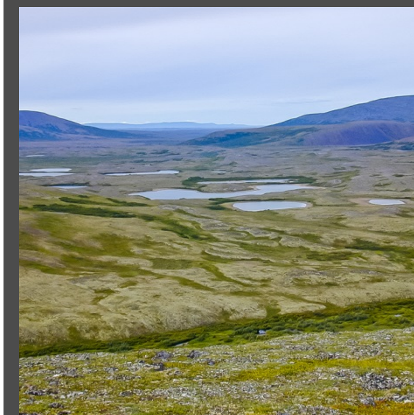
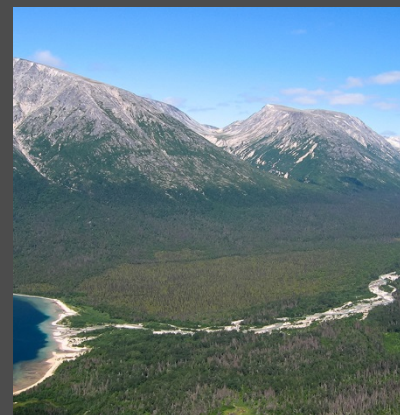




CHAPTER 10. TRANSPORTATION CORRIDOR

10.1 Introduction

Because the Bristol Bay watershed is located in one of the last remaining virtually roadless areas in the United States, development of any mine in the Bristol Bay watershed would require substantial expansion and improvement of the region's transportation infrastructure. There are few existing roadways, no improved federal or state highways, and no railroads, pipelines, or other major industrial transportation infrastructure (Figure 6-6). As described in Section 6.1.3, the mine scenarios evaluated in this assessment include a 138-km gravel surface, all-weather permanent access road (Figure 6-6) connecting the mine site to a new deep-water port on Cook Inlet (Ghaffari et al. 2011). This length does not include road sections within the mine site itself. Approximately 113 km of this corridor would fall within the Kvichak River watershed.

The transportation corridor area considered in the assessment comprises 32 subwatersheds draining to Iliamna Lake (Figure 2-7). These subwatersheds, referred to as the corridor subwatersheds, encompass approximately 2,340 km^2 and contain nearly 1,900 km of streams mapped for this analysis (see Chapter 3 for a description of these methods). The seven largest subwatersheds are, from west to east, the headwaters of Upper Talarik Creek, the headwaters of the Newhalen River, Chekok Creek, Canyon Creek, Knutson Creek, Pile River, and the Iliamna River. The Newhalen River is the largest river crossed by the corridor, draining Sixmile Lake and Lake Clark. Sockeye return to spawn in the Newhalen River and tributaries to Sixmile Lake and Lake Clark. The transportation corridor would cross the Newhalen River and parallel the north shore of Iliamna Lake (Figure 6-6). It would traverse rolling, glaciated terrain for approximately 60 road km until reaching steeper hillsides northwest of the village of Pedro Bay and the shoreline of Knutson Bay. After crossing gentler terrain around the northeast end of Iliamna Lake (Pedro Bay and Pile Bay), the corridor would cross the Chigmit Mountains (the highest source of runoff in the Bristol Bay watershed) along the route of the existing Pile Bay Road to tidewater at Williamsport. From there it would cross Iliamna Bay and follow the coastline to the port site on Iniskin Bay, off Cook

Inlet. Highly variable terrain and variable subsurface soil conditions, including extensive areas of rock excavation in steep mountainous terrain, are expected over this proposed route.

Although this route is not necessarily the only option for corridor placement, the assessment of potential environmental risks would not be expected to change substantially with minor shifts in road alignment. Along most feasible routes, the proposed transportation corridor would cross many streams (including unmapped tributaries), rivers, wetlands, and extensive areas with shallow groundwater, all draining to Iliamna Lake (Figures 10-1 and 10-2).

In this chapter, we consider the risks to fish habitats and populations associated with the transportation corridor, as illustrated in a conceptual model showing potential linkages among the corridor, associated sources and stressors, and assessment endpoints (Figure 10-3). We begin with a discussion of fish habitats and populations along the corridor. We then consider potential impacts on these habitats and populations resulting from its construction and operation. Although the transportation corridor would include the road and adjacent pipelines (Section 6.1.3), we focus primarily on the road component; potential pipeline failures are considered in Chapter 11.

Best management practices (BMPs) or mitigation measures would be used along the transportation corridor to minimize potential risks to salmonids and the ecosystems that support them. Relevant BMPs, and their likely effectiveness, are discussed in text boxes throughout the chapter.

Figure 10-1. Streams, wetlands, ponds, and lakes along the transportation corridor. Streams and rivers are from the National Hydrography Dataset (USGS 2012); wetlands, lakes, and ponds are from the National Wetlands Inventory (USFWS 2012).

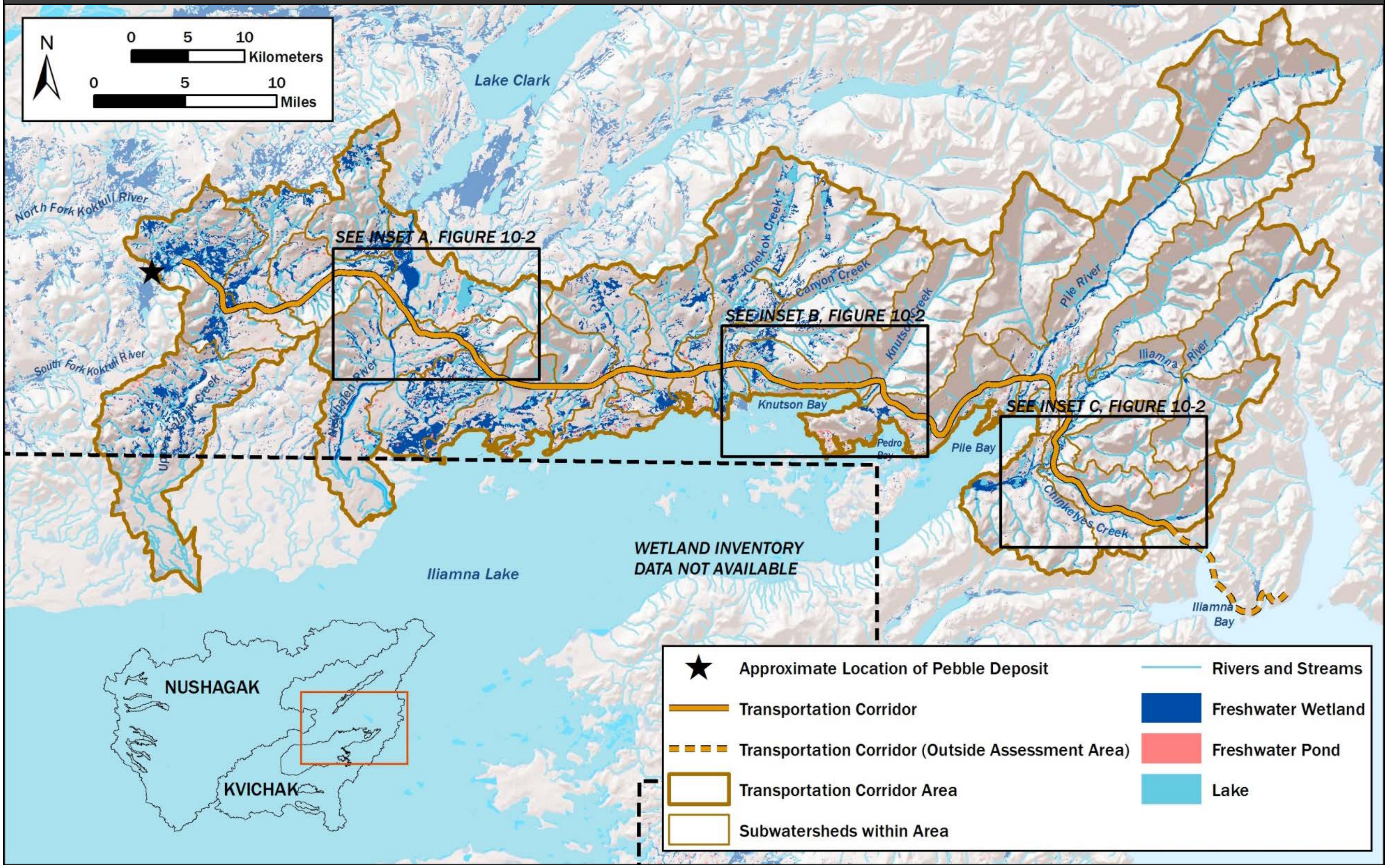


Figure 10-2. High-impact areas along the transportation corridor. Streams and rivers are from the National Hydrography Dataset (USGS 2012); wetlands, lakes, and ponds are from the National Wetlands Inventory (USFWS 2012). Image source: ESRI 2013. See Figure 10-1 for location of these areas along the transportation corridor.

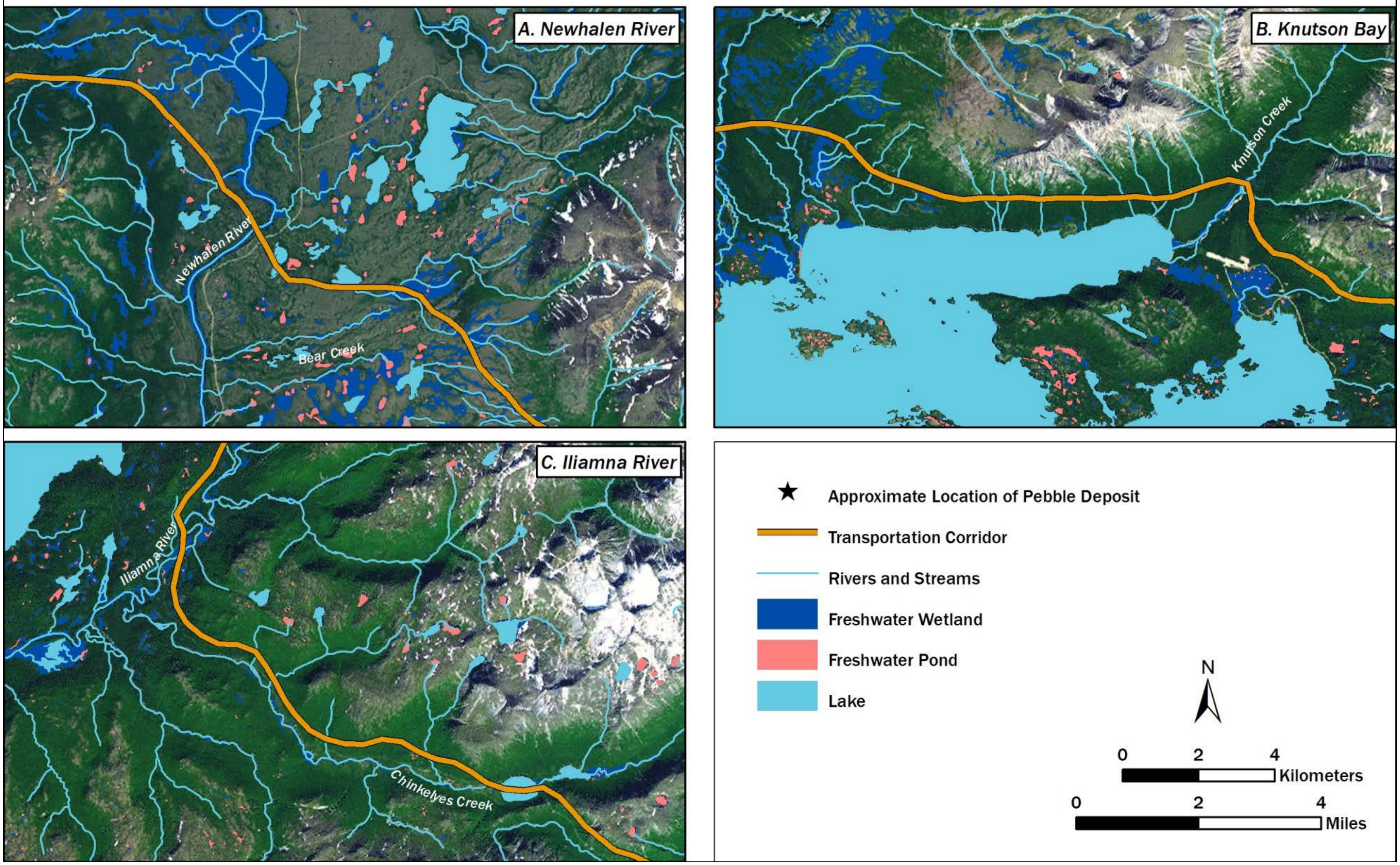
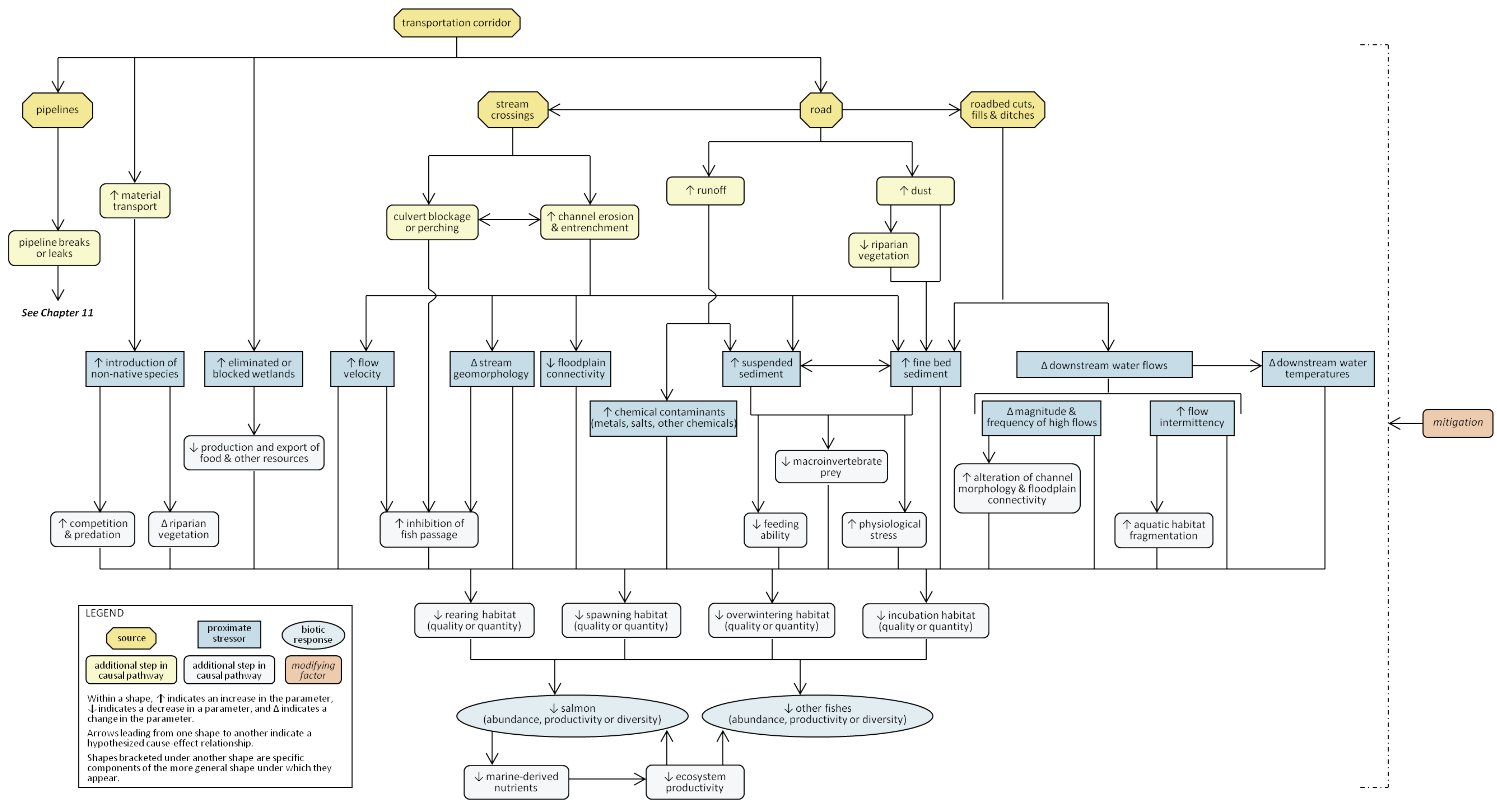


Figure 10-3. Conceptual model showing potential pathways linking the transportation corridor and related sources to stressors and assessment endpoints.



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10.2 Fish Habitats and Populations along the Transportation Corridor

In Chapter 3, we characterized stream segments in the Nushagak and Kvichak River watersheds by relative size (mean annual streamflow), channel gradient, and an index of the degree of channel constraint to describe floodplain potential (proportion of flatland in lowland, where stream segments with greater than 5% flatland in lowland in each reach's adjacent drainage basin are likely to be unconstrained and to exhibit floodplain potential). These attributes were selected because they represent fundamental aspects of the physical and geomorphic stream setting and provide context for stream and river habitat development and consequent fish habitat suitability (Burnett et al. 2007). Table 10-1 summarizes the proportion of stream channel lengths in the corridor subwatersheds (Scale 5), classified according to stream size, channel gradient, and floodplain potential. To allow direct visual comparison of the distribution of stream characteristics in the corridor subwatersheds relative to those in the entire Nushagak and Kvichak River watersheds (Scale 2), we present cumulative frequency plots in Figure 10-4. These plots show a frequency curve for each attribute at each geographic scale. Attributes are grouped into meaningful classes (Chapter 3), denoted by the vertical red classification bars. For example, the lowest gradient streams are classified as having gradients of less than 1% (Table 10-1), as shown by the vertical classification bar at 1% in Figure 10-4B. Cumulative frequency plots can be interpreted by evaluating the height at which the frequency curve is intersected by the red vertical classification bar. In Figure 10-4B, the 1% gradient classification bar intersects the Scale 5 frequency curve (solid black line) at a cumulative frequency value of approximately 32%. Thus, approximately 32% of the stream kilometers in the corridor subwatersheds (Scale 5) are less than 1% gradient. In comparison, approximately 64% of the stream kilometers in the Nushagak and Kvichak River watersheds (Scale 2) are less than 1% gradient.

Streams along the transportation corridor have not been sampled as extensively as streams near the Pebble deposit. Small to large rivers (2.8 m^3/s mean annual streamflow and larger) that would be crossed by the corridor (Table 10-1) provide spawning and rearing habitat, and are important routes for adult salmonid migration to upstream spawning areas and juvenile salmonid migration downstream to Iliamna Lake. Large and small streams with low to moderate gradients (3% or less) provide important high-quality spawning habitats, primarily for sockeye salmon. These streams also likely provide high-quality seasonal and some year-round habitats for resident Dolly Varden and rainbow trout. Dolly Varden are distributed across a much wider range of stream gradients (ADF&G 2012). The majority of stream length in the corridor subwatersheds consists of small headwater (58%) and medium (31%) streams, whereas small and large rivers make up 10 and 2% of stream length, respectively (Table 10-1). A majority (62%) of stream length in the corridor subwatersheds is classified as low to moderate gradient (32% at less than 1% gradient, and 30% at 1 to 3% gradient) (see Box 3-1 for discussion on how gradient was calculated). However, the corridor streams are generally steeper and have higher proportions of stream length without floodplain potential (i.e., less than 5% of flatland in lowland adjacent to stream) relative to those in the larger Nushagak and Kvichak River watersheds (Table 10-1,

Figure 10-4). Streams and rivers with high proportions of length with floodplain potential are more likely to be unconstrained and to develop complex off-channel habitats that provide a diversity of channel habitat types and create favorable conditions, particularly for salmonid rearing. However, the corridor streams are unique within the Nushagak and Kvichak River watersheds in that many of them are short and originate within the corridor subwatersheds. In addition, they all flow into Iliamna Lake, which provides high-quality habitat suitable for salmonid rearing and migration among streams.

Table 10-1. Proportion of stream channel length in stream subwatersheds intersected by the transportation corridor (Scale 5) classified according to stream size (based on mean annual discharge in m^3/s), channel gradient (%), and floodplain potential (based on % flatland in lowland). Gray shading indicates proportions greater than 5%; bold indicates proportions greater than 10%.

	Gradient							
	<1%		≥1% and <3%		≥3% and <8%		≥8%	
Mean annual discharge	FP	NFP	FP	NFP	FP	NFP	FP	NFP
Small headwater and Iliamna Lake tributary streams[a]	**11%**	3%	4%	**12%**	1%	**17%**	0%	10%
Medium streams[b]	7%	2%	1%	10%	1%	7%	0%	3%
Small rivers[c]	5%	2%	0%	3%	0%	0%	0%	0%
Large rivers[d]	2%	0%	0%	0%	0%	0%	0%	0%

Notes:

[a] 0–0.15 m^3/s; headwater tributaries of streams crossing the transportation corridor and small streams flowing directly to Iliamna Lake (e.g., Eagle Bay and Chekok Creeks).

[b] 0.15–2.8 m^3/s; upper reaches and larger tributaries of streams crossing the transportation corridor, and medium streams flowing directly into Iliamna Lake (e.g., Chinkelyes and Knutson Creeks).

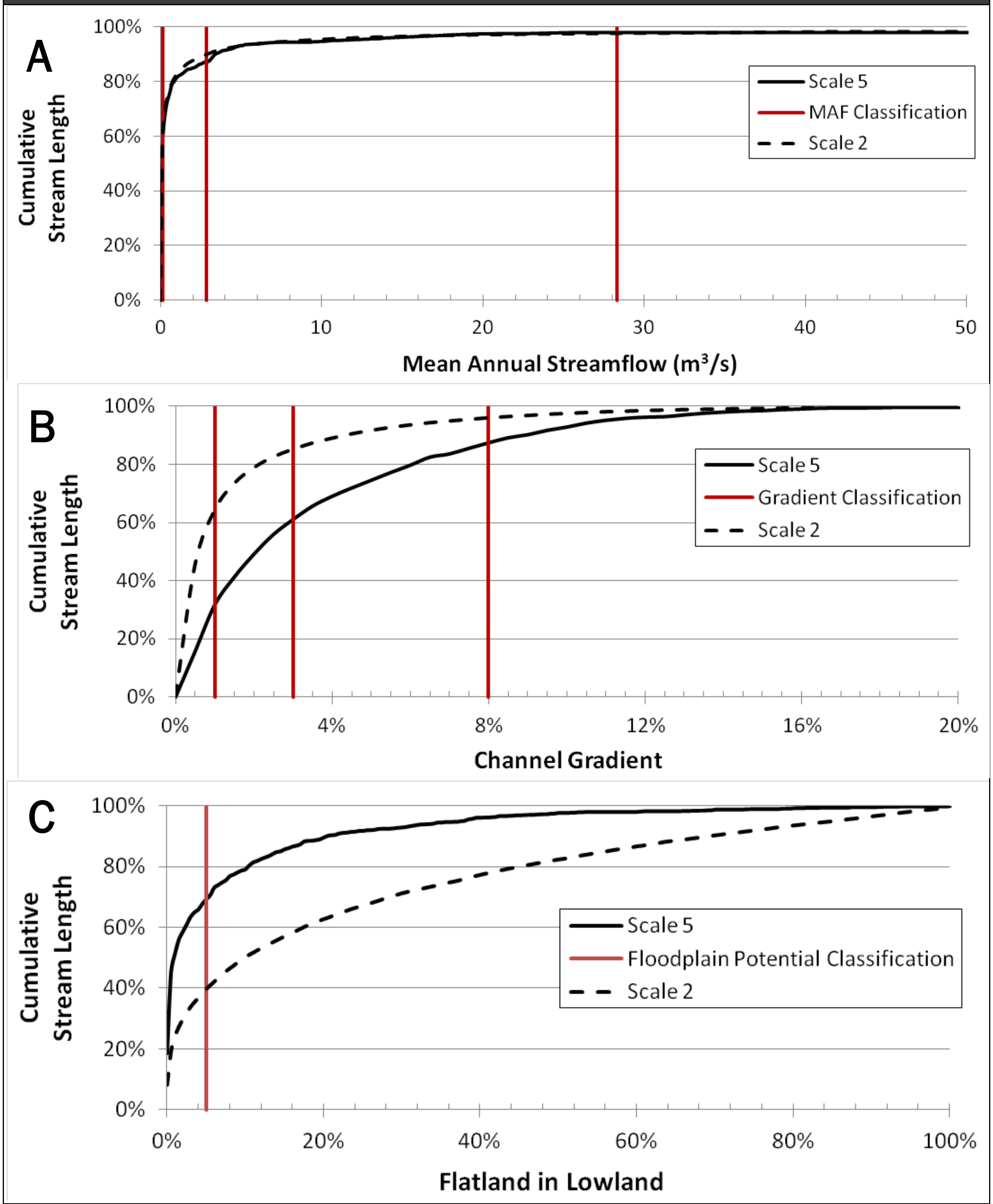
[c] 2.8–28 m^3/s; middle to lower portions of the Iliamna and Pile Rivers.

[d] >28 m^3/s; the Newhalen River.

FP = high floodplain potential (≥5% flatland in lowland); NFP = no or low floodplain potential (<5% flatland in lowland) (see Chapter 3 for additional explanation).

At the scale of the Nushagak and Kvichak River watersheds, 85% of stream length is classified as less than 3% gradient (64% at less than 1% gradient and 21% at 1 to 3% gradient), versus 62% in the corridor subwatersheds. Sixty percent of total stream length in the Nushagak and Kvichak River watersheds is classified as exhibiting floodplain potential, versus 31% in the corridor subwatersheds (Figure 10-4). These differences stem in large part from the large portions of the unconfined, low-gradient lower Nushagak River watershed. Percent of stream length less than 3% gradient is 73 and 91% in the Kvichak and Nushagak River watersheds, respectively; the percent of stream length classified as floodplain prone is 50% across the Kvichak River watershed and 65% across the Nushagak River watershed. Thus, stream characteristics in the transportation corridor area are generally more similar to those in the Kvichak River watershed. Characterization of stream segments for the entire Nushagak and Kvichak River watersheds, as well as the methods used, are described in Chapter 3.

Figure 10-4. Cumulative frequency of stream channel length classified by (A) mean annual streamflow (MAF) (m^3/s), (B) channel gradient (%), and (C) floodplain potential (based on % flatland in lowland) for stream subwatersheds intersected by the transportation corridor (Scale 5) versus the Nushagak and Kvichak River watersheds (Scale 2). See Section 3.4 for further explanation of MAF, gradient, and floodplain potential classifications.



These low- to moderate-gradient streams provide important spawning habitat for sockeye. The Kvichak River watershed includes over 100 separate sockeye salmon spawning locations (Demory et al. 1964, Morstad 2003), including small tributary streams, rivers, mainland beaches, island beaches, and spring-fed ponds. The spatial separation and diverse spawning habitat features within the watershed have influenced genetic divergence among spawning populations of sockeye salmon at multiple spatial scales (Gomez-Uchida et al. 2011). These distinct populations can occur at very fine spatial scales. For example, sockeye salmon that use spring-fed ponds and streams approximately 1 km apart exhibit differences in traits that are consistent with discrete populations, such as spawn timing, spawn site fidelity, and productivity (Quinn et al. 2012).

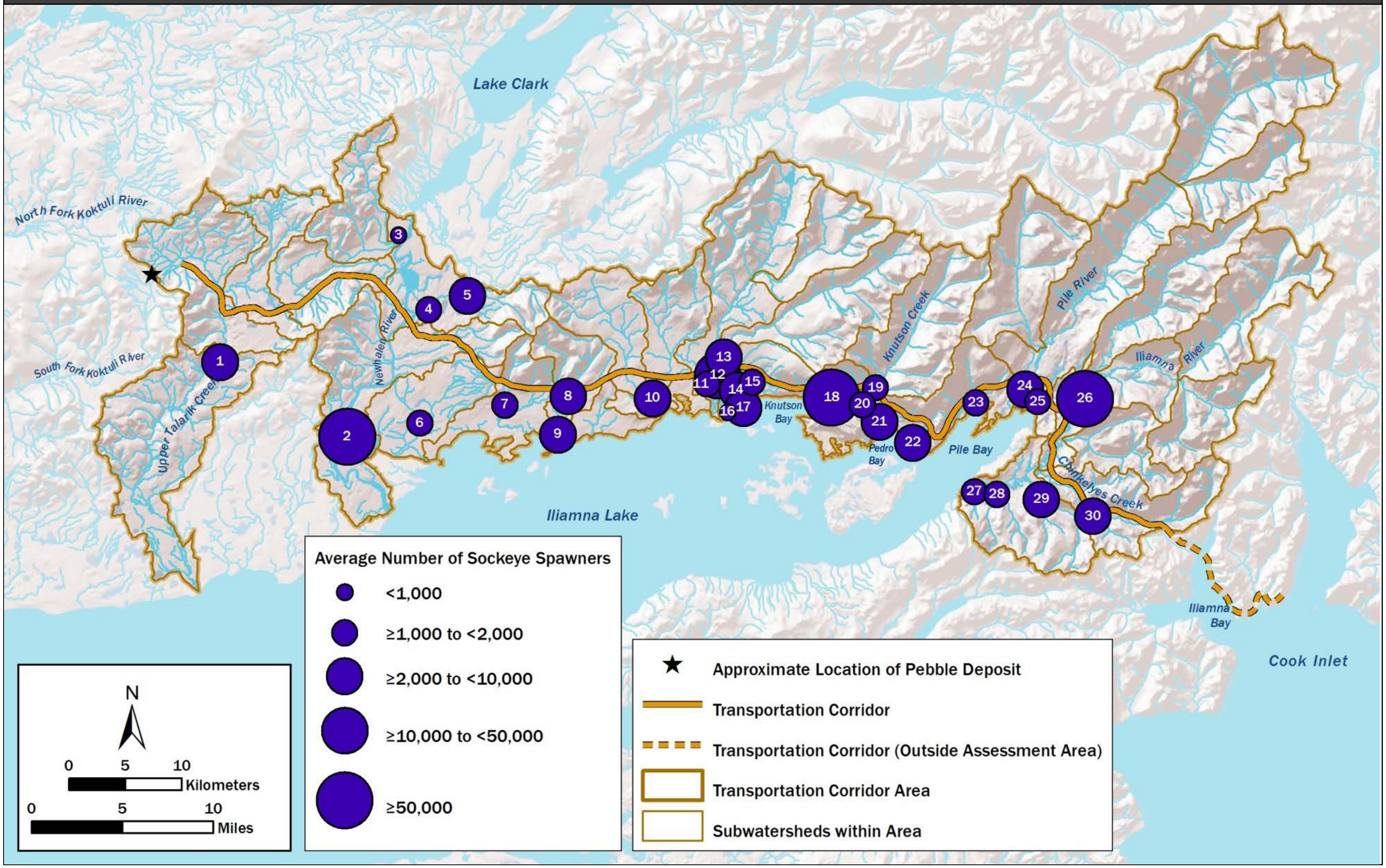
Sockeye spawning has been observed at 30 locations along the transportation corridor (Demory et al. 1964). The Alaska Department of Fish and Game (ADF&G) has conducted aerial index counts of sockeye salmon spawning abundance at these locations in most years since 1955 (Morstad 2003). We recognize that survey values tend to underestimate true abundance for many reasons. An observer in an aircraft is not able to count all fish in dense aggregations, and only a fraction of the fish that spawn at a given site are present at any one time (Bue et al. 1988, Jones et al. 2007). Surveys intended to capture peak abundance may not always do so. Weather, water clarity, and other factors influencing fish visibility can also contribute to underestimates. Finally, spawning locations along the corridor occur across a variety of habitats, including mainland beaches, small ponds, streams, and larger rivers. Aerial survey-based indices of sockeye salmon spawning abundance vary considerably. Sockeye index counts are highest in the Iliamna River (averaging over 100,000 spawners), the Newhalen River (averaging over 80,000 spawners), and on beaches in Knutson Bay (averaging over 70,000 spawners) (Table 10-2, Figure 10-5). In some years, these counts can be very large, as illustrated by the 1960 survey for Knutson Bay that reported 1 million adults (Demory et al. 1964). Sockeye spawning is associated with upwelling groundwater areas on beaches along the north and east shores of Knutson Bay, adjacent to the transportation corridor. In addition, sockeye use of spring-fed ponds has been observed at eight locations along the corridor. These locations tend to have fewer spawners (approximately 2,700 on average), but fish using these locations may be adapted to the unique abiotic features of ponds (Quinn et al. 2012).

Table 10-2. Average number of spawning adult sockeye salmon at locations near the transportation corridor. See Figure 10-5 for the locations of these areas.

Map Point	Area	Area Name	Type	Average Number of Sockeye Salmon Spawners (1955–2011)	Number of Years Spawners were Counted (Max = 57)	Range
1	Upper Talarik	Upper Talarik Creek	Stream	7,021	49	0–70,600
2	Newhalen River System	Newhalen River	River	84,933	34	97–730,900
3	Newhalen River System	Little Bear Creek/Ponds	Ponds	527	20	0–1,860
4	Newhalen River System	Alexi Creek	Stream	1,176	27	0–13,200
5	Newhalen River System	Alexi Lakes	Lake	7,121	33	11–38,000
6	North East	Roadhouse Creek	Stream	1,052	28	0–4,950
7	North East	Northwest Eagle Bay Creek	Stream	1,649	32	0–17,562
8	North East	Northeast Eagle Bay Creek/Ponds	Stream	3,416	38	0–18,175
9	North East	Northeast Eagle Bay Creek Ponds	Ponds	4,766	5	200–11,700
10	North East	Youngs Creek	Stream	3,532	38	0–26,500
11	North East	Chekok Creek/Ponds	Stream	1,840	32	0–8,700
12	North East	Tomkok Creek	Stream	10,882	38	300–56,600
13	North East	Canyon Creek	Stream	8,015	38	200–48,000
14	North East	Wolf Creek Ponds	Ponds	4,469	26	0–28,000
15	North East	Mink Creek	Stream	1,144	35	0–6,000
16	North East	Canyon Springs	Ponds	884	20	0–5,000
17	North East	Prince Creek Ponds	Ponds	3,797	34	5–34,800
18	North East	Knutson Bay	Lake	72,845	47	1,000–1,000,000
19	North East	Knutson Creek	Stream	1,548	41	1–6,600
20	North East	Knutson Ponds	Ponds	1,200	39	0–6,350
21	North East	Pedro Creek & Ponds	Ponds	4,259	48	0–38,150
22	North East	Russian Creek	Stream	2,263	17	0–20,000
23	North East	Lonesome Bay Creek	Stream	1,026	6	32–2,675
24	North East	Pile River	River	6,431	38	0–39,200
25	North East	Swamp Creek	Stream	1,091	18	25–7,700
26	Iliamna River System	Iliamna River	River	101,306	53	3,000–399,300
27	Iliamna River System	Bear Creek & Ponds	Ponds	1,748	30	40–10,300
28	Iliamna River System	False Creek	Stream	1,317	21	0–13,300
29	Iliamna River System	Old Williams Creek	Stream	3,726	27	0–38,000
30	Iliamna River System	Chinkelyes Creek	Stream	9,128	46	50–44,905

Notes:
Locations are organized from west to east along the corridor.
Sources: Morstad 2003, Morstad pers. comm.

Figure 10-5. Location of sockeye salmon surveys and number of spawners observed along the transportation corridor. Numbers refer to map points listed in Table 10-2.

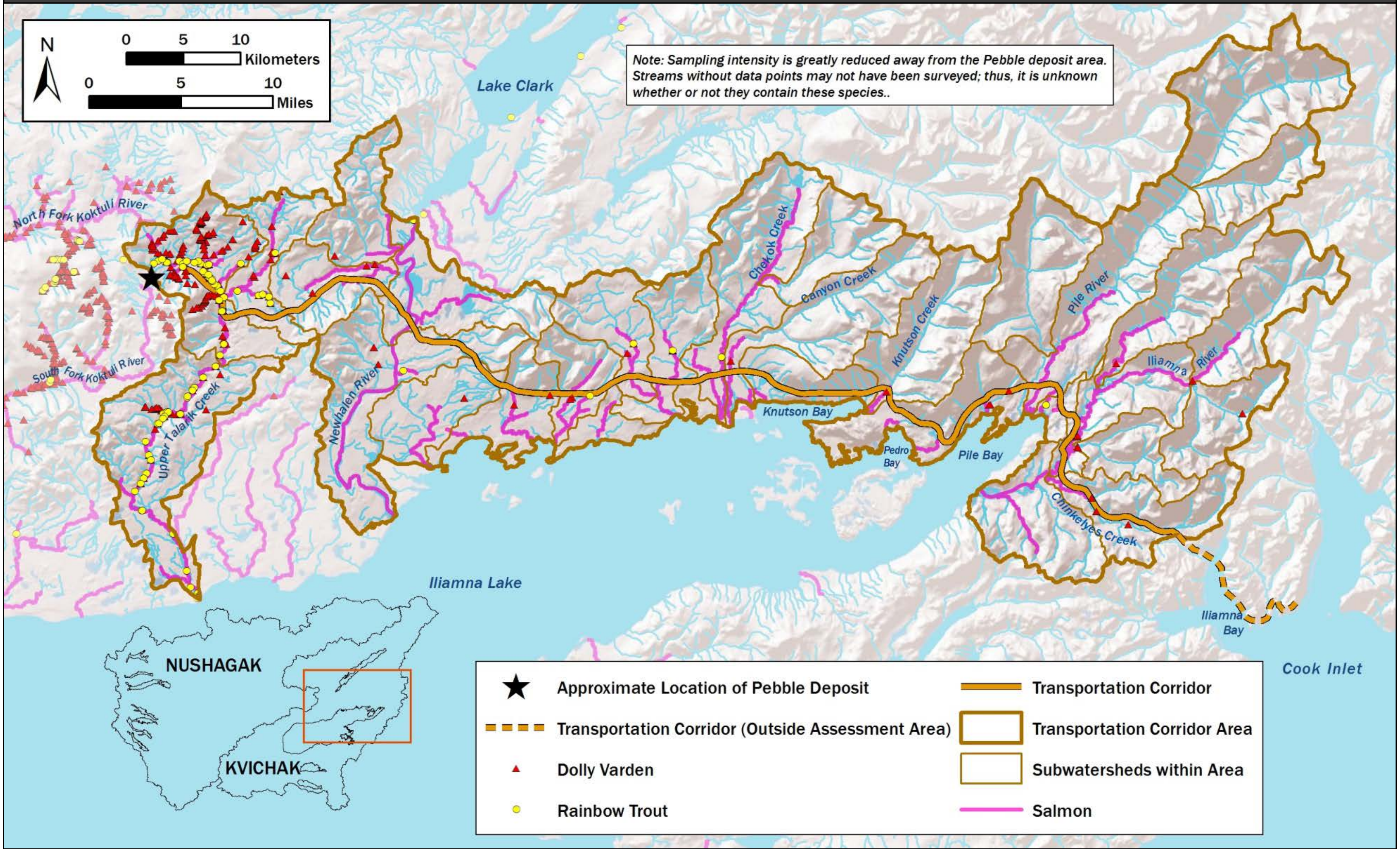


Less is known about the occurrence or abundance of other salmon species in streams and rivers crossing or adjacent to the transportation corridor. Chinook, coho, pink, and chum salmon are present in the Kvichak River watershed, but data for their spatial occurrences are for isolated points in the system (Johnson and Blanche 2012). In streams intersected by the transportation corridor, sockeye salmon are in all streams included in the *Catalog of Waters Important for Spawning, Rearing, or Migration of Anadromous Fishes—Southwestern Region* (also known as the Anadromous Waters Catalog [AWC]) (Johnson and Blanche 2012) (Figure 10-6). Working from west to east along the corridor, streams with salmon species in addition to sockeye are as follows: Upper Talarik Creek (Chinook, coho, chum, and pink salmon), the Newhalen River (Chinook and coho salmon), Youngs Creek (East and West Branches), Chekok and Tomkok Creeks (coho salmon), Swamp Creek (a tributary to Pile Bay) (Chinook salmon), and the Iliamna River (Chinook, coho, chum, and pink salmon).

Dolly Varden and rainbow trout distributions have not been surveyed as extensively as salmon distributions along the transportation corridor (ADF&G 2012). Dolly Varden have been documented in nearly every sockeye salmon-bearing stream that would be crossed by or adjacent to the corridor, as well as in locations upstream of reported anadromous salmon use (Figure 10-6). Rainbow trout presence along the corridor is reported for only a few streams, including Upper Talarik Creek, the Newhalen River, an unnamed tributary to Eagle Bay, Youngs Creek, Tomkok Creek, and Swamp Creek (ADF&G 2012). Rainbow trout have also been documented in the Iliamna River (Russell 1977) and Chinkelyes Creek (Berejikian 1992).

The distributions of both Dolly Varden and rainbow trout along the transportation corridor are likely much more extensive than reported in the Alaska Freshwater Fish Inventory (AFFI) resident fish database (ADF&G 2012), which does not account for seasonal movements or low sampling effort. Sockeye salmon provide an important food subsidy to Dolly Varden and rainbow trout. For example, Denton et al. (2009) reported Dolly Varden movement into multiple ponds used by spawning sockeye next to the Pedro Bay village, where they feed on sockeye salmon fry, eggs, and carcass-associated blowflies. Information on rainbow trout movement between Iliamna Lake and streams intersected by the corridor is not available, but these movements are likely to occur. Movements between lakes and tributary streams in response to feeding and spawning opportunities have been documented elsewhere in Iliamna Lake (Russell 1977), the Alagnak River system (Meka et al. 2003), and in the Wood River lake system (Ruff et al. 2011).

Figure 10-6. Reported salmon, Dolly Varden, and rainbow trout distributions along the transportation corridor. Salmon presence data are from the Anadromous Waters Catalog (Johnson and Blanche 2012); Dolly Varden and rainbow trout presence data are from the Alaska Freshwater Fish Inventory (ADF&G 2012). Note that rainbow trout have also been documented in the Iliamna River (Russell 1977) and Chinkelyes Creek (Berejikian 1992), although these points are not indicated on this map.



10.3 Potential Risks to Fish Habitats and Populations

Only rarely has it been possible to build roads that have no negative effects on streams (Furniss et al. 1991). Roads modify natural drainage networks and accelerate erosion processes, which can lead to changes in streamflow regimes, sediment transport and storage, channel bank and bed configurations, substrate composition, and the stability of slopes adjacent to streams. Road construction can increase the frequency of slope failures by orders of magnitude, depending on variables such as soil type, slope steepness, bedrock type and structure, and presence of subsurface water. These slope failures can result in episodic sediment delivery to streams and rivers, potentially for decades after roads are built (Furniss et al. 1991). All of these potential changes can have important biological consequences for anadromous and resident fishes by negatively affecting food, shelter, spawning habitat, water quality, and access for upstream and downstream migration (Appendix G) (Furniss et al. 1991).

In the Bristol Bay region, risks to fish from construction and operation of the transportation corridor would be complex and potentially significant, largely because of hydrological issues. Field observations in the mine area (Hamilton 2007, Woody and O'Neal 2010) indicate terrain with abundant near-surface groundwater and a high incidence of seeps and springs associated with complex glaciolacustrine, alluvial, and slope till deposits (Appendix G). The abundance of mapped wetlands (Figures 10-1 and 10-2) further demonstrates the pervasiveness of shallow subsurface flows and high connectivity between groundwater and surface-water systems in the areas traversed by the transportation corridor (Appendix G). As noted in Section 3.3, the strong connection between groundwater and surface waters helps to moderate water temperatures and streamflows, and this moderation can be critical for fish populations. The construction and operation of the transportation corridor could fundamentally alter connections between shallow aquifers and surface channels and ponds by intercepting shallow groundwater flowpaths, leading to impacts on surface water hydrology, water quality, and fish habitat (Darnell et al. 1976, Stanford and Ward 1993, Forman and Alexander 1998, Hancock 2002).

The lengths of the transportation corridor and their proximities to National Hydrography Dataset (NHD) streams (USGS 2012) and National Wetlands Inventory (NWI) wetlands, ponds, and small lakes (USFWS 2012) are shown in Tables 10-3 and 10-4, respectively (see Box 10-1 for a description of methods used to estimate these values). In sum, the length of road within 200 m of NHD streams or NWI aquatic habitats would be approximately 67 km (Table 10-5). These lengths do not encompass the section of corridor outside of the Kvichak River watershed (i.e., the watersheds flowing into Cook Inlet). The 200-m road buffer was derived from an estimate of the road-effect zone for secondary roads (Forman 2000). The largest impact on sockeye salmon would likely occur where the road would run parallel to the Iliamna River and Chinkelyes Creek, sites at which many sockeye salmon spawn (Figure 10-2, Inset C). Other high-impact areas include where the road would run parallel to Knutson Bay, intersecting many small streams and where groundwater upwelling supports spawning for hundreds of thousands of salmon (Figure 10-2, Inset B), and where the road crosses wetlands north of Iliamna Lake (Figure 10-2, Inset A).

In the following sections, we consider potential risks to fish habitats and populations resulting from construction and operation of the transportation corridor. We focus on risks related to filling and alteration of wetlands, stream crossings, fine sediments, dust deposition, runoff contaminants, and invasive species.

BOX 10-1. CALCULATION OF STREAM LENGTHS AND WETLAND AREAS AFFECTED BY TRANSPORTATION CORRIDOR DEVELOPMENT

We used the National Hydrography Dataset (NHD) (USGS 2012), the National Wetlands Inventory (NWI) (USFWS 2012), the Alaska Anadromous Waters Catalog (AWC) (Johnson and Blanche 2012), and the Alaska Freshwater Fish Inventory (AFFI) (ADF&G 2012) to evaluate potential effects of the transportation corridor on hydrologic features and fish populations.

The length of stream downstream of each crossing was estimated from NHD flowlines. Stream length by subwatershed, based on 12-digit hydrologic unit codes, was calculated as the total distance from each crossing to Iliamna Lake. In the multiple instances where stream crossings were tributaries to a single main channel, the mainstem length was only counted once (Table 10-3). Downstream lengths reported in Table 10-6 include mainstem lengths downstream of tributary crossings. In cases where the corridor crossed tributaries of a mainstem channel, the mainstem length is included in both crossings.

Mean annual streamflow of NHD streams upstream of the transportation corridor was estimated using methods described in Box 3-2.

The channel gradient of NHD stream segments intersected by and upstream of the corridor was estimated using a 30-m National Elevation Dataset digital elevation model (DEM) (Gesch 2007, Gesch et al. 2002, USGS 2013). A drainage network was developed from a flow analysis using the DEM and slope was estimated using this drainage network. The DEM-based drainage network paralleled the NHD stream flowlines and therefore, using the toolset in the spatial analyst extension in ArcGIS, slope from the drainage network was transferred to NHD reach segments. A 12% slope was used to calculate stream length likely to support fish (Table 10-6). Stream length upstream of the corridor with less than 12% slope was based on the NHD stream length to the first instance where slope was greater than 12%. The analysis of upstream fish habitat was extended to include streams in subwatersheds in the Headwaters Newhalen River, Tomkok Creek, Pile River, and Iliamna River.

For the analysis of road length intersecting and within 100 or 200 m of either a stream or wetland (Tables 10-3 through 10-5), each stream (NHD) or wetland (NWI) was buffered to a distance of 100 m and 200 m and the length of corridor within these ranges was summed. Similarly, for the area of wetlands, ponds, and small lakes within 100 m and 200 m of the road corridor, the road corridor was buffered and the area of wetlands, ponds, and small lakes within that buffered area was summed across the length of road. For the area of wetlands, ponds, and small lakes directly filled by the road corridor, we assumed a road width of 9.1 m.

The characterization of both stream length and wetland, pond, and small lake area affected is likely a conservative estimate. The NHD may not capture all stream courses and may underestimate channel sinuosity, resulting in underestimates of affected stream length. Additionally, the AWC and the AFFI do not necessarily characterize all potential fish-bearing streams due to limited sampling along the corridor. The characterization of wetland, pond, and small lake area is limited by the resolution of the available NWI data product. In this analysis, the transportation corridor often bisects wetland features and the wetland area falling outside the 200-m boundary was assumed to maintain its functionality. We were also unable to determine the effect that the transportation corridor may have on wetlands that had no direct surface water connection, but that may be hydrologically connected via groundwater pathways. Together, these limitations likely make our calculations an underestimate of the effect that transportation corridor development would have on hydrologic features in this region. These estimates could be improved with enhanced, higher-resolution mapping, increased sampling of possible fish-bearing waters, and ground-truthing of surface-water and groundwater connections.

Table 10-3. Proximity of the transportation corridor to National Hydrography Dataset streams (USGS 2012).

HUC-12 Name or Description	HUC-12 Digit	Proximity to Streams			
		Not nearby (km)	<100 m (km)	100–200 m (km)	Total (km)
Headwater, Upper Talarik Creek	190302060702	5.4	0.8	1.2	7.4
Upper tributary stream to Upper Talarik Creek	190302060701	4.3	0.2	0.1	4.6
Tributary to Newhalen River portion of corridor	190302051404	7.8	1.9	1.2	10.9
Headwaters, Newhalen River	190302051405	2.6	0.4	0.4	3.4
Outlet, Newhalen River	190302051406	4.2	1.5	0.8	6.5
Roadhouse Creek	190302060907	0.8	1.2	1.3	3.3
Iliamna Lake	190302060914	29.3	4.3	4.1	37.7
Eagle Bay Creek	190302060905	3.1	0.5	0.8	4.4
Youngs Creek Mainstem (Roadhouse Mountain HUC)	190302060903	3.0	0.1	0.2	3.4
Youngs Creek East Branch	190302060904	1.4	1.0	0.6	3.0
Chekok Creek	190302060302	1.8	0.3	0.3	2.5
Canyon Creek	190302060902	1.1	0.1	0.2	1.4
Knutson Creek	190302060901	1.2	0.3	0.4	2.0
Outlet, Pile River	190302060104	2.1	0.6	0.7	3.4
Middle Iliamna River	190302060205	4.5	1.1	0.7	6.4
Chinkelyes Creek	190302060206	9.6	0.8	2.1	12.5
Total length across all HUCs		**82.1**	**15.3**	**15.2**	**113**
Percentage across all HUCs		73%	14%	13%	100%

Notes:
HUC = hydrologic unit code.

Table 10-4. Proximity of the transportation corridor to National Wetlands Inventory wetlands, ponds, and small lakes (USFWS 2012).

HUC-12 Name or Description	HUC-12 Digit	Proximity to Wetlands				
		Not nearby (km)	Intersects (km)	<100 m (km)	100–200 m (km)	Total (km)
Headwater, Upper Talarik Creek	190302060702	0.2	1.9	4.0	1.2	7.4
Upper tributary stream to Upper Talarik Creek	190302060701	1.7	0.3	1.4	1.2	4.6
Tributary to Newhalen River portion upstream of corridor	190302051404	4.0	0.4	3.9	2.6	10.9
Headwaters, Newhalen River	190302051405	2.3	0.1	0.4	0.5	3.4
Outlet, Newhalen River	190302051406	1.1	2.4	1.7	1.4	6.5
Roadhouse Creek	190302060907	0.7	0.3	1.8	0.5	3.3
Iliamna Lake	190302060914	28.3	1.8	3.9	3.7	37.7
Eagle Bay Creek	190302060905	1.3	0.7	1.7	0.8	4.4
Youngs Creek Mainstem (Roadhouse Mountain HUC)	190302060903	0.9	0.2	1.1	1.2	3.4
Youngs Creek East Branch	190302060904	0.3	0.5	0.8	1.5	3.0
Chekok Creek	190302060302	1.8	0.2	0.3	0.2	2.5
Canyon Creek	190302060902	0.8	0.0	0.2	0.3	1.4
Knutson Creek	190302060901	1.0	0.1	0.6	0.3	2.0
Outlet, Pile River	190302060104	0.3	1.2	1.5	0.5	3.4
Middle Iliamna River	190302060205	2.7	0.6	1.7	1.3	6.4
Chinkelyes Creek	190302060206	7.7	1.4	1.9	1.5	12.5
Total length across all HUCs		**55.0**	**12.2**	**27.0**	**18.5**	**113**
Percentage across all HUCs		49%	11%	24%	16%	100%

Notes:
HUC = hydrologic unit code.

Table 10-5. Proximity of the transportation corridor to water, in terms of the length occurring within 200 m of National Hydrography Dataset streams (USGS 2012) or National Wetlands Inventory wetlands, ponds, and small lakes (USFWS 2012).

HUC-12 Name or Description	HUC-12 Digit	Proximity to Streams, Wetlands, Ponds, and Small Lakes		
		Not nearby (km)	Within 200 m (km)	Total (km)
Headwater, Upper Talarik Creek	190302060702	0.1	7.3	7.4
Upper tributary stream to Upper Talarik Creek	190302060701	1.5	3.1	4.6
Tributary to Newhalen River portion upstream of corridor	190302051404	3.8	7.0	10.9
Headwaters, Newhalen River	190302051405	2.3	1.1	3.4
Outlet, Newhalen River	190302051406	1.1	5.4	6.5
Roadhouse Creek	190302060907	0.0	3.3	3.3
Iliamna Lake	190302060914	22.1	15.5	37.7
Eagle Bay Creek	190302060905	0.9	3.5	4.4
Youngs Creek Mainstem (Roadhouse Mountain HUC)	190302060903	0.7	2.7	3.4
Youngs Creek East Branch	190302060904	0.3	2.8	3.0
Chekok Creek	190302060302	1.5	1.0	2.5
Canyon Creek	190302060902	0.8	0.5	1.4
Knutson Creek	190302060901	0.7	1.2	2.0
Outlet, Pile River	190302060104	0.3	3.1	3.4
Middle Iliamna River	190302060205	1.9	4.5	6.4
Chinkelyes Creek	190302060206	7.3	5.2	12.5
Total length across all HUCs		45.4	67.3[a]	113
Percentage across all HUCs		40%	60%	100%

Notes:
HUC = hydrologic unit code.
[a] Reported length is the sum of the road length within 200 m of a National Hydrography Dataset stream or National Wetlands Inventory wetland reported in Tables 10-3 and 10-4, respectively. In cases where the same section of road is near both types of water bodies, section is only reported once. Therefore total length is less than sum of lengths in Tables 10-3 and 10-4.

10.3.1 Filling and Alteration of Wetlands, Ponds, and Small Lakes

10.3.1.1 Exposure

Approximately 10% (12 km) of the transportation corridor would intersect mapped wetlands, ponds, and small lakes (Table 10-4). An additional 24% (27 km) would be located within 100 m of these habitats, and another 16% (19 km) would be located within 100 to 200 m (Table 10-4). In total, approximately 51% (58 km) of the corridor would fill or otherwise alter wetlands, ponds, and small lakes. These habitats encompass 2.3 km^2 (1.6, 0.1, and 0.6 km^2 of wetlands, ponds, and small lakes, respectively), or nearly 11% of the total area within 100 m of the transportation corridor. The area of NWI-mapped aquatic habitats within 200 m of the corridor would be 4.7 km^2 (3.3, 0.2, and 1.2 km^2 of wetlands, ponds, and small lakes, respectively). These areas do not include NWI-mapped aquatic habitats that would be covered by the mine footprints in the mine scenarios (Chapter 7). The area of these habitats filled by the roadbed would be 0.11 km^2 (i.e., approximately 12 km of road, assuming a road width of 9 m).

10.3.1.2 Exposure-Response

The distribution of salmonids in wetlands, ponds, and small lakes along the transportation corridor is not known. However, these aquatic habitat losses can result in the loss of resting habitat for adult salmonids and of spawning and rearing habitat in ponds and riparian side channels. These habitats can provide refuge habitats (Brown and Hartman 1988) and important rearing habitats for juvenile salmonids by providing hydraulically and thermally diverse conditions. In addition, by damming and diverting surface flow and inhibiting subsurface flow, road construction could block or limit access by fish to important habitats. Beaver ponds associated with small streams, ponds, and wetlands can be important winter refugia for coho salmon (Nickelson et al. 1992, Cunjak 1996). Beaver ponds provide high-quality habitat for salmon rearing, because they provide macrophyte cover, low-flow velocity, and increased temperatures and trap organic materials and nutrients (Nickelson et al. 1992, Collen and Gibson 2001, Lang et al. 2006).

These habitats can also provide enhanced foraging opportunities (Sommer et al. 2001). Floodplain wetlands and ponds can be an important contributor to the abundance and diversity of food (and foodwebs) upon which salmon depend (Opperman et al. 2010). Within aquatic habitats that are not blocked and are still accessible, the road bed could alter hydrology and flow paths from these habitats to the stream network. These alterations could mobilize minerals and stored organic carbon, and expose soils to new wetting, drying, and leaching regimes, thereby leading to changes in vegetation, nutrient and salt concentrations, and water quality (Ehrenfeld and Schneider 1991). These changes in wetland dynamics and structure could affect the availability of these habitats to fish and the contribution of nutrients, organic material, and a diverse array of macroinvertebrates from headland wetlands to higher order streams in the watershed (i.e., streams receiving wetland drainage) and downstream waters (Shaftel et al. 2011, Dekar et al. 2012, King et al. 2012, Walker et al. 2012).

10.3.1.3 Risk Characterization

Filling wetlands would eliminate habitat for salmonids and would indirectly alter wetlands in ways that could reduce the quality, quantity, and accessibility of habitat for fish. Effects on fish production cannot be estimated given available data; however, the loss of long riparian side channels to culvert or bridge crossings that do not span the entire floodplain could be locally significant. These wetlands provide important spawning and rearing habitats and resting areas for migrating adults. Other wetlands such as shallow ponds may also provide habitat, but all wetlands serve to moderate variation in flow and maintain water quality.

10.3.2 Stream Crossings

The transportation corridor would cross approximately 64 streams in the Kvichak River watershed. Of these streams, 20 are listed as supporting anadromous fish in the AWC (Johnson and Blanche 2012) at the crossing (Table 10-6). An additional 35 are likely to support salmonids (Table 10-6), and a number of these are anadromous downstream of the crossing. In total, the transportation corridor would cross 55 streams known or likely to support salmonids.

The physical effects of roads on streams and rivers often propagate long distances from actual stream crossings, because of the energy associated with moving water (Richardson et al. 1975). Thus, alteration of hydrology and sediment deposition by road crossings can change channels or shorelines many kilometers away. The transportation corridor could affect 272 km of stream between its road crossings and Iliamna Lake (Table 10-7). Fish may also be affected in the approximately 780 km of streams upstream of the transportation corridor that are likely to support salmonids (based on surveys and stream gradients less than 12%, Table 10-8). In this assessment, we assume streams with segment gradients less than 12% both downstream and upstream of the corridor-stream crossing are likely to support salmonids (i.e., salmon, rainbow trout, or Dolly Varden). The amount of upstream length that may be salmonid habitat is calculated as stream length to the first reach segment with a gradient greater than 12%. This criterion is used as an upstream limit for salmonid habitat, as Dolly Varden can be dispersed across a wide range of channel gradients (Wissmar et al. 2010) and have been observed in higher-gradient reaches (average 12.9% gradient) throughout the year in southeastern Alaska (Bryant et al. 2004).

Table 10-6. Road-stream crossings along the transportation corridor, upstream lengths of streams of different sizes likely to support salmonids (based on stream gradients of less than 12%), and downstream lengths to Iliamna Lake. Bold reach codes are those assumed to be bridged.

HUC-12 Name or Description	NHD Reach Code at Road-Stream Crossing	AWC (*Salmonid Potential)	Upstream Fish Habitat Length (km)					Downstream Length to Iliamna Lake (km)
			Small Headwater Streams[a]	Medium Streams[a]	Small Rivers[a]	Large Rivers[a]	Total	
Headwaters Upper Talarik Creek	19030206007354	Y *	3.5	0.0	0.0	0.0	3.5	57.6
	19030206007015	Y *	97.4	37.6	0.0	0.0	134.9	57.0
	19030206007159	Y *	1.4	0.0	0.0	0.0	1.4	55.6
Upper Tributary to Upper Talarik Creek[b]	19030206007175	N *	3.7	0.0	0.0	0.0	3.7	66.0
Tributary to Newhalen River[c]	19030205007587	N *	5.7	0.0	0.0	0.0	5.7	45.9
	19030205007593	N *	3.8	0.0	0.0	0.0	3.8	41.7
	19030205007598	N *	3.6	0.0	0.0	0.0	3.6	44.5
	19030205007606	Y *	6.8	0.0	0.0	0.0	6.8	37.2
	19030205007602	Y *	2.8	0.0	0.0	0.0	2.8	34.8
Headwaters Newhalen River	19030205007615	N *	3.1	0.0	0.0	0.0	3.1	29.4
	19030205000002	Y *	67.7	45.2	0.0	13.1	126.1	26.4
Outlet Newhalen River	19030205013069	N	0.0	0.0	0.0	0.0	0.0	1.1
	19030205013055	N *	6.2	2.6	0.0	0.0	8.8	1.3
	19030205013057	N *	1.8	0.0	0.0	0.0	1.8	3.7
	19030205013041	N *	3.2	0.0	0.0	0.0	3.2	3.7
Roadhouse Creek	19030206010623	N *	0.7	0.0	0.0	0.0	0.7	2.4
	19030206010628	N *	0.4	0.0	0.0	0.0	0.4	3.6
	19030206010629	N *	0.7	0.0	0.0	0.0	0.7	2.2
	19030206006712	N	0.0	0.0	0.0	0.0	0.0	15.7
Iliamna Lake–Eagle Bay	**19030206006678**	Y *	0.9	1.5	0.0	0.0	2.4	9.6
	19030206006677	N	0.0	0.0	0.0	0.0	0.0	10.3
	19030206006644	N *	1.6	0.0	0.0	0.0	1.6	11.1
Eagle Bay Creek	**19030206006671**	N *	0.4	5.5	0.0	0.0	5.9	6.4
	19030206006663	Y *	11.3	0.0	0.0	0.0	11.3	6.3
	19030206006654	Y *	4.0	0.0	0.0	0.0	4.0	6.4
Youngs Creek Mainstem (Roadhouse Mountain HUC)	**19030206006598**	Y *	25.7	16.3	0.0	0.0	42.0	10.4

Table 10-6. Road-stream crossings along the transportation corridor, upstream lengths of streams of different sizes likely to support salmonids (based on stream gradients of less than 12%), and downstream lengths to Iliamna Lake. Bold reach codes are those assumed to be bridged.

HUC-12 Name or Description	NHD Reach Code at Road-Stream Crossing	AWC (*Salmonid Potential)	Upstream Fish Habitat Length (km)					Downstream Length to Iliamna Lake (km)
			Small Headwater Streams[a]	Medium Streams[a]	Small Rivers[a]	Large Rivers[a]	Total	
Youngs Creek East Branch[d]	**19030206006553**	Y *	32.9	12.4	0.0	0.0	45.3	9.0
Chekok Creek	19030206006533	Y *	5.8	0.0	0.0	0.0	5.8	5.0
	19030206032854	Y *	36.1	42.5	7.9	0.0	86.6	8.4
Canyon Creek	**19030206006359**	Y *	0.0	1.2	8.6	0.0	9.8	12.1
Iliamna Lake–Knutson Bay	19030206006336	N *	4.4	0.0	0.0	0.0	4.4	3.8
	19030206006337	N *	0.3	0.0	0.0	0.0	0.3	3.6
	19030206006236	N *	1.0	0.0	0.0	0.0	1.0	3.4
	19030206006331	N *	0.6	0.0	0.0	0.0	0.6	4.2
	19030206006329	N *	0.6	0.0	0.0	0.0	0.6	3.9
	19030206006327	N *	0.2	0.0	0.0	0.0	0.2	1.9
	19030206006325	N *	0.8	0.0	0.0	0.0	0.8	2.6
	19030206006322	N	0.0	0.0	0.0	0.0	0.0	0.1
	19030206006320	N *	0.1	0.0	0.0	0.0	0.1	0.7
	19030206006321	N *	0.5	0.0	0.0	0.0	0.5	0.7
	19030206006318	N	0.0	0.0	0.0	0.0	0.0	0.8
	19030206006317	N	0.0	0.0	0.0	0.0	0.0	0.9
	19030206006316	N *	0.5	0.0	0.0	0.0	0.5	0.5
	19030206006315	N *	0.7	0.0	0.0	0.0	0.7	0.6
	19030206006314	N *	0.7	0.0	0.0	0.0	0.7	0.7
	19030206006251	N *	0.6	0.0	0.0	0.0	0.6	1.7
Knutson Creek	**19030206006255**	Y *	0.1	3.2	1.9	0.0	5.2	4.4
	19030206006280	N *	0.4	0.0	0.0	0.0	0.4	4.4
Iliamna Lake–Pedro Bay	19030206006239	N	0.0	0.0	0.0	0.0	0.0	2.5
	19030206006248	N *	0.3	0.0	0.0	0.0	0.3	4.7
Iliamna Lake–Pile Bay	19030206006231	N	0.0	0.0	0.0	0.0	0.0	0.6
	19030206006230	N	0.0	0.0	0.0	0.0	0.0	0.4
	19030206006228	Y *	0.0	0.3	0.0	0.0	0.3	1.5
	19030206006227	N *	0.0	0.9	0.0	0.0	0.9	3.0

Table 10-6. Road-stream crossings along the transportation corridor, upstream lengths of streams of different sizes likely to support salmonids (based on stream gradients of less than 12%), and downstream lengths to Iliamna Lake. Bold reach codes are those assumed to be bridged.

HUC-12 Name or Description	NHD Reach Code at Road-Stream Crossing	AWC (*Salmonid Potential)	Upstream Fish Habitat Length (km)					Downstream Length to Iliamna Lake (km)
			Small Headwater Streams[a]	Medium Streams[a]	Small Rivers[a]	Large Rivers[a]	Total	
Outlet Pile River	**19030206006222**	N *	0.0	3.4	0.0	0.0	3.4	6.3
	19030206000474	Y *	34.1	24.9	50.0	0.0	109.0	5.7
	19030206010632	Y *	4.2	0.0	0.0	0.0	4.2	0.9
	324-10-10150-2343-3006[e]	Y *	NO NHD DATA					1.0
Middle Iliamna River	**19030206000032**	Y *	27.9	36.5	40.6	0.0	104.9	10.2
Chinkelyes Creek	19030206005773	N *	0.3	0.0	0.0	0.0	0.3	13.4
	19030206005761	N *	0.5	2.7	0.0	0.0	3.2	14.5
	19030206005759	N *	0.4	0.0	0.0	0.0	0.4	18.0
	19030206005754	N *	0.7	1.0	0.0	0.0	1.7	21.6
	19030206005737	N *	0.0	8.5	0.0	0.0	8.5	22.1

Notes:

Values (lengths) are arranged by 12-digit HUC from west (top) to east (bottom) along the transportation corridor. Each upstream value is a sum of NHD stream segment lengths in the HUCs between the crossing and upper extent of salmonid habitat potential based on 12% gradient. Each downstream value is a sum of stream segment lengths in the HUCs between the crossing and Iliamna Lake. Because the lengths at each crossing represent contiguous lengths, a portion of stream may be included in more than one crossing.

[a] Small headwater streams = 0–0.15 m^3/s; medium streams = 0.15–2.8 m^3/s; small rivers = 2.8–28 m^3/s; large rivers = >28 m^3/s.

[b] 190302060701.

[c] 190302051404.

[d] 190302060904.

[e] AWC stream code used, because no corresponding NHD stream code (and no upstream habitat data) available.

NHD = National Hydrography Dataset; AWC = Anadromous Waters Catalog; HUC = hydrologic unit code.

Source: AWC data from Johnson and Blanche (2012); NHD data from USGS (2012).

Table 10-7. Stream lengths downstream of road-stream crossings, classified by stream size. Stream size was based on mean annual streamflow; downstream length was measured from the road-stream crossing to Iliamna Lake.

HUC-12 Name or Description	Downstream Length (km)				
	Small Headwater Streams[a]	Medium Streams[a]	Small Rivers[a]	Large Rivers[a]	Total
Headwaters Upper Talarik Creek	2.1	9.0	36.5	0.0	47.6
Upper Tributary to Upper Talarik Creek[b]	0.8	8.3	0.0	0.0	9.1
Tributary to Newhalen River[c]	4.1	14.5	0.0	0.0	18.6
Headwaters Newhalen River	0.9	0.0	0.0	8.3	9.2
Outlet Newhalen River	3.0	1.3	0.0	23.7	28.0
Roadhouse Creek	11.4	11.4	0.0	0.0	22.8
Iliamna Lake–Eagle Bay	4.4	11.9	0.0	0.0	16.3
Eagle Bay Creek	2.8	8.1	0.0	0.0	10.9
Youngs Creek Mainstem (Roadhouse Mountain HUC)	0.0	4.2	0.0	0.0	4.2
Youngs Creek East Branch[d]	0.8	8.0	0.0	0.0	8.7
Chekok Creek	2.9	0.0	5.8	0.0	8.7
Canyon Creek	4.8	0.0	6.5	0.0	11.3
Iliamna Lake–Knutson Bay	16.0	2.9	0.0	0.0	18.9
Knutson Creek	1.8	0.0	2.9	0.0	4.6
Iliamna Lake–Pedro Bay	6.8	5.5	0.0	0.0	12.3
Iliamna Lake–Pile Bay	3.5	4.5	0.0	0.0	8.0
Outlet Pile River	1.2	0.7	3.2	0.0	5.2
Middle Iliamna River	0.0	0.7	10.2	0.0	10.9
Chinkelyes Creek	1.3	4.4	10.7	0.0	16.4
Total length across all HUCS	**68.6**	**95.4**	**75.7**	**32.0**	**272**
Percentage across all HUCS	25%	35%	28%	12%	100%

Notes:

Values (lengths) are arranged by 12-digit HUC, from west (top) to east (bottom) along the transportation corridor. Downstream values are the sum of National Hydrography Dataset stream segment lengths in the HUCs between the crossing and Iliamna Lake.

[a] Small headwater streams = 0–0.15 m^3/s; medium streams = 0.15–2.8 m^3/s; small rivers = 2.8–28 m^3/s; large rivers = >28 m^3/s.

[b] 190302060701.

[c] 190302051404.

[d] 190302060904.

HUC = hydrologic unit code.

Table 10-8. Lengths of different stream sizes that occur upstream of road-stream crossings and are likely to support salmonids (based on stream gradients of less than 12%).

HUC-12 Name or Description	Upstream Fish Habitat Length (km)				
	Small Headwater Streams[a]	Medium Streams[a]	Small Rivers[a]	Large Rivers[a]	Total
Headwaters Upper Talarik Creek	69.5	17.8	0.0	0.0	87.4
Upper Tributary to Upper Talarik Creek[b]	36.5	19.7	0.0	0.0	56.2
Tributary to Newhalen River[c]	37.7	15.9	0.0	0.0	53.6
Headwaters Newhalen River	55.8	29.3	0.0	13.1	98.2
Outlet Newhalen River	11.9	2.6	0.0	0.0	14.5
Roadhouse Creek	1.7	0.0	0.0	0.0	1.7
Iliamna Lake–Eagle Bay	2.4	1.5	0.0	0.0	4.0
Eagle Bay Creek	15.6	5.5	0.0	0.0	21.2
Youngs Creek Mainstem (Roadhouse Mountain HUC)	25.7	16.3	0.0	0.0	42.0
Youngs Creek East Branch[d]	32.9	12.4	0.0	0.0	45.3
Chekok Creek	41.9	42.5	7.9	0.0	92.3
Canyon Creek	0.0	1.2	8.6	0.0	9.8
Iliamna Lake–Knutson Bay	11.0	0.0	0.0	0.0	11.0
Knutson Creek	0.6	3.2	1.9	0.0	5.7
Iliamna Lake–Pedro Bay	0.3	0.0	0.0	0.0	0.3
Iliamna Lake–Pile Bay	0.0	1.2	0.0	0.0	1.2
Outlet Pile River	38.3	28.3	50.0	0.0	116.6
Middle Iliamna River	27.9	36.5	40.6	0.0	104.9
Chinkelyes Creek	1.8	12.2	0.1	0.0	14.1
Total length across all HUCS	**411.7**	**246.2**	**109.1**	**13.1**	**780.1**
Percentage across all HUCS	53%	31%	14%	2%	100%

Notes:

Values (lengths) are arranged by 12-digit HUC, from west (top) to east (bottom) along the transportation corridor. Each upstream value is a sum of National Hydrography Dataset stream segment lengths in the HUCs between the crossing and upper extent of salmonid habitat potential based on 12% gradient.

[a] Small headwater streams = 0–0.15 m^3/s; medium streams = 0.15–2.8 m^3/s; small rivers = 2.8–28 m^3/s; large rivers = >28 m^3/s.

[b] 190302060701.

[c] 190302051404.

[d] 190302060904.

HUC = hydrologic unit code.

10.3.2.1 Exposure

Based on the assumption that crossings over streams with mean annual streamflows greater than 0.15 m^3/s would be bridged (Section 6.1.3), the transportation corridor would include 19 bridges, 12 over known anadromous streams and 7 over streams likely to support salmonids (Table 10-6). Mean annual streamflow at a crossing in the Eagle Bay Creek hydrologic unit code (HUC)-12 (reach code 19030206006663) was 0.14 m^3/s, but we assumed that this crossing would be bridged because the stream is anadromous and contains 11.3 km of upstream fish habitat. Culverts would be placed at all other stream crossings. Given that the transportation corridor would cross a total of 55 streams and rivers known or likely to support migrating or resident salmonids, culverts would be constructed on 36 presumed salmonid streams.

Bridges would generally have fewer impacts on salmon than culverts, but could result in the loss of long riparian side channels if they did not span the entire floodplain. Approximately 500,000 bridges listed in the National Bridge Inventory are built over streams, and many of these, especially those on more active streams, will experience problems with aggradation, degradation, bank erosion, and lateral channel shift during their useful life (FHWA 2012).

Where flow restrictions such as culverts are placed in stream channels, stream power increases. This can lead to increased channel scouring and down-cutting, streambank erosion, and undermining of the road. Salmonids and other riverine fishes actively move into seasonal floodplain wetlands and small valley floor tributaries to escape the stresses of main-channel flood flows (Copp 1989). Culverts can reduce flow to these habitats by funneling flow from the entire floodplain through the culvert and into the main channel. High water velocities in a stream channel may result from storm and snowmelt flows being forced through a culvert rather than spreading across the floodplain. Higher velocities cause scouring and down-cutting of the channel downstream of the culvert. This downstream erosion can result in perched culverts, impairing fish access to upstream reaches. In addition, it can hydrologically isolate the floodplain from the channel and block fish access to floodplain habitat. Entrenchment of the channel also prevents fish from reaching slow-water refugia during high-flow events and reduces nutrient and sediment cycling processes between the stream channel and the floodplain. Lastly, channel entrenchment may cause a change in the water table and the extent of the hyporheic zone, with consequences for floodplain water-body connectivity and water temperatures in the floodplain habitat.

Culverts are deemed to have failed if fish passage is blocked (e.g., by debris, ice, beaver activity, or culvert perching) or if streamflow exceeds culvert capacity and results in overtopping and road washout. Reported culvert failure frequencies vary in the literature but are generally high. Values of 30% (Price et al. 2010), 53% (Gibson et al. 2005), and 61% (Langill and Zamora 2002) have been reported, for an average culvert failure estimate of 48% (i.e., culvert surveys indicate that, on average, 48% block or inhibit fish passage at any given time).

When culverts are plugged by debris or overtopped by high flows, road damage, channel realignment, and severe sedimentation often result (Furniss et al. 1991). Changes in sediment load due to culvert failures can change stream hydraulics and geomorphic pressures. Generally, habitat value in the stream is diminished as the channel becomes wider and shallower and silt is deposited in the streambed. Stream crossing failures that divert streamflow outside of stream channels are particularly damaging and persistent (Weaver et al. 1987).

Free access to spawning and early rearing habitat in headwater streams is critical for a number of fish species, and culverts are common migration barriers. Culvert blockages are usually caused by woody debris and sometimes by woody material used by beavers to block a culvert and create a pond. In addition, aufeis—an ice feature that forms when water in or adjacent to a stream channel rises above the level of an existing ice cover and gradually freezes to produce a thickened ice cover (Slaughter 1982)—can completely fill culverts. When this occurs, water will run over the roadway unless flow is initiated through the culvert (Kane and Wellan 1985). The ice also reduces the cross-sectional area of flow so that high headwater conditions (and higher velocities than indicated by the culvert design) are produced during periods of peak flow. In some cases, considerable ice remains after the breakup period, particularly upstream of the culvert in the channel and floodplain (Kane and Wellan 1985).

Blockages could persist for as long as the intervals between culvert inspections. We assume that the transportation corridor would receive daily inspection and maintenance during operation of the mine. The level of surveillance along the corridor can be expected to affect the frequency of culvert failure detection. Driving inspections would likely identify a single erosional failure of a culvert that damaged the road or debris blockage sufficient to cause water to pool about the road, and in such cases temporary repairs would be made to protect the road. However, long-term fixes may not be possible until conditions are suitable to replace a culvert or bridge crossing. Further, multiple failures such as might occur during an extreme precipitation event would likely take longer to repair. These fixes may not fully address fish passage, which may be reduced or blocked for longer periods. Also, some failures that would reduce or block fish passage (e.g., gradual downstream channel erosion resulting in a perched culvert) might not be noticed by a driving inspection. Thus, blockage of migration could persist for an extended period. Extended blockage of migration would be less likely if daily road inspections included stops to inspect both ends of each culvert.

After mine operations end, traffic would decrease to that which is necessary to maintain any residual operations on the site, and inspections and maintenance would likely decrease. If the road was adopted by the state or local government, the frequency of inspections and quality of maintenance would likely decline to those provided for other roads. Either of these possibilities could result in a proportion of failed culverts similar to those described in the literature.

10.3.2.2 Exposure-Response

Blockage of a culvert by debris or downstream erosion would inhibit the upstream and downstream migration of salmon and the movement of other fish among seasonal habitats. The effects of a blockage would depend on its timing and duration. A blockage would result in the loss of spawning and rearing habitat if it occurred during adult migration periods and persisted for several days. It could cause the loss of a year class of salmon from a stream if it occurred during juvenile migration periods and persisted for several days or more.

Erosional failure of a road resulting from failure of a culvert would create suspended sediment that would be carried and deposited downstream. Relationships between the concentration and duration of elevated sediment concentrations and effects on fish and invertebrates are presented in Section 9.4.2.1.

10.3.2.3 Risk Characterization

The mine scenarios specify that culverts would be installed along the transportation corridor with adequate size for normal flows of the streams crossed, and that the roadway would be monitored daily to ensure that failures could be rapidly identified and repaired. Even with these assumptions, inhibition of fish passage and reductions in habitat still could occur. Although culverts would be designed to certain specifications (Box 10-2), they are not always installed correctly or do not stand up to the rigors of a harsh environment, as indicated by the failure frequencies cited in Section 10.3.2.1. The transportation corridor would traverse varied terrain and subsurface soil conditions, including extensive areas of rock excavation in steep, mountainous terrain where storm runoff can rapidly accumulate and result in intense local runoff conditions (Ghaffari et al. 2011). Although the road design, including placement and sizing of culverts, would take into account seasonal drainage and spring runoff requirements, culvert failures would still be expected. For example, heavy rains in late September 2003 washed out sections of the Williamsport–Pile Bay Road (Lake and Peninsula Borough 2009), and culverts on this road have been washed out on numerous occasions (PLP 2011: Appendix 7.3A).

Culverts are not always built to specifications and the behavioral responses of migrating salmonid life stages to culvert-induced changes in flow are not always anticipated correctly. Standards for culvert installation on fish-bearing streams in Alaska mainly consider fish passage (ADF&G and ADOT 2001). Additional factors unrelated to fish passage, such as the physical structure of the stream or habitat quality, are addressed on a project-specific basis during preparation of the Alaska Department of Transportation and Public Facilities environmental document. Culvert capacities are allowed to be less than channel capacity (ADF&G and ADOT 2001). In most cases culvert width must be greater than 90% of the ordinary high-water channel width, but where channel slope is less than 1.0% culvert width must only be greater than 75% of the ordinary high-water channel width. During flood flows, this reduced channel width results in slower than normal velocities upstream of the culvert and higher water velocities exiting the culvert. This could result in scoured downstream channel beds, altered channel dynamics, and disassociated channels and floodplains. These processes would reduce the capacity of downstream reaches to support salmonids. High flows in and immediately downstream of the culvert, as well as the structure of the culvert itself, could inhibit fish passage even if movement is not blocked. Downstream erosion could result in perched culverts that, if they were not inspected and maintained, would inhibit and ultimately block fish passage. Floodplain habitat and floodplain/channel ecosystem processes could be disrupted by channel entrenchment resulting from culvert-induced erosion. These potential reductions in downstream habitat quality and inhibited fish passage could occur in any of the 36 culverted streams that likely support salmonids.

BOX 10-2. CULVERT MITIGATION

Bridge or culvert installation and maintenance activities in fish-bearing water bodies require a fish habitat permit. Permit application information requirements for culvert installations in fish streams are detailed in a memorandum of agreement (MOA) between the Alaska Department of Fish and Game (ADF&G) and the Alaska Department of Transportation and Public Facilities (ADOT) (ADF&G and ADOT 2001). The MOA provides guidance to project designers and permitting staff to ensure that culverts are designed and installed to provide efficient fish passage and to ensure statewide consistency in Title 16 permitting of culvert related work. Title 16 is the statute by which the ADF&G performs Fish Habitat and Special Area permitting.

Fish habitat regulations under Title 16 include the Anadromous Fish Act and the Fishway (or Fish Passage) Act.

- The **Anadromous Fish Act** (AS 16.05.871-.901) requires that an individual or government agency provide prior notification and obtain permit approval from ADF&G before altering or affecting "the natural flow or bed" of a specified water body or fish stream. All activities within or across a specified anadromous water body—including construction; road crossings; gravel removal; mining; water withdrawals; the use of vehicles or equipment in the waterway; stream realignment or diversion; bank stabilization; blasting; and the placement, excavation, deposition, or removal of any material—require approval from ADF&G's Division of Habitat.
- The **Fishway (or Fish Passage) Act** (AS 16.05.841), requires that an individual or government agency notify and obtain authorization from the ADF&G's Division of Habitat for activities within or across a stream used by fish if it is determined that such uses or activities could represent an impediment to the efficient passage of resident or anadromous fish.

The MOA describes the procedures, criteria and guidelines used for permitting culvert related work in fish-bearing waters; these criteria augment but do not replace ADOT's standard design criteria presented in the Alaska Highway Drainage Manual (ADOT 1995). Culverts are designed and permitted using one of the following design approaches.

- **Tier I—Stream Simulation Design** (developed by the U.S. Department of Agriculture, Forest Service [FSSSWG 2008]). The Tier 1 approach most clearly replicates natural stream conditions, and is applicable in stream gradients less than 6%. Using this design, culverts are sized larger than culverts sized hydraulically for floodwater conveyance alone. The culvert width at the ordinary high water (OHW) stage waterline must be greater than 90% of the OHW width. The culvert grade should approximate the channel slope, but in no instance should it deviate more than 1% from the natural grade. In stream channels with slopes less than 1%, culverts may be installed at slopes less than 0.5% with culvert widths greater than 75% of the OHW width.
- **Tier II—FISHPASS Program Design.** Under this approach, culverts are designed using a combination of traditional hydraulic engineering methods and the Alaska Interagency Fish Passage Task Force's 1991 "FISHPASS" computer modeling program (Behlke et al. 1991). The FISHPASS program evaluates component hydraulic forces in a culvert against a fish's available power and energy capabilities.
- **Tier III—Hydraulic Engineering Design.** The Tier III approach is used where site-specific conditions preclude use of Tier I and Tier II designs. Under this approach, professionally recognized hydraulic engineering methods are used to ensure appropriate fish passage characteristics in the culvert.

Culverts and other road crossings that do not provide free passage between upstream and downstream reaches can fragment populations into small demographic isolates vulnerable to extinction (Hilderbrand and Kershner 2000, Young et al. 2005). In a study of natural long-term isolates of coastal cutthroat trout and Dolly Varden in southeastern Alaska, Hastings (2005) found that about 5.5 km of perennial headwater stream habitat, supporting a census population size of greater than 2,000 adults, is required for a high likelihood of long-term population persistence. Table 10-6 shows that, of the 55 known or likely salmonid-supporting streams that would be crossed by the transportation corridor, 39 contain less than 5.5 km of habitat (stream length) upstream of the proposed road crossings. These 39 stream crossings contain a total of 68 km of upstream habitat and 493 km of downstream habitat. Seven of these crossings would be bridged, leaving 32 with culverts. Assuming typical maintenance practices after mine operations, roughly 48% of these streams, or 15 streams, would be entirely or partially blocked at any one time. As a result, these streams would likely not be able to support long-term populations of resident species such as rainbow trout or Dolly Varden.

The risk of culvert failures is somewhat uncertain due to the paucity of literature on culvert failures both in Alaskan taiga and tundra and for modern mining roads crossing salmonid habitat. The most relevant studies on potential effects of roads, particularly as they relate to salmon, are from forest and rangeland roads. These roads may differ in important ways from mining roads. Forested streams inevitably carry more woody debris that could block culverts. However, forested vegetation types represent 68% of the potential transportation corridor area mapped by Pebble Limited Partnership (PLP) (2011: Chapter 13). Mine roads carry much heavier loads than logging roads, but would likely be better engineered. For example, the transportation corridor in this assessment would be designed to support 190-ton haul truck travel on the road surface (Ghaffari et al. 2011), compared to an average gross legal weight limit of approximately 44 tons per log truck (Mason et al. 2008). In any case, the culvert failure frequencies cited in this assessment are from modern roads and not restricted to forest roads, and represent the most relevant data available.

10.3.3 Chemical Contaminants

In this section we address three sources of potentially toxic chemicals related to the transportation corridor: traffic residues, road construction, and road treatment and chemical cargos.

During runoff events, traffic residues produce a contaminant mixture of metals (e.g., lead, zinc, copper, chromium, and cadmium), oil, and grease that can get washed into streams and accumulate in sediments (Van Hassel et al. 1980) or disperse into groundwater (Van Bohemen and Van de Laak 2003). It is unclear if the transportation corridor would have sufficient traffic to contaminate runoff with significant amounts of metals or oil (although stormwater runoff from roads at the mine site itself is more likely to contain metal concentrations sufficient to affect stream water quality). Therefore, this risk is not considered further.

Road construction involves the crushing of minerals for the road fill and bed and the exposure of rock surfaces at road cuts, which leads to leaching of minerals and increased dissolved solids. Fish mortality in streams, with effects on populations recorded as far as 8 km downstream, has been related to high concentrations of aluminum, manganese, copper, iron, or zinc from highway construction activities in geological formations containing pyritic materials (Morgan et al. 1983). Because it is not clear where materials for the road will come from or their composition, this risk is not considered further.

Two potentially significant contaminants of aquatic habitats may occur along the transportation corridor: chemicals released during spills from truck accidents and stormwater runoff of salts or other materials used for winter road treatment. It should also be noted that increased runoff associated with roads may increase rates and extent of erosion, reduce percolation and aquifer recharge rates, alter channel morphology, and increase stream discharge rates (Forman and Alexander 1998). These effects of stormwater runoff are not assessed, however, because they are highly location-specific and not quantifiable given available data. Increases in sediment associated with stormwater runoff are addressed in Section 10.3.4.

10.3.3.1 Exposure

Many chemical reagents would be used to process ore (Box 4-5), and these chemicals would be transported by road to the mine site. Truck accidents along the transportation corridor could spill reagents into wetlands or streams. To estimate how much reagent and thus how many transport trucks would be needed for the mine scenarios, we extrapolated from the number of trucks required to transport reagents at a smaller gold mine (175 trucks per year at Pogo Mine) to the mine scenarios, based on the relative annual ore production at the two mines. Assuming 20 tons of reagent per truck and expected annual production rates of 3,000 tons per day at Pogo Mine (USEPA 2003a) and 200,000 tons per day in the mine scenarios (Ghaffari et al. 2011), we estimate that transport of reagents would require approximately 11,725 truck trips per year.

The length of the transportation corridor within the Kvichak River watershed would be 113 km. The probability of truck accidents and releases was reported as 1.9×10^{-7} spills per mile of travel for a rural two-lane road (Harwood and Russell 1990). Based on this rate, the number of spills over the roughly 25-year life of the Pebble 2.0 scenario would be 3.9—that is, approximately 4 spills from truck accidents would be expected during mine operations. Over the roughly 78-year life of the Pebble 6.5 scenario, 12 spills would be expected. Only one-way travel is considered, because return trips from the mine would be with empty trucks or with a load other than process reagents. Because conditions on the mine road would be different from those for which the statistics were developed (e.g., more difficult driving and road conditions), this calculation provides an order of magnitude estimate. The reasonableness of this estimate is suggested by an assessment of the Cowal Gold Project in Australia, which estimated that a truck wreck would occur every 1 to 2 years, resulting in a spill every 3 to 6 years (NICNAS 2000).

For 14% of its length (15 km), the transportation corridor would be within 100 m of a stream or river (Table 10-3), and for 24% of its length it would be within 100 m of a mapped wetland (Table 10-4). If the probability of a chemical spill is independent of location, and if it is assumed that liquid spills within 100 m of a stream could flow to that stream, a spill would have a 14% probability of entering a stream within the Kvichak River watershed. This would result in roughly 0.5 stream-contaminating spills over the 25-year life of the Pebble 2.0 scenario or up to 2 stream-contaminating spills over the 78-year life of the Pebble 6.5 scenario. Similarly, a spill would have a 24% probability of entering a wetland, resulting in an estimate of 1 wetland-contaminating spill in the Pebble 2.0 scenario or 3 wetland-contaminating spills in the Pebble 6.5 scenario. A portion of those wetlands would be ponds or backwaters that support fish. It should be noted that the risk of spills could be somewhat mitigated by using spill-resistant containers.

Cyanide for gold processing would be transported as a solid. We assume containment equivalent to that at the Pogo mine (i.e., dry sodium cyanide pellets inside plastic bags inside wooden boxes inside metal shipping containers). Hence, even in a truck wreck, a cyanide spill is an unquantifiable but low probability occurrence. A spill on land could be collected, but during periods of rain or snowmelt it would rapidly dissolve and wash into surface or groundwater. A spill of pellets into a stream or wetland would rapidly dissolve and dissociate into free ions or, depending on the pH, hydrogen cyanide. Pellets spilled into a stream would be transported downstream as described for the copper concentrate (Section 11.3), but, rather than slurry water and solids, the transported material would consist of dissolving pellets and increasing cyanide or hydrogen cyanide solution.

In addition to process chemicals, the molybdenum concentrate (primarily molybdenum sulfide) would be transported by truck. The concentrate would be a dewatered fine granular material contained in bags packed in shipping containers. Thus, as with cyanide, a spill of molybdenum concentrate is an unquantifiable but low probability occurrence. A spill on land could be collected. A spill into water would be transported by streamflow as described for the copper concentrate (Section 11.3). Settled concentrate would oxidize, forming acidic pore water with dissolved molybdenum to which benthic invertebrates and fish eggs and larvae could be exposed.

Roads are treated with salts and other materials to reduce dust and improve winter traction. In Alaska, calcium chloride is commonly used for dust control and is mixed with sand for winter application. During periods of rain and snowmelt, these materials are washed off roads and into streams, rivers, and wetlands, where fish and their invertebrate prey can be directly exposed. We found no relevant data for calcium chloride levels in runoff or streams from roads treated in this way.

10.3.3.2 Exposure-Response

A principle processing chemical of concern would be sodium ethyl xanthate (Section 6.4.2.3). A risk assessment by Environment Australia estimated that a spill of as little as 10% of a 25-metric-ton-capacity truck carrying sodium ethyl xanthate into a stream would require a "650000:1 dilution before the potential hazard is considered acceptable" and that the spill could not be mitigated (NICNAS 2000).

Cyanide has acute and chronic U.S. ambient water quality criteria for freshwater of 22 and 5.2 μg free cyanide per liter. The geometric mean of 30 median lethal concentration (LC_{50}) values from acute tests of rainbow trout is 55.7 μg/L (USEPA 1985, 2013). In a 2-hour exposure to 10 μg/L cyanide, swimming speed of coho salmon was reduced (USEPA 1985). Unlike metals, cyanide is not more toxic to invertebrates than fish. Standard acute endpoints for invertebrates range from 17 to 210,000 μg/L (USEPA 1985, 2013).

Molybdenum's aquatic toxicity is relatively poorly characterized. The most directly relevant values are 28-day LC_{50} values for rainbow trout eggs of 730 and 790 μg/L (Birge 1978, Birge et al. 1979). The mean of two acute lethality tests with rainbow trout is 1,060,000 μg/L (USEPA 2013). Acute and chronic values for *Daphnia* are 206,800 and 4,500 μg/L (USEPA 2013). Hence, molybdenum appears to be much less toxic than copper. However, the small body of test data and lack of information on the influence of water chemistry on toxicity make judgments about the effects of aqueous molybdenum much more uncertain than copper or many other metals. Also unlike copper, there are no whole sediment benchmarks for molybdenum.

Compounds used to control ice and dust (Hoover 1981) have been shown to cause toxic effects when they run off and enter surface waters. Dissolved calcium, like sodium, has little influence on the toxicity of dissolved chloride salts (Mount et al. 1997). Based on that study, the toxicity of the calcium chloride commonly used in Alaska would be expected to be a little greater than the more studied sodium chloride, based on total chlorine concentrations. Alaska acute and chronic water quality standards for chloride are 860 and 230 mg/L, respectively (ADEC 2003). However, these values may not provide adequate protection from calcium salts. In addition, exceedances of the acute criterion could affect many species, because freshwater biota have a narrow range of acute susceptibilities to chloride (ADEC 2003). These standards and the associated federal criteria also may not be adequately protective due to the absence of tests of critical life stages (e.g., egg fertilization).

Rainwater tends to leach out the highly soluble chlorides (Withycombe and Dulla 2006), which can degrade nearby vegetation, surface water, groundwater, and aquatic species (Environment Canada 2005). Salmonids are sensitive to salinity, particularly at fertilization (Weber-Scannell and Duffy 2007). According to Bolander and Yamada (1999), application of chloride salts should be avoided within at least 8 m of water bodies (including shallow groundwater, if significant migration of chloride would reach the groundwater table), and restricted if low salt-tolerant vegetation occurs within 8 m of the treated area. Adverse biological effects are likely to be particularly discernible in naturally low-conductivity waters such as those of the Bristol Bay watershed, but research is needed to substantiate this (Appendix G).

10.3.3.3 Risk Characterization

Given the liquid form and toxicity of sodium ethyl xanthate (Section 8.2.2.5), it is expected that a spill of this compound into a stream along the transportation corridor would cause a fish kill. Runoff or groundwater transport from a more distant spill would cause effects that would depend on the amount of dilution or degradation occurring before the spilled material entered a stream. Although other process chemicals would also be used, xanthate is representative of the chemicals estimated to result in roughly two stream-contaminating spills over the 78-year life of the Pebble 6.5 scenario.

Cyanide pellets spilled by a truck wreck into a stream would be carried by the current but would rapidly dissolve into a cyanide solution and would ultimately disperse, volatilize, and degrade in Iliamna Lake. Spills into a wetland would dissolve in place. Spills on land would be collected unless they occurred during rain or snowmelt, in which case spilled pellets would dissolve and flow to surface or groundwater. Data needed to derive a cyanide spill scenario and quantify risks are unavailable, but given the toxicity of cyanide and its rapid action, effects on invertebrates and fish, including death, would be likely if a substantial spill into a stream or wetland occurred.

Molybdenum concentrate spilled by a truck wreck into a stream would be carried by the current and deposited in pools and backwaters and ultimately in Iliamna Lake. Compared to copper concentrate, relatively little is known about molybdenum concentrate. The solubility of the molybdenum in the Aitik copper concentrate is undefined but appears to be relatively low (Appendix H: Tables H-8 and H-9), and molybdenum is much less toxic than copper. The frequency of truck passages is also unknown, so the spill risk is unquantified. Therefore, the ecological risk from a molybdenum spill is unquantifiable but appears to be low relative to the risk from a copper concentrate spill (Section 11.3).

Risks to salmonids from de-icing salts and dust suppressants could be locally significant, but would depend on the amount and frequency of application. The transportation corridor would intersect 55 streams and rivers known or likely to support salmonids, and there would be approximately 272 km of streams between road crossings and Iliamna Lake (Table 10-7). Additionally, approximately 12 km of roadway would intersect wetlands within and beyond those mapped by NWI. Runoff from these road segments could have significant effects on fish and the invertebrates that they consume, particularly if sensitive life stages are present.

10.3.4 Fine Sediment

10.3.4.1 Exposure

During rain and snowmelt, soil eroded from road cuts, borrow areas, road surfaces, shoulders, cut-and-fill surfaces, and drainage ditches (as well as road dust deposited on vegetation; see Section 10.3.5), would be washed into streams and other water bodies. Erosion and siltation are likely to be greatest during road construction. The main variables determining surface erosion are the inherent erodibility of the soil, slope steepness, surface runoff, slope length, and ground cover. Mitigation measures for fine sediments are discussed in Box 10-3. It is worth noting that improvements have been proposed for the road between Iliamna and Nondalton, in part to alleviate erosion and sedimentation problems at some areas along the road (ADOT 2001).

BOX 10-3. STORMWATER RUNOFF AND FINE SEDIMENT MITIGATION

The Alaska Department of Environmental Conservation (ADEC) administers Alaska Pollutant Discharge Elimination System (APDES) stormwater general permits for construction activities and multi-sector general permits for industrial operation activities. ADEC also approves stormwater pollution prevention plans (SWPPPs) that include stormwater best management practices (BMPs).

A permittee covered under the APDES stormwater general permit for construction activities (ADEC 2011a) must comply with control measures that are determined by site-specific conditions. ADEC developed the *Alaska Storm Water Guide* (ADEC 2011b) to assist permittees with selecting, installing, and maintaining control measures that may be used for projects in Alaska. Erosion and sediment control measures covered under the stormwater general permit for construction activities (ADEC 2011a) are summarized below.

Erosion Control Measures

- Delineate the site, specifically the location of all areas where land disturbing activities will occur and areas that will be left undisturbed (e.g., boundaries of sensitive areas or established buffers).
- Minimize the amount of soil exposed during construction activity by preserving areas of native topsoil on the site where feasible and sequencing or phasing construction activities to minimize the extent and duration of exposed soils.
- Maintain natural buffer areas.
- Control stormwater discharges and flow rates, via the following mechanisms:
  - Diversion of stormwater around the site.
  - Slow down or containment of stormwater that collects and concentrates at the site.
  - Avoidance of structural control measure placement in active floodplains, to the degree practicable and achievable.
  - Placement of velocity dissipation devices (e.g., check dams, sediment traps, or riprap) along conveyance channels and where discharges from conveyance channels join water courses.
- Protect steep slopes, via the following mechanisms:
  - Design and construction of cut-and-fill slopes to minimize erosion.
  - Diversion of concentrated stormwater flows away from and around the disturbed slopes, using interceptor dikes, swales, grass-lined channels, pipe slope drains, surface drains, and check dams.
  - Stabilization of exposed slope areas.

Sediment Control Measures

Sediment control measures (e.g., sediment ponds, traps, filters) should be functional before other land-disturbing activities take place. These measures may include:

- Storm drain inlet protection measures (e.g., filter berms, perimeter controls, temporary diversion dikes), that minimize the discharge of sediment prior to entry into the inlet for storm drain inlets located on site or immediately downstream.
- Water body protection measures (e.g., velocity dissipation devices) that minimize the discharge of sediment prior to its entry into water bodies located on site or immediately downstream.
- Down-slope sediment controls (e.g., silt fences, temporary diversion dikes) for any portion of the down- and side-slope perimeters where stormwater would be discharged from disturbed areas of the site.
- Establishment and stabilization of construction vehicle access and exit points, limited to one route if possible.
- Minimization of dust generation through the application of water or other dust suppression techniques prior to vehicle exit.
- Stabilization or coverage of soil stockpiles, protection with sediment trapping measures, and, where possible, location away from storm drain inlets, water bodies, and conveyance channels.
- Design of sediment detention basins to capture runoff or conveyed stormwater and reduce water velocity to allow sediments to settle out before they can enter streams or other water bodies. Storm flows eventually pass through an outflow structure leaving the sediment (i.e., solids that can settle) in the basin. There are important design and management considerations for sediment detention basins for hard rock mining (USEPA 2003b: Appendix H, Section 6.1.6).

Soil Stabilization

All disturbed areas of the site should be stabilized to minimize on-site erosion and sedimentation and the resulting discharge of pollutants according to the requirements in ADEC (2011a). Existing vegetation should be preserved wherever possible.

Many of the BMPs for industrial operations associated with metal mining focus on sediment and erosion control and are similar to BMPs used in the construction industry (USEPA 2006). Some of these BMPs pertain specifically to haul and/or access roads (USEPA 2006).

- Construction of haul roads should be supplemented by BMPs that divert runoff from road surfaces, minimize erosion, and direct flow to appropriate channels for discharge to treatment areas. Examples of these BMPs include:
  - Dikes, curbs, and berms for discharge diversions.
  - Conveyance systems such as channels, gutters, culverts, rolling dips and road sloping, and/or roadway water deflectors.
  - Check dams, rock outlet protection, level spreaders, stream alternation, and drop structures for runoff dispersion.
  - Gabions, riprap, native rock retaining walls, straw bale barriers, sediment traps/catch basins, and vegetated buffer strips for sediment control and collection.
  - Vegetation to stabilize soils.
- Roads should be placed as far as possible from natural drainage areas, lakes, ponds, wetlands, and floodplains.
- Width and grade of roads should be as small as possible to meet regulatory requirements and designed to match the area’s natural contours.

All stabilization and structural erosion control measures should be inspected frequently and all necessary maintenance and repairs should be performed.

10.3.4.2 Exposure-Response

Sediment loading from roads can severely affect streams downstream of the roadbed (Furniss et al. 1991). Salmonids are adapted to episodic exposures to suspended sediment, but survival and growth can be affected as concentrations or durations of exposure increase (Section 9.4.2.1). Increased deposition of fine sediment decreases the abundance and production of fish and benthic invertebrates (Section 9.4.2.2). Fine sediments have been linked to decreased fry emergence, decreased juvenile densities, loss of winter carrying capacity, increased predation on fish, and reduced benthic organism populations and algal production (Newcombe and MacDonald 1991, Gucinski et al. 2001, Angermeier et al. 2004, Suttle et al. 2004). In low-velocity stream reaches, an excess of fine sediment can completely cover suitable spawning gravel and render it useless for spawning, and sediment deposited after spawning may smother eggs and alevins. Excessive stream sediment loading can also result in channel braiding, increased width-depth ratios, increased incidence and severity of bank erosion, reduced pool volume and frequency, and increased subsurface flow. These changes can result in reduced quality and quantity of available spawning habitat (Furniss et al. 1991).

Increased runoff associated with roads may increase rates and extent of erosion, reduce percolation and aquifer recharge rates, alter channel morphology, and increase stream discharge rates (Forman and Alexander 1998). During high-discharge events and in high velocity streams, accumulated sediment tends to be flushed out and re-deposited in larger water bodies (Forman and Alexander 1998). Because streams crossed by the transportation corridor connect downstream to Iliamna Lake and ponds, accelerated sedimentation could have an impact on the concentrated sockeye spawning populations in these habitats. Accelerated sedimentation could also have a localized impact on the clarity and chemistry of Iliamna Lake, affecting the photic zone (the depth of light penetration sufficient for photosynthesis) and thereby primary production and zooplankton abundance, which is critical to juvenile sockeye salmon.

10.3.4.3 Risk Characterization

Suspended and deposited sediment washed from roads, shoulders, ditches, cuts, and fills would likely diminish habitat quality in the streams below road crossings. The magnitude of effects cannot be estimated in this assessment. However, published studies of the influence of silt on salmonid streams (Section 9.4) indicate that even relatively small amounts of additional sediment could have locally significant effects on reproductive success of salmonids and production of aquatic invertebrates. Potential mitigation measures for stormwater runoff, erosion, and sedimentation are discussed in Box 10-3.

10.3.5 Dust

Dust results from traffic operating on unpaved roads in dry weather, grinding and breaking down road materials into fine particles (Reid and Dunne 1984). These fines are either transported aerially in the dry season or mobilized by water in the wet season. Dust particles may also include trace contaminants, including de-icing salts, hydrocarbons, and metals. Following initial suspension by vehicle traffic, aerial transport by wind spreads dust over long distances, so that it can reach surface waters that are otherwise buffered from sediment delivery via aqueous overland flow (Appendix G). Dust control agents such as calcium chloride have been shown to reduce the generation of road dust by 50 to 70% (Bader 1997), but these agents may cause toxic effects when they run off and enter surface waters (Section 10.3.3).

10.3.5.1 Exposure

The amount of dust derived from a road surface is a function of many variables, including composition and moisture state of the surface, amount and type of vehicle traffic, and speed. An Iowa Highway Research Board project (Hoover et al. 1973) that quantified dust sources and emissions created by traffic on unpaved roads found that one vehicle, traveling 1 mile of unpaved road once a day every day for 1 year, would result in the deposition of 1 ton of dust within a 1,000-foot corridor centered on the road (i.e., traffic would annually deposit 1 ton of dust per mile per vehicle).

To estimate truck traffic required by the mine scenarios, we extrapolated from vehicle use at a smaller gold mine (Pogo Mine) based on the rate of ore production at Pogo relative to the mine scenarios. Estimated production rate at Pogo is 3,000 tons per day (USEPA 2003a), versus 200,000 tons per day in the mine scenarios (Ghaffari et al. 2011). Overall mine-related vehicle use at Pogo averages between 10 and 20 round trips per day (USEPA 2003a). Approximately 175 truck trips per year (0.5 round trip per day) are required at Pogo to transport reagents, leaving 19.5 round trips per day for other purposes. The number of truck trips required for transport of reagents is assumed to be roughly proportional to ore production, resulting in an estimate of 33 round trips per day to transport reagents in the assessment mine scenarios. The number of daily round trips for purposes other than reagent transport was estimated at 19.5 round trips per day, for a total daily traffic estimate of 52.5 round trips in the mine scenarios. This value is likely an underestimate, as it does not account for potential effects of size differences between Pogo Mine and the mine scenarios or the number of trips for purposes other than reagent transport.

The length of the transportation corridor within the Kvichak River watershed would be 113 km. Based on the estimate from Hoover et al. (1973), the average amount of dust (in tons) generated per mile of road per year along the transportation corridor within the Kvichak River watershed would be equivalent to the daily average number of vehicles passing along the corridor (one vehicle making a round-trip constituting two passages). Using this method, the mine scenarios would generate approximately 105 tons of dust per mile (59 metric tons per km) annually or approximately 6,700 metric tons annually for the entire length of road within the Kvichak River watershed. This value may be an underestimate because smaller vehicles typically use rural roads in Iowa, or an overestimate if roads in Iowa are drier or if dust suppression is effective. Regardless, it indicates that dust production along the transportation corridor could be substantial.

10.3.5.2 Exposure-Response

Walker and Everett (1987) evaluated the effects of road dust generated by traffic on the Dalton Highway and Prudhoe Bay Spine Road in northern Alaska. Dust deposition altered the albedo of snow cover, causing earlier (and presumably more rapid) snowmelt up to 100 m from the road margin and increased depth of thaw in roadside soils. Dust was also associated with loss of lichens, sphagnum, and other mosses and reduced plant cover (Walker and Everett 1987). Loss of near-roadway vegetation has important implications for water quality, as that vegetation helps to filter sediment from road runoff. Thus, dust deposition can contribute to stored sediment that can mobilize in wet weather, and deposition can reduce the capacity of roadside landscapes to filter that sediment.

In a study of road effects in Arctic tundra at acidic (soil pH less than 5.0) and less acidic (soil pH at least 5.0) sites, Auerbach et al. (1997) found that vegetation effects were more pronounced at the acidic site. Permafrost thaw was deeper next to than away from the road at both sites, and could affect road structure detrimentally. Vegetation biomass of most taxa was reduced near the road at both sites. Species richness in acidic tundra next to the road was less than half the richness at 100 m away from the road. Sphagnum mosses, dominant in acidic low arctic tussock tundra, were virtually eliminated near the road. According to PLP (2011: Chapter 5), approximately 72% of the mine area is composed of well-drained acidic soils (58% strongly acidic); approximately 34% of the transportation corridor is composed of well-drained acidic soils (3.5% strongly acidic).

10.3.5.3 Risk Characterization

The main impact of dust from the transportation corridor on salmonids likely would be reduced habitat quality due to a reduction in riparian vegetation and subsequent increase in suspended sediment and fine bed sediment, especially during road construction. Potential effects of increased sediment loading are discussed in Section 10.3.4. Loss of riparian vegetation would also occur at the mine site, but there the main impact of dust would be a direct increase in fine bed sediment due to mine construction and operation.

10.3.6 Invasive Species

10.3.6.1 Exposure

Construction and operation of the transportation corridor would increase the probability that new terrestrial and aquatic species would be transported to and could establish themselves in the Bristol Bay region. Roads can facilitate introductions via contaminated soil or gravel used in road construction and maintenance, or via contaminated vehicles, equipment, cargo, and people that travel those roads. For example, road fill appears to be the mode of introduction and spread for invasive sweetclover (*Melilotus alba*) in central and southeast Alaska (Wurtz et al. 2010). Elsewhere, road maintenance further spreads invasive plants along suitable roadside habitat (Christen and Matlack 2009). Vehicles can carry contaminated equipment and cargo. Over the 2-year construction of a research station in Antarctica, an estimated 5,000 seeds from 14 different plant families were introduced on almost 15,000 m^3 of cargo (Lee and Chown 2009). Once docked, seeds on cargo could disperse at almost any location along the transportation corridor. Finally, people unintentionally introduce and spread invasive species in Alaska and other Arctic environments on their shoes (Bella 2011, Ware et al. 2012).

Once established along or near the transportation corridor, terrestrial species that thrive in riparian and floodplain areas could spread to salmon-bearing habitat at any of the points where the road crosses a river, stream, or other aquatic habitat. In a survey of 2,865 km (1,780 miles) of major highways in interior and south-central Alaska, 64 of 192 sampled bridge crossings (over 30%) were found to have sweetclover adjacent to them, and sweetclover had spread to downstream floodplains at 17 of these bridge crossings (Wurtz et al. 2010). This survey likely underestimates the number of floodplain invasions, because it did not sample numerous stream crossings serviced by culverts or other locations along streams where fill had been placed.

Aquatic invasive species, including macrophytes, shellfish, and salmonid pathogens and parasites can also be introduced along the transportation corridor on equipment that has come into contact with contaminated waters. Most literature emphasizes recreation equipment (Johnson et al. 2001, Arsan and Bartholomew 2008); little or no information exists about the incidence of aquatic or riparian species introductions specifically on construction or mining equipment. Transported equipment contaminated with aquatic invaders could spread those species to salmon-bearing habitat via direct contact with anadromous waters during stream crossing construction or during mining activity. Aquatic invaders could also be carried by water to other salmon-bearing habitats downstream of the initial introduction locations, including into Iliamna Lake and other parts of the Kvichak River watershed.

The likelihood that an aquatic invasive species will establish and spread successfully can depend heavily on environmental requirements. For instance, *Myxobolus cerebralis*, a cnidarian parasite that causes whirling disease, has already been detected in an Anchorage, Alaska, trout hatchery. This parasite has very specific abiotic and biotic conditions under which it infects salmonids. If the pathogen is introduced to a new area, susceptible genetic variants of the secondary host (the oligochaete worm *Tubifex tubifex*) must be present, seasonal water temperatures must exceed 10°C with approximately 1,500 degree-days, and susceptible salmonid species and life-stages must co-occur with the secondary host (Arsan and Bartholomew 2008). In addition to the hatchery location where whirling disease has already been found, favorable conditions exist for parasite establishment in two tributaries of Cook Inlet near Anchorage (Arsan and Bartholomew 2008). However, conditions for whirling disease establishment are not known for the Bristol Bay region.

10.3.6.2 Exposure-Response

Invasive species can drastically alter the composition of riparian and floodplain vegetation adjacent to salmon habitats. Invasive sweetclover, purple loosestrife (*Lythrum salicaria*), and giant knotweed (*Polygonum sachalinense*)—all current invaders in Alaska—can replace native riparian species (Blossey et al. 2001, Urgenson et al. 2009, Spellman and Wurtz 2011). In general, it has been difficult to show a direct effect of riparian vegetation alteration on fish diversity, abundance, or biomass (Smokorowski and Pratt 2007), but indirect effects on salmon via aquatic foodwebs have been documented (Wipfli and Baxter 2010). Giant knotweed was shown to release nitrogen-poor litter into a tributary of the salmon-bearing Skagit River in Washington, which can have cascading, negative effects on fish by altering their invertebrate food sources (Urgenson et al. 2009). Purple loosestrife was found to decompose four times faster than native sedge in the Fraser River, making detritus available in fall rather than winter and spring, when it was usually used by invertebrates that support salmon production (Grout et al. 1997).

Links between aquatic invaders, particularly macrophytes, and fish performance have been made in lentic, but rarely in lotic, habitats (Smokorowski and Pratt 2007). Effects of invasive macrophytes range from increased native fish abundance, to no effect, to detrimental effects on fish and their food sources via exuded toxic compounds, depending on the invasive species and fish species of interest (Schultz and Dibble 2012). Streambed coverage of several aquatic macrophyte species, both native and introduced (including the recent Alaska invader *Elodea canadensis*), reduced the number of Chinook salmon redds and the percentage of available spawners observed using infested habitat in northern California (Merz et al. 2008). This is significant in the regulated, low-flow Mokelumne River in California, where spawning habitat is considered a limiting resource.

Evidence of the effects of other aquatic invaders on salmonids also exists. Didymo (*Didymosphenia germinata*) is a colonial diatom capable of covering stream substrates with thick, slippery mats. Documented effects of didymo on salmonids vary with location and fish species. Effects of didymo on the invertebrate communities that serve as fish food sources could ultimately affect salmonid growth and abundance (Whitton et al. 2009). The aquatic invader that causes whirling disease (*M. cerebralis*) has had devastating effects on several wild fisheries in the United States intermountain west (Nehring and Walker 1996). The disease can cause lesions, neurological defects, skeletal deformities, and death. Both sockeye salmon and rainbow trout fry are highly susceptible to whirling disease, should conditions be right for infection.

10.3.6.3 Risk Characterization

The spread of aquatic, riparian, and floodplain invasive species along roads and into salmon-bearing habitats could occur during construction and operation of the proposed transportation corridor, although mitigation measures can lower the likelihood of invasion (Box 10-4). Invasion of riparian and floodplain species is occurring in Alaska via the use of contaminated gravel road fill. In the case of invasive sweetclover, subsequent dispersal to almost 9% of floodplains downstream of bridges along one major highway was observed (Wurtz et al. 2010). Assuming similar rates of invasion along both the transportation corridor and bridges and culverts, 9% of the 64 streams and rivers—5 to 6 streams—crossed by the corridor in the Kvichak River watershed would experience invasion. Given that 55 of the 64 streams crossed by the transportation corridor are known or likely to support salmonids, alteration of salmon habitats would be expected in approximately 5 streams. However, this is almost assuredly an underestimate because it is based on rate of invasion for only one species and assumes that the spread of that species has reached equilibrium.

BOX 10-4. MITIGATION FOR INVASIVE SPECIES

The use of contaminated gravel road fill in Alaska has fostered the invasion of nonnative riparian and floodplain plant species. In some cases, the species are subsequently dispersed to floodplains downstream of road-stream crossings. Introduction and invasion of nonnative riparian and floodplain species may also occur via contaminated cargo, equipment, and boots. The following steps can help to mitigate the introduction and spread of invasive species.

- Purchase of fill from existing or new gravel pits certified by the Alaska Department of Natural Resources Division of Agriculture as weed-free (ADNR 2013).
- Proper and thorough inspection and de-contamination of cargo, equipment, and boots, at the port and at the mine site.
- Use of new equipment, where possible.
- Use of a process for cleaning, draining, and drying equipment previously used at another site (including personal gear worn by workers) that is advocated by the Alaska Department of Fish and Game for recreational equipment.

Should sweetclover, purple loosestrife, giant knotweed or other species invade riparian areas and floodplains adjacent to salmon-bearing streams and wetlands in the Bristol Bay region, they could change organic matter inputs into those streams and affect salmon food sources (Blossey et al. 2001, Urgenson et al. 2009, Spellman and Wurtz 2011). The extent to which salmon growth, diversity, or abundance would be altered would depend on the extent and intensity of infestation. Once initiated, these invasions would be difficult to reverse.

Invasions by aquatic species seem less likely but cannot be quantified. The most likely vector is believed to be construction equipment that has been used at stream crossings in a prior project. Such equipment could carry microbes or propagules in mud that could be transferred when constructing road and pipeline crossings in the Bristol Bay watershed.

The spread of invasive species is highly stochastic and there are no good, relevant models for risk estimation. Therefore, it is not as clear a threat as other issues considered in this assessment. However, the introduction and spread of invasive species has been a major cause of environmental degradation in the United States, and mitigation measures could reduce the risks (Box 10-4).

10.4 Overall Risk Characterization for the Transportation Corridor

Risks to salmonids from filling of wetlands, hydrologic modifications, spillage or runoff of contaminants and fine sediment, dust deposition, and introduction of invasive species are likely to diminish the production of anadromous and resident salmonids in many of the 55 streams known or likely to support salmonids that would be crossed by the transportation corridor. Salmonid spawning migrations and other movements may be impeded by culverts in 36 streams, 32 of which contain restricted (less than 5.5 km) upstream habitat. Assuming typical maintenance practices after mine operations, approximately 15 of these 32 streams would be entirely or partly blocked at any time. As a result, salmonid passage—and ultimately production—would be reduced in these streams, and they would likely not be able to support long-term populations of resident species such as rainbow trout or Dolly Varden. Approximately 272 km of streams downstream of road crossings also could be affected.

The migratory barriers and degradation of stream habitat discussed herein could also reduce the high genetic diversity among sockeye populations reported by Gomez-Uchida et al. (2011) and Quinn et al. (2012). This loss in diversity may decrease the long-term viability of sockeye salmon and would negatively affect localized watershed food webs.

Truck accidents may spill xanthates, cyanide, or molybdenum concentrate into streams crossed by the road. Xanthate and cyanide are highly toxic and could kill fish and invertebrates in the receiving streams and, depending on the size of the spill, portions of Iliamna Lake. Molybdenum concentrate is much less toxic and unlikely to cause severe effects.

The exact magnitudes of changes in fish productivity, abundance, and diversity cannot be estimated at this time, but the species, abundances, and distributions that could be affected are summarized below.

- Sockeye salmon spawning has been observed at 30 locations along the transportation corridor. Highest average abundances are in the Iliamna River (100,000 spawners), the Newhalen River (80,000 spawners), and Knutson Bay (70,000 spawners), although abundances can be much higher (e.g., 1 million adults were reported in 1960 survey of Knutson Bay).
- Chinook, coho, pink and chum salmon have been reported at isolated points in the Kvichak River watershed, and all four species have been observed in Upper Talarik Creek and the Iliamna River.
- Dolly Varden have been reported in nearly every sockeye salmon-bearing stream that would be crossed by or adjacent to the corridor, as well as in locations upstream of sites with reported anadromous salmon use.

- Rainbow trout have been reported in Upper Talarik Creek, the Newhalen River, an unnamed tributary to Eagle Bay, Youngs, Tomkok, and Swamp Creeks, the Iliamna River, and Chinkelyes Creek.

10.5 Uncertainties

In this chapter we evaluated the risks to salmonid habitats and populations associated with the transportation corridor (Figure 10-3). A number of uncertainties are inherent in assessing these risks, which are summarized below (uncertainties related to the effectiveness of mitigation measures are discussed in Box 10-5).

- **Characterization of streams and wetlands affected by the transportation corridor**. The NWI, NHD, AWC, and AFFI were used to evaluate the effects of the transportation corridor on hydrological features and fish populations (Box 10-1). These datasets include the following limitations.
    - Underestimation of the number of stream crossings and degree of channel sinuosity, resulting in underestimates of affected stream lengths.
    - Underestimation of fish-bearing streams due to limited sampling.
    - Potential undercharacterization of wetland area due to limited resolution of available NWI data.
    - Underestimation of potential impacts on wetlands bisected by the transportation corridor, because wetland area outside the 200-m boundary was assumed to maintain functionality.

  Overall, these uncertainties likely result in a moderate underestimation of risks to fish.
- **Estimation of dust production from the transportation corridor.** Our dust production estimate is based on a study that quantified dust sources and emissions created by traffic on unpaved roads. Extrapolating that study to the transportation corridor does not take into account variables such as composition and moisture of the road surface, number and width of tires, and speed. In addition, road dust generation may be reduced by 50 to 70% by the application of dust control agents such as calcium chloride. Overall, these uncertainties likely have a negligible effect on risks to fish, but a moderate effect on our dust production calculations.
- **Estimation of chemical spill frequency due to truck accidents**. Extrapolation of truck accident probability from a study of rural two-lane roads does not take into account specific, generally more difficult road and weather conditions prevalent in the area of the Pebble deposit. However, the risk of spills could be at least partially mitigated by using spill-resistant containers. Overall, these uncertainties likely result in a moderate underestimation of risk to fish because of effects on spill frequency calculations. Frequencies of cyanide and molybdenum concentrate spills were not estimated due to uncertainties in the mining scenarios.
- **Estimation of risks to salmonids from spills.** A spill of cyanide, xanthate, or molybdenum concentrate could occur in various ways and at various locations. The sparse literature on the aquatic chemistry and toxicology of xanthates and molybdenum makes the consequences of these

events particularly uncertain. Given its high toxicity, we are confident that toxic effects would occur following a xanthate spill into a stream; we are simply uncertain of the magnitude and extent of effects.

- **Estimation of culvert failure frequencies.** These frequencies, derived from the literature, assume that culverts are designed to specifications but are not always installed correctly and/or do not stand up to the rigors of a harsh environment. This uncertainty likely has a moderate effect on risks to fish, with unclear direction. Nonetheless, this does not change overall conclusions reached with respect to reduction of passage and ultimately production of salmonids or the viability of long-term populations of resident species.
- **Risks from invasive species.** Roads serve as corridors for the spread of weeds, pathogens, and other invasive species. However, the list of potential invaders is ill-defined and the rate of their spread along an industrial road is unknown.
- **Climate change effects.** The potential impacts of road construction and operation discussed in this chapter do not take into account potential effects of climate change. Over the timeframe considered in this assessment (approximately 80 years), the physical environment of the Bristol Bay watershed is likely to change substantially as a result of increases in temperature and precipitation (Section 3.8). Increases in rain-on-snow events are likely to increase flood frequency. Such changes could undermine the structure of the transportation corridor and its stream crossings. The variability and magnitude of streamflows could also enhance other impacts described in this chapter, including channel entrenchment and the loss of water-body connectivity. Collectively, these impacts would likely further reduce the diversity of fish habitat, causing a loss of population genetic diversity over time that would reduce the resiliency of salmon stocks to environmental fluctuations related to climate change. Overall, these climate-related uncertainties result in a moderate underestimation of risk to fish.

BOX 10-5. LIKELY EFFECTIVENESS OF MITIGATION MEASURES

Environmental characteristics along the transportation corridor would likely render the effectiveness of standard or even state-of-the-art mitigation measures highly uncertain.

- Subarctic extreme temperatures and frozen soil conditions could complicate planning for remediation, with uncertain outcomes due to variable conditions and spill material characteristics.
- Subarctic climatic conditions could limit the lushness and rapidity of vegetation growth or re-growth following ground disturbance, reducing the effectiveness of vegetated areas as sediment and nutrient filtration buffers.
- Widespread and extensive areas of near-surface groundwater and seasonally or permanently saturated soils could limit the potential for absorption or trapping of road runoff, and increase likelihood of its delivery to surface waters.
- The likelihood of ice flows and drives during thaws could make water crossing structures problematic locations for jams and plugging.
- The region is seismically active (Section 3.6), and even a small increment of ground deformation could easily disturb engineered structures and alter patterns of surface and subsurface drainage in ways that render engineered mitigations inoperative or harmful.
- Remote locations that are not frequented by humans mean that mitigation failures and accidents could go undetected until substantial harm to waters has occurred unless frequent inspections are conducted.

Although many possible mitigation measures can be identified and listed in a mitigation plan, they cannot all be ideally applied in every instance. Mitigation measures are often mutually limiting or offsetting when applied in the field. As a salient example for the transportation corridor, choosing a road location that minimizes crossings of streams, wetlands, and areas of shallow groundwater in a landscape that is rich in those hydrologic features could result in a tortuous alignment that is excessively long and curved to accommodate the upland terrain. This alignment would greatly increase the total ground area disturbed, and increased road curvature in either horizontal and vertical dimensions may increase risk of traffic accidents and consequent spills. It would also increase the length and structural complexity of the road-parallel pipelines (Chapter 11). Thus, avoidance of sensitive habitat features could elevate other environmental risks.