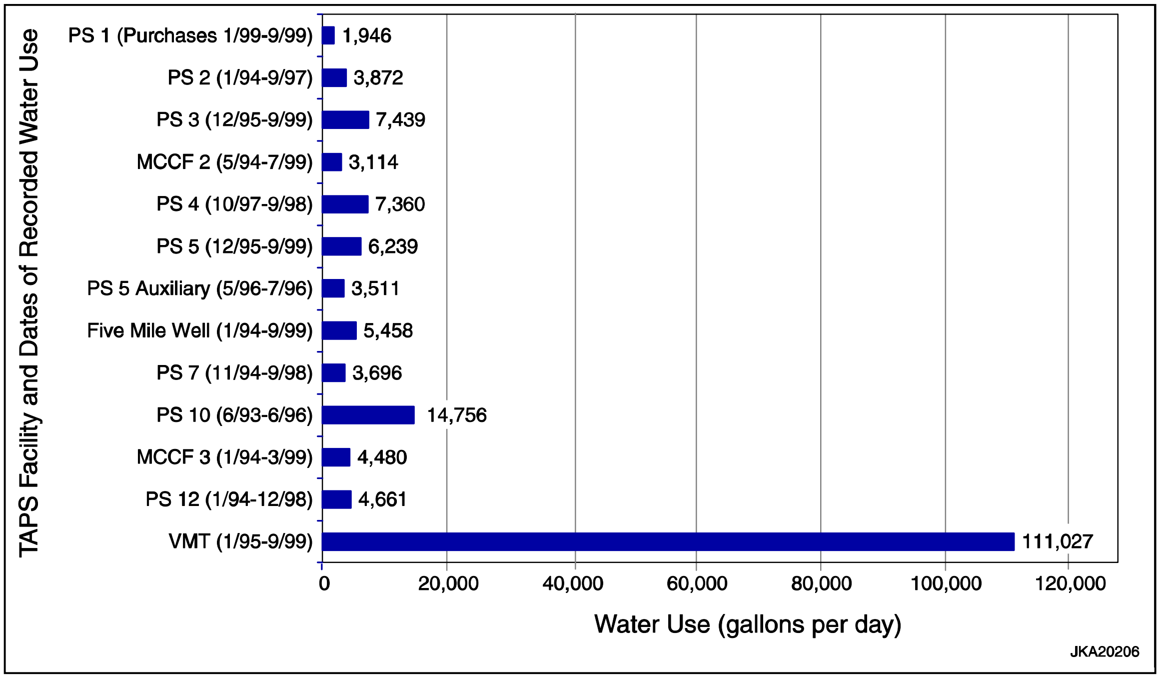

FIGURE 3.1-1 Water Use at TAPS Facilities, 1994–1999 (Source: TAPS Owners 2001a, Figure 4.11-3)

8, and 9 because of their proximity to local communities or other facilities; thus, the amount of potable water used is much lower at these stations. Currently, only PS 1, 3, 4, 5, 7, 9, and 12 are in use, further diminishing total water use. As additional pump stations are ramped down (operated at reduced levels), water use will be diminished or discontinued at those stations as well.

Industrial Water Use. The amount of water used for industrial cooling or process needs at the active pump stations is far less than that used for domestic purposes. Hydrostatic testing occurs only infrequently as part of pipeline replacement or tank repair activities. The use of water for washing down equipment, such as vehicles, turbine fans, and other equipment, is occasional, and dust suppression water uses are nominal (Jokela 2001).

Sanitary Discharges from Pump Stations and MCCFs. Discharges of sanitary wastewater take place in accordance with state and federal permits, including the EPA NPDES permits. Table 3.1-3 summarizes typical sanitary discharges from pump stations and MCCFs.

These discharges are treated by various means. In permafrost areas, discharge to groundwater is impracticable, and long-term discharge of wastewaters across tundra is viewed as increasing the potential for thermal erosion. Only PS 5 has ongoing discharge of sanitary wastewater to tundra wetlands. For years, this facility was served by a lagoon system. Wastewater was contained and treated via facultative biological decomposition, with discharge to tundra wetlands. In 1999, the lagoon system was upgraded to conventional aerobic secondary treatment using a small mechanically activated sludge plant. Discharge from this process is distributed through a diffuse outfall across tundra wetlands.

At PS 1, 3, and 4, sanitary wastewater is screened by using a fine-mesh rotary strainer. The screened wastewater is stored in a holding tank and then pumped to the exhaust stacks of the engines powering the crude oil pumps. High-pressure nozzles inject the wastewater into the hot exhaust flow, where it is atomized and evaporated. Any remaining organic material dissolved in the liquid stream is volatilized and disinfected in the hot exhaust. The exhaust-gas

TABLE 3.1-2 Location and Characteristics of Water Wells along the TAPS ROW

Well Identifier	Depth (ft)	Capacity (gal/min)	Source	Active?
5796 MP 200 Campsite	9	30	Dietrich River	No
11506 Old Man 2	420	Not reported	Talik and Kanuti River	No
25086 Sag River Pump Station 2	32	75	Sagavanirktok River	No
25087 Pump Station 3 PW-1	30	40	Sagavanirktok River	Yes
25088 Pump Station 3 PW-2	39	Not reported	Sagavanirktok River	No
25089 Pump Station 3	37	Not reported	Sagavanirktok River	No
25090 Pump Station 4	171	75	Atigun River	Yes
25091 Pump Station 5	48	Not reported	Jim River	Yes
25092 Pump Station 6	800	30	Subpermafrost	No
25093 Pump Station 6	275	20	Subpermafrost	No
25094 Pump Station 7	345	17.5	Subpermafrost	Yes
25095 Pump Station 8	28	Not reported	No ice mentioned	No
25096 Pump Station 8	302	Not reported	No ice mentioned	No
25097 Pump Station 9	520	25	Subpermafrost	Yes
25098 Pump Station 9	300	No groundwater found	Dry well	No
25099 Pump Station 10	75	40	Delta River	No
25100 Pump Station 10	90	72	No ice mentioned	No
25101 Pump Station 10	240	Not reported	Subpermafrost	No
25102 Pump Station 12	77	35	No ice mentioned	Yes
25103 Pump Station 12	80	Not reported	Talik and Little Tonsina River	No

Source: Keyes (2002).

flow disperses the relatively small volume of sterilized water particles into the atmosphere. To ensure that full dispersal takes place, APSC has established operating procedures in conjunction with the ADEC. Sewage injection can commence only when reaction turbines are running at least 2,350 rpm, and exhaust gas temperatures exceed 750°F. Air is injected in conjunction with the wastewater flow at a minimum pressure of 70 psig, and liquid pressure is continuously monitored to ensure appropriate atomization. Nozzles are inspected regularly and replaced as needed. Screenings are incinerated at each pump station. Periodically, holding tank sludge is trucked away for disposal to a private wastewater treatment facility located off the pipeline corridor, thereby eliminating local sanitary discharges to surface or groundwater at these facilities. If injection is impractical because of maintenance or inadequate exhaust gas temperatures, wastewater is trucked to a remote permitted disposal facility.

Sanitary wastewater at PS 7 through 12 and at the Fly Camp at PS 6 is treated through conventional septic treatment systems. These systems are serviced regularly to maintain appropriate septage levels for waste treatment.

TABLE 3.1-3 Typical Sanitary Discharges from Pump Stations and Mobile Contingency Camp Facilities

PS or Camp	Status	Permanent Living Quarters	Current Population	Typical Flow (gal/d)	Design Capacity (gal/d)	Current Wastewater Disposal
1	Open	No	50 day-use	2,000	10,000	Stack injection
2	Ramped down 1996	Yes	0	4,000	10,000	Not in use
3	Open	Yes	45	7,500	10,000	Stack injection
MCCF #2	Inactive	NA[a]	0	2,900	14,000	Secondary biological
4	Open	Yes	40	4,700	10,000	Stack injection
5	Relief only; no pumps	Yes	60	6,300	8,000	Secondary biological
6	Ramped down 1997	Yes	0	6,500	6,000	Not in use
Fly Camp at PS 6	Open	Yes	16	950	850	Septic
7	Open	Yes	30	3,800	3,400	Septic
8	Ramped down 1997	No	0	600	1,000	Septic
9	Open	No	25 day-use	780	1,000	Septic
10	Ramped down 1997	Yes	0	4,200	12,000	Septic
MCCF#3	Inactive	NA	0	3,500	14,000	Secondary biological
11	Never constructed	NA	NA	NA	NA	NA
12	Open	Yes	35	4,200	9,100	Septic

[a] NA = not applicable.

Source: Based on TAPS Owners (2001a).

Each MCCF has a self-contained sanitary wastewater secondary treatment system that uses rotating biological contractor technology and a holding tank. Treated wastewater from each site is discharged locally in accordance with the linewide NPDES permit.

Disposal of Other Wastewater Discharges. Wherever possible, wastewaters, such as washwaters, hydrotest waters, storm water, and snowmelt, are discharged to dry channels, tundra, or upland areas. Direct discharges to surface water are uncommon. The linewide NPDES discharge permit specifies rules for the discharge of sanitary wastewater, hydrotest waters, and excavation dewatering. In applying for a renewal of that permit in 1998, APSC inventoried all types of wastewater discharges from normal operation.

Hydrotesting. Hydrostatic testing is conducted to ensure that repair work on pipeline segments or tank components are leak proof. Hydrostatic testing occurs infrequently. The maximum annual volume of water for hydrostatic testing was 3.8 million gal in 1991, when more than 8 mi of pipeline was reconstructed because of corrosion of the pipeline in the Atigun River valley. Water from hydrostatic testing is discharged in accordance with the linewide NPDES permit, which mandates laboratory characterization, documentation, and erosion protection requirements for the discharge.

Excavation Dewatering. Excavation of buried pipeline segments is performed to confirm pipeline pig findings or other test data and to repair the pipe and coating system. Whenever groundwater is encountered during these excavations, the water must be removed and discharged away from the trench. Dewatering is performed in a manner that permits safe working conditions within the trench, allows for unhindered examination of the portion of the pipeline in question, and poses no significant environmental concerns. Dewatering discharge has been regulated through various permits, beginning with a State of Alaska wastewater discharge permit since 1983. The current NPDES permit requires notification, volume estimates, and descriptions of procedures employed to minimize erosion and discharge of pollutants from excavation dewatering.

Draining of Secondary Containment Dikes. Secondary containment structures along the TAPS serve as catchments for oil and incidental snowmelt and rainwater that accumulate in the impervious enclosure. These structures are drained periodically to maintain their full retention capacity. Snowmelt and rainwater removed from the containment systems are typically unaffected by contact with the tanks and other structures. Dewatering of secondary containment of waters is allowed by a State of Alaska Wastewater General Permit, which established monitoring requirements and effluent limitations. To guard against discharge of pollutants, the discharge is visually inspected for sheen. No discharge of waters bearing hydrocarbon sheen is allowed by the general permit.

In 1997, more than 60 different secondary containment structures along the pipeline were drained. There were 297 occasions for dewatering, including more than a dozen repeat visits to a few stations. Total water drained was 15,678,000 gal. More than two-thirds of the volume came from early summer dewatering of the tank farm at PS 1, where the secondary containment volume was highest. At the Valdez Marine Terminal, discharge from secondary containment structures is directed to the BWTF to remove oil.

Storm-Water Runoff. Currently, only a limited number of facilities along the TAPS meet the applicability criteria of the EPA Storm Water Multi-Sector General NPDES Permit (MSGP) for Industrial Activities and have the potential to affect waters. APSC operates the sites in conformance with the MSGP standards. The affected sites are all material sites that may, under certain circumstances as specified by MSGP, discharge rainwater or snowmelt from mined areas to surface waters. Construction activities that disturb more than 5 acres, do not involve excavation dewatering, and have the potential to impact waters of the United States are covered under the NPDES Permit for Storm Water Discharge from Construction Activities Associated with Industrial Activity. For TAPS projects that meet criteria for coverage under this permit, specific notices of intent are submitted to the EPA (TAPS Owners 2001a).

3.1.2.1.4 Road System. Overall, the road infrastructure in Alaska is not well-developed, which explains, in part, the popularity of air travel in the state. Roads and highways that provide access to and support the TAPS include Dalton, Elliott, Steese, Alaska, Richardson, and Glenn Highways and Chena Hot Springs and Dayville Roads (Map 3.1-1). In addition, there are approximately 284 secondary roads that provide access to the pipeline, pump stations, and airstrips. Roads are now used to carry supplies to the North Slope and to various pipeline-related facilities, and roads would be used to haul dismantled sections of the pipeline if the ROW were not renewed. Access roads range in length from 120 ft to 7.5 mi and are generally 28 ft wide with a mineral material base (APSC 2001a).

The Dalton Highway is a 28-ft-wide crushed-rock road that extends 416 mi from the town of Livengood to the industrial complex of Deadhorse. Dalton Highway was built to provide an overland route between Fairbanks and Prudhoe Bay for construction of the TAPS and now provides overland access to the northern half of Alaska (TAPS Owners 2001a).

Roads along the TAPS segment from the Yukon River to Delta Junction include Elliott, Steese, and Richardson Highways and Chena Hot Springs Road, along with connections to the Alaska Highway.

3.1.2.1.5 Communication System. The TAPS communication system has a total of 71 stations, including 42 microwave stations, 7 satellite earth stations, and 22 very high frequency (VHF) repeater stations (APSC 2001a). The primary system for communication is the microwave, with satellite-based communications as backup (TAPS Owners 2001b). Networks are provided for supervisory control and telemetering, seismic monitoring, RGV status monitoring and control, administrative and logistical data, en route mobile radio, in-plant radio, marine and aircraft radio, voice telephone service, and oil spill prevention and response communications.

APSC uses microwave, satellite, and radio technology for remote monitoring and control of pipeline operations. The TAPS voice communication system consists of a private telephone network and a mobile radio system. Two party-line channels on the microwave system are allocated for voice communications between all stations and Valdez. The mobile radio system consists of a VHF radio base and microwave repeater stations located at strategic sites, microwave control channels, and interconnecting links to the telephone network throughout the system. Other systems are being considered to serve as the primary communication system for TAPS: fiber optics and digital microwave systems. A fiber-optic communication system has already been installed along the TAPS and is currently used for noncritical voice and data communication.

The TAPS OCC is situated at the Valdez Marine Terminal. The basic functions of the control system are to provide real-time monitoring, control all significant aspects of operation, and detect pipeline leaks. Operators in the OCC monitor the system 24 hours per day and control oil movement through the pipeline and loading of tankers (APSC 2001a). A picture of the inside portion of OCC is shown in Figure 3.1-2. The OCC continually monitors the status of all pump stations and critical valves by using supervisory control and data acquisition (SCADA) systems with remote sensors. Data on parameters such as pressure, flow rate, temperature, tank level, and valve position are recorded and analyzed for abnormal operations or any indication of a pipeline leak.

The Pipeline Controller at the OCC can rectify any abnormal operation by changing settings for pump speed or relief valves or by issuing idle or stop commands to the main-line pumps. The OCC Controller can also activate remote control valves. The monitoring and analysis systems include backup communications equipment and computers. Leak detection for the pipeline consists of three independent systems: line volume balance (LVB) compares the volume of oil entering the line with the volume leaving the line; transient volume balance (TVB) compares reported flow with calculated flow and can identify the probable location of a leak by pipeline section; and alarms will signal deviations in pressure, flow, or flow rate balance. If emergency conditions occur, the Pipeline Controller can shut down an entire pump station and isolate it from the line or shut down the entire pipeline. Pressure relief systems are in place to prevent overpressurization during each type of shutdown (TAPS Owners 2001a). Table 3.1-4 summarizes some of the salient aspects of the TAPS control system.

3.1.2.1.6 Site Safety Services. Safety services supporting the TAPS operation include fire protection and management, oil spill emergency response, security, and seismic monitoring.

Fire Protection. Warnings of potential and actual fires are conveyed to operations personnel by various fire detection systems installed along the pipeline. Various devices detect anomalies and alert people through numerous alarms (TAPS Owners 2001b).

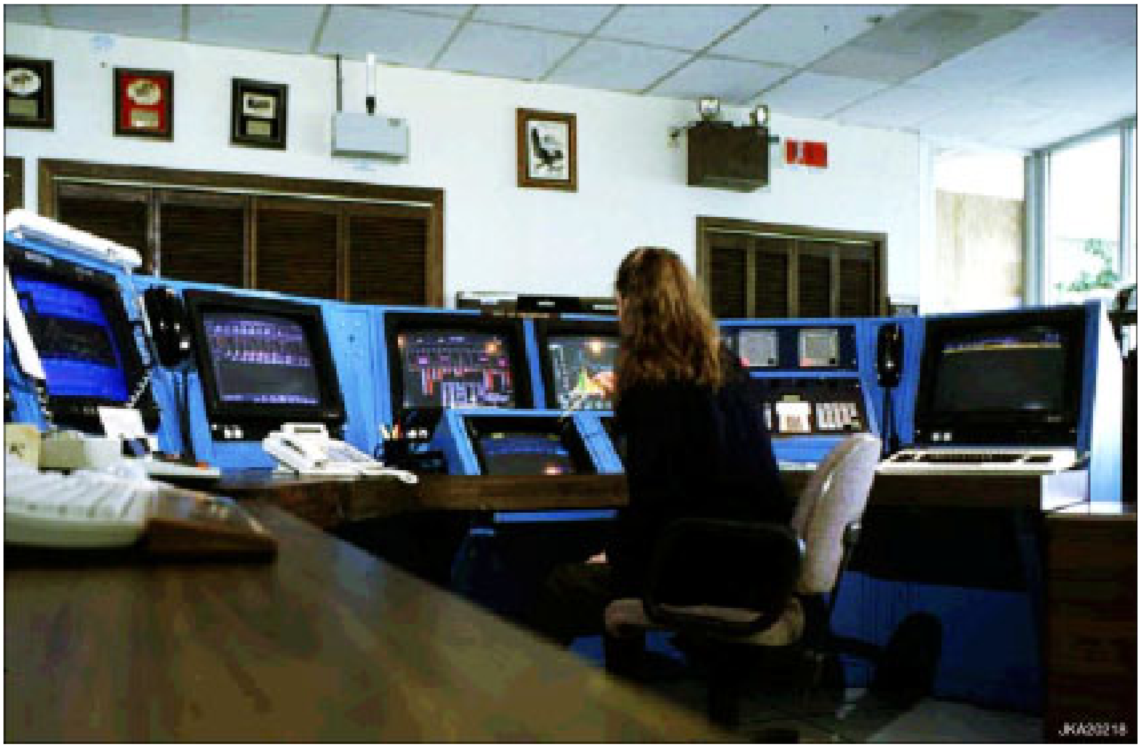

FIGURE 3.1-2 Operations Control Center at Valdez Marine Terminal (Source: TAPS Owners 2001a, Photo 2.1-3)

Automatic fire detection systems are installed throughout the pump station facilities. The main fire-alarm system at each station provides coverage in all buildings that are linked by the station hallway system. Fire suppression systems are automatically activated when a fire has been detected. Pump station fire panels normally operate in automatic mode, which allows all actions to occur expeditiously. Actions can also be initiated manually at the fire control panel or at the local fire alarm stations. Automatic actions will also occur when the amount of hydrocarbon gases in an area reaches threshold levels (TAPS Owners 2001b).

Halon is the primary fire retardant agent used in buildings where flammable hydrocarbons may be found. It can be discharged automatically by ultraviolet (UV) detectors, thermal detectors, or by a hazardous atmosphere detection system. Manual discharge could be accomplished either by pull stations in the hallways or by firing switches on the fire control panel. The aqueous film forming foam (AFFF) system serves as a backup to the Halon system (Technica, Inc. 1991).

All pump stations have at least one fire truck, with the following extinguishing agents on board: water, foam, and purple K dry chemical powder. Hose stations and portable fire extinguishers are located throughout the pump stations (Technical, Inc. 1991). Some of the personnel at each pump station also serve on the Emergency Response Team for their station. They undergo periodic training to fulfill this duty. Table 3.1-5 summarizes the various aspects of the TAPS Fire Protection Response Teams.

Fire Management Relating to Wilderness Fires. Fires along the TAPS ROW are subject to the jurisdiction of various state or federal agencies. The Alaska Division of Forestry provides fire protection and management for the southern half of the ROW, while the northern part is covered primarily by the BLM's Alaska Fire Service with support from the U.S. Forest Service (TAPS Owners 2001a). The Alaska Interagency Fire Management Plan

TABLE 3.1-4 Features and Capabilities of the TAPS Control System

Aspects	Description
Computer type	Data General MV/20000, IBM RS/6000, various personal computers
Software programming functions	Data acquisition and control, alarm and data processing and display, hydraulic modeling, leak detection, historical archiving and reporting, and seismic evaluation
Points monitored along the pipeline	3,047 input points, 352 control points
Points monitored at the marine terminal	1,074 input points, 461 control points
Remote data acquisition units for pipeline	14 (one for each pump station plus the North Pole Metering Facility and Petro Star Refinery)[a]
Remote data acquisition units for Valdez Marine Terminal	24

[a] Data-gathering units are installed in all 11 pump stations. The communication facilities at North Pole metering facility and the Petro Star Refinery are now shut down.

Source: Based on APSC (2001a).

TABLE 3.1-5 Salient Aspects of the TAPS Fire Protection Response Teams

Aspect	Description
Fire response team	Pump station personnel or crew
Crew size	Varies per station, 10-15 APSC employees
Crew shifts	One week on/one week off or two weeks on/two weeks off, depending on the station; 12-hour workday
Fire system types	Halon, water, foam, dry chemical, wet chemical, and carbon dioxide
Fire trucks	One per station; pump stations associated with airports have additional designated airfield fire-fighting trucks
Fire training	Annual live fire training and monthly fire response training; airfield rescue fire training provided at stations associated with airports
Fire training facilities	Each station has fire extinguisher training props

Source: Based on APSC (2001a).

provides for a full range of suppression responses, from aggressive control that extinguishes the fire to surveillance. Suppression action is based on the fire's threat to human life, inhabited property, designated physical developments, structural resources such as those designated as National Historic Landmarks, natural resource high-value areas, and other high-value areas such as identified cultural and historical sites. Decisions on fire suppression are at the discretion of the state or federal agency involved. Fires that threaten pump stations receive more control action than most of the pipeline route (TAPS Owners 2001a).

Fire is a natural force in Interior Alaska, and most forest communities have been extensively influenced by recurring fire. Much debate has been engendered on the effect that fire suppression has on the natural fire cycle, which has been estimated to range from 50 to 200 years. Gabriel and Tande (1983) suggest that Alaska may still be in a "wilderness fire" stage and that fire suppression has had no pronounced effect on the natural fire cycle (TAPS Owners 2001a).

Oil Spill Emergency Response. APSC uses an Incident Command System that, in a response to an oil spill, transforms into a unified command with state officials from ADEC and federal officials from the EPA or U.S. Coast Guard. At each online pump station, APSC maintains a seven-member team of oil spill response personnel designated as the Initial Response Team (IRT). An IRT should be able to control a small-volume spill. Details on pertinent spill response actions are given in Section 4.1.4.

The TAPS is required to comply with the *TAPS Oil Discharge Prevention and Contingency Plan* (CP-35-1) approved every three years by multiple federal and state agencies. The plan covers the following: (1) equipment and resources and field training for spill responders; (2) electronic leak detection capabilities; (3) improved leak detection and leak prevention alarm systems for pump station tanks; (4) more than 220 sites along the pipeline ROW designated as oil spill equipment staging and deployment areas, and dedicated oil spill contingency plan buildings and equipment at each pump station; (5) mutual aid agreements with villages near the pipeline to use residents and equipment in the event of a spill; (6) 12 spill scenarios covering a variety of terrain, oil products, spill volumes, and seasonal conditions; and (7) aerial photographs of the pipeline to aid in spill response planning. Table 3.1-6 summarizes the spill response equipment available along the TAPS.

Security. Security for the TAPS is an issue of national importance. Elaborate security measures and plans involving numerous federal and state agencies are in place, are regularly updated, and are tested in joint exercises. The BLM has reviewed in detail these confidential plans and the various components of them, including overflights, remote camera surveillance, alarms (including leak detection systems), and other surveillance measures. The BLM is cognizant of them and is prepared to fully participate in planning and response activities, as appropriate. Opportunities to strengthen these measures will always be pursued diligently by the agencies involved.

Earthquake Monitoring System. The earthquake monitoring system processes seismic data to evaluate the severity of earthquake ground shaking along the pipeline route and to assess the potential for damage to the pipeline and supporting facilities. The system's most important objectives are to determine whether the pipeline should be shut down in response to an earthquake and to delineate inspection requirements for the affected portion of the route (TAPS Owners 2001b).

On the basis of preestablished criteria, the earthquake monitoring system will sound alarms, generate event reports, and describe recommended structural inspections and their locations. The system also maintains a historical database of event parameters for detailed analysis. An earthquake monitoring system has been part of the pipeline control system since start-up in 1977. The earthquake monitoring system consists of 11 remote digital strong-motion accelerograph (DSMA) stations located at PS 1, PS 4 through 12, and the Valdez Marine Terminal.

The DSMA stations use a network to share data among the various processes at each station and between stations. All stations sense and process ground-motion data and perform systemwide processing of data that are broadcast and shared with all other DSMAs. The central computer for the pipeline control system is also connected to the earthquake monitoring system network to retrieve information to create displays and alarms at the Pipeline Controller's console in the Valdez Marine Terminal OCC.

If an earthquake is detected, the DSMA switches into event mode and records the time histories for each of the three axes' measurements. Visual and audible alarms are activated, and event alarms are passed to the pipeline control system for display at the OCC. When the earthquake has ended, the DSMA switches to post-event mode and computes and stores event parameters that characterize earthquake severity.

Immediately after an earthquake, the earthquake monitoring system network distributes data from each affected DSMA so that all sites have data on the earthquake. Each

TABLE 3.1-6 TAPS Oil Spill Major Contingency Equipment

Category	Type/Description	Quantity
Vessels	Work barge with trailer	2
	River boat with trailer	13
	Airboat with trailer	11
	Boat without trailer	1
	Inflatable rafts	13
	Anchors	30
	Personal flotation devices	>250
	1/2-in. line	42,000 ft
Boom	Fire resistant boom	2,156 ft
	Protected-water boom	33,400 ft
	Palletized boom	32
Skimmers	Weir skimmers	22
	Manta bay skimmers	12
	Skimpack skimmers	11
	Oleophilic skimmers	27
Storage	Tanks/bladders	961,300 gal
	Drums (55-gal)	220
Miscellaneous	Mobile camp	1
	Communication modules	2
	Portable shelters	24
	Portable generators	24
	Helicopters	4
	Helitorch	1
	Push trucks	3
	Light vehicles	59
	Tractors, semis	11
	Fork lifts	12
	Backhoes	5
	Vacuum trucks	11
	Space heaters	22
	Light tower/plant	22
	Pressure washers	11

Source: Based on TAPS Owners (2001a); APSC (2001b).

DSMA processes the data to determine the severity of ground shaking along the pipeline route. The computer generates graphs and printed reports that assist the Pipeline Controller in decision making and guide post-earthquake inspection efforts. A key report section compares computed earthquake parameters to design limits. If the shaken area requires an inspection, a checklist is generated to guide the field response teams.

The Pipeline Controllers determine the need for pipeline shutdown and field inspection by reviewing earthquake monitoring system-generated alarm displays and other control system information. Shutdowns are initiated manually by the Pipeline Controller; however, a shutdown sequence will occur automatically if system alarms are not acknowledged at the OCC within a preset period.

3.1.2.1.7 Other Support Services and Facilities. Other facilities that are scattered along the pipeline and used to support the operation of the pipeline include airstrips, material storage, and disposal sites.

Airstrips. Currently, two permanent airfields directly support the operation of the TAPS. Galbraith Lake (near PS 4) and Prospect (near PS 5) Airfields. Galbraith Lake is a 5,200-ft long runway situated on federal land but operated under state lease. Prospect is a 5,000-ft airfield also on federal land and subject to state lease. These two airfields are part of about 14 temporary airstrips used during the construction of the TAPS (TAPS Owners 2001a). Several other active airstrips are also utilized by the TAPS. Map 3.1-1 shows the locations of various airstrips along the TAPS ROW. Additional details on the State's and the TAPS-related aviation transportation network are provided in Section 3.15.1.

Operations Material Sites and Disposal Sites. Mineral mining sites and disposal sites are located at numerous points along the TAPS ROW in support of general pipeline maintenance and handling of materials. Operations material sites usually contain gravel and other natural materials (sand, bedrock, etc.) intended primarily for use as refill materials for various excavation works associated with pipeline maintenance as well as for repair of workpads and access roads. Currently, 69 active operations material sites are located along the TAPS ROW on either federal or state lands (TAPS Owners 2001a). Disposal sites are essential for handling routine and nonroutine wastes generated as part of the TAPS operation. Disposal sites include landfills, incinerators, and other solid and liquid waste disposal sites (APSC 2000a). A detailed discussion of the operation of disposal sites, including their specific locations along the TAPS ROW, is presented in Section 3.16 (Waste Management).

3.1.2.1.8 Valdez Marine Terminal. The Valdez Marine Terminal is the southern terminus of the TAPS and is located on ice-free Port Valdez at the northeastern end of Prince William Sound. The Valdez Marine Terminal site occupies approximately 1,000 acres on the southern shore of Port Valdez, extending from sea level to 538 ft in elevation at the West Tank Farm (Figure 3.1-3).

Table 3.1-7 summarizes the facilities located at the Valdez Marine Terminal, where oil is loaded onto tankers for shipment to markets. The terminal has storage facilities for 9.18 million bbl of crude and four loading berths (Berths 1, 3, 4, and 5; Berth 2 was never built). Berths 4 and 5 have vapor-control systems and will be the primary loading berths in the future. Berths 1 and 3 are not vapor controlled but remain available for use in special situations. Future use of Berths 1 and 3 is under study.

Crude oil arriving at the Valdez Marine Terminal is measured at the East Metering Building and then transferred to storage tanks or can be directly loaded onto tankers. Ballast water from incoming tankers is piped to the BWTF for treatment before discharge to Port Valdez, in accordance with state and federal permits. Vapor from tankers and crude storage tanks is piped to the vapor recovery system. Approximately 350 people work at the Valdez Marine Terminal (TAPS Owners 2001b), which also houses the OCC for the TAPS.

As mentioned in Section 3.1.2.1.5 (Communication System), the OCC is key to pipeline operations and control. Pipeline controllers at the OCC monitor and control the

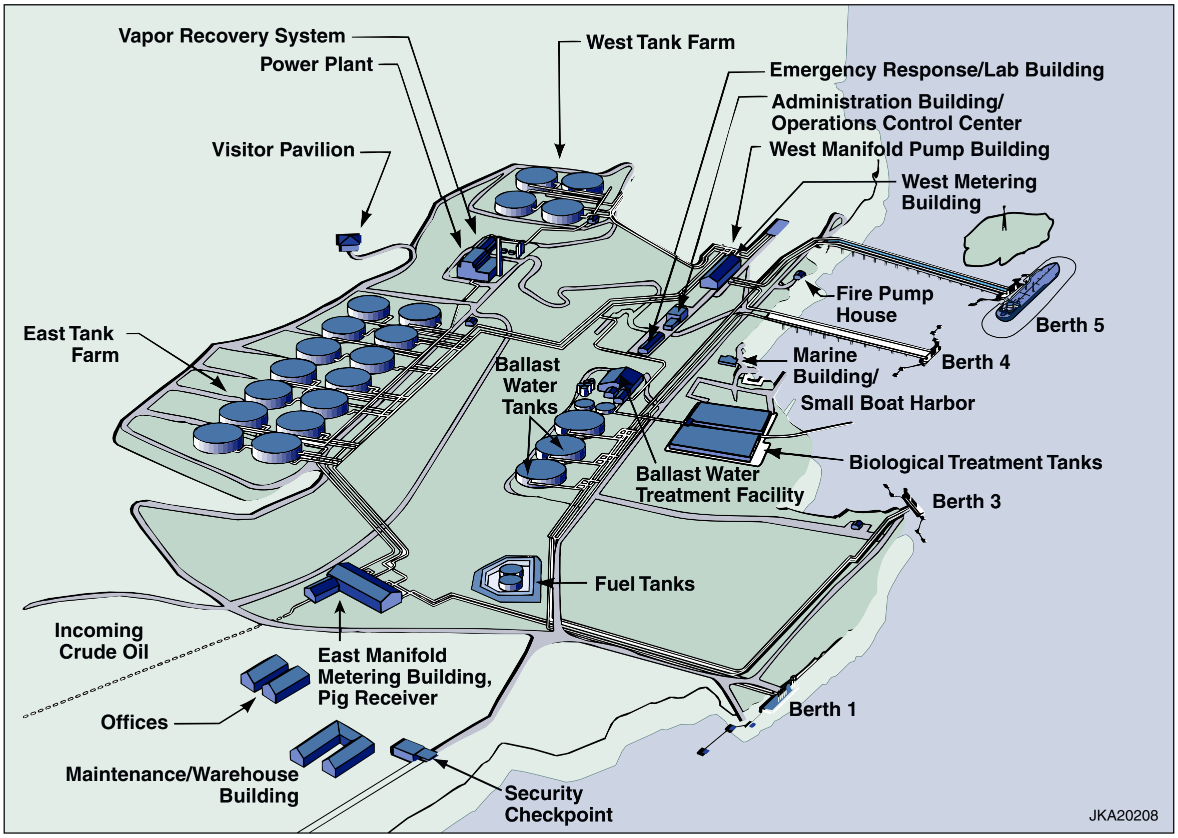

FIGURE 3.1-3 Valdez Marine Terminal (Source: TAPS Owners 2001a, Figure 2.1-5)

pipeline to ensure safe and reliable operation. Central to OCC is the SCADA host computer and associated equipment. The host computer interfaces between the OCC controllers (people) and computers at remote locations such as pump stations and RGVs.

Water Treatment and Vapor Control. The BWTF processes ballast water off-loaded from incoming tanker ships and wastewater from a variety of waste streams collected in the Valdez Marine Terminal industrial wastewater sewer system.

The vapor control system for the Valdez Marine Terminal controls atmospheric emissions of crude oil vapors from storage tanks and from the tankers during loading. The vapor control system also provides inert (oxygen-deficient) vapor to the crude oil storage tanks, thus maintaining a safe operating condition by preventing the hydrocarbon vapor in the storage tanks from becoming combustible. Because a fire cannot sustain itself without oxygen, limiting the amount of oxygen in the tanks is a very effective fire prevention measure.

Electrical System. The Valdez Marine Terminal's primary power plant facilities include three steam boilers coupled to three condensing steam turbine generators, each with a rated output of 12.5 MW (total of 37.5 MW). Two generators with a total capacity of 2.8 MW serve as backup (secondary) power sources. For essential control equipment, four uninterruptible power supply systems supported by a 125-volt battery bank are deployed (APSC 2001a).

Potable Water Use. The Valdez Marine Terminal operates continually; however, no living quarters are provided for the staff at the terminal. Most of the staff reside in Valdez and use municipal water supplies as a principal source of potable water. As a result, potable water use at the terminal is generally less than

TABLE 3.1-7 Summary of Facilities at Valdez Marine Terminal

Facility	Function
Operations Control Center	This center controls the entire pipeline, directs the flow of oil to the tank farms and to vessels at the berths, and monitors the operation of the ballast water treatment system and the tanker loading berths.
18 crude oil holding tanks	Four tanks are at West Tank Farm, and 14 are at East Tank Farm. Each tank has a 510,000-bbl capacity; total capacity is 9.18 million bbl. All tanks are within secondary containment and are connected to a vapor control system.
Two manifold/metering buildings	These measure incoming oil from the pipeline (East Manifold/Metering Building). Pressure relief valves prevent incoming oil pressure from exceeding design limits and divert oil to relief tanks, if necessary. Oil is routed to berth meters for loading onto tankers or into storage tanks (East Metering). Oil loaded onto tankers is measured.
Four tanker loading berths (1, 3, 4, and 5; 2 was never built)	Berth 1 is a floating berth with up to 80,000 bbl/h capacity. The other three berths are fixed berths with up to 110,000 bbl/h capacity each. Two loading arms at Berth 1 can also off-load fuel oil from tankers. Berths 4 and 5 have tanker vapor collection systems.
Ballast water treatment system	All oily water collected in the Valdez Marine Terminal, including ballast water, is processed through this system; it handles an average of 400,000 bbl/d. It recovers an average of 2,000 bbl/d of oil; recovered oil is returned to the crude oil system. After treatment, ballast water is discharged into Port Valdez.
Major support systems	These are power generation and other utility systems; systems for maintenance, security, materials receiving and control, emergency response, and tanker escort; harbor facilities for support vessels; and systems for tanker and tank farm vapor recovery.

Source: Based on TAPS Owners (2001a).

25 gal per person per day (TAPS Owners 2001a).

Fire Protection. The Valdez Marine Terminal is equipped with fire detection and suppression systems. Suppression systems include portable fire extinguishers, water and foam systems, Halon, and carbon dioxide (CO_2). The Valdez Marine Terminal has at least four fire trucks and six tugboats equipped with fire fighting equipment. Regular training of personnel is also part of the fire protection program at the terminal (APSC 2001a).

Spill Response. The Valdez Marine Terminal is also equipped with spill response equipment to handle potential spills. In addition, the terminal deploys a 10-person spill response team on continuous duty. Major spill equipment includes five self-propelled skimmers, several workboats, and about 6 mi of oil boom. The Valdez Marine Terminal is required to adhere closely with the rules set forth in APSC's ADEC-approved *Valdez Marine Oil Discharge and Prevention Plan (CP-35-2)* (APSC 2001c).

Other Support Systems. The Valdez Marine Terminal's other support systems include maintenance, security, materials receiving and control, and other utility systems (e.g., telecommunication and industrial water).

3.1.2.2 Infrastructures for Other Components of the Alaska North Shore Oil Production and Transportation System

Support infrastructures under this category pertain to related aspects outside the TAPS ROW but are an integral part of the overall operation of the TAPS. These include the North Slope and Prince William Sound.

3.1.2.2.1 Marine Transportation System. Currently, a fleet of 26 tankers — 3 with double hulls and 13 with double sides — serves the Valdez Marine Terminal. However, the composition of the fleet must change in the future to stay in compliance with the Oil Pollution Act of 1990. Beginning in 2014, the fleet will consist entirely of double-hulled tankers. Double-hulled tankers offer environmental advantages in terms of a reduced likelihood and reduced volumes of oil spills. The number of tankers will decrease substantially from the present 26 to 8 to 10 tankers by 2020. Reduced tanker transit, use of double-hulled tankers, and other improvements will substantially reduce the annual probabilities of accident and oil spills (TAPS Owners 2001a).

Since the Exxon Valdez spill in 1989, significant improvements have been made in spill prevention and response capability for Prince William Sound, including the creation of APSC's Ship Escort/Response Vessel System (SERVS). SERVS is responsible for the safe transit of oil tankers from the Valdez Marine Terminal to approximately 17 mi outside of Hinchinbrook Entrance. Its duties are primarily related to spill prevention and spill response. A study by Det Norske Veritas et al. (1996), which did not consider future benefits of double-hulled tankers, estimated that the risk of a large oil spill was reduced by 75% as a result of the creation of SERVS and related measures.

SERVS has nine vessels assigned to escorting, docking, and response duties, and at least two escort vessels are required for each laden tanker transiting the sound. Tethered escort is required through the Valdez Narrows. In the northern sound, the escort vessel is within one quarter nautical mile of the tanker when not tethered. In the central sound, a conventional tug or a prevention and response tug maintains close escort, while the second escort vessel goes on sentinel duty to provide response coverage to a larger area. A vessel is on sentinel duty in the Hinchinbrook Entrance area (Map 3.1-2). A third escort vessel may be added, depending on weather conditions. Additional vessels are available if needed for a response or to fill in during scheduled and unscheduled maintenance.

In addition, APSC spill response equipment includes more than 70 oil skimming systems, seven storage barges, and 35 mi of containment boom. Equipment is stationed in Port Valdez and at five response centers across Prince William Sound. In addition, APSC has contracts with 300 fishing vessel owners to respond to a potential spill. Fishermen also provide local knowledge to help identify at-risk areas and provide protection methods.

Other improvements made in the wake of the Exxon Valdez oil spill include (1) regular oil spill drills and training exercises at a variety of locations along the pipeline and in Prince William Sound and (2) formation of the Prince William Sound Regional Citizens Advisory Council in accordance with the Oil Pollution Act of 1990. This citizens group participated in the design of APSC's new system based on prevention and readiness for response.

3.1.2.2.2 North Slope. The TAPS was built for the specific purpose of transporting crude oil produced from the North Slope region to the Valdez Marine Terminal. The North Slope is a gently sloping to flat, treeless plain, covering about 88,000 mi^2, extending from the foothills of the Brooks Range to the Beaufort Sea (Arctic Ocean). It encompasses the coastal plain portion of the Arctic National Wildlife Refuge, the westernmost boundary of which is located about 90 mi east of the Prudhoe Bay oil field. Prudhoe Bay is also used generally to describe the oil exploration and development province on Alaska's North Slope, which includes more than a dozen separate oil fields spread across several hundred square miles of land in the vicinity of Prudhoe Bay.

Modern petroleum exploration and development on the North Slope began in the late 1950s and continued for more than 20 years. (Some of the earliest drillings and explorations in the early 1900s were conducted by the Navy and U.S. Geological Survey.) Many unsuccessful exploratory wells were drilled, and many companies gave up the search before the Prudhoe Bay discovery well was drilled by Atlantic Richfield Company and Humble Oil and Refining Company in 1967. A confirmation well the following year proved the discovery of the large reservoir of oil (23 billion bbl) and gas (26 trillion ft^3) (TAPS Owners 2001a; APSC 2001a). Field development began in 1969 (TAPS Owners 2001a).

Map 3.1-3 shows the distribution of producing units presently operating on the North Slope. Oil fields are legally organized into producing units, which customarily group all of the owners of the leased area over a petroleum accumulation to avoid conflicts over extraction and ownership of the resource. The Prudhoe Bay Unit, discovered in 1967, was the first oil-producing area on the North Slope. This unit began production as soon as the TAPS was opened in 1977. Recent developments in this unit include the Lisburne (2 billion bbl), Point McIntyre (800 million bbl), and Niakuk (reserves figure not available) oil fields, which began production in 1986, 1993, and 1994, respectively (TAPS Owners 2001a).

The Kuparuk River Unit (5.3 billion bbl), the second-oldest oil-producing area in the region, began production in 1981. In 2000, production from Kuparuk averaged 236,000 bbl/d. A seawater treatment plant and waterflooding facility, along with a 700-ft dock, were established at Oliktok Point in 1985 to support this and potentially other units (e.g., Alpine). Production from the Milne Point Unit (100 million bbl) began in 1985, establishing it as the third major oil field in the region. Production from this unit was suspended in early 1987 because of unfavorable oil prices; the unit resumed production in 1989 (TAPS Owners 2001a).

Endicott (350 million bbl) was the fourth producing oil field on the North Slope, beginning production in 1987. It was the first off-shore production facility in the North American Arctic. Built in the winter of 1984 to 1985, Endicott's two artificial islands were connected by a curved, 3.7-mi-long, gravel-fill causeway; this segment is connected to shore by a 1.6-mi-long causeway, which contains three breaches for fish passage (TAPS Owners 2001a).

The Badami, Alpine, and Northstar oil fields are the most recent developments reflecting the most modern technology. The Badami and Alpine fields began production in 1998 and 1999, respectively. The Northstar fields began production in 2001. Collectively, the oil fields of the Prudhoe Bay region were, and still are, the largest oil and natural gas discoveries in the history of North American petroleum exploration.

3.2 Physiography and Geology

The TAPS crosses a wide variety of terrains, including three mountain ranges, several intermontane basins, and an arctic coastal plain. The land features along the ROW comprise 10 physiographic provinces (Wahrhaftig 1965) (Map 3.2-1 and Table 3.2-1). The characteristics of each province are briefly summarized in the following sections. Because the ROW is narrow and the TAPS facilities are on or very near the ground surface, the descriptions emphasize the surface landforms and the near-surface geology. For areas where bedrock is exposed, the description summarizes general rock types and geologic ages. However, most of the pipeline is on unconsolidated sediments of Quaternary age (see Table 3.2-2 for geologic time line). The surficial geology rather than bedrock geology is described for such areas.

The threat posed to the pipeline by volcanic activity is not considered significant. The volcanic field closest to the pipeline is in the Wrangell Mountains to the east. The volcanic field is characterized by nonexplosive summit calderas (craters) and is separated from the pipeline by the Copper River Valley. The closest crater (Drum Volcano) is about 20 mi east of the pipeline.

The following subsections provide background physiographic and geologic information for the TAPS. The impacts of TAPS construction on physiography and geology were negligible and local.

Physiography and Geology

Physiography is the physical geography of an area, or the description of its physical features.

A *physiographic province* is a region in which the landforms are similar in geological structure and differ significantly from the landform patterns in adjacent regions.

Geology deals with the materials that make up the planet earth and the processes that act on them.

3.2.1 Arctic Coastal Plain (MP 0–60)

The Arctic Coastal Plain extends from the Beaufort Sea south to the Arctic Foothills. It is a smooth plain, rising gradually for 60 mi to the south to an elevation of about 600 ft (Wahrhaftig 1965). This physiographic province is characterized by a network of polygonal ground and oriented thaw lakes in low-lying areas (see Table 3.2-3 for definitions of special terms). Locally, pingos form in nearly level, low-lying ground on drained or sediment-filled ponds or lakes (BLM and Alaska Natural History Association 1993). Bedrock hills composed of poorly consolidated shale and sandstone of Tertiary age are scattered on the smooth plain. The Sagavanirktok River that drains this area is braided.

Through most of this province, the pipeline is buried in the floodplain of the Sagavanirktok River (MP 12–60). The river has many shallow water channels. Sheet ice from successive overflows develops on various sections of the floodplain in winter (TAPS Owners 2001a). The first 12 mi of the pipeline (MP 0–12) crosses an area rich in polygonal ground and thaw lakes developed on marine, fluvial, eolian, and lacustrine sediments of Quaternary age (Kreig and Reger 1982).

3.2.2 Arctic Foothills (MP 60–140)

The Arctic Foothills Province is a generally hilly area formed of glacial moraines and bedrock hills of sandstone, siltstone, and shale of Cretaceous age (BLM and Alaska Natural History Association 1993). The area is drained primarily by the north-flowing Sagavanirktok River. This river is characterized by a meandering channel in its upper reach (MP 85–110) and a braided river system in the lower reach (MP 60–85).

TABLE 3.2-1 Physiographic Provinces Crossed by the TAPS ROW

Province	Extent of Pipeline Crossing[a]
Arctic Coastal Plain	60 miles (MP 0–60)
Arctic Foothills	80 miles (MP 60–140)
Brooks Range	97 miles (MP 140–237)
Chandalar Ridge and Lowland Section	20 miles (MP 237–257)
Kokrine-Hodzana Highlands and Yukon-Tanana Uplands	258 miles (MP 257–515)
Tanana Lowland	45 miles (MP 515–560)
Alaska Range and Northern Foothills	50 miles (MP 560–610)
Gulkana Upland	35 miles (MP 610–645)
Copper River Lowland	75 miles (MP 645–720)
Chugach Mountains	80 miles (MP 720–800)

[a] MP = Milepost. Milepost 0 is at the start of the pipeline on the North Slope; MP 800 is at the end of the pipeline at the Valdez Marine Terminal (Port of Valdez).

TABLE 3.2-2 Geologic Time Line

Era/Period	Time Period
Cenozoic Era	Present to 65 million years ago (MYA)
Quaternary Period	Present to 1.8 MYA
Holocene Epoch	Present to 8,000 years ago
Pleistocene Epoch	8,000 years ago – 1.8 MYA
Tertiary Period	1.8 – 65 MYA
Mesozoic Era	65 – 248 MYA
Cretaceous Period	65 – 145 MYA
Jurassic Period	145 – 210 MYA
Triassic Period	210 – 248 MYA
Paleozoic Era	248 – 570 MYA
Permian Period	248 – 290 MYA
Pennsylvanian Period	290 – 330 MYA
Mississippian Period	330 – 365 MYA
Devonian Period	365 – 408 MYA
Silurian Period	408 – 430 MYA
Ordovician Period	430 – 500 MYA
Cambrian Period	500 – 570 MYA
Proterozoic Era	570 – 2,500 MYA

Source: USGS (2001a).

TABLE 3.2-3 Special Terms Used in Section 3.2

Term	Definition
Alluvial fan	A gently sloping mass of alluvium deposited where a stream issues from a narrow canyon onto a plain or valley floor. Viewed from above, it has the shape of an open fan, the apex being at the valley mouth.
Alluvium	Unconsolidated material deposited by a stream or river in relative recent geologic time.
Braided river	A river with an interlacing network of channels.
Cirque	A semicircular recess with steep walls located at the head of a mountain valley.
Colluvial	Pertaining to or composed of colluvium (i.e., loose deposits of rock, usually at the foot of a slope or cliff and brought there under the influence of gravity [a process known as mass wasting]).
Eolian	Pertaining to the wind or deposits that have been laid down by the wind.
Fluvial	Of or pertaining to rivers or to deposits laid down by rivers.
Glaciofluvial	Pertaining to meltwater streams flowing from glaciers or to the deposits made by such streams.
Hanging valley	A glacial valley whose mouth is at a relatively high level on the steep side of a larger glacial valley.
Lacustrine	Pertaining to or produced by a lake or lakes, e.g., lacustrine sands.
Moraine	A mound, ridge, or plain material deposited by the direct action of glacial ice.
Oriented thaw lake	A lake or pond in a permafrost area formed by the thawing of ground ice and enlarged by wind currents.
Outwash fan	A fan-shaped body of sediments deposited by streams of a melting glacier.
Permafrost	Ground that has been frozen for two or (often) more consecutive years (see Section 3.3).
Pingo	A rounded or conical mound containing ice at its core; raised in part by hydrostatic pressure of water within or below the permafrost.
Polygonal ground	A form of patterned ground outlined by cracks that are filled with ice wedges and produced by frost action.
Talus	Accumulation of rock debris at the base of cliffs.
Thermokarst lake	A lake formed in a depression by the thawing of ground ice in soil above permafrost.
Till	Unstratified mixture of clay, silt, sand, gravel, and boulders deposited directly by a glacier without reworking by meltwater.

The pipeline follows the valley of the Sagavanirktok River from MP 60 to 90 and is mostly buried in the coarse-grained floodplain of the river (TAPS Owners 2001a). Sedimentary rocks of Cretaceous age are exposed and form hilly areas near the flanks of the river. To the south (MP 90-140), the pipeline traverses a series of glacial moraines until it reaches Galbraith Lake. Tilted, bedded sandstone, siltstone, and clay shale of Cretaceous age are exposed in scattered bedrock hills near the ROW (e.g., Slope Mountain near MP 115) (BLM and Alaska Natural History Association 1993).

3.2.3 Brooks Range (MP 140–237)

The Brooks Range Province contains rugged glaciated east-west trending mountains. It rises from the Arctic Foothills to elevations of about 8,000 ft in the northern part. The elevations in the southern part range from 4,000 to 6,000 ft (Wahrhaftig 1965). Erosional landforms associated with alpine glaciers, such as cirques and U-shaped valleys, are common in the mountains. Talus slopes, alluvial fans, moraines, and outwash fans are well developed at the base of steep slopes of valleys and cirques.

The drainages in the northern part of the mountains discharge to the Arctic Ocean, and the drainages in the southern part discharge to the Bering Sea. Most of the major drainages flow in U-shaped valleys that were scoured by Pleistocene glaciers.

The bedrock in the Brooks Range includes three belts. Folded and thrusted Paleozoic and Mesozoic sedimentary rocks are exposed in the northern flank of the range, deformed Paleozoic metamorphic rocks occur in the central Brooks Range, and Late Proterozoic to Paleozoic metamorphic rocks occur in the southern Brooks Range (Moore et al. 1994).

The pipeline follows the U-shaped valley of the Atigun River from Galbraith Lake to the Continental Divide (MP 166) and then follows the valleys of the Dietrich and Middle Fork Koyukuk Rivers to Coldfoot (MP 237) before entering the Chandalar Ridge and Lowland Province. Except near the Continental Divide, where bedrock units are exposed, the surficial deposits are of fluvial, colluvial, glacial, and glaciofluvial origin in the valleys.

3.2.4 Chandalar Ridge and Lowland Section (MP 237–257)

Near the southern end of the Alaska Range, the pipeline enters the Chandalar Ridge and Lowland Section (MP 237-257) near Coldfoot (MP 237). This section consists of low ridges and lowlands. The pipeline follows the floodplain of the Middle Fork Koyukuk River, which cuts across a low mountain ridge, and crosses the lowlands drained by the South Fork Koyukuk River (Wahrhaftig 1965). The lowlands are underlain by Quaternary unconsolidated deposits. Late Paleozoic and Mesozoic igneous rocks (both volcanic and intrusive) are exposed on the ridges (BLM and Alaska Natural History Association 1993). The South Fork Koyukuk River marks the location of the South Fork Fault

Rock Types

The rocks that form the earth's solid crust are of three basic types: sedimentary, igneous, and metamorphic.

Sedimentary rocks: Rocks formed by consolidation of loose sediment that has accumulated in layers through deposition by wind, water, or ice. Sandstone is an example.

Igneous rocks: Rocks formed by the solidification of molten magma. Examples are *volcanics* (rocks formed near the earth's surface by the rapid cooling of molten magma from a volcano) and *intrusives* (formed when molten material solidified deep in the earth). Examples are basalt (a volcanic) and granite (an intrusive).

Metamorphic rocks: Rocks formed from preexisting rocks by mineralogical, structural, and chemical changes in response to extreme changes in temperature, pressure, and shearing stress. Metamorphism occurs deep in the earth's crust, below the zone of weathering and sedimentation. Metamorphic rocks are sometimes referred to simply as *metamorphics.* An example is slate.

that separates this section from the Kokrine-Hodzana Highlands Physiographic Province to the south. The pipeline in this section is located in the floodplain of the Middle Fork Koyukuk River, except for the last 5 mi (MP 252–257), where it is in the valley bottom of the South Fork Koyukuk River.

3.2.5 Kokrine-Hodzana Highlands and Yukon-Tanana Uplands (MP 257–515)

The Kokrine-Hodzana Highlands (MP 257–377) consist of rounded hills rising to 2,000 to 4,000 ft and extending from MP 257 to the Hess River, which marks the Rampart Trough (Wahrhaftig 1965). The highlands have not been glaciated and are commonly covered with colluvial and eolian deposits. The low-lying areas are covered with retransported eolian deposits. The northern part of the province is composed primarily of Proterozoic through Paleozoic metamorphic rock, with some igneous intrusions of Cretaceous age (BLM and Alaska Natural History Association 1993). The southern part consists predominantly of fine-grained, massive volcanics and relatively thin beds of fossilized chert of Late Paleozoic to Middle Mesozoic ages (BLM and Alaska Natural History Association 1993). The Yukon and Koyukuk Rivers and their tributaries are major systems draining the highlands.

The Rampart Trough near the Hess River (MP 257) is a narrow depression. It was created by erosion along a tightly folded belt of soft coal-bearing rocks of Tertiary age. Topographically, it is 500 to 2,500 ft below the Kokrine-Hodzana Highlands and the Yukon-Tanana Uplands on either side (Wahrhaftig 1965).

South of the Rampart Trough to Tanana River (MP 515), the Yukon-Tanana Uplands are characterized by rounded hills with gentle side slopes. The hills, at elevations of 1,500 to 3,000 ft, rise 500 to 1,500 ft above adjacent valleys. The valleys are generally a quarter to a half mile wide within a few miles of headwaters and are filled with alluvium. Most streams are tributaries of the Yukon and the Tanana Rivers (Wahrhaftig 1965). They flow either northeast to the Yukon River or southeast to the Tanana River. The two rivers supply the silt that is deposited on the top of the hills by wind. The bedrock in the uplands contains metamorphic rocks of Paleozoic age (Foster et al. 1994).

From the South Fork Koyukuk River to the Jim River (MP 277), the pipeline follows the valleys of local streams and the Jim River. It then crosses a series of hills and lowlands. Several major lowlands are drained by the Yukon River, Hess Creek, Tolovana River, Tatalina River, Chatnika River, Chena River, and Salcha River. These river valleys contain extensive Quaternary fluvial and eolian sediments.

3.2.6 Tanana Lowland (MP 515–560)

The Tanana Lowland is a broad depression between the Yukon-Tanana Upland on the north and the Alaska Range on the south. Coalescing outwash fans from the Alaska Range are present in the lowland. Near the heads of the fans, rivers, including the Delta River, flow in broad terraced valleys that can be up to several hundred feet deep. Glacial moraines lie on the upper end of some fans (Wahrhaftig 1965). Thermokarst lakes are well developed on the terraces and the low-lying areas away from the heads of the fans. The Delta and Tanana Rivers are two major rivers draining in this province.

The pipeline is in the floodplains of the Tanana and Delta rivers until MP 550 to 560, where it is on the outwash fan of the Delta River.

3.2.7 Northern Foothills and Alaska Range (MP 560–610)

The Northern Foothills consist of a belt of flat-topped east-trending hills (Wahrhaftig 1965) that are separated by lowlands composed of moraines or outwash plains deposited by the glaciers from the Alaska Range. The hills are largely unglaciated. Thermokarst lakes develop in the lowlands.

The Alaska Range is characterized by rugged glaciated terrain, 6,000 to 9,000 ft in elevation (Wahrhaftig 1965). Landforms associated with Alpine glaciers are common, including cirques, U-shaped valleys, moraines, outwash fans, and alluvial fans. The pipeline crosses several faults, including the Denali Fault and the Hines Creek Fault (or McGinnis Glacier Fault), near MP 589 (Nokleberg et al. 1994). North of the Denali Fault, metamorphic rock is exposed near the pipeline. Late Paleozoic marine sedimentary and volcaniclastic rocks are exposed south of the Denali Fault (TAPS Owners 2001a). Most of the glacier-fed streams drain to the Tanana River to the north.

The pipeline passes the Northern Foothills near the Donnelly Dome and enters the valleys of the Delta River and Phelan Creek. Several alpine glaciers, such as Black Rapids, Castner, and Cantwell, come within 1 to 2 mi of the pipeline. These glaciers have been retreating during the last few decades. The pipeline is situated on the Pleistocene moraines on the side of the U-shaped valley and the floodplain of the Delta River and Phelan Creek. The valley and the floodplain are underlain by glacial, colluvial, lacustrine, fluvial, and glaciofluvial deposits.

The Black Rapids Glacier (MP 579) and Castner Glacier (MP 587) are more than 1 mi from the pipeline. The Black Rapids Glacier made a rapid advance of 4 mi in 1937. However, both glaciers have been retreating since the pipeline was built (TAPS Owners 2001a). No proglacial lake is present in front of the Black Rapids and Castner Glaciers. Currently, none of the glaciers pose a threat to the pipeline.

3.2.8 Gulkana Upland (MP 610–645)

The Gulkana Upland is in the southern flank of the Alaska Range, elevated above the Copper River Lowland to the south. The upland is characterized by round east-west trending ridges and broad lowlands (Wahrhaftig 1965). From Isabel Pass (MP 610) to Hogan Hill (MP 645), the upland crossed by the pipeline contains moraines, outwash plains, and river terraces. Summit Lake and Paxson Lake adjacent to the pipeline are located in basins that were scoured by Pleistocene glaciers from the Alaska Range. Both lakes are fed by melted water from Gulkana Glacier. Small thermokarst lakes are common in this area.

Igneous and metamorphic bedrock of late Paleozoic and Mesozoic ages is exposed on the upland ridges (Nokleberg et al. 1994; Kreig and Reger 1982).

3.2.9 Copper River Lowland (MP 645–720)

The Copper River Lowland is bounded on the north by the Alaska Range, on the west by the Talkeetna Mountains, on the south by the Chugach Range, and on the east by the Wrangell Mountains. It is a relatively flat plain, 1,000 to 2,000 ft in elevation, trenched by the valleys of the Copper River and its tributaries (Wahrhaftig 1965). The relief of the valley can be as much as 500 ft. The central part of the lowland was occupied by Lake Atna, an ancient glacier-dam lake, during the Pleistocene (Hamilton 1994). Adjacent to the lowland, the terrain consists of hilly areas at the foothills of the Alaska Range on the north (the Gulkana Uplands) and the Chugach Range on the south.

From Hogan Hill (MP 645) to Willow Mountain (MP 710), the pipeline crosses the floor of the Copper River Lowland where ancient Lake Atna was located and then crosses the meandering Gulkana River. This area is underlain by complexly interlayered glacial, glaciofluvial, glaciolacustrine, colluvial, eolian, and fluvial deposits (Kreig and Reger 1982). The lake received sediments from glacier-fed streams from the mountains surrounding the Copper River Lowland during the Pleistocene. Pleistocene deposits can be more than 500 ft thick locally (TAPS Owners 2001a). Thermokarst ponds are common in the area.

From Willow Mountain (MP 710) to the Tonsina River crossing (MP 720), the pipeline crosses the margin of ancient Lake Atna that is dissected by the valley of the Tonsina River. Bedrock hills are common on the western side of the pipeline. The upper reach of the Tonsina River is in a U-shaped valley of glacial origin. This area contains complex alluvial fan, glaciofluvial, and glacial deposits. The bedrock on the hills consists of Paleozoic metamorphic rocks (Nokleberg et al. 1994) and Late Triassic to Early Cretaceous mélange (rock that includes fragments and blocks of all sizes, both native and exotic, embedded in a fragmented and fine-grained matrix) (McHugh Complex) (Plafker et al. 1994a).

3.2.10 Chugach Mountains (MP 720–800)

The Chugach Mountains Physiographic unit is characterized by rugged mountains 7,000 to 13,000 ft high along the coast of the Gulf of Alaska (Wahrhaftig 1965). The range has been heavily glaciated and is dominated by ridges, cirques, hanging glaciers, U-shaped valleys, and moraines. Major drainages, including the Tiekel, Tsaina, and Lowe Rivers, are situated in U-shaped valleys and are fed by the meltwater of glaciers.

The pipeline traverses the mountains between MP 720 and the Valdez Marine Terminal at MP 800 (TAPS Owners 2001a). It follows the valleys of the Tonsina, Little Tonsina, Tickel, Tsaina, and Lowe Rivers. Most of the pipeline is buried in the glacial, colluvial, and glaciofluvial deposits within the valleys. The valleys are flanked by outcrops of folded and faulted metamorphic and volcanic rocks of Late Cretaceous age (Plafker et al. 1994a). The Border Ranges Fault System crosses the northern part of this province, where sedimentary, metamorphic, and volcanic rocks are exposed.

The Worthington Glacier (MP 772) in the Chugach Mountains is about 0.4 mi from the pipeline. The glacier has been retreating over the last 25 years (TAPS Owners 2001a). A small pond is present in front of the glacier. Currently, the glacier does not pose a threat to the pipeline.

3.3 Soils and Permafrost

Soil and permafrost characteristics vary greatly along the 800 mi of the TAPS ROW. The origins of the soil range from weathered bedrock; glacial till and outwash; fluvial gravel, sand, silt and clay; lacustrine silt and clay; colluvium; to windblown silt and fine sand. During construction of the pipeline, borings were taken to evaluate the soil conditions along the ROW. Areas with soils prone to liquefaction (temporary transformation into a fluid mass) or landslides were avoided to the maximum extent possible.

Soil and Permafrost

Soil, as the term is used in this section, consists of the unconsolidated sediment on the surface of the ground. The type and origins of soil can vary greatly from place to place. Soil can have formed from the weathering of underlying rock or can have been deposited by various geologic processes.

Permafrost is ground that has been frozen for two or (often) more consecutive years. The depth, distribution, and characteristics of permafrost can vary greatly with distance and climatic influences.

Permafrost table is the top of the permafrost layer within soil or rock.

Active layer is the layer of soil above the permafrost table that is subject to seasonal freezing and thawing.

Permafrost is encountered extensively along the TAPS ROW (Map 3.2-1). Above the permafrost table, the soil will undergo seasonal freezing and thawing, producing an active layer. The depth of the active layer ranges from 1 ft to about 15 ft, depending on climate, vegetation cover, soil moisture content, slope aspect, depth of snow cover, and other factors (TAPS Owners 2001a). On the basis of its extent, permafrost is classified as continuous (covering from 90% to 100% of an area), discontinuous (50 to 90% coverage), sporadic (10 to 50% coverage), or isolated patches (up to 10% coverage) (Brown et al. 1997). Within each type of permafrost, the presence of frozen ground also depends on the presence of surface water bodies, disturbance of the ground, and the types of soils beneath the areas. Permafrost can occur in soils as well as bedrock. Generally, the ice content in the soil or bedrock is related to porosity and the moisture content of the material before the geologic material is frozen. Higher ice content occurs in finer grained soil than in coarser grained soil. The latter, in turn, has more ice content than fractured bedrock. Stability of the permafrost can be disrupted naturally (e.g., disturbance of vegetative ground cover by forest fires, drainage of lakes) or artificially. Climate warming can cause the degradation of permafrost (Thomas and Ferrell 1983; Klinger et al. 1983; Lawson 1986).

Evidence shows that regional warming has occurred over the last 25 years in Alaska (Osterkamp et al. 1998) and along the pipeline (see Section 3.12.7). The evidence includes the general retreat of glaciers in Alaska. Near the southern margin of the permafrost (MP 735–736), the permafrost table has lowered because of thawing (Michael Baker, Jr., Inc., 2001). In the southern end of the discontinuous permafrost zone, warming of the permafrost may have contributed to soil creep on slopes on the banks of Squirrel Creek (MP 715–720), Klutina Hill (MP 698), and Tazlina Hill (MP 687) (APSC 2000b). Degradation of permafrost has also been evidenced by continuous soil creep movement at various rates on slopes near Treasure Creek (MP 442) (APSC 2000b).

The degradation of permafrost could impact the integrity of the pipeline. Previously stable slopes on permafrost may become unstable, requiring that corrective maintenance be taken to stabilize the pipeline. Thawing in near-surface permafrost may also create a perched saturated zone over the deepening permafrost table. A thawed, loose granular soil deposit located below a groundwater table may become liquefied when it is subjected to sudden movements such as a strong earthquake. A detailed analysis of liquefaction potential along the TAPS is beyond the scope of this study. In the following paragraphs, the general soils and permafrost conditions along the pipeline are described for the individual physiographic provinces crossed by the ROW. The soil and the permafrost conditions in the 10 physiographic provinces along the ROW (Map 3.2-1) are described in Section 3.3.1, and the geomorphic processes related to soil and permafrost that may affect the stability of the pipeline are introduced in Section 3.3.2.

3.3.1 Descriptions of Soils and Permafrost Conditions by Physiographic Province

3.3.1.1 Arctic Coastal Plain (MP 0–60)

Typical soil in the Arctic Coastal Plain consists of several feet of ice-rich organic silt over coarse sands and gravels (TAPS Owners 2001a). Massive ground ice is widespread as vertical wedges, films, lenses, pore-fillings and segregated masses. Networks of ice wedges create a polygonal pattern on the ground surface. Along the braided Sagavanirktok River, unvegetated coarse-grained alluvium predominates on the active floodplain (BLM and Alaska Natural History Association 1993). Locally, the channel may be floored with sandy silt that represents former floodplain deposits overlying sand and gravel (Kreig and Reger 1982).

The coastal plain is underlain by thick, continuous permafrost with a temperature less than -7°C (Brown et al. 1997; Ferrians 1965). The permafrost is 670 to 2,150 ft thick (Péwé 1975). Frozen soil rich in ice occurs at a shallow depth. Polygonal ground and oriented lakes formed by the thawing of ice-rich soils characterize the low-lying areas. Beneath active river channels and lakes deeper than 6 ft, shallow thaw bulbs may be present (Kreig and Reger 1982).

3.3.1.2 Arctic Foothills (MP 60–140)

The moraines in the Arctic Foothills are composed of coarse-grained till deposits covered with organic windblown silt. Flat-floored upland depressions are partially filled with ice-rich peat and organic-rich slope wash deposits. Colluvium may partially fill thaw ponds and basins.

This province is underlain by continuous permafrost with a temperature of less than -7°C (Brown et al. 1997). Massive ground ice, up to 50% by volume (Kreig and Reger 1982), is common in the till. Old till generally contains more massive ground ice than young till. In the floodplain of the Sagavanirktok River, frozen ground occurs in the area away from the active channel, and discontinuously frozen ground is present adjacent to the active channel.

3.3.1.3 Brooks Range (MP 140–237)

Coarse-grained sand and gravel are believed to underlie the Atigun River and Dietrich River valleys that the pipeline traverses in the Brooks Range province. Windblown silt and sand may deposit in part of the Atigun River floodplain (Kreig and Reger 1982). Near the toe of steep slopes where alluvial fans, moraines, and talus are located, unsorted coarse to very coarse sediments are common. In previously glacier-scoured basins (e.g., Galbraith Lake), lacustrine silt and clay may overlie the more coarse-grained glaciofluvial and glacial deposits.

The Brooks Range province is underlain by continuous permafrost that has temperatures of -3° to -7°C. Ground ice content varies from up to 15% in fluvial silt and sand to 25 to 95% in lacustrine silt and clay near Galbraith Lake. In the river valleys, the vegetated areas of moraine, fan, and alluvial deposits are continuously frozen from the ground surface to more than 50 ft deep in the northern Brook Range (Kreig and Reger 1982). The depth to the permafrost increases with the grain size of the sediment and from north to the south. Permafrost is discontinuous in the alluvium beneath major active streams (Ferrians 1965; Kreig and Reger 1982).

3.3.1.4 Chandalar Ridge and Lowland Section (MP 237–257)

The soils of this section are strongly influenced by the several glacial advances in the area during the Pleistocene (see Table 3.2-2 for geologic time line). Generally, coarse-grained glacial and glaciofluvial sediments are distributed near the main channels of the Middle Fork Koyukuk and the South Fork Koyukuk Rivers. Away from the channels, the soils consist of fine-grained silt and clay of eolian and lacustrine origin over coarse-grained glacial till (Hamilton 1986).

This section is underlain by discontinuous permafrost with a temperature of -1° to -3°C (Brown et al. 1997). Permafrost is generally absent beneath the floodplains that are not vegetated. However, on old floodplains, permafrost can be 5 to 50 ft thick (Kreig and Reger 1982). Thaw lakes are well developed in the silt of the lowland between the Middle and the South Fork Koyukuk Rivers.

3.3.1.5 Kokrine-Hodzana Highlands and Yukon-Tanana Uplands (MP 257–515)

The soil types on the uplands depend on the distance from the Tanana and Yukon Rivers. In areas far from the rivers, residual soils from weathering bedrock are dominant on hilltops and are generally a few feet thick. Windblown sand and silt there are not significant. In the bottom of the valleys, soils can be more than 40 ft thick. The soils here are a combination of colluvium, fluvial sand and gravel, and weathered bedrock (Kreig and Reger 1982).

Windblown silt is very common on the uplands near the Tanana and the Yukon Rivers. The silt is transported from the floodplains of the rivers and deposited as a mantle over coarser textured subsoil. The thickness of the mantle declines with distance from the rivers and can be several tens of feet thick (Péwé 1975). Colluvium deposits, mostly composed of coarse-grained rock debris, and retransported silt from the hills are transported by mass wasting and become dominant on the lower hillsides away from the river valleys. The colluvium is estimated to be 1 to 18 ft thick. In the lowlands between the hills, silty colluvium from the hills is incorporated with organic matter (Péwé 1975; Péwé and Reger 1983).

The entire area is underlain by discontinuous permafrost with a temperature of -1° to -3°C (Brown et al. 1997). The depth to the frozen ground in general increases from north to south.

Near the main channels of major streams, frozen ground may be absent (Ferrians 1965). However, older floodplains and river terraces may have permafrost underneath as the permafrost aggrades into new floodplains because of the migration of the rivers. Near the Yukon and the Tanana Rivers, the thick windblown silt on the uplands can contain massive ice as thick as 55 ft (Kreig and Reger 1982). The lowlands between the uplands where retransported silts accumulate may have even thicker ice-rich soils.

In uplands where the windblown silt is thin or absent, the ice content in colluvium or weathered bedrock is substantially less. The soils in valley bottoms among the rounded hills are ice-rich and at a depth from the ground surface to more than 50 ft deep (Kreig and Reger 1982). Thermokarst lakes are common in the valley bottoms.

3.3.1.6 Tanana Lowland (MP 515–560)

Windblown silt and sand dominate the surface material in the area. The silt and sand were derived from the braided floodplains and outwash plains of the major rivers. Coarse-grained sand and gravel are common near the active channel of the main rivers. Coarse-grained glacial till is present below the elevated moraine on the Donnelly Dome (MP 560) (Péwé 1975; Kreig and Reger 1982).

The lowland and the terraces along the Delta River have shallow and discontinuous permafrost with a temperature of -1° to -3°C (Brown et al. 1997). The permafrost can be more than 50 ft thick, but frozen ground is absent under the river. Isolated masses of permafrost are present in areas with coarse-grained deposits (Ferrians 1965; Kreig and Reger 1982).

3.3.1.7 Northern Foothills and Alaska Range (MP 560–610)

Coarse-grained sediment is expected along most of the pipeline. Locally, fine-grained loess (a wind blown silty deposit) may cover some of the outwash deposits in the lowland of the Northern Foothills.

Permafrost is extensive in both the Northern Foothills and the Alaska Range, with a temperature of 0° to -1°C (Brown et al.1997). Ice-rich permafrost and thermokarst lakes develop in the lowland of the Northern Foothills where loess was deposited. Near the floodplains of the Delta and the Phelan Rivers, however, permafrost is present at much greater depth. Permafrost may be absent on south-facing slopes with coarse-texture soils.

3.3.1.8 Gulkana Upland (MP 610–645)

Coarse-grained gravels are common in the moraines, outwash terraces, and fluvial terraces on the Gulkana Upland. They were deposited by glaciers and glacier-fed streams from the Alaska Range on the north (Ferrians 1965). The coarse sediment may complexly interbed with finer lacustrine and fluvial sediments deposited from previous proglacial lakes and braided outwash streams. Windblown silt and sand may be present on the top of the coarse sediment.

The upland is underlain by discontinuous permafrost with a temperature of 0° to -1°C (Ferrians 1994). The coarse-grained gravel deposits along streams, as well as in areas near large water bodies (e.g., Summit and Paxson Lakes), are free of permafrost (Kreig and Reger 1982). The lowland between the ridges may contain fine-grained sediment and commonly has underlying permafrost, as demonstrated by small thermokarst ponds or lakes. On the uplands where the ice-rich sand and silt are present, thaw lakes may occur.

3.3.1.9 Copper River Lowland (MP 645–720)

Along the pipeline, the greater part of the lowland is primarily underlain by sand, silt, and clay of lacustrine (lake) origin. Near the lowland margin on the south near the Chugach Mountains, course-grained gravels become dominant. After ancient Lake Atna drained, permafrost developed into the Copper River Lowland. The fine-grained unconsolidated deposits in the lowland are perennially frozen from a few feet below the ground surface to depths of up to 200 ft (Ferrians 1965). The shallow permafrost creates an impermeable subsoil layer and promotes the formation of saturated soils and ponds in the floor of the lowland. Areas near highways and developed areas have a permafrost table from 10 to 20 ft below the surface (Ferrians 1965).

Along the pipeline, discontinuous permafrost with a temperature of 0° to -1°C (Brown et al. 1997) extends north of the Tazlina River (MP 687). Sporadic permafrost (up to 50% perennially frozen ground) covers an area south of the Tazlina River crossing (MP 687) south to Willow Mountain (MP 710) (Kreig and Reger 1982).

3.3.1.10 Chugach Mountains (MP 720–800)

The majority of the U-shaped valleys traversed by the pipeline are underlain by gravelly sediments. They were deposited by glaciers, glacial-fed streams, and rock slides.

In the north slope of the Chugach Mountains near the Tonsina River valley, patchy permafrost is encountered, with a temperature between 0° and -1°C. Near PS 12 (MP 735–736), where the patchy permafrost zone is about to end, previous permafrost has thawed since the pipeline was constructed. Permafrost is absent south of MP 736 (the Upper Tiekel River) (TAPS Owners 2001a).

3.3.2 Geomorphic Processes Related to Soils and Permafrost

Because of the wide variety of landforms, geologic material, and climates that occur along the 800-mi pipeline, numerous geomorphic processes can occur. These processes may present challenges and engineering problems in the operation of the TAPS and must be considered from two perspectives: (1) the potential impacts of the geomorphic processes on the integrity of the TAPS; and (2) the environmental impacts of the TAPS on the processes and the environment. Processes working on the TAPS can increase the risk of spill and thus the potential for contamination of the environment. The effects of TAPS on the processes can involve disruption of the stability of the thermal regime of the permafrost, resulting in degradation (melting) or aggradation (propagation) of permafrost that can change the local conditions of hydrology. Increased warming due to climate change (see Section 3.12.7) further complicates the situation. Various geomorphic processes that are related to the operation of the TAPS are described in the following sections.

Geomorphic Processes

Geomorphic processes are processes at the earth's surface that shape the landscape and result in specific deposits. The processes can be physical, chemical, or biological. For example, eolian processes (involving wind action) can produce dunes and loess deposits; glacial processes can result in moraine land forms and till deposits. Mass wasting and glacial action can give rise to particular land forms, like talus slopes.

3.3.2.1 Mass Wasting Processes

Mass wasting is a general term used to describe the geologic processes that are primarily driven by the action of gravity. These processes include avalanches, rock falls, and slides, and slumps on steep slopes, as well as widespread solifluction in cold regions. Where freezing and thawing of soil moisture are very active processes, frost action can fracture rocks to produce debris. Gravity creates an erosional landform by moving the debris down slope. Depending on the water, ice, and snow content in the loose material and the slope angles, the transport processes may include frost creep, rockfall and slide, solifluction, and slopewash (Davis 2000). These processes produce depositional landforms such as talus at the footslopes or valley bottoms.

The effects of mass wasting can be seen at several locations along the pipeline. Near Atigun Pass (MP 167), several avalanches, rock falls, and ice expansions caused extensive damage to heat pipes (Shannon & Wilson, Inc. 1997). Slow creeps on slopes caused by the degradation of permafrost due to warming climate change and ground surface disturbance pose pipeline stability concerns at the Treasure Creek Hill site (MP 442), PS 11 site (MP 686), Tazlina Hill site (MP 687), and the Squirrel Creek site (MP 717) (APSC 2000b). These areas are under close surveillance and monitoring (see Section 4.1, Existing Mitigation Measures). The remainder of the TAPS route is also being monitored for changes in geotechnical conditions.

3.3.2.2 Permafrost Degradation and Aggradation

Permafrost degradation occurs by progressive warming of soil temperature, melting of near-surface permafrost, and lowering of the permafrost table. Permafrost aggradation is the result of cooling soil temperature and expansion of permafrost. Both degradation and aggradation can be triggered naturally or artificially. Examples of natural causes are disturbance of vegetative cover by forest fires, climate change, migration of drainage channels, and drainage of surface water bodies. Artificial causes include the alteration of surface material by mining and construction, clearing or compaction of vegetative cover, diversion of drainage channels, presence of road dust, and activities that cause heating or cooling of the ground (Thomas and Ferrell 1983; Klinger et al. 1983; Lawson 1986).

Special Terms

Frost creep: Soil movement caused by frost heaving and subsequent settling after thawing.

Frost heave or jacking: Expansion in soil volume due to the formation of ice; generally expressed as an upward movement of the ground surface.

Ice surge: Fast advance of a glacier in response to melting.
Periglacial: Area where geomorphic processes are dominated by frost action.

Proglacial lake: A lake formed by the damming action of moraines in front of a glacier as the glacier melts.

Slopewash: The action of water from rain or melted snow carrying (washing) soil down a slope.

Solifluction: Slow movement of soil caused by a combination of *frost creep* and down-slope movement of wet, unfrozen soil.

Thaw bulb: In permafrost, an area of thawed ground below a building, pipeline, river, or other heat source.

Thermokarst: Pits and depressions in the ground resulting from the thawing of ground ice.

The effects of the degradation and aggradation of permafrost on the TAPS is primarily through heaving, subsidence, or thermokarst, and solifluction of the soil near the pipeline, access roads, workpads, and operational material sites (borrow pits). The magnitude of the effects is closely related to the ground ice content and the nature of the soil. Frost heaving commonly occurs in silty soil and is caused by expansion in soil volume because of the formation of ice in soils and also by drawing water to the freezing front where ice lenses form. Subsidence or thermokarst is caused by the melting of ice within the soil material, causing the ground surface to lower or settle. Subsidence is most pronounced in ice-rich soils, especially those with large bodies of ground ice. This ground ice is formed by the migration of moisture to a freezing surface, creating a mass of ice that forms along the freezing front. With time, ground ice builds up. In general, potential problems of frost heave, subsidence, thermokarst, and solifluction are greater when the ice content of the soil is greater and when the soil contains more silt and clay particles. Areas of coarse-grained sediment and bedrock are less susceptible.

Frost heave and subsidence, particularly in silty soils, have historically occurred along the ROW. Subsidence is observed at aboveground VSMs (APSC 2001b). If not corrected, it can cause integrity problems when it occurs unevenly (differential settlement). Occasionally, differential settlement is large enough to buckle the pipeline and cause leakage. For example, in 1979, melting of thick ice lenses in weathered bedrock beneath a section of buried pipeline at Atigun Pass (MP 166) caused the loss of pipe support, resulting in a leak of 63,000 gal of crude oil. The oil reached the adjacent Atigun River (TAPS Owners 2001a).

In the same year, the settlement of the pipeline near PS 12 (MP 734) caused by melting of ground ice and subsidence of silty sediment resulted in a leak of 168,000 gal of crude oil. Further investigation in the late 1970s identified eight additional locations where the pipe was approaching buckling curvature (Thomas and Ferrell 1983). In 1985, several feet of vertical settlement of a segment of buried pipeline occurred at MP 200 in the Dietrich River floodplain (TAPS Owners 2001a). Near MP 680 in the Copper River Lowland, horizontal frost heaving creates alignment problems of the pipeline support system (APSC 2000b). The thawed ground at MP 735–736 may create potential for soil liquefaction if a major earthquake occurs near that general area.

Minor ground surface cracking, sinkhole formation, and ponding due to ground subsidence were observed in the late 1970s along several segments of buried pipeline (Thomas and Ferrell 1983). These features are local and have many causes, including lateral growth of thaw bulbs aggravated by groundwater convection below the warm pipeline, poor compaction and thawing of backfill material, and melting of massive ice, such as ice wedges.

Although many of these effects are short term, long-term effects, such as flooding and ponding along workpads and gravel roads, have also occurred in cold regions. For example, Klinger et al. (1983) reported that elevated gravel roadbeds on the Arctic Coastal Plain promoted the formation of snowbanks. Also, the road dust along heavily used roads hastens snowmelt in the spring. Drainage of meltwater through culverts can be blocked by snowbanks. Shallow permafrost table prevents the meltwater from infiltrating into the subsurface, producing extensive early summer flooding near the roads.

Workpad areas, access-road embankments, and a pipeline that is warmer than the adjacent ground can also promote local degradation of permafrost, increased meltwater, and subsequent ponding. The historical excavation and placement of the buried pipeline and the building of access roads and workpads disturbed the vegetative covers that previously insulated the permafrost. These activities caused the ground to absorb more solar energy, resulting in thawing of near-surface permafrost, increased meltwater, and perching of the meltwater on the lowered permafrost table. In addition, a thaw bulb developed in the permafrost around the warm pipeline. Thawing of the permafrost can induce both subsidence of the ground surface and formation of small ponds in areas that are ice rich. Cases of ponding along workpads can be observed on aerial photographs taken near MP 12 to 18 and MP 500 (APSC 1995b) and as reported in the Environmental Report (TAPS Owners 2001a, Figure 4.3-2).

3.3.3 Existing Contaminated Sites

Soil contamination has occurred during the construction and operation of the TAPS. The contamination has resulted primarily from the release of fuels and crude oil at pump stations and previous constructional camps both along the TAPS right-of-way and at the Valdez Marine Terminal. Additional sites of contamination include locations of road accidents. The causes of the releases on land include traffic accidents, operational errors, corrosion, mechanical failures, and vandalism. The range of releases has been from less than 1 gal to 672,000 gal (TAPS Owners 2001c). It should be noted that cleanup responses immediately after the releases reduce the number of contaminated sites that require long-term cleanup. Currently, 87 sites have been categorized as contaminated, about 2% of the total number of spills reported since 1977 (OASIS Environmental 2001). Seventy of the 87 sites are along the pipeline; the rest are at the Valdez Marine Terminal (OASIS Environmental 2001). Detailed information on historical volumes of contaminated soils and wastes and their treatment is provided in Appendix C.

Of the 70 contaminated sites along the pipeline, 23 are officially “closed” (no further action required) by the ADEC because they are deemed to pose little to no risk to human health or the environment. Twenty contaminated sites have been proposed for no further remediation, and official closure has been requested. The remaining 27 sites are active sites that are being monitored or remediated (OASIS Environmental 2001) (Table 3.3-1). Of the 17 contaminated sites at the Valdez Marine Terminal, 8 have been closed, 1 is planned for no further remedial action, and 8 are active (Table 3.3-2). The contaminants at the active sites include gasoline, diesel fuel, turbine fuel, therminol (a synthetic heat transfer fluid), and crude oil.

The spill volume for the active sites has ranged from less than 25 to 34,076 gal. The spills span the time from the mid-1970s, when the pipeline was constructed, to August 2001, and most occurred at former construction camps and pump stations. (The most recent spill, the Livengood spill, released approximately 285,600 gal of crude oil near MP 400 on October 4, 2001). One active contaminated site involves mechanical failure of a check valve (Check Valve 92, MP 594).

Generally, the extent of soil contamination in each site is local, at a maximum a few acres. The Livengood Spill at MP 400 resulted (including suprapermafrost groundwater and regular groundwater) in a contaminated area of about 3 acres. However, contaminants have spread to subsurface water in many other sites because of the presence of permafrost and a shallow groundwater table (OASIS Environmental 2001). These sites may need additional cleanup and monitoring. The impact of the groundwater contamination is described in Section 3.8.

TABLE 3.3-1 27 Active Contaminated Sites along the TAPS[a]

ID #	Location - Site Name	Year of Spill or Discovery	Type of Spill	Spill Volume (gal)	APSC Relative Priority	Year 2001 Status Comments
6 & 61	PS 6 - Leach Field/Fuel Island and Fueling Area	1992, 1997, 1998	DRO (and gasoline?)	87	High	Possible sources: fuel island, tank farm, generator building, and fueling area spill. Soil-vapor extraction pilot testing performed in 2000; system installation planned for 2001.
15	PS 1 - Former Gas Tank Area	1992	Gasoline	112	High	Gasoline-contaminated soil removed or being remediated in situ. Groundwater monitoring results indicate benzene levels decreasing near gasoline spill.
41	Happy Valley (former construction camp)	1970-1975	Diesel	16,800	High	Cleanup efforts significant in 1970s following spill, and closure status assigned in early 1980s. Site assessment was initiated in 1996 based on possible change in land use. Additional site assessment and remediation may be required.
42	Toolik (former construction camp)	1974, 1975	Diesel	13,500	High	Cleanup efforts significant in 1970s following spill, and closure status assigned in early 1980s. Site assessment was initiated in 1996 based on possible change in land use. The site may be closed after 2001 groundwater and surface water monitoring if contaminant levels continue to exhibit stable or decreasing trend documented since 1997.
4	PS 3 - Fuel Island	1992, 1993	Petroleum hydro-carbons	<25	Medium	Groundwater monitoring conducted from 1994 through 1996. Additional work to be conducted in 2002 if required.
18	PS 10 - Tank 200	1980, 1992	Crude oil	11,555	Medium	Risk reduced because facility on standby, groundwater not used for drinking water. ADEC not requiring new groundwater sampling. Respiration test planned for 2001.
36	PS 1 - Equipment Shop	1994	Petroleum hydro-carbons	<25	Medium	Ongoing ground/surface-water monitoring since 1995. Low risk.
50	Franklin Bluffs (former construction camp)	1975	Diesel	30,000	Medium	Cleanup efforts significant in 1970s following spill, and closure status assigned in early 1980s. Site assessment initiated in 1996 based on possible changes in land use. Additional monitoring planned for 2001. Environmental consultant recommends limited removal of additional contaminated soils in 2001. Closure expected in 2001.

TABLE 3.3-1 (Cont.)

ID #	Location - Site Name	Year of Spill or Discovery	Type of Spill	Spill Volume (gal)	APSC Relative Priority	Year 2001 Status Comments
51	Check Valve 92	1996	Crude oil	34,076[b]	Medium	Continue groundwater monitoring and product recovery in 2001. APSC will examine alternatives for site closure in 2001.
53	PS 5 - Tank Farm	1998	Therminol	33	Medium	Annual groundwater monitoring conducted 1998-2000. APSC will propose to discontinue monitoring after 2001 if monitoring results show stable or decreasing trend. NFRAP status has been requested from ADEC.
54	PS 9 - Former Mainline Turbine Sump	1996	Diesel	55	Medium	Continue groundwater monitoring and product recovery in 2001.
1	PS 2 - Underground Storage Tank	1990	Petroleum hydro-carbons	<25	Low	Contaminated soil excavated. No groundwater observed during tank excavation. No further work planned. Closure expected in 2001.
7	PS 1 - Therminol	1990	Therminol 44	Not available	Low	Releveling project near Tank 111 resulted in segregation of 10,000 cubic yards of Therminal 44-contaminated soil. Stockpiled soil has been treated; NFRAP will be requested in 2001.
11	PS 12 - Fuel Island Area	1992	Turbine fuel	90	Low	DRO in soil up to 5,000 milligrams/ kilogram under liner for turbine fuel offloading area. Requested institutional control (NFRAP).
16	PS 4 - Deadleg Ex.	1984	Crude oil	Not available[c]	Low	Low priority based on limited extent of impact; last ADEC correspondence in 1994.
35	PS 1 - Turbine Fuel Offloading Area	1994	Diesel	<1[b]	Low	Annual groundwater monitoring performed since 1995. Monitoring planned for 2001 to further document stable plume.
55	Van Horn Facility	1984	Diesel	4,000	Low	Continue groundwater monitoring/product recovery in 2001.
57	PS 2 - Therminol Spill	1998	Therminol	5	Low	Site assessment planned for demobilization in 2002.
58	Galbraith Airport Spill	1999	Diesel	Not available[c]	Low	Site assessment in 2000 to support planned excavation of contaminated soils in 2001.
60	PS 12 - Mainline Turbine Sump	1996	Turbine fuel	30[b]	Low	Contaminated soils remain under adjacent building. NFRAP will be requested in 2001.

TABLE 3.3-1 (Cont.)

ID #	Location – Site Name	Year of Spill or Discovery	Type of Spill	Spill Volume (gal)	APSC Relative Priority	Year 2001 Status Comments
63	PS 8 – Manifold Bldg.	1996	Diesel	5[b]	Low	Alternative cleanup levels being developed for closure.
66	PS 3 – Man Camp Generator Release	1998	Diesel	40	Low	NFRAP to be requested due to low risk from remaining contamination. Additional remediation may be required, however.
68	MP 108 Spill	1997	Diesel	56	Low	Closure requested in 1997; requesting closure again because correspondence was misfiled at ADEC.
71	PS 1 – Mainline Turbine Sump	1996	Turbine fuel	<25	Low	Closure requested in 1996; requesting closure again because correspondence was misfiled at ADEC.
77	PS 5 – Vehicle Fuel Dispenser Island	1991	DRO, gasoline	<25	Low	Reviewing 1991 report for status of recommendations.
130	PS 1 – Generator Building	2000	Diesel	25	Low	Assessment planned for 2001 season.
131	Remote Gate Valve 123	2000	Diesel	50	Low	Groundwater monitoring to start in 2001. If monitoring results below maximum contaminant levels for two spring seasons, site will be closed.

[a] Notes:

- PS = pump station; DRO = diesel-range organics (mid-range petroleum products such a diesel fuel); ADEC = Alaska Department of Environmental Conservation; NFRAP = no further remedial action planned.
- APSC has managed Dan Creek as a contaminated site, but was not the responsible party. That site is not included in this table.
- For all sites, immediate responses were conducted to stop or contain releases and to remove/recovery product as much as practical (to the agency's satisfaction).
- Institutional controls may include fences, deed restrictions, or other mechanisms typically designed to limit access.

[b] From TAPS spills database (TAPS Owners 2001c).

[c] Spill or cleanup status descriptors not discernable in the TAPS spills database.

Source: Modified from OASIS Environmental (2001, Table 3-2a).

TABLE 3.3-2 Active Contaminated Sites at the Valdez Marine Terminal

ID#	Location Site Name	Year of Spill or Discovery	Type of Spill	Spill Vol. (gal)	Soil Vol. Treated (yd^3)	APSC Relative Priority	Status Comments
118	Power Vapor	1995	Petroleum condensate	341	<100	High	Initial response included soil excavation, groundwater monitoring, and product removal. Soil vapor extraction initiated in 1999 (ongoing). Site located more than 1/4 mi from marine waters.
95/88/ 94/101/ 103	East Tank Farm	1991, 1992	Oily water	~5	5,500 (in situ)	Medium	Remediation included in situ bioventing and groundwater extraction. In 2000, ADEC approved discontinuing operation of three bioventing systems. Groundwater extraction discontinued, groundwater monitoring continues.
107	East Metering Building - Valve L11	1993	Crude oil	3	100	Medium	Weathered crude discovered, excavated to 16 ft. ADEC approved excavation backfilling 9/1/93. Site is monitored, but no further work planned.
114	West Fire Foam Building	1994	Crude oil	84	550	Medium	No groundwater impact documented, some contaminated soil could not be removed. Bioventing to continue in 2001 (spill volume 84 gal).
124	West Tank Farm Catch Basin #2	1997	Crude oil	42[a]	Not available	Medium	Approximately 42 gal crude recovered initially. Surface water monitoring is ongoing. One in situ bioventing well installed, will be connected to ID#114 bioventing system in 2001.
92	"U" Site ("Q" included)	1987	Oil water	2,940[a]	Not available	Low	Crude-contaminated soils excavated in 1993. Site is monitored, but no further work since 1993 due to low risk, extensive piping in area (none planned in 2001).
104	Tank 51/52 - Arctic Diesel	1992	Diesel	32.5[a]	~200	Low	No-further-action status proposed to ADEC on the basis of institutional controls – waiting for ADEC approval.
105	80s Tanks	1994	Crude oil	Not available	Not available	Low	Liner and tank repairs completed. Groundwater diverted to Ballast Water Treatment Plant. Risk reduced, so no further work planned.

[a] From TAPS spills database (TAPS Owners 2001c).

Source: Modified from OASIS Environmental (2001, Table 3-4a).

3.4 Seismicity

Earthquakes can pose a major hazard to human beings and man-made structures. Information on faults and historical earthquakes can be used to assess seismic potential. Such assessments then can be used along with information on the types of geologic material on the surface to determine the seismic hazard in a particular area and to design and build structures accordingly.

Another earthquake-related hazard in addition to ground movement that must be considered in coastal areas is seismic sea waves (tsunami). Tsunamis are generated when earthquakes occur under the sea, deforming the nearby sea floor. They propagate across an ocean and can cause substantial damage in coastal areas hundreds, or even thousands, of miles away. When the TAPS was built, the potential threat of tsunami was recognized. The only nearshore facility, the Valdez Marine Terminal, was purposely built on high ground beyond the reach of potential seismic sea waves. Therefore, the threat of tsunami damage to the TAPS is considered insignificant.

The following sections describe the fault systems and seismicity (distribution of earthquake magnitudes and their occurrence in time and space) in areas along the pipeline, the seismic hazards, and the basic assumptions used in the seismic design of the TAPS.

Seismic Activity

Generally, seismic activities, or earthquakes, are closely related to movements of land along faults or ruptures in the geological material. The faults may be exposed on the ground surface or buried in the subsurface. Long faults are likely to be sites for large earthquakes. Faults that have had more recent movements tend to be more active.

3.4.1 Seismicity and Faults

The northern part of the pipeline from the Arctic Coast to the Brooks Range (MP 0–237) is a region of low seismicity, although numerous faults have been identified in the Brooks Range (Plafker et al. 1994b). From 1880 to 2000, 76 small earthquakes with magnitudes of 4.0 to 5.5 on the Richter scale were recorded (TAPS Owners 2001a; Wesson et al. 1999). Only one with a magnitude as high as 5.5 was recorded. It occurred in the Brooks Range, more than 100 mi from the pipeline (TAPS Owners 2001a). Seismic activity is low between the Brooks Range and Yukon River (MP 237–355).

South of the Yukon River, the pipeline crosses three seismic zones (the Minto Flats, Fairbanks, and Salcha seismic zones) that trend northeast in the Yukon-Tanana Upland (AEIC 2001). Fourteen earthquakes with Richter magnitudes of 5 or greater have been recorded in these zones since 1904. Three had Richter magnitudes of 7.2 to 7.3 and occurred between 1904 and 1937 within 100 mi of what is now the pipeline ROW (AEIC 2001; TAPS Owners 2001a). Prior to November 2002, no rupture was documented on the ground surface from these earthquakes. The November 3, 2002 earthquake is discussed in the text box on the following page.

The most significant fault crossed by the pipeline is the Denali Fault in the Alaska Range at MP 589 (Map 3.4-1). This fault is several hundred miles long, and movement has been recorded in a few segments of the fault (TAPS Owners 2001a; Plafker et al. 1994b). Two other smaller faults, the McGinnis Glacier Fault and Donnelly Dome Fault, are present near the Denali Fault. The Denali, McGinnis, and Donnelly Dome faults are considered active. An earthquake of magnitude of 7.2 was recorded in the Alaska Range in 1912 with an epicenter west of Paxson and about 18.5 mi from the current location of the pipeline (TAPS Owners 2001a; AEIC 2002).

Southern Alaska, especially south of the Chugach Mountains, is a very seismically active area. Most of the earthquakes in this area occur along faults where the Pacific Plate slides and thrusts under the North America Plate (the Alaska-Aleutian megathrust). The famous Great Alaska Earthquake of 1964, which had an epicenter about 40 mi west of what is now the Valdez Marine Terminal, occurred along the Alaska-Aleutian megathrust. The earthquake

November 2002 Earthquake

An earthquake registering 7.9 on the Richter scale occurred at 1:12 p.m. (AST) on November 3, 2002, on the Denali Fault 55 mi west of the pipeline. The TAPS Earthquake Monitoring System (EMS) performed as designed by initiating automatic shutdown of the pipeline, calculating the severity of the event, and identifying locations and features to be evaluated for damage. Pipeline controllers brought the pipeline to a safe shutdown condition an hour later. The pipeline was not breached and no oil was released.

The earthquake damaged eight aboveground vertical support members near MP 589; eight pipeline support shoes separated from the pipe at those locations and five cross beams were damaged (see Figure 4.1-3 for an illustration of a vertical support member). A number of shoes displaced longitudinally, including those at the Denali Fault crossing. Longitudinal movement of the pipe tripped a number of anchor assemblies, which were installed on the pipeline to absorb energy from external initiating events such as this earthquake. Soil cracks were noted along the TAPS ROW and near remote gate valve 91.

On the basis of output from the EMS, a list of approximately 160 items was prepared for inspection and evaluation of the pipeline. These items include detailed inspections of the aboveground and belowground portions of the pipeline, valves, communications equipment, vertical support members, and bridges in this area. The belowground ROW will be inspected for depressions, mounds, or cracks that might indicate pipeline movement, and an internal inspection of the belowground pipe will be performed using a pig (see Section 4.1.3.2.1 for a description of pigs). Following an inspection of critical items and completion of a number of repairs, such as temporary supports for the damaged vertical support members, the flow of oil through TAPS was restarted on November 6. Work on repairing the damaged sections of the pipeline continues and should be completed by early December.

had a moment magnitude (a calculated magnitude based on the actual physical area of a moving fault, the average amount of slip, and the rigidity properties of the rocks that slip) of 9.2 and a magnitude of 8.2 to 8.7 on the Richter scale. The old town of Valdez, which was located on a delta with unconsolidated sediment underneath, was destroyed in the earthquake (Cohen 2000). The Valdez Marine Terminal was built on bedrock on high ground on the south shore of Valdez Arm. Since the TAPS was built, three large earthquakes with moment magnitudes of 7.5 (1979), 7.8 (1988), and 7.9 (1987) have been recorded in southern Alaska (AEIC 2001). All were more than 190 mi east or southeast of Valdez, and no damage occurred to the TAPS.

Richter Scale and Moment Magnitude Scale

The magnitude of an earthquake is a measure of the energy released during the event. It is measured on the Richter scale, which runs from 0.0 upwards, with the largest earthquakes recorded having a magnitude of 8.6. The Richter scale is logarithmic, so a quake of magnitude 5.0 is 10 times more destructive than a quake of magnitude 4.0. Earthquakes greater than magnitude 6.0 can be regarded as significant, with the likelihood of damage to nearby structures not designed to withstand such forces and loss of life (Press and Siever 1982).

Scientists and seismologists prefer to use the “moment magnitude scale,” which is a measure of total energy released by an earthquake. The moment scale is more precise.

3.4.2 Seismic Hazards, Designed Seismic Zones, and Ground Motions

A seismic hazard can be evaluated to estimate the probabilities that various levels of earthquake ground motion will be exceeded at a site in a period of time. Basically, the evaluation uses three inputs: the seismic source, seismicity, and a ground motion attenuation function (a function of earthquake magnitude and distance). The results of the evaluation can be

TABLE 3.4-1 Seismic Design Zones for Design Contingency Earthquake

Zone	Pipeline Milepost	Richter Magnitude
A	0 – 258	5.5
B	258 – 560	7.5
C	560 – 620	8.0
D	620 – 710	7.0
E	710 – Valdez	8.5

Source: APSC (2001e)

Plate Tectonics

The crust of the earth is composed of a small number of plates that independently float on the more fluid underlying mantle of the earth. The edges of these plates can rub together as they slide in opposite directions, or they can even overlap, with the edge of one plate thrusting over or under the edge of another, in areas where two or more plates converge. Such movement is generally extremely slow, averaging a few centimeters a year. These areas of contact are often locations of considerable seismic activity.

used to compare ground motions (primarily the acceleration) used in the TAPS design.

Two levels of earthquake hazards were considered in designing the TAPS — the design contingency earthquake and design operating earthquake (APSC 2001e). The design contingency earthquake is a rare, intense earthquake with an estimated occurrence frequency (return period) of 500 years or more (Nyman 1995). In design concept, a design contingency earthquake could possibly lead to some damage of the TAPS and require repair. However, the design of TAPS was intended to ensure that no structural collapse or release of oil or hazardous substances would be likely. The functionality of essential control, communications, and emergency systems should be maintained without interruption. The design operating earthquake is a lower intensity earthquake with ground motion amplitudes about one-half of those associated with the design contingency earthquake. A design operating earthquake or smaller earthquake would not cause significant deformation of the TAPS or interrupt its operation (TAPS Owners 2001a).

In the design of the TAPS, the 800-mi route was divided into five seismic zones on the basis of the expected Richter magnitude of a design contingency earthquake in that zone (Table 3.4-1). The division was based on the findings of a USGS study (APSC 2001e). The design seismic motions were developed for a design contingency earthquake on the basis of both damage assessments and observed ground motions of major earthquakes around the world (including the 1964 Great Alaska Earthquake) (Table 3.4-2). The values in the table represent effective peak values (or design ground acceleration values that represent the means of peak values). It should be noted that absolute peak acceleration that is from a field measurement could be two or more times the design ground acceleration. The design ground values are used for evaluating landslides, rock falls, mudflows, and other types of mass movements that might cause damage to the pipeline (APSC 2001e). Because of the interaction of the soils and structures and the amount of ductility and energy dissipation in the structures, the design ground values are further reduced by a factor of approximately two when they are used to develop design response spectra for structural design (APSC 2001e).

In the late 1990s, the USGS (Wesson et al. 1999) conducted a seismic hazard analysis for Alaska. The seismic sources used in the analysis included (1) those explicitly identified, such as the Alaska-Aleutian megathrust and active faults (e.g., the Denali Fault) with known slip rates, (2) shallow earthquakes from sources not included above, and (3) deeper earthquakes.

The results of the analysis of the peak ground acceleration (in %g) with a 2% probability of exceedance in 50 years (which corresponds to a recurrence interval of 2,500 years, resulting in a much more conservative estimate than the recurrence interval of 500-1,000 years used for the TAPS) are presented in Table 3.4-3 and Map 3.4-2. The values of the peak ground

TABLE 3.4-2 Design Ground Motions for Design Contingency Earthquake

Richter Magnitude	Zone	Acceleration (g)	Velocity (in./s)	Displacement (in.)
8.5	E	0.6	29	22
8.0	C	0.6	29	22
7.5	B	0.45	22	16
7.0	D	0.3	14	11
5.5	A	0.12	6	4.5

Source: APSC (2001e)

TABLE 3.4-3 Peak Ground Acceleration and the Design Ground Acceleration for a Design Contingency Earthquake

Milepost	Seismic Zone	Peak Ground Acceleration (g)	Design Ground Acceleration for DCE (g)	Maximum Ratio between Peak and Design Ground Acceleration
0 – 258	A	0.08 – 0.23	0.12	1.9
258 – 560	B	0.23 – 0.4	0.45	0.67
560 – 620	C	0.3 –1.2	0.6	2.0
620 – 710	D	0.18 – 0.3	0.3	1.0
710 – Valdez	E	0.3 – 0.6	0.6	1.0

Sources: APSC (2001e); Wesson et al. (1999).

acceleration along the TAPS ranges from 0.08 g (8% g) to 0.9 g (90% g). The highest peak ground accelerations are in the Alaska Range (Seismic Zone C, 0.3 to 0.9 g) and the Chugach Mountains (Seismic Zone E, 0.4 to 0.6 g) (Wesson et al. 1999). The ratio between the upper bound of the peak ground acceleration and the design ground acceleration ranges from 0.67 to 1.9 (Table 3.4-3), which is equal to or less than 2, and is consistent with the claim used in the design (APSC 2001e). The originally specified TAPS seismic design criteria met the seismic zoning criteria proposed by the USGS (Wesson et al. 1999).

In addition to consideration of the dynamic loading produced by the design contingency earthquake as indicated in Table 3.4-2, the TAPS was designed to accommodate permanent ground deformation related to liquefaction, slope movements, or surface-fault offsets that might be triggered by earthquakes.

For belowground segments of pipeline, areas that have potential slope instabilities or liquefaction-susceptible soils were identified, and the pipeline was routed to avoid those potential hazards to the extent possible. The pipe was designed so that if liquefaction did occur and the extent of the area was small or extremely large, the pipeline would bridge the small liquefaction area to conform to large deflections without unreasonable, large strains (APSC 2001e). However, locally overstressed conditions might develop along the pipeline if the extent of the liquefaction area was intermediate. The pipeline would also become vulnerable if a landslide occurred on a cross slope, resulting in the pipe's being carried down the slope with the slide (APSC 2001e). On the basis of available geotechnical data and ongoing surveillance and monitoring programs, APSC is unaware of any field geotechnical conditions that could potentially lead to earthquake-induced ground failure of sufficient severity to cause pipeline failure.

A strong earthquake can rupture the ground surface in addition to causing movements along a surface fault, producing a large displacement near the surface. At any arbitrary location, the belowground pipeline is designed to survive an offset of a 2-ft horizontal displacement with a two 2-ft vertical displacement (APSC 2001e). In crossing the three active faults, the pipeline was designed to be aboveground so it can glide on long supported beams to accommodate large offsets across the active faults. The design movements for the active faults for the aboveground pipeline are shown in Table 3.4-4.

In the 1964 Great Alaska Earthquake (which occurred before the TAPS was built), ground cracks and landslides were observed in the Copper River Lowlands and the Chugach Mountains (Ferrians 1966). The majority of ground cracks occurred in coarse-grained unconsolidated deposits in proximity of steep slopes, along shores of lakes, or in areas cleared of vegetation for several years within a radius of 100 mi from the earthquake epicenter. These areas are characterized as follows: (1) permafrost was absent or deep lying, (2) the groundwater table was near the surface, (3) slopes were steep, and/or (4) bedrock was relatively deep lying. Besides the ground cracks, a few earthquake-triggered landslides, rockslides, and avalanches were also recorded, especially in the Chugach Mountains (Ferrians 1966).

An example of a landslide site is near mile 65 of the Richardson Highway (near the current TAPS PS 12) by the Little Tonsina River. At this location, a slide occurred by a small hill underlain by unconsolidated silt, sand, and gravel deposits. Ground cracks with a maximum width of 3 ft and a depth of about 5 ft and pressure ridges appeared near the toe of the landslide (Ferrians 1966).

TABLE 3.4-4 Engineering Design Criteria of Pipeline for Ground Movement for Active Fault Zone Crossings

Active Fault	Horizontal Movement (ft)	Vertical Movement (ft)
Denali	20	7
McGinnis Glacier	8	6
Donnelly Dome	3	10

Source: APSC (2001e).

3.5 Sand, Gravel, and Quarry Resources

Deposits of sands, gravels, and quarry stones are abundant along the TAPS ROW. Because of previous glacier advances and the mechanical breakdown of bedrock under periglacial conditions, sands and gravels are plentiful in glacial till deposits and in floodplains along river valleys, especially near the three mountain ranges crossed by the pipeline. In areas on the Kokrine-Hodzana Highlands and the Yukon-Tanana Uplands where the windblown silt is thin, bedrock is easily available in hills for mining of quarry stones. Sands and gravels are abundant in the glaciated Brooks Range, Alaska Range, and Chugach Mountains and are good sources of construction material for the TAPS.

Sands, gravels, and quarry stones have been mined for TAPS construction, regular operation, and maintenance of workpads, road beds and surface materials, flood damage control, and river embankments. Currently, APSC has contracts to purchase granular materials from 69 borrow sites (or operational material sites, OMSs) (TAPS Owners 2001a). All of these sites are on public lands. The sites include bedrock quarries and sand and gravel pits on floodplains, alluvial fans, outwash fans, and glacial moraines. Most of the sites are jointly used with the State of Alaska (Table 3.5-1).

The OMSs range in size from 4 to 80 acres and are scattered along the TAPS ROW; they are located from a quarter mile to a few miles from the ROW. Half of the OMSs are stone quarries and half are sand and gravel pits. Most of the bedrock quarries are located on the Kokrine-Hodzana Highlands and the Yukon-Tanana Uplands. The majority of the sand and gravel pits are on the floodplains of major rivers. From 1995 to 1999, the annual use of borrow material from the 69 sites ranged from about 30,000 to 97,000 yd^3 (TAPS Owners 2001a).

Because the borrow sites are a quarter mile or more from the TAPS, the impacts of their use do not extend to the TAPS itself. In the bedrock quarries, geologic materials are removed to produce riprap, leaving locally visible scars on newly exposed bedrock outcrops.

Historically, the impacts of the sand and gravel mining on the environment varied. For sites located on braided river floodplains or alluvial fans, permafrost was absent and the drainage channels shifted regularly. The sediment load in the rivers may have temporarily increased because of the mining operations. However, the time needed to reestablish equilibrium conditions in the environment was short.

For sites located on stabilized floodplains or river terraces, sand and gravel mining operations disturbed vegetative cover and, in some instances, the underlying permafrost. The resulting impacts included removal of the sand and gravel resources, and increased soil erosion and siltation temporarily.

TABLE 3.5-1 Active TAPS Operations Material Sites (OMSs) on Public Lands

OMS No.	Pipeline MP	Land Owner[a]	Joint Use[b]	Material Type	Volume Extracted (yd^3)	Remaining Estimated Yield (yd^3)	Work Area (acres)
3-1.1	787	S		Sand/Gravel	200,000	70,000	8
3-2	785	S	Yes	Sand/Gravel	143,000	190,000	55
5-2	779	S		Gravel	212,000	90,000	25
7-1M	769	S	Yes	Sand/Gravel	112,000	70,000	31
7-2M	768	S		Bedrock	85,000	40,000	11
9-4R	753	F		Sand/Gravel	230,000	100,000	9
13-3.1	732	F		Sand/Gravel	270,000	1,230,000	80
14-0	724	F	Yes	Bedrock	13,000	100,000	13
27-3N	647	F	Yes	Gravel/Bedrock	392,000	172,000	21
28-1R	642	F		Sand/Gravel	105,000	250,000	13
30-0	633	F		Gravel/Sand	25,000	344,000	13
30-2R	630	F		Gravel/Sand	54,000	150,000	14
32-0.0	623	F		Bedrock	300,000	100,000	37
35-1.2	604	S	Yes	Sand/Gravel	100,000	50,000	12
37-0R	595	F		Bedrock	455,000	800,000	41
38-1R	586	F		Sand/Gravel	33,000	54,000	9
39-1.1	580	F	Yes	Bedrock	106,000	180,000	13
39-4	575	F		Gravel	160,000	165,000	10
41-1R	569	S		Sand/Gravel	150,000	200,000	28
44-1R	553	F		Gravel/Sand	185,000	200,000	4
49-3	520	S		Sand/Gravel	220,000	230,000	14
53-2	498	S		Gravel	35,000	200,000	13
55-1	489	FNSB		Gravel/Sand	NA	NA	NA
56-3	480	F		Gravel	NA	NA	NA
63-1	440	S		Bedrock	95,000	140,000	13
63-4	463	S		Bedrock	138,000	100,000	9.5
64-2	433	F	Yes	Bedrock	110,000	50,000	10
65-1M	426	S		Bedrock	125,000	200,000	23
66-1R	419	S		Gravel/Bedrock	130,000	230,000	17
67-1	413	S		Bedrock	50,000	200,000	8.5
68-1	409	S		Bedrock	200,000	100,000	15
68-4	406	S		Bedrock	100,000	174,000	10
69-1R	403	S		Bedrock	95,000	155,000	5
70-0.0	397	S	Yes	Bedrock	42,661	157,339	30
71-0	393	S		Bedrock	133,000	75,000	11
71-1HR	390	S	Yes	Bedrock	231,000	150,000	34
72-1	384	S		Bedrock	69,483	143,517	5
73-1R	381	S		Bedrock	80,000	80,000	11
74-2HR	375	S	Yes	Bedrock	120,000	100,000	46

TABLE 3.5-1 (Cont.)

OMS No.	Pipeline MP	Land Owner[a]	Joint Use[b]	Material Type	Volume Extracted (yd^3)	Remaining Estimated Yield (yd^3)	Work Area (acres)
75-1R	369	S	Yes	Bedrock	80,000	1,300,000	37
76-2.1	361	S		Bedrock	246,000	373,000	13
78-1	349	F	Yes	Bedrock	720,000	600,000	17
79-2	344	F	Yes	Bedrock	232,000	100,000	34
82-0	330	F		Gravel/Sand	310,000	350,000	20
83-1	322	F	Yes	Bedrock	476,000	70,000	23
83-2	320	F	Yes	Bedrock	476,000	100,000	45
86-2	304	F	Yes	Bedrock	600,000	330,000	60
88-3	293	F	Yes	Bedrock	352,000	110,000	33
89-3	285	F	Yes	Silt/Gravel	344,000	150,000	22
91-3.1A	274	F	Yes	Bedrock	300,000	30,000	15
92-3.1	267	F	Yes	Sand/Gravel	400,000	300,000	40
94-0	259	F	Yes	Gravel/Sand	100,000	50,000	7.5
95-1	255	F	Yes	Bedrock	466,000	144,000	13
95-2	253	F	Yes	Sand/Gravel	140,000	75,000	13
96-1	252	F	Yes	Sand/Gravel	138,000	150,000	33
97-2	244	F	Yes	Sand/Gravel	98,890	60,000	11
98-3.1	235	S	Yes	Gravel/Sand	700,000	500,000	40
100-1.2	226	F	Yes	Gravel/Sand	360,000	370,000	14
100-2.1	227	F	Yes	Bedrock	80,000	200,000	24
102-1	215	F	Yes	Gravel	500,000	300,000	49
105-1	199	F		Sand/Gravel	416,000	64,000	26
106-1	192	F		Gravel	290,000	400,000	29
106-1.1	190	F	Yes	Bedrock	192,000	200,000	7
111-2	160	F	Yes	Gravel	600,000	100,000	62
112-3.1	152	F	Yes	Bedrock	108,000	300,000	14
114A-2	138	F	Yes	Gravel/Sand	200,000	60,000	25
117-2BD	125	F	Yes	Bedrock	600,000	450,000	42
119-4	111	S	Yes	Gravel	400,000	500,000	30
133-2A	26	S		Peat/Silt	125,000	400,000	18

[a] Landowner abbreviations: F = federal, S = state, FNSB = Fairbanks North Star Borough.

[b] Jointly used by APSC and Alaska Department of Transportation and Public Facilities.

Source: TAPS Owners (2001a, Table C-1).

3.6 Paleontology

Paleontological resources are any physical evidence of past life, including fossilized remains, imprints, and traces of plants and animals. Fossilized plants of marine and terrestrial origin, as well as invertebrate and vertebrate animal remains, have been found along the length of the TAPS ROW. These fossils document nonhuman life in Alaska during the last 570 million years.

As nonrenewable resources, no matter how common or rare they may be, fossils of scientific value are protected by the Antiquities Act of 1906. Fossils on federal lands are protected by the Federal Land Policy and Management Act of 1976. Two other federal laws, the Archaeological Resources Protection Act of 1979 and the Federal Cave Resources Protection Act of 1988, protect fossils in archaeological context and fossils from significant caves, respectively. Paleontological resources are protected in Alaska under the state's Alaska Historic Preservation Act.

The underlying bedrock along the TAPS ROW consists of igneous, metamorphic, and sedimentary rocks of varying age and depth. The sedimentary rocks often contain fossil-bearing strata. Along the ROW, these sedimentary rocks usually are overlain by fossil-bearing, unconsolidated glacial, fluvial, and eolian deposits (see Section 3.2).

Fossils can occur throughout the state and range from single-celled organisms to large vertebrates — the latter including Mesozoic dinosaurs and Pleistocene mammoths. (See text box; a broader coverage of geologic time periods is provided in Table 3.2-2.) The amount of paleontological evidence in Alaska varies, and with respect to the TAPS can be characterized broadly by location (see Map 3.6-1, Alaska chronology by area). The North Slope is particularly rich in paleontological remains. The oldest fossil from that area is a tooth plate from a vertebrate fish found in a Middle Devonian rock formation from 380 million years ago (Lindsey 1986). Post-Devonian sedimentation on the North Slope has, in some cases, developed up to 20,000 ft of fossil-bearing strata. Fossils of marine invertebrates include bryozoans, brachiopods, pelecypods, gastropods, ostracods, cephalopods (e.g. belemnites, ammonites), crinoids, trilobites, belemnites, ammonites, and coral (see Table 3.6.1). Marine plants also occur in these sedimentary rocks. By the Middle Jurassic and continuing into the Cretaceous (c. 160 million years ago), wood and nonmarine plants appear in the North Slope fossil assemblages, indicating episodic retreats and advances of the sea. Twelve types of dinosaurs, from Late Cretaceous beds (c. 72–68 million years ago), have been found on the North Slope (BLM 2001b). Although the TAPS parallels Late Cretaceous sandstones for approximately 11 mi (MP 57–68), no dinosaur fossils have been found near the ROW. Fewer invertebrate fossils occur in Tertiary beds along the Arctic Coastal Plain. The post-Eocene fossil record on the North Slope does not resume until the Pliocene and Pleistocene (see text box, next page). Marine and terrestrial mammals (such as otter, seal, whale, mammoth, moose, caribou, musk ox, bison, antelope, camel, horse, lion) and birds have been found in Quaternary glacial deposits along the Colville River, approximately 90 mi west of the TAPS ROW. Possibly because of the effects of later glacial activity, no Pleistocene faunal remains have been discovered in the part of the North Slope

Epochs of the Quaternary Period

The Quaternary Period (1.8 million years ago [MYA] to present) can be subdivided into two epochs: the Pleistocene and the Holocene.

The Pleistocene (1.8 MYA to 11,000 YA) is characterized by alternating advances and recessions of moraine ice sheets (glaciers) in North America, southern Europe, and northern Asia. Large mammals roamed unglaciated forests and plains. Modern humans developed during this epoch.

During the Holocene (11,000 YA to present), the large ice sheets have retreated. Landforms, vegetation, and fauna have developed into what is seen today.

Epochs of the Tertiary Period

The Tertiary Period (65–1.8 MYA) can be subdivided into five epochs: the Paleocene (65–54 MYA), the Eocene (54–38 MYA), the Oligocene (38–23 MYA), the Miocene (23–5 MYA), and the Pliocene (5–1.8 MYA).

Mammals became the dominant land vertebrates during the Eocene. By the Pliocene, distinctly modern flora and fauna appeared.

occupied by the TAPS (Lindsey 1986; Péwé 1975; Guthrie and Stoker 1990).

The TAPS ROW crosses three mountain ranges: the Brooks Range, Alaska Range, and Chugach Mountains. These mountains are composed of sedimentary rocks, interspersed with metamorphic and igneous strata. Upthrusts and faulting have exposed fossil-bearing strata at ground surface. In areas where it is buried, the pipeline lies in weathered bedrock and in glacial, colluvial, alluvial, lacustrine, and aeolian deposits across these ranges. Concentrations of invertebrate fossils from sedimentary and metamorphic rocks are found along mountainous stretches and paralleling the TAPS ROW.

Three of the physiographic units that the TAPS ROW crosses are associated with major river drainages: the South Fork Koyukuk, Yukon, and Tanana in the Yukon-Tanana Uplands; the Tanana River Valley; and the Gulkana and Copper Rivers in the Copper River Basin. The pipeline also crosses numerous smaller rivers and creeks in these units. The underlying bedrock associated with these river units is usually metamorphic, with sedimentary and igneous episodes. The bedrock often is deeply buried by Quaternary glacial, glaciofluvial, outwash, lacustrine, alluvial, and eolian deposits derived from flanking mountainous zones (Péwé 1975; Hamilton and Ashley 1993). Fossils of many mammals (such as mammoth, mastodon, antelope, musk ox, elk, moose, saber-toothed cats, voles) have been found in frozen silts and organic deposits, primarily Wisconsinan in age (75,000–10,000 years ago). Approximately one-third of these mammals are now extinct (Foster et al. 1994). Invertebrate fossils (pelecypods, gastropods, and insects) also occur in Quaternary deposits in these valleys (Péwé 1975).

Data on paleontological sites in Alaska are maintained by the State Historic Preservation Office and by the Department of Paleontology at the University of Alaska-Fairbanks. Table 3.6-2 lists how many known paleontological resources have been recorded in the vicinity of the ROW.

TABLE 3.6-1 Marine Invertebrate Fossils

Fossil	Description
Brachiopods	Asymmetrical bivalves (Cambrian to Recent)
Bryozoans	Aquatic, colonial animal with moss-like or branching growths (Ordovician to Recent)
Cephalopods	Class of mollusk with internal or external shell and tentacles, such as ammonites, belemnites (Mid-Cambrian to Recent)
Coral	Aquatic solitary or colonial coelenterates. Bodies have a two-layered wall and a single opening for ingestion and excretion (Pre-Cambrian to recent)
Crinoid	Echinoderm with long, segmented anchoring stalk surmounted by a cup with attached, radiating, feathery arms (Ordovician to Recent)
Gastropods	Mollusk with a single, usually coiled, shell (Cambrian to Recent)
Ostracod	Small crustacean with bivalved carapace (Cambrian to Recent)
Pelecypod	Bivalved mollusk, such as oysters, clams, mussels (Ordovician to Recent)
Trilobite	Marine anthropod with three major divisions of the body and a three-lobed, segmented thorax (Cambrian to Permian)

TABLE 3.6-2 Paleontological Sites near the TAPS ROW

Proximity to TAPS[a]	North Slope	Brooks Range	Yukon-Tanana Uplands	Tanana River Valley	Alaska Range	Copper River Basin	Chugach Mountains
Within 1/4 mi of the TAPS							
Vertebrates	0	0	3	0	0	0	0
Invertebrates	1	6	0	0	1	0	0
Plants	0	0	0	0	0	0	0
Within 1/2 mi of TAPS							
Vertebrates	0	0	3	0	0	0	0
Invertebrates	4	11	5	0	8	0	0
Plants	1	0	1	0	0	0	0

[a] See Map 3.6-1.

3.7 Surface Water Resources

The 800-mi long pipeline crosses 80 major rivers and approximately 800 smaller streams (TAPS Owners 2001a). These surface water bodies range in size from the Yukon River (typically 1,900 ft wide at the pipeline crossing [APSC 2001a] with an average maximum flow of 476,000 cubic feet per second [ft^3/s] at Stevens Village) to creeks only a few feet wide. The primary river and creek types crossed by the pipeline include braided channels, split channels, single channels, and alluvial fans.

In addition to the river crossings, the pipeline is often located within or parallel to the active channels or floodplains of the Sagavanirktok, Atigun, Chandalar, Dietrich, Middle Fork Koyukuk, and Delta Rivers and Phelan Creek (TAPS Owners 2001a). Hydrological characteristics of the streams crossed by the ROW are varied, and stream flows vary considerably with the time of year (TAPS Owners 2001a). Water velocities in the rivers and streams vary considerably from each other and vary within themselves according to season. Velocities, in general, range from 0.0 to 10 ft/s, with zero to low velocities occurring during the winter when significant portions of the rivers are frozen (APSC 2001g).

Surface water along the TAPS ROW can be affected by the following:

- Sanitary wastewater discharges,
- Water from hydrostatic testing of the pipeline,
- Water from dewatering construction and maintenance sites,
- Water from draining secondary containment structures, and
- Rainwater or snowmelt runoff.

Surface water is used along the ROW and at the Valdez Marine Terminal for many purposes, including fresh water for potable purposes at manned facilities, equipment washing, tank cleaning, dust abatement on roads and workpads, and hydrostatic testing.

River and Stream Types

Braided channels: Wide, steep, high-bedload, multichannel systems such as the Sagavanirktok, Delta, and Dietrich Rivers, and Phelan Creek.

Split channels: Rivers with more than one main channel, such as the lower parts of the Middle Fork Koyukuk.

Single channels with floodplains: Rivers or streams that exhibit one primary channel, such as the South Fork Koyukuk, Chena, and Salcha Rivers and Moose Creek, or deeply incised channels with no floodplains, such as Sulphide Gulch.

Alluvial fans: The majority of creeks that flow into the Delta River in the vicinity of PS 10, and Sheep, Brown, and unnamed creeks flowing into the Lowe River.

3.7.1 Hydrological Regions

Five hydrological regions have been used by APSC to characterize naturally occurring surface flows along the ROW: North of the Brooks Range, South of the Brooks Range, Interior, Alaska Range, and Glennallen to Valdez (TAPS Owners 2001a) (Map 3.7-1).

3.7.1.1 North of the Brooks Range

The North of the Brooks Range Hydrological Region extends from MP 0 to about MP 166 (Continental Divide). This region is located within the Arctic Slope Drainage that extends from MP 0 to 170 (TAPS Owners 2001a). Important rivers in this region are the Sagavanirktok, Kuparuk, and Atigun. The dominant drainage in this region is the Sagavanirktok River, which flows north to the Beaufort Sea. The Sagavanirktok River and smaller channels are classified as anadromous fish habitat and are an important component of the coastal zone management plan. Peak flows in these rivers are highly variable and are driven by a combination of weather conditions (including the history of precipitation and time of year).

Peak flows in the Brooks Range are the result of heavy rains in July and August. Flows increase and decrease rapidly in response to the rainfall events because the characteristics of the Brooks Range and the permafrost conditions of the slope result in little capacity for storing precipitation. Winter flows in these rivers are small to nonexistent. Low flows during the winter in the Sagavanirktok River lead to extensive accumulations of groundfast ice (aufeis). Aufeis is a seasonal accumulation of ice that is superimposed on the frozen surface of a stream or landscape (Slaughter 1990). Aufeis accumulations constitute a major management problem for roadways, culverts, and structures that are located in areas subject to ice accumulation. Breakup flows (river flows during ice breakup in the spring) over the aufeis generally produce maximum water levels in the rivers.

Between MP 20 and 54, the buried pipeline crosses more than 36,900 ft of Sagavanirktok floodplain and crosses the Sagavanirktok River four times. In this region, the Sagavanirktok River floodplain is more than 4 mi wide and is a highly braided system with multiple channels. Such braided systems tend to develop where flood discharges are high and fluctuate rapidly, where sediment transport rates along the stream bed are high, where the channel gradient is steep, and where the stream banks are formed in weak noncohesive sand and gravel (Dunne and Leopold 1978). In general, channel patterns of such systems are controlled predominantly by sediment supply conditions (Thorne et al. 1987) and are active, high-energy sediment transport systems that frequently re-form and destroy sedimentary structures (Richards 1982). Changes in these types of systems are difficult to predict and exhibit random variability.

3.7.1.2 South Side of the Brooks Range

The South Side of the Brooks Range Hydrological Region extends from the Continental Divide (MP 166) to about MP 265. This region is part of the Yukon Drainage that extends from MP 170 to 605 (TAPS Owners 2001a). Principal rivers within this region are the Dietrich, Bettles, Middle Fork Koyukuk, Hammond, and the South Fork Koyukuk. The principal rivers flow into the Koyukuk River, a major tributary of the Yukon River. The Yukon River discharges to the Bering Sea. Flows within the Dietrich River are classified as critically sensitive for fish populations year-round; its tributaries are sensitive habitats during May to October (TAPS Owners 2001a). The Dietrich River and its tributaries do not support anadromous fish, but the Dietrich River is a tributary of the Middle Fork of the Koyukuk River, which does support anadromous fish. The Hammond River is also classified as anadromous. It flows through the eastern wilderness section of Gates of the Arctic National Park and Preserve and joins with the Middle Fork Koyukuk River at about MP 222.

Maximum flows are usually triggered by intense rainfall, similar to maximum river flows on the north side of the Brooks Range. Between MP 208 and 213, the aboveground pipeline crosses more than 18,000 ft of the Middle Fork Koyukuk floodplain; between MP 200 and 201, the aboveground pipeline crosses about 5,800 ft of Dietrich River floodplain.

3.7.1.3 Interior

The Interior Hydrologic Region extends from MP 265 to Donnely Dome (MP 560). This region is also part of the Yukon Drainage (TAPS Owners 2001a). Important surface water features within this region include the Jim River, Bonanza Creek, Kanuti River, Ray River, Yukon River, Hess Creek, Tolovana River, Chatanika River, Chena River, Little Salcha River, Salcha River, Redmond Creek, Shaw Creek, Tanana River, and Delta River. Principal rivers in the Interior Region flow into the Yukon River, which discharges into the Bering Sea. The Jim and Yukon Rivers are classified as critically sensitive all year for fish species. The Tolovana River (MP 399) supports anadromous fish about 25 mi downstream of the TAPS. The following streams and creeks are major anadromous water bodies in this region: Yukon River (MP 352), Chatanika River (MP 438), Chena River (MP 460), Little Salcha River (MP 491), Salcha River (MP 496), Redmond Creek (MP 500), Shaw Creek

(MP 520), and Tanana River (MP 531). The Delta River supports anadromous fish near its confluence with the Tanana River (MP 531). Other nonanadromous streams and segments are sensitive from April through October.

The Yukon River is the largest river in Alaska and carries a substantial load of suspended glacial sediment during the spring. The Tanana River is an extensively braided river that flows to the west and north to the Yukon River after joining the Delta River near the former Delta Campsite at MP 531. Flows within the Interior Hydrological Region are highly variable and depend largely on the watershed and its runoff characteristics. Along the Jim River from MP 271 to 272, the pipeline parallels the riverbed and crosses more than 7,000 ft of Jim River floodplain. Both elevated and buried crossings occur here.

3.7.1.4 Alaska Range

The Alaska Range Hydrologic Region extends from Donnelly Pass (MP 560) to Isabel Pass (MP 610). This region is located within the Yukon Drainage (TAPS Owners 2001a). The Delta River (Wild and Scenic River designation) and Phelan Creek are the principal surface water bodies of this region. The pipeline is also in a National Conservation Area (OASIS Environmental 2001). Streams in the Alaska Range Region flow into the Tanana River, a major tributary of the Yukon River, which discharges into the Bering Sea. No anadromous fish streams are found between the Tanana River (MP 531) and Sable Pass (MP 605) (TAPS Owners 2001a). The Delta River and Phelan Creek are considered to be critically sensitive for fish species during spring and fall.

Rivers in the Alaska Range Region are characterized by low winter flows and significant aufeis development in their wide, braided systems. Near the confluence of Phelan Creek and the Delta River (MP 594), the braided systems have a width of almost 1 mi. Between MP 584 and 585, the underground pipeline crosses 3,735 ft of Delta River floodplain.

3.7.1.5 Glennallen to Valdez

The Glennallen to Valdez Hydrologic Region extends from Isabell Pass (MP 610) to the end of the pipeline at Valdez (MP 800). This region is within the Copper River Drainage (MP 606–800) (TAPS Owners 2001a). Important surface waters within this region include Summit, Mud, Willow, Pippin, Paxson, and Meier's Lakes; the Gulkana (Wild and Scenic River designation), Copper, Tazlina, Klutina, Tonsina, Little Tonsina, Tsina, and Lowe Rivers; and Sheep, Brown, and Allison Creeks. These water bodies eventually discharge into Prince William Sound. The Copper, Gulkana, Tazlina, Tonsina, Little Tonsina, Lowe, and Klutina Rivers and Allison Creek are classified as anadromous (TAPS Owners 2001a). From the Lowe River crossing (MP 780) to the Valdez Marine Terminal, nearly all tributaries, streams, and creeks are considered to be anadromous fish habitat. They are sensitive year round and critically sensitive from late summer through much of the winter in conjunction with fish spawning and overwintering.

Maximum flows in these water bodies are generally triggered by releases from glacier-dammed lakes (TAPS Owners 2001a). In the Valdez area, heavy rains can produce high flows on the Lowe River and its major tributary, Brown Creek. Near MP 778, the underground pipeline crosses about 2,500 ft of Sheep Creek floodplain.

3.7.2 Existing Conditions and Historical Impacts

Existing conditions and historical impacts and their mitigation are used as a baseline to evaluate the proposed action and no-action alternatives. The topics discussed below include erosion and sedimentation, flooding, water use, contingency planning, water quality, and historical spills.

3.7.2.1 Erosion and Sedimentation

Erosion and sedimentation in streams and rivers are common natural processes along the TAPS ROW. Braided systems, such as the Sagavanirktok and Delta Rivers, are particularly subject to bed and bank erosion and subsequent downstream sediment deposition because of their physical characteristics. Two types of impacts are possible for erosion and sedimentation. First, the erosion of the beds and banks of surface water bodies can affect the pipeline by destabilizing its supports. Second, the pipeline and its structures can modify the rate of erosion in areas where they are in contact with flowing water. Pipeline structures and supports can be eroded by general scour (i.e., geomorphic processes, such as long-term adjustments of a channel from changes in basin hydrology, hydraulics, or sediment movement), contraction scour (i.e., the general lowering of the channel bed under the structure), and local scour (i.e., the removal of material around piers, abutments, spur dikes, and embankments caused by acceleration of the flow and turbulence near bridge substructural elements and embankments) (Heinreichs et al. 2001). Scour processes are accelerated during high-flow conditions. Under high-flow conditions (e.g., 100-year floods), contraction scour and pier scour can extend deeper than 10 ft. Similarly, sedimentation can impact structures in streams and river channels, and the structures within the channels can affect the deposition of sediment downstream.

The ROW crosses 80 major rivers, either buried or aboveground, and is in or adjacent to a number of river valleys (TAPS Owners 2001a). About 96 mi of the pipeline consists of buried or elevated river crossings, instream alignments, or alignments near major river channels, such as the Sagavanirktok, Atigun, Dietrich, Middle Fork Koyukuk, and Delta Rivers and Phelan Creek. These crossings were designed to accommodate foreseeable erosion, scour, ice conditions, and river meanders under Stipulation 3.6.1.1 (TAPS Owners 2001a).

Depending on the magnitude, duration, and time of the flow and characteristics of the materials involved, beds and banks can undergo significant scour, erosion, and sedimentation. Floodplain overflow during spring ice breakup, when the ground is still frozen, produces few channel modifications or new channels. For example, frequent and almost annual overflows occur along and across the Dalton Highway along certain sections of the Sagavanirktok River (TAPS Owners 2001a). These overflows produce minor changes in the floodplain. However, dramatic scour, bank erosion, enlargement of channels, and development of new channels can occur if the ground is thawed during a flood event. For example, major late-summer floods (e.g., the August 1992 flood on the Sagavanirktok River and the very high flows on the Dietrich/Middle Fork Koyukuk River systems in 1994) produced substantial changes to the river systems and their floodplains.

Glacial melt during long warm periods can produce relatively high, sustained flows that scour and erode stream beds and banks. The sudden release of multiple glacier-dammed lakes, in combination with high prior rainfall, can produce extremely high flows in rivers and induce major changes in the channel morphology (e.g., high release flows on the Tazlina River in 1997 significantly modified its channel morphology) and require a timely response to protect the pipeline. Similarly, debris accumulations in small streams can produce significant local bank or bed scour and significant changes in flow patterns, particularly in the area of alluvial fans, which have a high potential for bedload sedimentation, bank erosion, and the development of new channels (TAPS Owners 2001a).

The effect of erosion on the pipeline system is well studied, monitored, and surveyed along the ROW, and many mitigation activities have been implemented to reduce adverse impacts. These mitigation measures have been performed as routine maintenance along the ROW and as immediate responses to prevent adverse impacts to the pipeline. Some specific remediation methods include the following:

- Adding spur dikes (elongated structures having one end on the bank of a stream and the other end projecting perpendicularly into the current, used to protect eroding stream banks and shallow buried pipeline in the floodplain),

- Constructing revetments (armored structures parallel to the flow in a river or stream) to prevent further movement of the river toward the pipeline,
- Adding riprap (large rocks placed in the water and up the slope of an eroding shoreline) to control erosion along streambanks and lakeshores where vegetation is not sufficient to prevent erosion caused by high water or wave action,
- Armoring (placing riprap) to control erosion, and
- Adding gabion guidebanks (wire mesh baskets filled with cobblestones that range in size from 4 to 8 in.) to control erosion.

Some of the major repairs and new structures for river control are listed in Table 3.7-1. These repairs and new structures have been very effective in preventing adverse impacts to the pipeline.

In addition to erosion having a potential impact on the pipeline, the presence of the pipeline can also affect local rates of erosion. The degree of impact depends on whether river training structures such as spur dikes, revetments, and guidebanks, are used; what type of structure is used; and whether the pipeline is located in the active or main channel area or in floodplain fringe areas (TAPS Owners 2001a). In areas where the pipeline is buried, its presence no longer has any effect on river flows or erosion potential. Any adverse impacts were eliminated after ditches and low spots were filled with flood sediment during the first year of pipeline operation.

At aboveground river crossings, the amount of impact created by the pipeline depends on whether there are river training structures present to guide flow. These structures are necessary to reduce scour and bank erosion, thereby protecting the integrity of the bridge piers and abutments. No training structures are located at the Yukon River Bridge and the Atigun River Bridge. These bridges have had little or no impact on erosion, except for a local deepening of the river immediately in front of and alongside the piers, at a distance of about one to two times the size of the pier (Norton 2001a). Increased erosion on the opposite bank has not been documented.

Bridged crossings at the Tanana, Middle Fork Koyukuk, and Hammond Rivers employ river training structures. Riprap was placed along the banks of the Middle Fork Koyukuk River in 1996 near the location of the bridge crossing. The riprap did not extend very far into the water and had little or no effect on the river.

TABLE 3.7-1 Historical Activities Performed for River Control along the ROW

River	Activity	Location	Year
Sagavanirktok River	Spur dike added	MP 22	1993
	3 spur dikes added	MP 47	1993
Dietrich River	New spur constructed	MP 196	1995
	New revetment constructed	MP 198	1997
	Emergency armoring at valve site	MP 186	1998
	Revetment constructed	MP 188	1999
Middle Fork Koyukuk River	Spur repaired	MP 218	1995
	Revetment constructed	MP 231	1995
	Revetment constructed	MP 218	1999

Source: TAPS Owners (2001a).

The large guidebanks at the Middle Fork Koyukuk and Hammond River bridges are parallel to the flow and have had little impact on the rivers, except for limiting local movement of the water.

Along the ROW, many stream crossings are on VSMs. Bank erosion or channel scour can erode the bases of the VSMs, causing them to “stick up” excessively. Riprap islands have occasionally been placed around the piles or training structures to modify the flow regime and reduce erosion at the base of the VSMs. For example, high flows in Vanish Creek (MP 145) in 1999 resulted in significant VSM stick-ups. This situation was corrected by deflecting the flow in the channel, without measurably impacting the behavior of the creek or its flow pattern (TAPS Owners 2001a). Riprap is also used on alluvial fans to reduce erosion. The effect of riprap on wide alluvial fans (such as those at Snowden Creek) is insignificant. A similar method of protection is used to armor pipeline valve installations, including the accessories. For example, valve RGV 34 (MP 186) in the Dietrich River was armored for protection. This armoring prevented further movement of the river but did not impact downstream reaches of water.

In addition to river training structures and riprap, revetments and spurs are used to reduce erosion and protect the pipeline. On the Middle Fork Koyukuk and Delta Rivers, the impacts of revetments on flow patterns and overall river behavior are minimal. At the alluvial fan at Trims Creek, a revetment prevents spillage of the creek into PS 10. When spur dikes are added to a river system, such as the Sagavanirktok River, the flow deflection created by the structure forms new channels or vegetates bars, or deepens existing channels. In 1994, natural erosion near MP 231 was almost 100 ft. Construction of the revetment in 1995 (Table 3.7-1) halted erosion of the bank. A similar reduction in bank erosion occurred along the Sagavanirktok River at MP 47 as a result of spur construction (Table 3.7-1). Because an integral component of river training structure design is selecting a design that minimizes the impact on erosion of the opposite bank, as well as impacts on upstream and downstream erosion, impacts on the system have been local and negligible. Erosion typically occurs in the immediate vicinity of the structure and extends outward for only 10 to 20 ft (Norton 2001a). Deposition of the eroded material has also been local and not measurable in a braided system such as the Sagavanirktok.

Pipeline maintenance or extension of structures or construction of new structures is done in accordance with construction plans approved by regulatory agencies in order to reduce potential erosion and sedimentation. In the design and layout of all structures and maintenance work, the impacts on adjacent structures, natural vegetation, and flow patterns are considered to ensure that impacts are minimal and well within the kinds of changes produced by natural river processes, which can be very large and unpredictable in braided systems. Winter scheduling is also used to minimize instream work on waterways that have little or no flow during the winter, such as the Dietrich and Sagavanirktok Rivers.

Erosion and sedimentation were widespread problems during the initial construction and operation of the pipeline; most have been eliminated by corrective maintenance (TAPS Owners 2001a). APSC’s environmental monitors issued 190 noncompliance reports related to erosion control and surface drainage problems in 1977. This number was reduced to 24 in 1979, and to 3 in 1980 (GAO 1981). Since 1980, events of noncompliance have been sporadic. None of these noncompliance events has caused any oil spills. The most serious problems were associated with cross-drainage, caused by combined thermal and hydraulic erosion downslope from the Haul Road. Impacts of these processes were sufficiently small to be considered a negligible component of habitat impacts (Pamplin 1979). Successful mitigative strategies included use of mulches, benches, diversion barriers, rock armoring, and gabions. Many culverts were also replaced with low-water crossings.

3.7.2.2 Flooding

Because the pipeline crosses 80 major rivers and more than 800 streams along the ROW and because 96 mi of the pipeline consists of buried or elevated river crossings, instream alignments, or alignments near major river channels and their floodplains, the effects of floods on the pipeline were a major consideration during the pipeline's original design and continue to be so during ongoing maintenance. Because of prompt mitigation and continuous surveillance, impacts on the pipeline have been negligible. As discussed in the Environmental Report (TAPS Owners 2001a), the pipeline was designed for the pipeline design flood (PDF). The PDF is a theoretical flood size computed for every significant river and river crossing under Stipulation 3.6.1.1.1.2 of the Federal Grant. South of the Brooks Range, the PDF was computed by using 50% of the probable maximum precipitation (PMP); to the north of the Brooks Range, the PDF was computed by using 100% of the PMP in 1973 and 1974 (Norton 2001a) because of a lack of site-specific information. The PMP is the critical depth-duration-area rainfall relationship that would be produced by a storm containing the most severe meteorological conditions probable for a given location during the seasons of the year (Viessman et al. 1972).

The PDF does not have a specified return period. A 1:200 year flood calculated by the USGS (Jones and Fahl 1994 as cited in TAPS Owners 2001a) is used by regulators as a check on flood flows to compare the relative magnitude of flood events that have occurred during the period of pipeline operation. The major flood that occurred on the Sagavanirktok River in 1992 produced an estimated peak flow of about 42,900 ft^3/s at the monitoring station near Sagiwan. Because of high flows from the Ivishak River, downstream flows were much higher and estimated to be about two times the pipeline design flood, which exceeded the estimated PDF. The flood required the immediate placement of riprap and large, gravel-filled bags and the installation of a short rock spur at MP 47 to protect the overland buried pipeline from bank erosion. In the winter of 1993, three gravel spurs were built to deflect the main channel permanently away from the eroding west bank. These structures were designed for the higher 1992 peak flow (Norton 2001a).

At small stream crossings, the pipeline has produced local ponding of water. This ponding is often in ruts (created by vehicular traffic) that are deep enough to impede the free flow of water along the natural drainage. Such local damming of streams can adversely affect the migration of fish (TAPS Owners 2001a). Activities that can obstruct fish movements are reviewed under ADF&G Alaska Statute Title 16 and the Fish Habitat Permit processes. Historically, APSC has removed these flow impediments as part of its routine pipeline maintenance and surveillance programs.

3.7.2.3 Surface Water Use along the ROW

Pipeline operations require fresh water for drinking, cooking, and personal hygiene at manned facilities; equipment washing; dust abatement on roads and workpads; and hydrostatic testing (TAPS Owners 2001a). The ADNR regulates use of Alaska's water resources. That agency issues permits for temporary or long-term appropriation of water. APSC has certificates of appropriation for water use at permanent facilities, including each pump station, except PS 1 and PS 6. For example, temporary water use permit PCOTWP 97-3 permitted APSC to appropriate 20,000 gallons of water per day (gal/d), not to exceed a total withdrawal of 80,000 gal for tank cleaning purposes, and 3,000,000 gal/d, not to exceed a total withdrawal of 9,000,000 gal for hydrostatic testing during the life of the permit. This water was to be withdrawn from surface impoundments near PS 1 between July 1 and September 30, 1997 (ADNR 1997). APSC maintains other temporary water-use permits for facilities such as MCCFs and for special projects.

The largest single project for which temporary-water-use permitting was required occurred in 1997. At that time, 7.4 million gal of water (170 acre-ft — an acre-ft of water is the amount of water contained in a volume that has a surface area of one acre [43,560 ft^2] and a depth of 1 ft) were withdrawn from East Lake near MP 0 for tank cleaning and testing at PS 1. Because this lake occupies more than about 300 acres and has an assumed depth of about 8 ft, typical of lakes and the North Coastal Plain of Alaska (Ryan 1990), removing 170 acre-ft of water (about 10% of the available water) had a small, temporary effect. The water was discharged under the linewide NPDES permit, which mandates laboratory characterization, documentation, and erosion protection requirements for the discharge.

In addition to complying with ADNR regulations and permits, temporary and permanent withdrawals of water must be consistent with the Alaska Coastal Management Program. Withdrawals are acceptable if all water withdrawals cumulatively do not reduce the instream flows below the level necessary to support anadromous and resident fish.

Water used at PS 1 is purchased from the North Slope Borough's Service Area 10 water utility. At PS 6, a well at 5-Mile Camp is used as a source of water and then trucked across the Yukon River Bridge. Each active pump station uses between 4,500 and 7,500 gal/d for primarily domestic purposes. Water in the North Slope Borough is obtained from the Isatkoak Reservoir. Supplies average about 200,000 gal/d (AWWA 2002). Maximum pump station use from the borough is therefore negligible (less than 4% of typical water use by the borough).

The largest user of water along the ROW is the Valdez Marine Terminal (TAPS Owners 2001a). Industrial water is used there for power plant boiler water, stack-scrubber systems, steam-cleaning of equipment, and other washdown processes. The Valdez Marine Terminal has an appropriation permit for withdrawing water from Allison Creek. Since October 1995, the average water withdrawn from the creek has been about 110,000 gal/d.

Because all of the surface water uses along the TAPS ROW are strictly regulated by the ADNR through various appropriation permits and must be consistent with the Alaska Coastal Management Program, and because the historical appropriations have been small, impacts on surface water resources have been negligible to small.

3.7.2.4 Contingency Plans

Operation of TAPS is governed by the TAPS Oil Discharge Prevention and Contingency Plan (CP-35-1) (APSC 2001g). This plan is approved by the ADEC and the BLM every 3 years. The contingency plan divides the 800 mi of the pipeline into five regions (APSC 2001g). Region 1 extends from MP 0 to 206, Region 2 from MP 206 to 353, Region 3 from MP 353 to 496, Region 4 from MP 496 to 648, and Region 5 from MP 648 to 800.

The plan provides detailed information for reconnaissance, response, and containment actions in the event of an oil spill within each region. To facilitate response, the pipeline is further divided into a three-tiered hierarchy of regions, contingency areas, and segments. The five regional boundaries, in general, represent major river drainages crossed by the pipeline. These boundaries have been modified to take into account geographic features in APSC business unit boundaries. Each region is divided into contingency areas that cover a distinct drainage pattern. The contingency areas are then divided into segments for containment actions, access, and detailed environmental information. For example, Region 1 is divided into 10 contingency areas between MP 0 and 206. One of these areas is the Atigun River Contingency Area, which extends from MP 141 to 167. The Atigun River Contingency Area is further subdivided into four segments.

The plan provides for the following:

- Equipment and resources and field training for spill responders,
- Electronic leak detection capabilities,
- Improved leak detection and leak prevention alarm systems for pump station tanks,
- More than 220 sites along the ROW that are designated as oil-spill equipment staging and deployment areas, and dedicated oil-spill contingency plan buildings and equipment at each of the pump stations;
- Mutual aid agreements with villages near the pipeline to use residents and equipment in the event of a spill;
- Thirteen spill scenarios that cover a variety of terrains, oil products, spill volumes, and seasonal conditions; and
- Aerial photographs of the pipeline to aid in spill-response planning.

Table 3.1-5 summarizes oil-spill contingency equipment along the TAPS ROW. If water velocities in the rivers or streams exceed safe operating limits, APSC is to continue to monitor and track oil until an appropriate containment and recovery area becomes available.

In addition to stipulating on the equipment and person power needed to respond to a spill, the plan also provides specific instructions on how to respond to a spill in each specific contingency area. For example, the following contingency plan applies to a spill occurring during the summer in Segment 2 (MP 144) of the Atigun River Contingency Area (APSC 2001g). This spill occurs over land, with subsequent overland flow to the nearby river. Specifics of the plan include:

- Confining the spill to the workpad by using materials from the pump station pad to construct berms and barriers.
- Constructing berms or barriers in front of the leading edge of the spill to prevent oil from reaching flowing water.
- Deploying booms to contain the oil in the ponds, if oil reaches a pond or ponds west of the pump station. Constructing an underflow dam at CS3-31 (a small drainage at the confluence with the Atigun River west of PS 4) to prevent oil from reaching the Atigun River.
- Deploying a series of diversion booms downstream from the Dalton Highway Bridge to divert oil to the south bank, if oil reaches the Atigun River.

Any oil that escapes containment by the booms is assumed to form patches of sheen. These sheens would follow river currents downstream. The sheens would evaporate, dissolve in the water column, bind with inorganic silt particles, and be removed from the water surface quickly because of vertical mixing.

In addition to outlining detailed response activities, the plan also provides detailed response strategies for 13 hypothetical spills (APSC 2001g). These spills are assumed to occur along various sections of the ROW. The hypothetical spills illustrate the implementation of a range of response strategies within the framework of the response organization and use real data and locations to demonstrate how resources will be allocated in the event of a spill.

3.7.2.5 Surface Water Quality along the ROW

In cold regions, such as those traversed by the ROW, the following water quality characteristics are applicable (Jokela 1990):

- Glacial streams have high turbidity in summer, which limits light penetration and plant productivity.
- Ice cover on streams and lakes can prevent or retard reaeration, leading to hypoxic or anoxic (little oxygen) conditions in water beneath the ice.
- Stream flows during ice breakup tend to contain a relatively small amount of dissolved solids because of their high proportion of snowmelt when compared with the groundwater contribution of the stream flows.
- Groundwater-fed streams tend to have higher concentrations of dissolved solids and nutrients than do glacial streams.

Little information is available on the quality of surface water along the ROW. Some water quality measurements were made by the U.S. Geological Survey (USGS) before installation of the pipeline (Childers 1975; Nauman and Kernodle 1973), but there have been no comprehensive follow-up studies on water quality. Although no complete field studies have been performed to evaluate surface water quality along the ROW after installation of the pipeline, operations have not significantly affected stream or river flows, and the existing surface water quality conditions along the ROW are expected to be similar to pre-pipeline conditions. These conclusions follow from three arguments.

First, of more than 800 rivers and streams crossed by the pipeline, only two (Goldstream Creek [MP 448] and the Chena River [MP 460]) have impaired water quality according to ADEC. Water-quality-limited water bodies are surface waters for which actual or imminent persistent exceedances of water quality criteria, and/or adverse impacts to designated uses, as defined in the state's water quality standards (ADEC 2002), have been documented. ADEC maintains a list of impaired waters in accordance with Section 303(d) of the Clean Water Act (33 USC §1313(d)). The pipeline near Fairbanks crosses both of these streams. Neither of these streams has been impaired by TAPS operation. Placer mining is reported to be the cause of turbidity increases in Goldstream Creek, whereas runoff from urban and military lands may be introducing sediment and petroleum compounds into the Chena River.

Second, observations by nonprofit organizations have not identified any specific degradation of water quality or habitat that is attributable to TAPS operations (TAPS Owners 2001a). These nonprofit organizations include the Yukon River Intertribal Watershed Council, the Copper River Watershed Council, and the Tanacross Village Watershed Council. All of these councils are interested in maintaining pristine conditions in specific waterways along the ROW and are funded by the EPA for certain activities, such as visual observations of water bodies, envisioned as promoting the health of a watershed.

Third, all surface water discharges along the ROW are regulated under various release permits, including a linewide NPDES Permit, a State of Alaska Wastewater General Permit, and an NPDES Permit for Storm Water Discharge from Construction Activities Associated with Industrial Activity. These permits delineate the type and concentrations of compounds that can be discharged to Alaska waters. Compliance with these permits ensures that any water released will not have a substantial adverse effect on the waters of the United States. Some minor noncompliances with the linewide permit have been self-reported by APSC. These noncompliances have not measurably affected surface water quality (TAPS Owners 2001a).

The linewide NPDES permit regulates the release of treated wastewater from each MCCF, in addition to discharges released onto the workpads. In permafrost areas, discharge to groundwater is not practical, and long-term discharge of wastewater across the tundra can promote erosion. Only PS 5 has a permanent discharge of sanitary wastewater to tundra wetlands (TAPS Owners 2001a). (MCCFs can discharge wastewater, but their locations are temporary.) In 1999, the lagoon treatment system at PS 5 was upgraded to a conventional aerobic secondary treatment process by adding a small mechanically activated sludge plant. Discharge from this process is distributed through a diffuse outfall across the tundra under the linewide NPDES permit.

Placer Mining

A placer is a deposit of gravel that may contain gold particles. The word placer was derived from the Spanish word meaning "sand bank." Early forms of placer mining included gold panning, sluicing, and the use of a rocker (a "cradle" or a "dolly" used when water is in short supply or when the depth of the stream or creek is too shallow to use a sluice-box) (Davies 1998).

In addition to treated wastewater, the linewide NPDES permit specifies rules for discharging hydrostatic-test waters and excavation dewatering (TAPS Owners 2001a). Hydrostatic testing is performed on segments of the pipeline or on tankage brought into service following installation or repair to ensure that the repair or construction is soundproof and leakproof. Hydrostatic testing occurs infrequently. In 1991, 3.8 million gal of water was released when more than 8 mi of pipeline was reconstructed to improve pipeline stability in the Atigun River valley.

In 1996 and 1997, a total of about 7,800,000 gal of hydrostatic test water was released. The composition of the discharge generated by hydrostatic testing includes small quantities of inorganic residual materials left in the pipe prior to testing, such as dust and welding slag. The linewide permit mandates laboratory characterization of the water, documentation, and erosion protection at the point of release. Most water is discharged to dry channels or snow (TAPS Owners 2001a). The appropriate technologies for these discharges are physical treatment methods, such as filtration, overland treatment, and/or settling ponds that can control settleable solids and turbidity (EPA 1997a). This technology is established as best conventional pollutant control technology and best available technology technically achievable.

Excavation of buried pipeline is occasionally required to confirm findings of pipeline pigs (instrumented probes used in the pipeline to determine its condition and operation) or other test data and to make necessary repairs. If groundwater is encountered during the maintenance digs, the water must be removed and discharged away from the trench. Dewatering discharge has been regulated through various permits, beginning with a State of Alaska wastewater discharge permit in 1983. The current line-wide permit requires notification, volume estimates, and descriptions of procedures employed to minimize erosion and the discharge of pollutants (e.g., filtration, overland treatment, and/or settling basins). Between 1993 and 1999, there were about 90 reported discharges. Of these, 12 were to surface water. The total volume of water released was on the order of 1 billion gal. Most of this water was released during 1996 (approximately 800 million gal in 25 releases).

Secondary containment structures at pump stations and the Valdez Marine Terminal may trap snowmelt and rainwater. These structures must be periodically drained to ensure that the full capacity of the secondary containment systems is maintained (TAPS Owners 2001a). Dewatering of secondary containment structures is allowed by a State of Alaska Wastewater General Permit. This permit establishes monitoring requirements and effluent limitations. To guard against discharge of pollutants, the discharge is visually inspected for sheen. No discharge of water that bears hydrocarbon sheen is allowed; water with a sheen must be treated prior to release. In 1997, more than 600 secondary containment structures along the ROW were drained. The total volume of water drained was 15,678,000 gal. More than two-thirds of this water came from early summer dewatering of the tank farm at PS 1, where the secondary containment volume is the greatest. At the Valdez Marine Terminal, discharge from the secondary containment structures is to the Ballast Water Treatment Facility.

Eleven of the ROW facilities currently meet the applicability criteria of the EPA Storm Water Multi-Sector General NPDES Permit (MSGP) for Industrial Activities that can potentially affect surface water. APSC operates the sites in conformance with the MSGP standards. The affected sites are all material sites that might discharge rainwater or snowmelt from areas used to mine sand and gravel to surface water. To mitigate the discharge of potentially contaminated storm water and to comply with the general storm-water permit, APSC performs the following storm-water monitoring and inspections (TAPS Owners 2001a):

- Evaluation of non-storm-water discharges at the site,
- Quarterly inspections,
- Quarterly visual examinations of storm-water runoff (performed during a storm event), and
- Quarterly analytical monitoring for total suspended solids, pH, and nitrate/nitrogen (performed during a storm event).

Compliance with the permit ensures that impacts from releases are minimized and that water quality is maintained.

Construction activities that disturb more than 5 acres, do not involve excavation dewatering, and have a potential to impact waters of the United States are covered under an NPDES Permit for Storm Water Discharge from Construction Activities Associated with Industrial Activity. Specific notices of intent are submitted to the EPA, and for projects that meet the criteria for coverage under the permit, regulations are adhered to.

3.7.2.6 Historical Spills of Crude Oil

Between 1977 and 1999, more than 4,400 spills were recorded for the pipeline and Valdez Marine Terminal (TAPS Owners 2001a). The spills included about 38,000 bbl of crude oil, 60% of which came from the Steel Creek and Livengood pipeline sabotage events. Almost all of the other spills were either contained in a lined area or cleaned up within about 1 year.

Spills of crude oil to inland surface waters have been very infrequent. One of the largest spills that affected surface water occurred on June 10, 1979. It resulted from a hairline crack in the pipeline caused by settlement at Atigun Pass (MP 166.43). In this spill, approximately 1,500 bbl (63,000 gal) of oil was released, and the pipeline was shut down for about 54 hours (APSC 2002). The crude oil migrated from the point of release through a culvert downslope to the Atigun River, where it produced some impacts (TAPS Owners 2001a), including an oil slick that traveled 25 mi downstream (Behr-Andes et al. 2001). Impacts of this spill have produced no long-term effects on surface water quality in the area of the spill. Spill sites can be grouped according to the location of the event: pump station facilities, the Valdez Marine Terminal, construction-era camps, disposal sites, and miscellaneous sites (e.g., sites along the TAPS ROW but outside the boundaries of any pump station or the Valdez Marine Terminal).

Currently, there are 87 spill sites in the APSC database that require management under the APSC Contaminated Site Management Program (OASIS Environmental 2001). These spills represent less than 1% of the number of spills reported since 1977 for TAPS and the Valdez Marine Terminal. Seventy of these sites occur along the pipeline, and 17 are located at the Valdez Marine Terminal. Twenty-seven of the sites along the pipeline are classified as active; that is, the sites are currently being assessed, monitored, or remediated. Twenty sites are classified as requiring no further action. (These are sites for which an application for closure has been submitted to the ADEC, but for which closure has not been formally approved.) Twenty-three sites are classified as closed. (These are sites that have been formally closed by the ADEC, with regulator concurrence that the sites present little to no risk to human health or the environment.) Of the 17 sites at the Valdez Marine Terminal, 8 are active, 1 requires no further action, and 8 are inactive.) Detailed information on historical volumes of contaminated soils and wastes and their treatment is given in Appendix C.

In the event of a spill along the ROW, a predefined management process is implemented in accordance with the contingency plan (APSC 2001g). This process includes discovery, characterization, remediation, monitoring (if needed), and, finally, closure (OASIS Environmental 2001). Following discovery and characterization of the spill, a variety of contaminant management strategies have been used at contaminated sites. The response always includes removal of as much free product as possible, and, in most cases, excavation of the most contaminated soil to minimize the potential of direct exposure and to inhibit contaminant migration to both surface and groundwater resources. ADEC cleanup standards adopted in January 1999 are the current basis for investigation, cleanup, and monitoring activities at the contaminated sites.

Four high-priority contaminated sites along the ROW are Happy Valley Camp, the PS 6 leach field/fueling island, the PS 1 former gas tank area, and Toolik Camp. The Power Vapor Area at the Valdez Marine Terminal (OASIS Environmental 2001) also has a high priority (see Table 3.8-1). All of these sites are actively being managed. Spills at these sites ranged from 87 gal at PS 6 to 33,619 gal at Check Valve 92 (medium priority). One of these sites has produced measurable contamination of some surface water seeps from the gravel pad that enter Happy Valley Creek. This site is a construction-era facility, Happy Valley Camp (MP 80). Four spills, each of more than 1,000 gal of diesel fuel, occurred at Happy Valley West, a gravel pad located at a former construction campsite west of the Dalton Highway. These spills included 6,000 gal in 1970, 1,000 gal in 1972, 8,000 gal in 1973, and 1,800 gal in 1975.

Response actions to the above spills included excavating interceptor trenches and recovering free product. The site was subsequently restored in accordance with the APSC Erosion Control Plan and reclamation was approved through the formal “Greensheet” process in the early 1980s (OASIS Environmental 2001). APSC voluntarily undertook a program to reevaluate residual impacts at the site in 1996. Since 1996, surface water monitoring in Happy Valley Creek has indicated hydrocarbon contamination originating from residual soil contamination in the adjacent gravel pad. Stained soil near the surface was excavated and treated off site in 1998. APSC is currently evaluating remedial options and was to perform additional water quality sampling in 2001.

A large spill recently occurred near MP 400 (TAPS MP 400 event; see Section 4.1.1.8) when the pipeline was shot with a high-power rifle. This event released 285,600 gal of oil to the environment. About 175,793 gal of free product has been recovered at the site with interceptor trenches (TAPS Owners 2002a). Removal of the contaminated soils and vegetation is underway.

Because surface water quality has not been significantly affected by pipeline operations, as discussed in the previous section, the remediation activities detailed in the TAPS contingency plan apparently have been successful.

3.8 Groundwater Resources

Groundwater is subsurface water that occupies the spaces between particles within a geologic formation (Todd 1980). In Alaska, where permafrost occurs beneath about 85% of the land surface, groundwater is further designated as *subpermafrost* or *suprapermafrost*, depending on whether it occurs below or above permafrost, respectively (Nelson and Munter 1990). In the zone of continuous permafrost, suprapermafrost groundwater is available seasonably as part of the active zone (the zone in which the permafrost thaws) and is subject to contamination. The underlying permafrost forms a confining unit for the subpermafrost aquifers (Miller and Whitehead 1999). In northern regions, the active zone and any associated suprapermafrost aquifers can be very thin, approaching a thickness of only a few inches (Davis 2001).

Suprapermafrost groundwater occurs beneath rivers and lakes as a thin layer above the top of the permafrost, and in aquifers above permafrost at depths of tens of feet (Nelson and Munter 1990). If the thickness of the permafrost is great, suprapermafrost groundwater may be the only groundwater resource available. Suprapermafrost groundwater plays an important role in creating distinctive geomorphic features, such as wetlands, patterned ground (a mosaic of polygons ranging up to 20 ft in diameter on the tundra that are formed by freeze/thaw cycles), pingos (Inuit word for ice-cored hills in permafrost formed when the hydrostatic pressure of freezing groundwater causes the upheaval of a layer of frozen ground), and shallow lakes.

Subpermafrost aquifers occur in permeable material below the base of permafrost. In areas of continuous permafrost, these aquifers consist mostly of bedrock. In the zone of discontinuous permafrost, they commonly consist of unconsolidated deposits (Miller and Whitehead 1999). When present, subpermafrost groundwater can be expensive to extract and commonly brackish to saline, particularly near coastal areas. Subpermafrost groundwater from alluvium is generally unavailable in the zone of continuous permafrost; however, some wells have obtained water from sedimentary, metamorphic, or igneous rocks (Nelson and Munter 1990). Within areas of discontinuous permafrost, groundwater supplies can generally be developed, but the occurrence and distribution of permafrost may affect the placement and operation of the wells.

Groundwater also occurs in taliks and thaw bulbs. As indicated in Table 3.1-1, taliks have been, and are still being, used to supply water along the TAPS ROW. At PS 3, water is being obtained from a large talik along the pipeline (Keyes 2002). This talik was formed by warm oil in the pipeline flowing through thaw-stable permafrost. The talik conveys water from the Sagavanirktok River year round.

Taliks and Thaw Bulbs

In areas of permafrost, taliks and thaw bulbs can be sources of groundwater.

Taliks are unfrozen zones that occur beneath lakes and rivers that are either underlain by permafrost at depth or that are completely open to subpermafrost groundwater.

Thaw bulbs are localized regions of melted permafrost produced by some local source of heat, for example, by the warm oil flowing through buried pipeline along the TAPS ROW.

Pipeline operations require fresh water for drinking, cooking, and personal hygiene for manned facilities; equipment washing; dust abatement on roads and workpads; and hydrostatic testing. Potable use at pump stations averages about 100 gal of water per day per person (TAPS Owners 2001a). At the pump stations and camps, potable water is generally obtained from local wells that are maintained by APSC. At PS 1, potable water is purchased from the North Slope Borough's Service Area 10 water utility. A well at 5-Mile Camp is used as a water source for PS 6.

As shown in Table 3.1-1, 20 wells along the ROW have been used for the production of potable water, except for well 25098 which is dry (no groundwater was found in this well to a depth of 300 ft). Currently, six wells are active. Each active pump station uses between 4,500 and 7,500 gal of water per day (gal/d), mostly for domestic use (TAPS Owners 2001a). The wells range in depth from 28 ft at PS 8 to 800 ft at PS 6 (MWH 2001). Most of the wells extract water from taliks. The capacities of the wells along the ROW are all low, ranging from 20 to 75 gallons per minute (gal/min) (well 25093 at PS 6 and well 25086 at PS 2, respectively). The well capacities thus greatly exceed the daily use even for maximum use (7,500 gal/d, or 5.2 gal/min). The combined current capacity for active wells used for groundwater TAPS operations along the ROW is at least 190 gal/min (270,000 gal/d). The well at PS 5 is active, but has no reported capacity (estimated to be about 25 gal/min). Use of water along the TAPS ROW is regulated by the ADNR. Historical compliance with water-use permits has limited the impacts of water withdrawal to minor, local, and temporary.

The major user of groundwater in the vicinity of the TAPS ROW is the City of Fairbanks. It derives all of its water from wells in an adjacent, hydraulically independent aquifer. In 1996, the monthly mean water withdrawal was about 6 million gal/d (USGS 2002). The total groundwater use by the TAPS is, by comparison, less than 1% of the use at Fairbanks. For a typical single well along the TAPS ROW that extracts 5 gal/min (7,200 gal/d), the percentage of Fairbanks water use is even less.

The quality of groundwater in Alaska can range from very good to saline, depending on the location and depth of the well. In regions near Fairbanks, groundwater tends to have high arsenic levels derived from formations of schist rocks (Farmer et al. 1998). Regular water-quality monitoring is required for public water supply systems, such as those at each pump station along the ROW. Under State of Alaska regulations (18 AAC 80), nitrate monitoring is required annually. Generally, the concentration of nitrates found in wells at the TAPS pump stations is about 0.3 mg/L (TAPS Owners 2001a). This value is within the U.S. Environmental Protection Agency (EPA) drinking water standard (maximum contaminant level, MCL) for nitrate as nitrogen (10 mg/L) (EPA 1996). Similarly, the arsenic concentration in pump station wells (about 0.01 mg/L) (TAPS Owners 2001a) is less than the current EPA MCL (0.05 mg/L). By January 2006, the EPA MCL for arsenic will be reduced to 0.01 mg/L (EPA 2001c). At that time, compliance of water from the pump station wells may become an issue.

No direct releases of untreated wastewater to groundwater occur along the ROW. Indirect releases of treated sanitary wastewater can occur from conventional septic systems at PS 6 (Fly Camp), 7, 9, 10, and 12, and discharges of sanitary wastewater to the ground at PS 5 can indirectly affect groundwater through infiltration. The septic systems leachfields at PS 7, 9, 10, and 12 (capacities of 3,400, 1,000, 12,000, and 9,100 gal, respectively [Mikkelsen 1997]) will be nearing their typical useful life in the next decade and will be replaced if necessary (TAPS Owners 2001a). Historical impacts from sanitary wastewater management are expected to have been small and localized because of the presence of permafrost that limits deep percolation of the water, the assimilation properties of the local groundwater, and compliance with other regulatory requirements.

Groundwater can also be affected by spills along the ROW. Between 1977 and 1999, 4,283 spills were recorded and reported (OASIS Environmental 2001). Approximately 98% of those spills were either contained in a lined area or were cleaned up within about 1 year. Spill sites can be grouped according to the location of the event: pump station facilities, the Valdez Marine Terminal, construction-era camps, disposal sites, and miscellaneous sites (e.g., sites along the ROW, but outside of the boundaries of any pump station or the Valdez Marine Terminal).

As discussed in the Section 3.3.3, there are 87 spill sites in the APSC database that require management under the APSC's Contaminated Site Management Program (OASIS Environmental 2001). These spills represent about 2% of the number of spills reported since 1977 for the TAPS and the Valdez Marine Terminal. Of the 70 spill sites along the pipeline (17 spill sites are located at the Valdez Marine Terminal), the ADEC has approved closure for 23, 20 have no further remediation planned (closure pending), and 27 are active (remediation or monitoring being planned or underway). A predefined management process is implemented in the event of a spill along the ROW. This process includes discovery, characterization, remediation, monitoring (if needed), and finally closure (OASIS Environmental 2001). Following discovery and characterization of the spill, a variety of contaminant management strategies have been used at contaminated sites. ADEC cleanup standards adopted in January 1999 are the current basis for investigation, cleanup, and monitoring activities at the sites. The response always includes removal of as much free product as possible and, in most cases, excavation of the most contaminated soil to minimize the potential of direct exposure and to inhibit contaminant migration to both surface and groundwater resources. Detailed information on historical values of contaminated soils and wastes and their treatment is given in Appendix C.

Four active contaminated sites occur along the ROW: Happy Valley Camp, the PS 6 leach field/fueling island, the PS 1 former gas tank area, and Toolik Camp. The Power Vapor Area is a high-priority site at the Valdez Marine Terminal (OASIS Environmental 2001). Check Valve 92 is a medium-priority site along the pipeline. Table 3.8-1 summarizes information for these sites. Sites that have high priorities require the greatest attention to ensure protection of people and the environment. The other 21 active sites have relative priorities of either medium or low. All of these sites are being actively managed and have contaminated groundwater (suprapermafrost meltwater in the active zone). The spills that occurred at these sites ranged from 87 gal at PS 6 to 33,619 gal at Check Valve 92. The extent of groundwater contamination at these sites is also variable; the largest occupies an area of about 2 acres (Toolik Camp).

An even larger spill has recently occurred near MP 400 (Livengood spill) due to shooting of the pipeline with a high-power rifle. This event released 285,600 gal of oil to the environment. About 160,000 gal of free product have been recovered at the site with interceptor trenches; however, shallow groundwater has become contaminated. Additional characterization is currently underway and remediation activities appropriate for the site have commenced. As of April 2002, the following activities have been completed at the Livengood site: an estimated 300 yd^3 of oiled trees and 1,480 yd^3 of heavily oiled vegetative mat removed from the site; an estimated 3,280 yd^3 of lightly oiled soil removed from a Department of Transportation pit; a total of 22,610 yd^3 of lightly oiled soil and 720 yd^3 of heavily oiled soil removed from the spill site; and 175,793 gal of recovered oil reinjected into the pipeline at PS 7 (Willson 2002).

The Valdez Marine Terminal has 17 contaminated sites, with 8 sites being active. All of these sites are located within the confines of an industrial facility and currently pose no threat to drinking water supplies or the marine water (OASIS Environmental 2001). The contaminated sites are generally located in oil storage or process areas, including the East Tank Farm, the Power Vapor Area, and the BWTF. The primary contaminants released include crude oil, diesel fuel, and oily ballast water. As part of the remediation activities for the contaminated sites, a soil-vapor extraction system was operated from June to October 1999. This system removed more than 3,000 lb of volatile organic compounds from contaminated soil. System operation was resumed during the summers of 2000 and 2001. In addition, the remediation consisted of free-product removal from the groundwater and groundwater extraction at the source area to control off-site migration of contaminated groundwater during periods of high seasonal watertables. This remediation has decreased benzene concentrations and free-product thickness at the Power Vapor Site, and monitoring results indicate that contamination will not reach marine waters of Port Valdez.

Procedures for remediation of contaminated groundwater at spill sites along the ROW include removing the sources of contamination (free-product recovery by use of interceptor trenches and skimmers and removal of contaminated soil and vegetation) and various in-situ techniques, such as:

- Soil vapor extraction — An in-situ remedial technology that reduces the concentration of volatile constituents in petroleum products that are adsorbed to the soil by applying a

TABLE 3.8-1 Six Contaminated Sites along the TAPS ROW

Site	Date of Occurrence or Discovery	Contaminant	Estimated Volume (gal)	Comments
Happy Valley	1970 - 1975	Diesel	16,800	Spill at former construction camp. Cleanup in 1970s after spills. Closure status issued in early 1980s. Change in land use in 1996 required site assessment. Additional assessment and remediation may be required.
Pump Station 6 leach field	1992, 1997, 1998	Diesel-range organics (DRO)	87	Fuel island, tank farm, generator building, and fueling area may be sources. Pilot soil-vapor extraction system tested in 2000. System installation planned for 2001.
Check Valve 92	1996	Crude oil	33,619	Groundwater monitoring and product recovery continued in 2001. Site closure alternatives will be examined in 2002.
Pump Station 1	1992	Gasoline	112	Former gas tank area. Contaminated soil removed or being remediated in-situ. Benzene levels decreasing near gasoline spill location.
Toolik Camp	1974, 1975	Diesel	13,500	Former construction camp. Cleanup in the 1970s after spill. Closure status assigned in early 1980s. Change in land use status in 1996. Site may be closed in 2002 after groundwater and surface water monitoring if contaminant concentrations continue to exhibit stable or decreasing trends documented since 1977.
Power vapor condensate release at Valdez Marine Terminal	1995	Petroleum condensate	341	Soil excavation, groundwater monitoring, and product removal. Soil-vapor extraction initiated in 1999 continues.

Source: OASIS Environmental (2001).

vacuum to create a negative pressure gradient that causes movement of vapors toward extraction wells in regions in which the void spaces are not filled with water (unsaturated zone) (EPA 1995a);

- Air sparging — An in-situ remedial technology that reduces the concentrations of volatile constituents in petroleum products that are adsorbed to soil and dissolved in groundwater by injecting contaminant-free air into the region of saturated groundwater (all void spaces are filled with water) (EPA 1995a); and

- Biodegradation — A process of adding oxygen-releasing compounds (ORC) that enhance biodegradation of the contaminants.

Lined dikes are also used to limit the migration of mobilized contaminants. Characterization of the extent of contaminated groundwater and evaluation of the effectiveness of the remediation methods rely on groundwater monitoring.

By quickly implementing the provisions of the ROW site contingency plans (e.g., APSC 2001g) and following the existing contaminated sites' management processes, historical groundwater contamination has been limited to a few small sites. Remediation of these contaminated areas is ongoing, and the extent and magnitude of groundwater contamination is being reduced with time, as evidenced by the 23 sites that have attained closure.

3.9 Physical Marine Environment

3.9.1 Location and Description

Port Valdez is a fjord approximately 5 km wide by 18 km long that extends in an easterly direction and is separated from the Valdez Arm of Prince William Sound by the Valdez Narrows (Map 3.9-1). The Valdez Narrows is a narrow channel that trends north-northeast. It is considered the dividing line between Port Valdez and the Valdez Arm of Prince William Sound (Colonell 1980). Port Valdez and the Valdez Arm together are about 45 km long and form a northeasterly extension of Prince William Sound (Colonell 1980). The Hinchinbrook Entrance, located approximately 100 km from the Valdez Narrows, connects Prince William Sound with the Gulf of Alaska and the Pacific Ocean (Map 3.1-2). The Town of Valdez is near the northeastern corner of Port Valdez, and the Valdez Marine Terminal is on the southern shore.

Location of Valdez and Prince William Sound

Port Valdez is a narrow, deep, glaciated water-filled valley (fjord) with steep rocky shores in the Chugach Mountains. About 5 km wide and 18 km long, it extends east and is separated from the Valdez Arm of Prince William Sound by the Valdez Narrows. Prince William Sound covers about 6,500 km^2 and extends about 90 km from Cape Hinchinbrook to Cape Puget.

Port Valdez is a narrow, deep, glaciated fjord with steep rocky shores in the Chugach Mountains. The Lowe and Robe Rivers and the Valdez Glacier stream empty into the head of Port Valdez and have formed an extensive outwash plain where the old Town of Valdez was located. The old Town of Valdez was destroyed by the Great Alaska Earthquake of 1964. The new Town of Valdez is located on an outwash plain from Mineral Creek on the northern shore (near the eastern end) of the fjord. Both outwash plains are poorly consolidated alluvial and glacial deposits of silt, sand, and gravel (Hood et al. 1973). Large tidal flats have formed on the edges of these outwash plains because of the relatively high tidal range of 5.5 m (Hood et al. 1973) and the large amount of fine sediments deposited in the fjord from the local streams and rivers.

Prince William Sound covers approximately 6,500 km^2 (Det Norske Veritas et al. 1996) and extends about 90 km from Cape Hinchinbrook (east) to Cape Puget (west) (Map 3.1-2). Prince William Sound has numerous islands, the largest being Montague Island, which extends into the Gulf of Alaska near the Hinchinbrook Entrance. The Hinchinbrook Entrance is the main entrance to Prince William Sound for marine traffic. It is about 10 km wide and provides a clear passage, with the exception of Seal Rocks (Det Norske Veritas et al. 1996). The shoreline of Prince William Sound is generally steep and rocky, with numerous bays and fjords.

The waters of Prince William Sound are chilled by surrounding glaciers and cold, freshwater inflows (Det Norske Veritas et al. 1996), although the waters are protected by the surrounding land mass. The meeting of cold water and cold air from the Chugach Mountains and the warmer water and moist air from the Gulf of Alaska causes sudden squalls, and thick fog is common (Det Norske Veritas et al. 1996). Weather in Prince William Sound and Port Valdez can be significantly different.

The shoreline of Port Valdez is composed of interbedded, dark gray to black, hard, slaty shales and dark gray, hard, fine-grained shaly siltstones with quartz veins. The bedding plains strike in an east-west direction and have an average dip of approximately 55° to the north (Hood et al. 1973). The exposures in Port Valdez have a complex system of fractures, the larger of which are perpendicular to the strike and influence the north-south orientation of the streams that enter Port Valdez.

Glaciers moved from the Chugach Mountains into Port Valdez, then west and south into Prince William Sound, as recently as the late Pleistocene era. Glaciation is ongoing in Prince William Sound and the mountains above Port Valdez. Evidence of glaciation has been found as high as 975 m above sea level in Port Valdez. When the glaciers receded, the fjord was filled with morainal material. Seismic surveys have identified three separate units in the fjord. The bottom unit is bedrock, the middle unit is unconsolidated outwash material, and the third unit consists of post-glacial deposits and is finer grained (Hood et al. 1973). The unconsolidated material of the second and third units ranges in depth from 400 m thick near the center of Port Valdez to the shallow sills[1] at the mouth of Port Valdez. At the Valdez Narrows, little Pleistocene or Holocene deposition occurred, and the bedrock unit is near the surface.

3.9.2 Bathymetry

The east-west trending Port Valdez has a morphology that is typical of a glaciated fjord and consists of a U-shaped valley with a complex sill near the entrance (Hood et al. 1973). The bottom of the fjord has a very flat bottom at a depth varying between 230 and 250 m. The bottom of the fjord rises steeply on the north and south, but more gently at the eastern end, beginning 2 or 3 km east of the Valdez Marine Terminal, to the Valdez outwash delta created by fluvial deposits (Hood et al. 1973). The Valdez Narrows, which form the mouth of the fjord, are approximately 1.5 km wide and have two sills, with the shallower one at a depth of between 110 and 128 m (Map 3.9-1). The Port Valdez depth-volume curve (which plots the volume of water in the basin versus the water depth for the basin) is almost linear (i.e., the change in depth plotted against the change in volume is a straight line), reflecting the regular nature of the bathymetry of the fjord (Colonell 1980).

Water in Prince William Sound is deep, averaging about 300 m (Det Norske Veritas et al. 1996). The shorelines are generally steep, both above and below the water; however, there are outwash plains in the bays and fjords.

3.9.3 Hydrography and Circulation

Hydrography and circulation in Port Valdez depend on variables, such as tides, precipitation, freshwater inflows, winds, air temperatures, and mixing with the waters of Prince William Sound (Hood et al. 1973). Port Valdez waters are generally stratified (layered) with respect to both salinity and temperature from May to October, when freshwater inflows are high. During one field season, Hood et al. (1973) observed the maximum stratification to occur in July. During the period from December to April, when freshwater inflows are at a minimum and surface cooling and wind mixing are at a maximum, the waters of Port Valdez were found to be well mixed vertically (Hood et al. 1973). A longer study was conducted by Colonell (1980) over a 36-month period beginning in 1976. That study supported the earlier findings that Port Valdez waters have a pronounced annual cycle; they are strongly stratified in the summer, and, from the late fall to early spring, they completely mix, resulting in a nearly homogenous state. Both

Port Valdez
Hydrography and Circulation

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A conservative estimate is that waters reside in Port Valdez for only a few weeks.

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[1] The “shallow sills” constitute a bedrock ridge at a shallow depth near the mouth of a fjord. It separates the deep water of the fjord from the deep ocean water.

studies (Hood et al. 1973; Colonell 1980) show that mixing occurs to the bottom of the water column in the fjord, producing oxygen-rich water at depth. Seasonal changes in density structure are illustrated in Figure 3.9-1. Hood et al. (1973) noted that the Prince William Sound waters appeared to have a similar regime of summer stratification and winter mixing of both salinity and temperature.

Port Valdez tides are mixed, semidiurnal type with a maximum range of approximately 5.3 m and a mean amplitude of about 3 m (Colonell 1980). Mixed, semidiurnal tides occur twice a day, with a period of about 12 hours, with two high tides and two low tides per day. High-tide and low-tide amplitudes are unequal. The tidal prism (the volume delineated by the shoreline and the high and low tide levels)

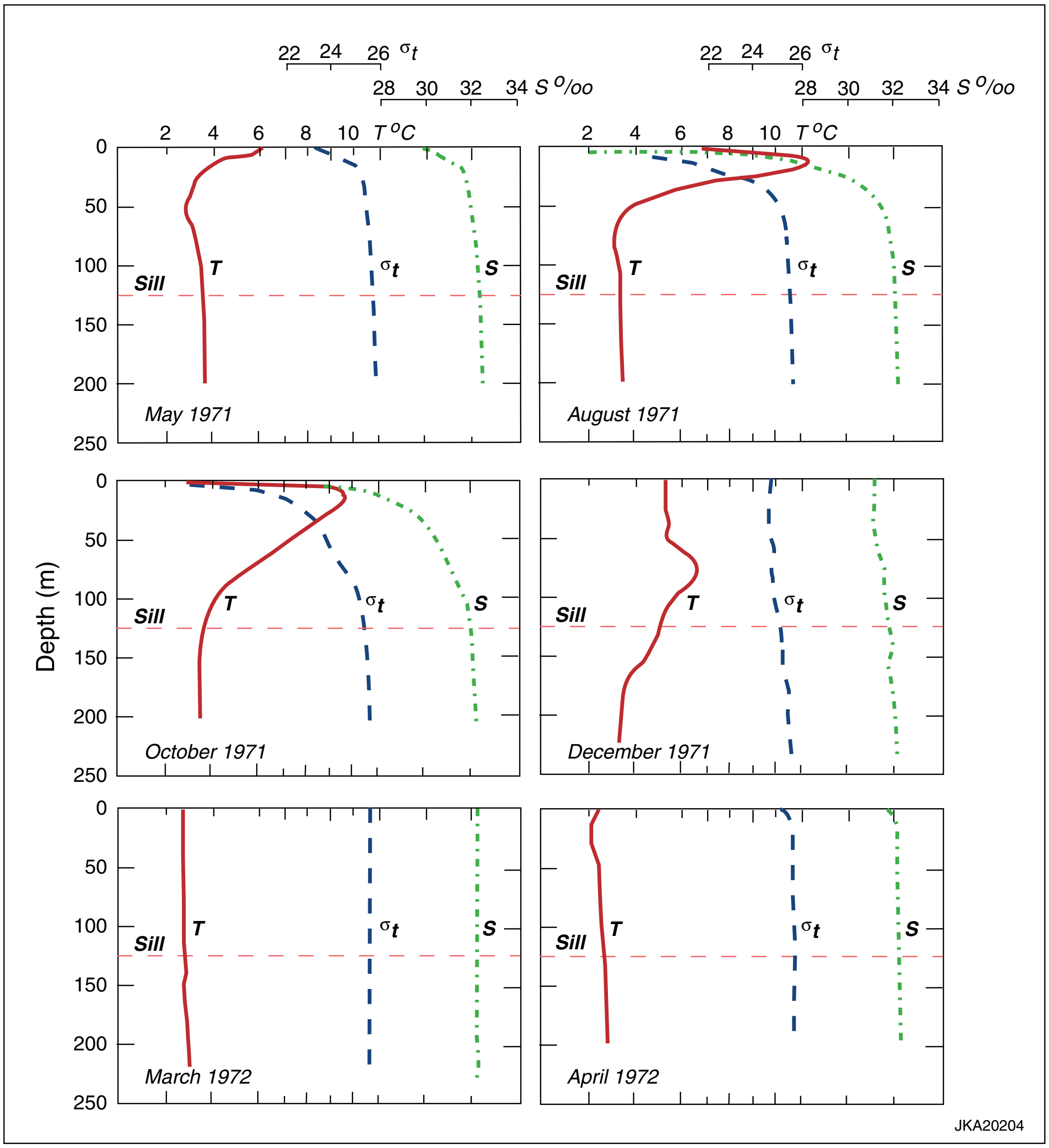

FIGURE 3.9-1 Changes in Temperature and Salinity Distributions in Port Valdez (T = temperature, S = salinity, σ = density) (Source: TAPS Owners 2001a, Figure 3.1-14)

corresponds to about 1.6% of the total volume of water contained in Port Valdez, and during well-mixed winter conditions, provides for refreshment of half the volume of Port Valdez about every 22 days (TAPS Owners 2001a).

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 water and ongoing inflow to provide for a hydraulic residence time for these deep waters of approximately 40 days (TAPS Owners 2001a).

Summer flows in Port Valdez are characterized as typical of estuarine flow. These flows are driven by the thin layer of fresh water on the surface of the fjord that moves seaward, while the return flow occurs in the deeper layers. Field studies have estimated the maximum tidal current velocity to be approximately 20 cm/s, while nontidal water velocities are approximately 2 to 3 cm/s (Hood et al. 1973). Below about 15 m, water movements are slow, less than 5 cm/s (Colonell 1980), and they have a random direction, with bursts of motion that do not seem related to either winds or tides (Colonell 1980).

In addition to the noted estuarine-type flows (i.e., surface flows seaward and deep flows inward), Colonell (1980) noted that when field-measured flow data were processed to remove tidal influences, reverse estuarine flow events were occasionally noticeable. These events appeared to be weather related. Colonell (1980) noted that, because of the volume of these events, it would take only a few such events to flush Port Valdez thoroughly.

In addition to these flows, during certain weather conditions, 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. Measurements of currents in the Valdez Narrows by Colonell (1980) suggest that residence times for deep waters in Port Valdez during passage of weather systems could be reduced to a few days. Thus, climatological influences may be more important in promoting deep-water exchange than are either tides or mixing with surface waters (TAPS Owners 2001a).

Colonell (1980) suggests that specifying a “typical” residence time for waters in Port Valdez is inappropriate. Colonell (1980) notes three main drivers for flushing: tidal flushing, seasonal deep water exchange (estuarine flow), and surges related to weather systems with accompanying large flows. The first two factors are largely seasonal and predictable; the third is more random. On the basis of these observations, Colonell (1980) suggests that a conservative estimate of residence time of waters in Port Valdez does not exceed a few weeks.

The surface temperature of waters in Port Valdez ranges from −1.2°C in winter to a typical maximum of 16°C in the summer (TAPS Owners 2001a). Previous studies have noted a smaller variation; Hood et al. (1973) noted a low water temperature of only 2°C, while Colonell (1980) noted a high of 15°C.