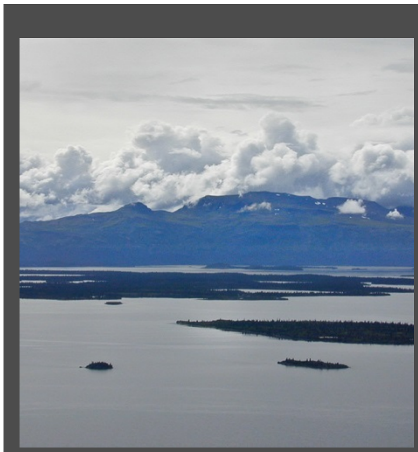
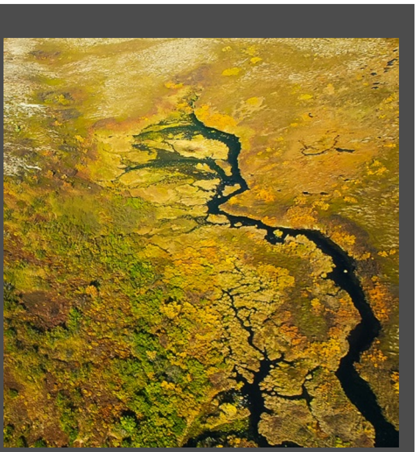




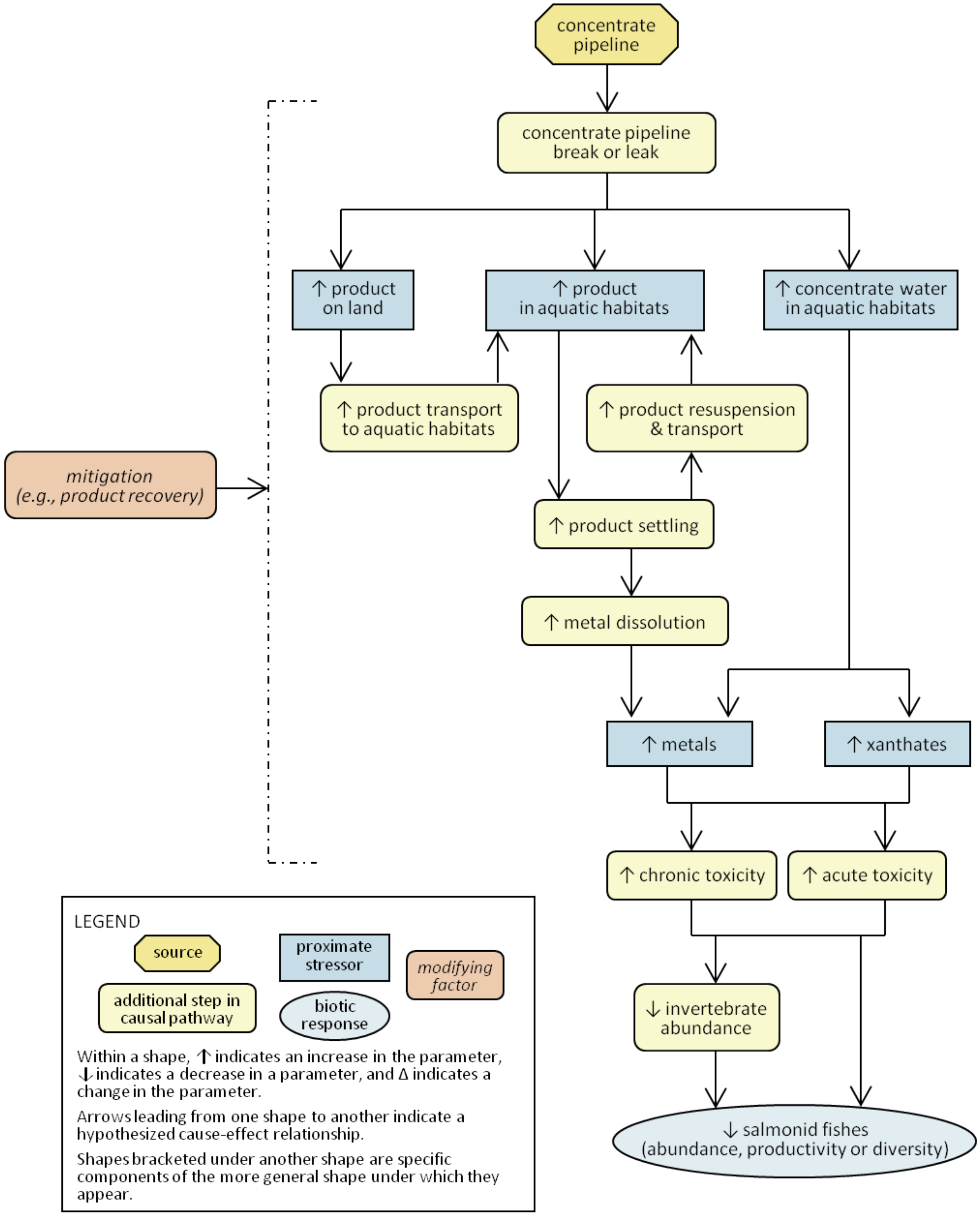
CHAPTER 11. PIPELINE FAILURES

As described in Section 6.1.3, the mine scenarios include four pipelines along the transportation corridor—one each for natural gas, diesel, product concentrate, and return water—and various pipelines on the mine site. Any of these pipelines could fail and release their contents to the environment. The risks from failure of product concentrate (Figure 11-1), return water (Figure 11-2), and diesel (Figure 11-3) pipelines are considered particularly high. These failure scenarios are evaluated in the following sections. Other pipelines are discussed briefly below.

On the mine site, the largest pipelines would carry tailings slurry from the mill to the tailings storage facilities (TSFs) and reclaimed water from the TSFs to the mill (Table 6-4). Smaller pipelines would convey water for processing and other uses and wastewater for treatment or storage. Other pipelines would carry diesel and natural gas from storage tanks to points of use. On-site pipeline spills have occurred at porphyry copper mines in the United States and some have resulted in significant aquatic exposures (Earthworks 2012). Such spills are possible at a future mine and could result in uncontrolled releases within the mine site; however, these spills are more likely to be contained or controlled without significant environmental effects than pipeline spills along the transportation corridor. In this assessment, we decided that leakage from on-site pipelines would be captured and controlled by the mine's drainage system and either treated prior to discharge or pumped to the process water pond or TSF.

Natural gas is lighter than air, so any release due to a natural gas pipeline failure would rise and dissipate. If the gas cloud ignited most of the heat would travel upward, but the initial blast and subsequent radiation heating could affect the road and nearby environment. During dry periods, a wildfire could result. Such failures were considered to pose relatively low risks to the assessment endpoints and are not evaluated further in this assessment.

Figure 11-1. Conceptual model illustrating potential stressors and effects resulting from a concentrate pipeline failure.



Within a shape, ↑ indicates an increase in the parameter, ↓ indicates a decrease in a parameter, and Δ indicates a change in the parameter.

Arrows leading from one shape to another indicate a hypothesized cause-effect relationship.

Shapes bracketed under another shape are specific components of the more general shape under which they appear.

Figure 11-2. Conceptual model illustrating potential stressors and effects resulting from a return water pipeline failure.

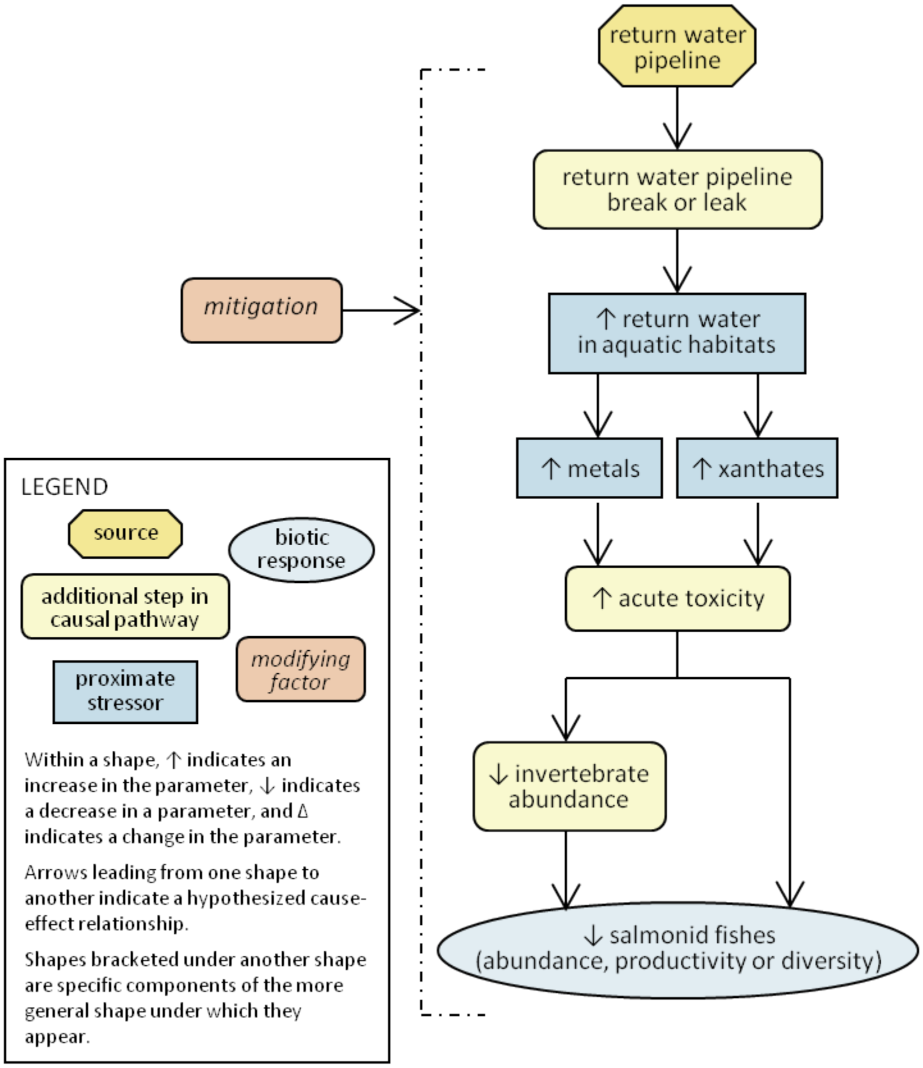
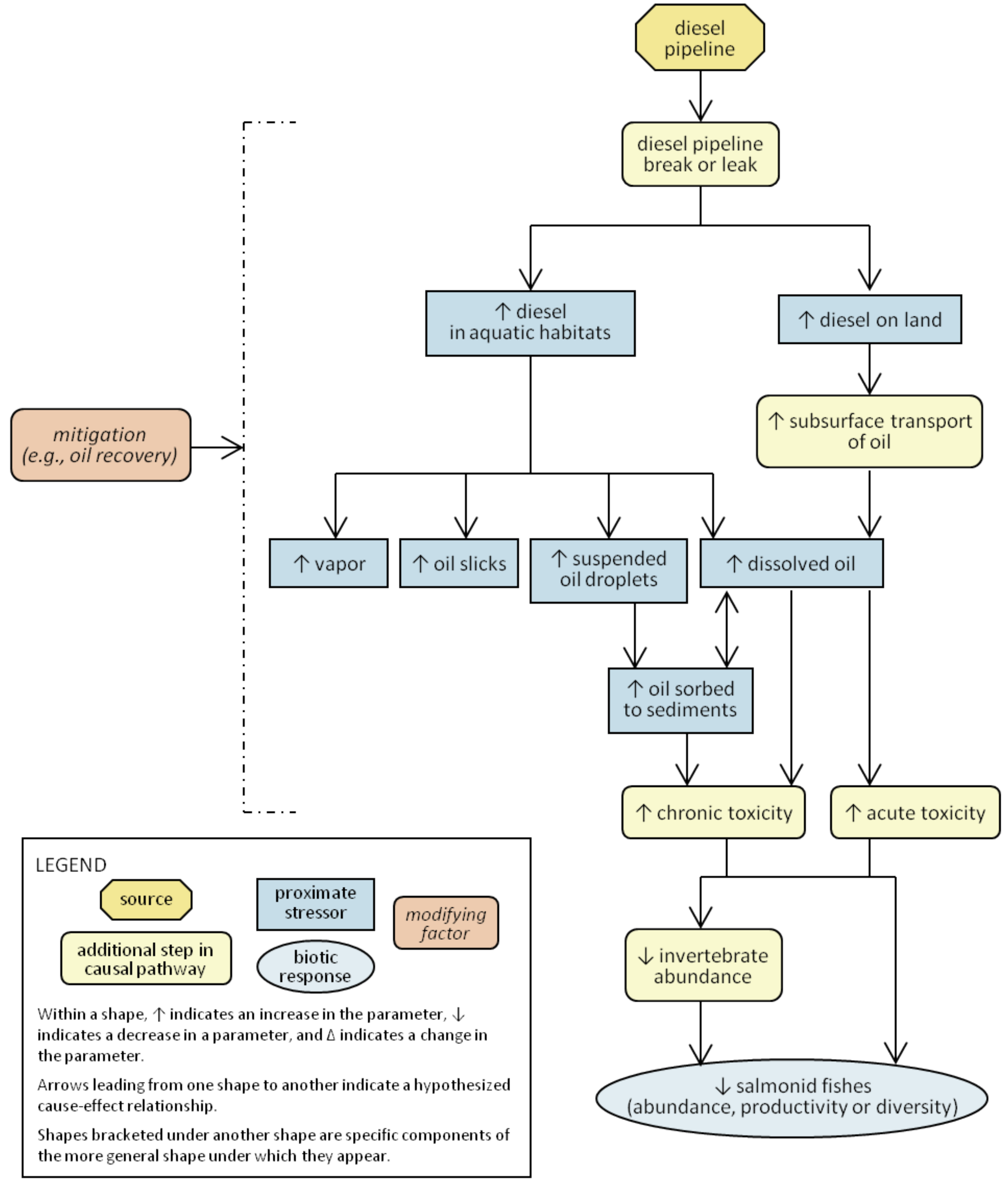


Figure 11-3. Conceptual model illustrating potential stressors and effects resulting from a diesel pipeline failure.



Within a shape, ↑ indicates an increase in the parameter, ↓ indicates a decrease in a parameter, and Δ indicates a change in the parameter.

Arrows leading from one shape to another indicate a hypothesized cause-effect relationship.

Shapes bracketed under another shape are specific components of the more general shape under which they appear.

11.1 Causes and Probabilities of Pipeline Failures

The U.S. transportation system includes more than 4 million km of pipeline, of which more than 3.8 million km are gas transmission or natural gas distribution mains and more than 280,000 km carry hazardous liquids, primarily petroleum products (PHMSA 2012). The principal causes of failures along these pipelines are external corrosion and mechanical damage such as impacts by excavating equipment. Internal corrosion and material breakdown also may cause pipeline failures, but are less common. The failure rate from impacts, such as can occur during road, pipeline, or bridge maintenance, tends to be steady over the lifetime of a pipeline, whereas corrosion failures tend to increase with age of the pipe.

Pipeline failures include both leaks and ruptures. Leaks are small holes and cracks that result in product loss but do not immediately prevent the functioning of the pipeline. Ruptures are larger holes or breaks that render the pipeline inoperable. A study of over 2 million km-yr of pipelines in Canada indicated that leaks account for 87% of failures and ruptures account for 13% (EUB 1998). A rupture could result in the immediate release of a significant amount of pipeline material. A leak would allow pipeline material to escape more slowly than a rupture, but a leak could remain undetected for a much longer time, ultimately releasing quantities comparable to or exceeding a rupture.

The most extensive pipeline failure statistics are derived from oil and gas industry data (Table 11-1). The industry's record of pipeline failures is directly relevant to the oil and gas pipelines considered in the pipeline failure scenarios. The failure rate of metal concentrate slurry pipelines is unknown, because few such pipelines are in operation and no published failure rates are available for those that are in operation. Oil pipeline failure rates are used as the best available estimate, although it is possible that the erosive or corrosive nature of the product concentrate slurry would increase pipeline failure rates.

Although the range of published annual failure rates for U.S. oil and gas pipelines spans more than one order of magnitude (0.000046 to 0.0011 per km-yr) (URS 2000), the range for pipelines most similar to the assessment pipelines along the transportation corridor is much narrower. For example, the failure rate is 0.0010 failure/km-yr for pipelines less than 20 cm in diameter (OGP 2010), 0.0015 failure/km-yr for pipelines in a climate similar to Alaska (Alberta, Canada) (ERCB 2013), and 0.00062 failure/km-yr for pipelines run by small operators (those operating total pipeline lengths less than 670 km) (URS 2000). The geometric mean of these three values yields a failure probability of 0.0010 failure/km-yr.

This overall estimate of annual failure probability, coupled with the 113-km length of each pipeline as it runs along the transportation corridor within the Kvichak River watershed, results in an 11% probability of a failure in each of the four pipelines each year. Thus, the probability of a pipeline failure occurring over the duration of the Pebble 2.0 scenario (i.e., approximately 25 years) would be 95% for each pipeline. The expected number of failures in each pipeline would be about 2.2, 2.8, and 8.6 over the life of the mine in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively. The chance of a large rupture in each of the three pipelines over the life of the mine would exceed 25%, 30%, and 67% in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively. In each of the three scenarios, there would be a greater than

99.9% chance that at least one of the three pipelines carrying liquid would fail during the project lifetime.

Table 11-1. Studies that examined pipeline failure rates.

Study	Km-Years Analyzed	Pipeline or Failure Parameter Assessed	Annual Failure Rate (per km-year)
OGP 2010 (oil pipelines)	667,000	Diameter <20 cm	0.0010
		Diameter 20–36 cm	0.00080
		Wall thickness ≤5 mm	0.00040
		Wall thickness 5–10 mm	0.00017
OGP 2010 (gas pipelines)	2,770,000	1970–2004	0.00041
		2000–2004	0.00017
Caleyo 2007	34,595	Mexican gas pipelines	0.0030
	28,270	Mexican oil pipelines	0.0052
URS 2000 (56 U.S. oil pipeline operators)	1,268,370	Highest failure rate	0.0011
		Average failure rate	0.00028
		Minimum failure rate	0.000046
		10 smallest operators (<670 km)	0.00062
		10 largest operators (>6,900 km)	0.00020
ERCB 2013	285,000	2000, Alberta, Canada	0.0033
	380,331	2007, Alberta, Canada	0.0022
	395,479	2008, Alberta, Canada	0.0021
	386,930	2009, Alberta, Canada	0.0016
	398,253	2010, Alberta, Canada	0.0015
	406,974	2011, Alberta, Canada	0.0015

Although data are insufficient to determine failure probabilities specific to the metal mining industry, the record suggests that pipeline failures at mines are not uncommon. A review of 14 operating porphyry copper mines in the United States (including all operating U.S. porphyry copper mines except two that have been operating for less than 5 years) found that all had experienced pipeline spills or accidental releases and that pipeline failures have continued into 2012 (Earthworks 2012).

It may be argued that engineering can reduce pipeline failures rates below historical levels, but improved engineering has little effect on the rate of human errors. Many pipeline failures, such as the cyanide water spill at the Fort Knox mine (Fairbanks, Alaska) that resulted from a bulldozer ripper blade hitting the pipeline (ADEC 2012), are due to human errors. Perhaps more important, human error can negate safety systems. For example, on July 25 and 26, 2010, crude oil spilled into the Kalamazoo River, Michigan, from a pipeline operated by Enbridge Energy. A series of in-line inspections had showed multiple corrosion and crack-like anomalies at the river crossing, but no field inspection was performed (Barrett 2012). When the pipeline failed, more than 3 million L (20,000 barrels) of oil spilled over 2 days as operators repeatedly overrode the shut-down system and restarted the line (Barrett 2012). The spill was finally reported by a local gas company employee who happened to witness the leak. The spill may have been prevented if repairs had been made when defects were detected, and the release could have been minimized if operators had promptly shut down the line.

11.2 Potential Receiving Waters

The transportation corridor pipelines evaluated in the assessment would cross approximately 64 streams and rivers in the Kvichak River watershed, 55 of which are believed to support salmonids and all of which could convey contaminants to Iliamna Lake. This number of crossings is much larger than the number of hydrologic units presented in Tables 10-3 through 10-5, because hydrologic units may contain multiple watersheds and each watershed may include crossings of multiple tributaries.

For approximately 14% of their length (15 km), these pipelines would be within 100 m of a stream or river (Table 10-3), and for 24% of their length (27 km) they would be within 100 m of a mapped wetland, pond, or small lake (Table 10-4). This proximity would create the potential for spilled slurry to flow into surface waters either directly or via overland flow. Some of the affected ponds support salmonids, but the number and distribution of salmonids in the area's wetlands, ponds, and small lakes are unknown. Approximately 272 km of streams, as well as Iliamna Lake, are downstream of these pipeline crossings (Table 10-7).

Although exposure pathways for all failure locations are considered, the quantitative analysis addressed two stream crossings along the assessment's transportation corridor: Chinkelyes Creek and Knutson Creek. Channel velocities for these creeks were calculated to estimate the time it would take for a spill to reach Iliamna Lake. Information from the Pebble Limited Partnership (PLP) (2011: Chapter 15.3) was used to develop channel width and depths. Streamflows were calculated from precipitation models used to determine mean annual runoff for the assessment's stream culvert analysis (Section 10.3.2). These mean annual streamflows applied to the basic channel geometry yielded channel velocities and thus travel times from each crossing to Iliamna Lake.

From the Chinkelyes Creek crossing, the creek flows 14 km to a confluence with the Iliamna River that continues for 7.6 km to Iliamna Lake. Lake levels can be seasonally high and create a backwater effect in the lower 3.5 km of the Iliamna River; however, most of the year the river flows freely for the entire distance to the lake shore. From the Knutson Creek crossing, the creek flows 2.6 km to Iliamna Lake. As Knutson Creek approaches the lake, the creek is steeper than the Iliamna River and it flows freely into the lake year-round. Total travel times to Iliamna Lake are estimated to be 170 minutes and 19 minutes for a Chinkelyes Creek and a Knutson Creek spill, respectively (Table 11-2). More details concerning these and other stream crossings are presented in Section 10.3.2.

Table 11-2. Parameters for concentrate pipeline spills to Chinkelyes Creek and Knutson Creek.

Parameter	Spill into Chinkelyes Creek		Spill into Knutson Creek
	Chinkelyes Creek	Iliamna River	Knutson Creek
Water Flow			
Discharge (m^3/s)	1.8	22	3.4
Velocity (m/s)	2.2	2.0	2.2
Channel Length (km)	14	7.6	2.6
Pipeline Drainage and Dilution			
Flow rate while draining (m^3/s)	0.11	-	0.07
Flow rate while pumping (m^3/s)	0.04	-	0.04
Release time—draining (minutes)	9.3	-	5.6
Release time—pumping (minutes)	5.0	-	5.0
Volume of slurry spilled (L)	75,000	-	37,000
Mass of concentrate solids spilled (metric tons)	66	-	32
Volume of aqueous phase spilled (L)	58,000	-	28,000
Maximum fully mixed dissolved copper concentration (μg/L)	37	3.3	16
Quotient[a], acute copper criterion	13	1.3	5.9
Quotient[a], chronic copper criterion	22	2.1	9.6
Travel time to confluence (minutes)[b]	110	64	19
Pipeline and Slurry Specifications			
Length from top of nearest hill to valve (m)	2100	-	810
Elevation drop (m)	150	-	25
Viscosity of slurry (cP)	9.5		
Density of slurry (metric tons/m^3)	1.7		

Notes:
Dashes (-) indicate that spill is not directly into Iliamna River, which receives flow from Chinkelyes Creek.
[a] See Box 8-3 for a description of how risk quotients were calculated.
[b] Confluence with Iliamna River for Chinkelyes Creek; confluence with Iliamna Lake for the Iliamna River and Knutson Creek.

11.3 Concentrate Pipeline Failure Scenarios

11.3.1 Sources

A full pipeline break or a defect of equivalent size in the copper (+gold) concentrate pipeline (Table 6-4) at the Chinkelyes Creek or Knutson Creek crossing would release slurry into these water bodies. This kind of failure could result from mechanical failure of the pipe due to ground movement, vehicle impact, maintenance error, or material failure. Parameters for the concentrate pipeline failure scenarios are summarized in Table 11-2.

In the concentrate pipeline failure scenarios, a single complete break of the pipeline would occur at the edge of the stream, just upstream of an isolation valve. These valves would be placed on either side of major crossings (Ghaffari et al. 2011) and could be remotely activated. Pumping would continue for 5 minutes until the alarm condition was assessed and an operator shut down the pumps. The estimated total slurry volume draining to the stream would equal the pumped flow rate times 5 minutes, plus the volume between the break and local high point in the pipeline (i.e., the nearest watershed boundary)

(Table 11-2). During the entire spill, gravity drainage would govern the flow rate based on calculations for free-flowing pipes.

The product concentrate would have a density of 3.8 metric tons/m^3 and would sink rapidly if released into a water body at low flows. The slurry water would have a density near 1.0 metric ton/m^3 and would mix readily with surface waters. No analyses of product concentrate or concentrate transport water are available for the Pebble deposit or any other ore body in the region. To estimate the concentration of metals and other constituents in the concentrate, we used analyses from the Aitik (Sweden) porphyry copper mine as described in Appendix H.

The fine particles of product concentrate would, like spilled tailings (Section 9.3), degrade habitat quality for fish and benthic invertebrates. However, these potential physical effects would be much lower in magnitude than for a tailings dam failure because of the much lower volume of material, and would be less important than potential toxic effects. Thus, we focus on toxic effects rather than effects of sediment deposition on habitat.

11.3.2 Exposure

In these concentrate pipeline failure scenarios, 66 metric tons of product concentrate would be released into Chinkelyes Creek or 32 metric tons into Knutson Creek. Based on its size and the well-established relationship between particle size and particle mobilization and transport (commonly represented by the Hjulström diagram), the concentrate would be transported in suspension by streamflows greater than approximately 20 cm/s and would be transported as bedload between approximately 1 and 20 cm/s. Estimated mean velocities of the streams (2.2 m/s for Chinkelyes Creek and Knutson Creek and 2.0 m/s for the Iliamna River) are consistent with those described for these streams (PLP 2011) and are well above the transport velocities. Therefore, the fine sand-sized concentrate would be carried downstream during typical or high flows, even given that the concentrate is denser (3.8 metric tons/m^3) than typical rock (2.8 metric tons/m^3 for granite) and would move less readily. Concentrate would be deposited in any backwaters, pools, or other low-flow locations. If the spill occurred during a period of high flow, it would be carried downstream immediately, reaching Iliamna Lake within 3 hours (via Chinkelyes Creek and Iliamna River) or 0.5 hour (via Knutson Creek). Because flood flows are a potential cause of pipeline failure at stream crossings, this is a reasonable possibility. If the spill occurred during low flows, concentrate that is not collected would be spread downstream by erosion during subsequent typical or high-flow periods, eventually entering Iliamna Lake. Concentrate that entered the lake could mix into sand and gravel beaches used by spawning sockeye salmon. These transport and deposition processes cannot be quantified with existing data and modeling resources.

The estimated annual failure rate of one per 1,000 km per year (Section 11.1) results in an estimated failure rate of 0.11 per year for the 113 km of concentrate pipeline within the Kvichak River watershed. If the probability of a pipeline failure is independent of location, and if it is assumed that 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 an estimate of 0.015 stream-contaminating concentrate spills per year, or 1.2 stream-contaminating concentrate spills over the duration of the

Pebble 6.5 scenario (approximately 78 years). In other words, we expect roughly 1 such spill in the Pebble 6.5 scenario. Similarly, a spill would have a 24% probability of entering a wetland, resulting in an estimate of 0.026 wetland-contaminating spills per year or 2 wetland-contaminating spills in the Pebble 6.5 scenario. A portion of those wetlands would be ponds or backwaters that support fish.

Spills from the pipeline failure would contaminate 2.6 km of Knutson Creek or 14 km of Chinkelyes Creek and 7.6 km of the Iliamna River with product concentrate and leachate (the slurry water that has leached ions from the product concentrate) before entering Iliamna Lake. The potential extent of wetland, pond, and small lake contamination cannot be readily estimated.

As with a tailings spill (Chapter 9), toxicologically relevant exposures could occur via multiple routes following a concentrate pipeline spill. During and immediately following a spill, organisms would be acutely exposed to leachate and suspended particles. After a spill, product concentrate deposited on a stream or lake bed would result in chronic aqueous exposures to pore water and acute aqueous exposures during resuspension events. Unlike the tailings spill, which would inevitably enter a stream and its floodplain, a slurry spill might directly enter a stream, pond, or wetland; it might flow over land to a nearby water body; or it might flow across the landscape without reaching water. Terrestrial slurry deposits are likely to be collected by the operator, so rain and snowmelt are unlikely to leach those concentrate deposits and significantly contaminate streams. However, spilled leachate from the pipeline slurry could enter a stream, wetland, pond, or lake by overland or groundwater flow. Contaminated groundwater could upwell through the gravels and cobbles of streams or deltaic gravels and sands in Iliamna Lake, and benthic invertebrates and fish eggs and larvae could be exposed to toxic concentrations if sufficient dilution did not occur.

11.3.2.1 Aqueous Phase Chemical Constituents

The concentrate slurry is estimated to contain 77% water by volume, with dissolved constituents that include dissolved salts of the product and trace metals, as well as process chemicals. Copper is the primary ecotoxicological concern, because it is the principal product and is highly toxic to aquatic life. Analyses of aqueous filtrate from samples taken on 3 different days, from a concentrate pipeline at a porphyry copper mine with a separation process similar to that considered in the mine scenarios (Section 6.1.2), reported copper concentrations of 500, 664, and 800 μg/L (Adams pers. comm.). The mean of these values (655 μg/L) was used as the estimated copper concentration in this assessment.

Due to its relatively high toxicity, sodium ethyl xanthate is the highest risk ore-processing chemical that could occur in the product concentrate slurry. We were unable to find an estimate of process chemical concentrations in the concentrate slurry, but xanthate concentration would be 1.5 mg/L if we assume that it occurs in the concentrate slurry at the same concentration as in tailings slurry (NICNAS 1995). Unlike the metals, xanthate would degrade, but because its environmental half-life is approximately 260 hours (at pH 7 and 25°C) (NICNAS 2000) it could persist long enough to cause significant exposures until diluted in Iliamna Lake.

Flows in the potential receiving streams vary considerably. Measurements in streams along the transportation corridor in 2004 and 2005 yielded a maximum observed flow of 58,000 L/s in the Iliamna River and a minimum observed flow of 2.8 L/s in an unnamed stream (PLP 2011). Thus, full mixing of spilled leachate could result in as much as a 33-fold dilution, but in smaller streams dilution effectively would not occur. Of 12 monitored streams along the transportation corridor, only two had observed flows in August 2004 (an estimate of summer low flow) that were greater than the estimated flow of the aqueous phase of the slurry (PLP 2011: Table 7.3-10).

11.3.2.2 Solid Phase Chemical Constituents

If spilled product concentrate entered a stream, wetland, pond, or small lake directly or by overland flow or erosion, it would flow for some distance, settle, and become substrate for invertebrates and possibly salmon eggs and fry. In streams, it would be carried downstream by the current and would collect in pools, behind debris, and in other localized low-flow areas. Some would settle into the cobble substrate until high flows mobilized the bed. Much of the product concentrate could wash into Iliamna Lake, where it could contribute to the substrate for spawning sockeye salmon.

Metal concentrations in the solid phase are expected to be similar to those of the Aitik product concentrate (Table 11-3). Settled concentrate would be leached, resulting in direct aqueous exposure of benthic invertebrates and fish eggs and larvae that inhabit the substrate to concentrations similar to leachates from the Aitik product concentrate (Table 11-4). Local accumulation in streams could result in local exposures to nearly pure concentrate and leachate. However, concentrate in Iliamna Lake would be distributed and diluted to an extent that could not be estimated. Dietary exposure of fish is not considered, because invertebrate abundance would be greatly diminished due to sediment toxicity, even with considerable dilution by clean sediment.

11.3.3 Exposure-Response

Acute water quality criteria (criterion maximum concentrations [CMCs]), chronic criteria (criterion continuous concentrations [CCCs]), and equivalent benchmark values are used as thresholds for aqueous toxicity. Consensus sediment quality guidelines are used as thresholds for sediment solids toxicity. These aqueous and sediment benchmark values are discussed in Section 8.2 and Section 9.5, respectively. The biotic ligand model (BLM) generates low acute and chronic water quality criteria and other toxicity values because of the extreme water chemistry of the leachate and receiving waters (Section 8.2.2). However, the parameters are all within calibration range of the model (except for alkalinity and dissolved organic carbon, which were set to minimum values because they were absent from the leachate; this slightly raises criteria values) (HydroQual 2007).

In addition to the product concentrate and its dissolved constituents, the slurry would contain process chemicals. Sodium ethyl xanthate is sufficiently toxic that it has been used as a pesticide (NICNAS 2000). Exposure-response information for xanthates is summarized in Section 8.2.2.

Table 11-3. Comparison of mean metal concentrations in product concentrate from the Aitik (Sweden) porphyry copper mine (Appendix H) to threshold effect concentration and probable effect concentration values for fresh water. Values are in mg/kg dry weight.

Concentrate Constituents	Concentrations	TEC[a]	TEC Quotient[b]	PEC[a]	PEC Quotient[b]
Ag	>10	-	-	-	-
As	12	9.8	1.2	33	0.36
Ba	59	-	-	-	-
Bi	45	-	-	-	-
Cd	2.4	0.99	2.4	5.0	0.48
Co	54	-	-	-	-
Cu	>10,000	32	>310	150	>67
Ga	0.88	-	-	-	-
In	2.4	-	-	-	-
Mn	345	630	0.55	1,200	0.29
Mo	1,100	-	-	-	-
Ni	72	23	3.1	49	1.5
Pb	65	36	1.8	130	0.50
Sb	43	-	-	-	-
Te	4.1	-	-	-	-
Th	1.5	-	-	-	-
Tl	0.2	-	-	-	-
U	2.2	-	-	-	-
V	23	-	-	-	-
Zn	2,200	120	18	460	4.8
Sum of metals	-	-	>340	-	>75

Notes:

Dashes (-) indicate that values are not available.

[a] TECs and PECs are consensus values from MacDonald et al. (2000), except for Mn values, which are the TEL and PEL for *Hyalella azteca* 28-day tests from Ingersoll et al. (1996).

[b] See Box 8-3 for a description of how risk quotients were calculated.

TEC = threshold effect concentration; PEC = probable effect concentration; TEL = threshold effect level; PEL = probable effect level.

11.3.4 Risk Characterization

Toxicological risk characterization is performed primarily by calculating risk quotients based on the ratios of exposure concentrations to aquatic toxicological benchmarks (Box 8-3). However, it also includes consideration of actual concentrate spills, the potential for remediation, and site-specific factors.

11.3.4.1 Concentrate Pipeline Failure Scenarios

The concentrate pipeline failure scenarios and resulting spills would release 58,000 L of leachate to Chinkelyes Creek or 28,000 L to Knutson Creek (Table 11-2). Risks to aquatic biota would result from direct exposure to the aqueous phase of the slurry, the deposited concentrate, and *in situ* leachate from the concentrate.

Table 11-4. Aquatic toxicological screening of leachates from Aitik (Sweden) product concentrate (Appendix H) based on acute (criterion maximum concentration) and chronic (criterion continuous concentration) water quality criteria or equivalent benchmarks, and quotients of concentrations divided by benchmark values. Values are in µg/L unless otherwise specified.

Analyte	Concentrations	Acute/Chronic Benchmarks	Quotients[a]
pH (standard units)	5.4	6.5–9	-
Spec. conductivity (µS/cm)	260	-	-
Alkalinity (mg/L)	0	-	-
SO_4 (mg/L)	120	-	-
SiO_2 (mg/L)	59	-	-
Ag	<1	0.90[b]/-	<1/-
Al	840	750/87	1.1/9.7
As	<1	340/150	<0.0029/<0.0067
Ba	38	46,000/8,900	0.0008/0.0043
Ca	27,000	-	-
Cl	800	19/11	42/73
Cd	3.5	1.7/0.22[b]	2.0/16
Co	140	89/2.5	1.5/54
Cr	<1	500/65[b]	<0.002/<0.007
Cu	8,400	12/7.9[b] 0.05/0.03[c]	720/1,100 180,000/290,000
F	1,600	-	-
Fe	210	350/-	0.60/-
K	4,000	-	-
Mg	4,500	-	-
Mn	640	760/690	0.85/0.93
Mo	<2	32,000/73	<0.0001/<0.03
Na	890	-	-
Ni	480	410/46[b]	1.2/10
Pb	11	54/2.1[b]	0.20/5.0
Sb	13	14,000/1,600	0.0009/0.008
Se	7.3	-/5.0	-/1.5
U	11	33/15	0.32/0.70
Zn	1,300	100/100[b]	13/13
Sum of metals	-	-	740[b]/1,300[b] 180,000[c]/290,000[c]

Notes:

Dashes (-) indicate that benchmarks are not available or, in the case of pH, that the value is not applicable.

[a] See Box 8-3 for a description of how risk quotients were calculated.

[b] Hardness-based criterion or standard based on hardness of 85.5 estimated from 2.5 Ca + 4.1 Mg in mg/L.

[c] From the national ambient water quality criterion for copper based on the biotic ligand model and leachate chemistry.

The estimated dissolved copper concentration in the aqueous phase of the slurry is 655 µg/L, which is roughly 240 times the acute water quality criterion and 390 times the chronic criterion for Upper Talarik Creek, the nearest stream with complete water quality data (Table 8-11). Clearly, this would be sufficient to cause severe toxic effects in small streams, large streams at low flow, and wetlands. The dilution provided by the receiving waters considered here would not be enough to prevent acute, much less chronic, toxicity based on the copper criteria. These criteria are based on toxicity to sensitive invertebrates, so the food base for salmonids could be severely reduced.

In all three streams, the diluted values are below the BLM-derived acute lethal levels for rainbow trout, so a fish kill would not be expected (Table 8-13). Therefore, copper is not predicted to cause a kill of adult salmonids in the receiving streams once mixing has occurred, but localized mortality could occur in the mixing zone in the absence of avoidance behavior. However, fully diluted concentrations in Chinkelyes Creek are above the chronic toxicity value for rainbow trout, suggesting that fry would be affected. Concentrations at mean flow in Knutson Creek are a little below the rainbow trout chronic toxic level (22 versus 26 μg/L), suggesting that effects on fry could occur at low flows.

Sodium ethyl xanthate, after fully mixing in Chinkelyes and Knutson Creeks, would occur at approximately 0.1 and 0.07 mg/L. These values are at the low end of observed acutely lethal concentrations for aquatic biota and below the observed median lethal concentrations for rainbow trout (Section 8.2.2.5). Hence, the processing chemicals could contribute to acute toxicity in sensitive species.

The occurrence of acute toxicity depends on the exposure duration relative to the concentration. The 5.6- to 9.3-minute exposure duration (Table 11-2) may be sufficient to cause acute injury or lethality to invertebrates or fish in receiving streams, given the high concentrations of copper (the rate of toxic response is a function of the concentration) and given that the chronic effects of copper on fish include lethality to fry. However, it would be more likely to cause acute effects in backwaters and ponds that retained spilled water, and those areas are important rearing habitat for salmon (Appendix A).

Where the 32 to 66 metric tons of concentrate settled, sediment and benthic invertebrates and fish eggs and fry would be exposed. The Aitik concentrate exceeds the sediment probable effect concentration (PEC) for copper by more than a factor of 67 (Table 11-3). Hence, based on experience with other high-copper sediments, any product concentrate from the Pebble deposit would be certain to cause toxic effects on benthic organisms, including invertebrates and fish eggs and larvae. Because copper is aversive to salmonids (Goldstein et al. 1999, Meyer and Adams 2010), the chronic leaching of copper from deposited product concentrate may prevent returning salmon from using a contaminated stream or river.

Exposure to pore water in sediments consisting of spilled product concentrate would be chronic. The screening assessment performed here on Aitik concentrate leachate suggests that spilled concentrate would cause severe toxic effects (Table 11-4). The 8,400 μg/L of dissolved copper in leachate would be sufficient to kill benthic or epibenthic invertebrates and fish eggs and fry.

At mine closure, concentrate and return water pipelines would be removed. Therefore, these risks would be limited to the approximately 78-year maximum operational life of the mine in the Pebble 6.5 scenario.

11.3.4.2 Analogous Mines

No Alaskan mine has a product concentrate pipeline, but the 316-km, 175-mm-diameter product slurry pipeline for the Bajo de la Alumbrera porphyry copper-gold mine in Argentina provides an analogue for the pipeline considered here. It was reported that a 6.5-magnitude earthquake on September 17, 2004, caused a break in the pipeline, releasing an unknown quantity of concentrate that caused the Villa Vil River to overflow for approximately 2 km (Clap 2004, Mining Watch Canada 2005). The operators reported that the 2004 spill was controlled in less than 2 hours and water for drinking and irrigation was not contaminated (Minera Alumbrera 2004). They do not mention an earthquake, do not explain why control required 2 hours, and attribute the failure to “an existing outer mark on the pipe” (Minera Alumbrera 2004). Other pipeline failures with concentrate spills were reported in 2006 and 2007, but not in other years (Minera Alumbrera 2004, 2005, 2006, 2007, 2008, 2009, 2010). They claimed that those releases were small due to automatic shutoff, that concentrate did not reach water, and that “no hazard is involved in concentrate handling since it is a harmless product consisting of ground rock” (Minera Alumbrera 2006). Composition of this ground rock included 28% copper and 32% sulfur (Minera Alumbrera 2006).

Operators subsequently built collection pits at pumping stations, monitored streams at pipeline crossings, and brought water into the community of Amanao in part to mitigate effects of “potential pipeline failure” (Minera Alumbrera 2008, 2010). They stated based on monitoring that pipeline crossings of streams have no adverse effects on biodiversity, but they do not report monitoring to address the effects of or recovery from the 2004 spill (Minera Alumbrera 2010). Although the interval during which Minera Alumbrera has provided sustainability reports is too short to reliably estimate an annual failure probability, it is notable that, despite International Organization for Standardization 14001 certification of the pipeline, it failed and released concentrate in 3 of 7 years.

More recently (July 25, 2012), a joint broke on the product slurry pipeline for the Antamina copper and zinc mine in Peru (Briceno and Bajak 2012, Taj and Cespedes 2012). It released 45 metric tons of slurry over 2 hours, of which 3 metric tons escaped the containment area. Local villagers intervened to stop the flow of slurry to the nearby Rio Fortenza. A mine spokesperson stated that the river showed no signs of contamination and the material was only an irritant, although a company document called the concentrate very toxic (Taj and Cespedes 2012). An Associated Press photo shows workers in white protective suits apparently cleaning a channel. News reports and Minera Antamina’s press releases on the event emphasized human health effects: 210 people received medical treatment and 45 were hospitalized, apparently due to inhalation of aerosolized slurry. People reported a strong pesticide odor, which suggests significant concentrations of a xanthate collector chemical, but no analyses have been reported. Ecological effects are unknown. Antamina is a modern mine (operation began October 1, 2001) where sustainability is said to be given a higher priority than cost or profitability (Caterpillar Global Mining 2009). As in the mine scenarios evaluated here, the pipeline is buried except at bridges and is monitored using a parallel fiber optic system.

Product concentrate spills from pipeline failures have also occurred at the Bingham Canyon mine in Utah. Between May 31 and June 2, 2003, operators reported to the U.S. Coast Guard's National Response Center a spill of 70 tons (63.5 metric tons) of product concentrate from a pipeline failure. On October 2, 2009, they reported a pipeline leak that spilled 1,400 gallons (5,300 L) of copper concentrate.

Although the Alumbrera, Antamina, and Bingham Canyon cases do not provide evidence concerning the ecological effects of a concentrate spill, they do support the plausibility of pipeline failures leading to concentrate spills. Our estimated pipeline failure rate of one per 1,000 km-year (Section 11.1) implies a failure rate of 0.32 per year for the 316-km Alumbrera pipeline, which is similar to the 0.43 observed rate at Alumbrera from 2004 to 2010. These cases indicate that concentrate pipeline failures do occur at modern copper mines operated by large international mining companies, and that they can result in spills that are potentially larger than our assumptions indicate.

11.3.4.3 Concentrate Spill Remediation

Remediation of a product concentrate spill would be less problematic than remediation of a tailings spill. The concentrate is valuable, it would be spilled near a road, and the volume would be much smaller than a potential tailings spill. Hence, remediation would likely occur relatively quickly if the spill occurred on land or in a wetland, by excavating or dredging the concentrate and trucking it back to the mine. However, because concentrate would be carried downstream by high or typical flows in the receiving streams, substantial recovery of material spilled into a stream is unlikely except possibly during low-flow periods (less than one-ninth of mean flows). The proportion recovered by dredging would depend on the circumstances, the rapidity of response, and the balance between the desire to minimize habitat damage and to reduce potential toxic effects. If the spill was associated with high flows, it is likely that little of the material would be recovered from a stream even if the entire stream was dredged. Dredging in Iliamna Lake might be feasible if concentrate was not too dispersed or diluted by other sediment.

11.3.4.4 Weighing and Summarizing the Evidence

Past experience with pipelines in general, and with the Alumbrera, Antamina, and Bingham Canyon product concentrate pipeline failures in particular, suggests that pipeline failures and product spills would be likely in the Pebble 6.5 scenario. A concentrate spill into a stream is likely to kill invertebrates and early fish life stages immediately. If it is not remediated (and remediation of streams may not be possible), it would certainly cause long-term local loss of fish and invertebrates. The settled concentrate would become sediment, which would be toxic to fish and invertebrates in the receiving streams for many years. Ultimately, this settled concentrate would reach Iliamna Lake, where it could be toxic to the eggs and larvae of sockeye salmon until it was sufficiently mixed with or buried by clean sediment. The length of streams affected in the scenarios would be 14 km of Chinkelyes Creek and 7.6 km of the Iliamna River for a release to Chinkelyes Creek, or 2.6 km of Knutson Creek for a release there. The area of the lake that would experience toxic effects cannot be estimated at this time.

The weighing of these lines of evidence is summarized in Table 11-5. For each route of exposure, sources of the exposure estimate and the exposure-response relationship are indicated. All evidence is qualitatively weighed based on three attributes: its logical implication, its strength, and its quality (Suter and Cormier 2011). For logical implication, possible scores are indicated as (+) for results supportive of adverse effects on the endpoint populations, (−) for results contrary to adverse effects on assessment endpoints, and (0) for neutral or ambiguous results. In this case, the logical implication is that the concentrate pipeline failure scenario evaluated here would have adverse effects. The strength of the evidence is based primarily on the magnitudes of the hazard quotients (exposure concentrations divided by effects concentrations): a low quotient is indicated as (0), a moderate quotient as (+), and a high quotient as (++). Quality is a more complex concept. It includes conventional data quality issues, but in this case the primary determinant is the relevance of the evidence to the mine scenario. Separate quality scores are provided for the exposure estimate and for the exposure-response relationship. The scores are intended to remind the reader what evidence is available and show the pattern of strength and quality of the several lines of evidence and to transparently present our weighing process and results.

Table 11-5. Summary of evidence concerning risks to fish from a product concentrate spill. The risk characterization is based on weighing four lines of evidence for different routes of exposure. All evidence is qualitatively weighed (using one or more +, 0, - symbols) on three attributes: logical implication, strength, and quality. Here, all lines of evidence have the same logical implication—that is, all suggest a concentrate spill would have adverse effects. Strength refers to the overall strength of the line of evidence, and quality refers to the quality of the evidence sources in terms of data quality and relevance of evidence to the spill scenario.

Route of Exposure Source of Evidence (Exposure/E-R)	Logical Implication	Strength	Quality		Results
			Exposure	E-R	
Dissolved copper Measurements from analogous mine and dilution model/Laboratory-based benchmarks	+	++	+	++	Lethality to invertebrates is certain and sensitive larval fish may also be killed.
Concentrate particles Undiluted concentration from analogous mine/Field–based benchmarks	+	++	0	+	The concentrate would clearly form toxic sediment but its distribution in unclear.
Concentrate leachate Leachate from analogous mine/ Laboratory-based benchmarks	+	++	0	++	Invertebrates and fish in sediment would experience toxic effects unless the concentrate was highly diluted.
Actual spills Amount spilled/None	0	0	0	0	The record indicates that concentrate spills occur but exposure and effects have not been studied.
Summary weight of evidence	+	++	0	+	A spill is likely to occur and toxicity to aquatic biota is highly likely.

Notes:
E-R = exposure-response relationship.

Overall, available lines of evidence for effects of a concentrate spill are positive (i.e., supportive of the hypothesis that acute and chronic toxic effects would occur) (Table 11-5). The quality of the exposure-response information is good, but the quality of the exposure information for the deposited concentrate and its leachate is uncertain because of the uncertain potential for dispersal in streams. The analogous spills provide no information on exposure or effects beyond confirming that concentrate spills do occur. However, this evidence supplements the more extensive experience with oil pipelines (Section 11.1), which suggests that a spill is likely.

If the spill could be remediated, some fraction of the concentrate (but none of the leachate) could be recovered and the extent of chronic (but not acute) toxic effects would be diminished. The proportion of concentrate recovered would depend on spill location, time of year, diligence of the operator, and the amount of physical damage due to remediation that is considered acceptable. Concentrate spilled into streams would be unlikely to be recovered unless streamflows were particularly low. Recovery of the concentrate would require excavation of streambeds, wetlands, or uplands, depending of the location of the spill. When determining how thoroughly to excavate and, in particular, how far downstream to dredge the stream, reduction in toxicity would need to be balanced against habitat destruction.

The effects of a spill on salmonid populations would depend on the receiving waters. Streams along the transportation corridor that might receive a spill (described in Section 10.1) are quite variable. Chinkelyes Creek receives an average of more than 9,000 spawning sockeye salmon and flows to the Iliamna River, which receives an average of more than 100,000 sockeye spawners (Table 10-2). Knutson Creek receives an average of roughly 1,500 sockeye spawners and flows to Knutson Bay, which receives an average of 73,000 beach spawning sockeye (Table 10-2). Not all of those salmon spawn below stream crossings, but copper leaching from concentrate spills could be aversive to salmon and thereby reduce spawning production along the entire stream lengths. Also, the concentrate deposited in Knutson Bay would persist and could render a considerable area unsuitable for spawning and rearing for years. In any case, these values indicate that a non-trivial number of spawners and potential salmon production would be at risk.

Potential effects on those salmon and other fishes in the receiving waters would include the following.

- Reduced production of salmon fry and parr and all life stages of other salmonids from the loss of invertebrate prey due to extensive acute lethality during the spill and persistent chronic toxicity in areas where the concentrate deposited.
- Loss of a year-class of salmon and other salmonids due to direct acute toxicity during and immediately following a concentrate spill.
- Loss of salmon spawning habitat due to avoidance of copper in areas of deposition and possibly in the entire stream, if aqueous concentrations from leaching concentrate were sufficiently high.
- Persistent chronic toxicity to salmonid eggs and fry in areas of concentrate deposition, where it is not aversive to spawning adults.

11.3.5 Uncertainties

Based on multiple lines of evidence, it is certain that a spill from a product concentrate pipeline into a stream would cause toxic effects. However, there are uncertainties regarding individual pieces of evidence, which are summarized below.

- The composition of the product concentrate and its leachate are uncertain, because they are based on a surrogate material and because leaching test conditions are inevitably somewhat artificial. Copper concentrations in North and South American copper concentrates generally fall in the 200 to 340 mg/kg range, so variance of a factor of 2 is a reasonable estimate for potential variance in Pebble deposit concentrate from Aitik concentrate. Hence, uncertainty concerning the major source of toxicity is not large, and therefore it is implausible that the concentrate and its leachate would be nontoxic to aquatic biota. An informal internet search for copper concentrate compositions suggests that minor metals differ by an order of magnitude among copper concentrates. Thus, it is possible that metals other than copper may be significant contributors to toxicity.
- The copper concentration of the aqueous fraction of the slurry is also based on analyses from an existing mine. However, estimates based on the existing mine are realistic, given that the ore type and processing are believed to be very similar and that the leachate was formed during actual operations rather than in a test. Therefore, this uncertainty is estimated to be at least a factor of 2 but no more than 5. Effects on invertebrates are certain, but effects on fish may not occur or may be more severe than estimated.
- The composition of the aqueous fraction of the slurry is unknown for constituents other than copper. Although it is certain that copper is by far the most toxic metal in the slurry, the composition of other constituents is unknown. Sodium ethyl xanthate is highly toxic and might increase the toxicity of a spill. Combined metal toxicity would make some difference but is unlikely to change the qualitative conclusions.
- The 5-minute time to shut-off is uncertain, and this estimate appears to be conservative. For example, Trans Canada's risk assessment for the Keystone XL pipeline assumed that the time to detection would range from 90 days for a small leak (1.5% of pumping volume) to 9 minutes for a large leak (50% of pumping volume), and that an additional 2.5 minutes would be required for the shutdown sequence (DNV Consulting 2006, O'Brien's Response Management 2009). This suggests that a large spill like the one assessed here would leak for 11.5 minutes based on a state-of-practice design from an experienced company, which is more than twice our assumed duration.
- The 5-minute time to shut-off depends on successful operation of a remote shutoff system. The potential for a larger spill if the shutoff failed (e.g., if an earthquake damaged the pipeline and the shutoff system) or was overridden by the operators is unknown. There are precedents for large spills but not enough data to quantify the risk.
- The frequency and location of spills are also uncertain. The extensive experience with oil and gas pipelines provides probabilistic estimates, but these estimates vary considerably among studies. The more directly relevant experiences with concentrate pipelines at Alumbrera, Antamina, and Bingham Canyon mines suggest that estimates based on oil and gas pipeline failure rates are consistent with mining-related pipeline failures.

11.4 Return Water Pipeline Failure Scenarios

A spill from a return water pipeline would result in an acute aqueous exposure (Table 11-6), as discussed above for a product concentrate spill. The return water is expected to be the same as the aqueous phase of the concentrate slurry (i.e., it would not be treated at the port), although estimated flow rates would differ. Hence, copper concentration in the return water is assumed to be the mean of analyses of the aqueous phase of slurry from a Rio Tinto mine (655 μg/L). Both acute and chronic criteria would be exceeded, but because of the short spill duration and the absence of a persistent solid phase, toxic effects would not be expected to be so severe as a product concentrate spill. Effects would be most likely in low-flow habitats such as backwaters, ponds, and bays. We know of no analogous return water pipeline failures that might be used to assess this risk; however, experience with pipelines in general suggests that multiple failures and spills would occur over the life of the mine, and at least one would be expected to occur at or near a stream (Section 11.1).

Table 11-6. Parameters for return water pipeline spills to Chinkelyes and Knutson Creeks.

	Spill into Chinkelyes Creek		Spill into Knutson Creek
Parameter	Chinkelyes Creek	Iliamna River	Knutson Creek
Water Flow			
Discharge (m^3/s)	1.8	22	3.4
Velocity (m/s)	2.2	2.0	2.2
Channel Length (km)	14	7.6	2.6
Pipeline Drainage and Dilution			
Flow rate while draining (m^3/s)	0.09	-	0.06
Flow rate while pumping (m^3/s)	0.03	-	0.03
Release time—draining (minutes)	8.6	-	5.1
Release time—pumping (minutes)	5.0	-	5.0
Volume spilled (L)	56,000	-	27,000
Maximum concentration dissolved copper (μg/L)	39	3.5	17
Travel time to confluence (minutes)[a]	110	64	19
Pipeline and Return Water Specifications			
Length from top of nearest hill to valve (m)	2100	-	810
Elevation drop (m)	150	-	25
Viscosity of return water (cP)	1		
Density of return water (metric tons/m^3)	1		

Notes:
Dashes (-) indicate that spill is not directly into Iliamna River, which receives flow from Chinkelyes Creek.
[a] Confluence with Iliamna River for Chinkelyes Creek; confluence with Iliamna Lake for the Iliamna River and Knutson Creek.

11.5 Diesel Pipeline Failure Scenarios

As with the product concentrate pipeline, effects of a diesel pipeline failure would depend on many factors, including pipeline design, location of the pipeline failure along the transportation corridor, and time of year at which the pipeline failure occurred. Parameters for the diesel pipeline failure scenarios are presented in Table 11-7.

Table 11-7. Parameters for diesel pipeline spills to Chinkelyes and Knutson Creeks.

	Spill into Chinkelyes Creek		Spill into Knutson Creek
Parameter	Chinkelyes Creek	Iliamna River	Knutson Creek
Water Flow			
Discharge (m^3/s)	1.8	22	3.4
Velocity (m/s)	2.2	2.0	2.2
Channel Length (km)	14	7.6	2.6
Pipeline Drainage and Dilution			
Flow rate while draining (m^3/s)	0.035	-	0.023
Flow rate while pumping (m^3/s)	0.005	-	0.005
Release time—draining (minutes)	13	-	7.9
Release time—pumping (minutes)	5	-	5
Volume—total (m^3)	30	-	12
Volume % diesel to water in stream at spill	2.2%	-	0.83%
Mass of diesel in stream at input (mg/L)	17,000	1,500	6,500
Maximum concentration dissolved diesel (mg/L)	1.9–7.8	1.7–7.2	1.9–7.8
Distance traveled during release (km)	1.7		1.1
Travel time to confluence (minutes)[a]	110	64	19
Pipeline and Diesel Specifications			
Length from top of nearest hill to valve (m)	2100	-	810
Elevation drop (m)	150	-	25
Viscosity of diesel at 15°C (cP)	2		
Density of diesel at 15°C (metric tons/m^3)	0.85		

Notes:
Dashes (-) indicate that spill is not directly into Iliamna River, which receives flow from Chinkelyes Creek.
[a] Confluence with Iliamna River for Chinkelyes Creek; confluence with Iliamna Lake for the Iliamna River and Knutson Creek.

11.5.1 Sources

11.5.1.1 Pipeline Failure

The volume of material released from a pipeline leak would depend on the type of failure, rate of loss from the pipe, pumping rate, leak duration, pipe diameter, distance to the nearest shutoff valves, and time until those valves are closed. For the purposes of this assessment, we evaluate a full break or a defect of equivalent size in the diesel pipeline that occurs at a stream crossing, thereby releasing fuel into that aquatic ecosystem. This could occur as a result of mechanical failure of the pipe from ground movement, vehicle impact, material failure or other cause. Characteristics of the pipeline are described in Table 6-4. We analyzed spills to two streams that would be crossed by the transportation corridor, Chinkelyes Creek and Knutson Creek (Section 11.2).

11.5.1.2 Diesel Fuel Composition

In the diesel pipeline failure scenarios, the pipeline would contain fuel from one of the Alaskan refineries and would have a composition similar to those presented by Geosphere and CH2M Hill (2006). Diesel fuel is a mixture of many hydrocarbon compounds, and its composition is a function of the petroleum feedstock source and the refining process. The type and amount of water-soluble hydrocarbons in the diesel determine the dissolved aqueous concentration when mixed with water. The most soluble compounds in diesel are the volatile aromatic hydrocarbons benzene, toluene, ethylbenzene and xylene (together, BTEX). Most diesel fuels have a low proportion of these soluble compounds and therefore have low solubilities. The bulk of diesel fuel is made up of heavier hydrocarbons that are essentially insoluble. A study of the composition of four diesel fuels from Alaskan refineries showed that the fuels had less than 2% BTEX and resulting diesel solubilities of 1.89 to 7.81 mg/L.

In the analysis of concentrations and solubilities, we incorporate all hydrocarbon compounds in the diesel samples and calculate the solubility based on Raoult's Law to account for effects of the mixture on the solubility of individual compounds.

11.5.2 Exposure

11.5.2.1 Background

A failure of the diesel pipeline in these scenarios could occur in the buried or above-ground portions. An above-ground failure would occur at a bridged stream or river crossing. An underground failure would result in diesel leaking into the soil and flowing down-gradient (e.g., as in the Trans-Alaska pipeline failure described in Section 11.5.3.3). If the underground failure occurred below a stream, it would float upward and into the surface water. An above-ground failure would release diesel directly to a river or stream, a wetland, or upland soil.

The behavior of diesel fuel in fresh water is less well-studied than the behavior of crude oil or diesel in marine environments. Diesel fuel has a density of less than 1.0 metric ton/m^3 and floats on water. It typically dissolves or evaporates within a day. In turbulent stream reaches, diesel would form small droplets suspended in the water column.

The soluble fraction would mix into the streamflow, be transported by advection and dispersion, and flow with the water. Solubility decreases with temperature, so in colder temperatures a smaller amount is dissolved in the stream. The soluble fraction is attenuated through dilution (advection and dispersion), biological activity, photodegradation, and aeration in turbulent streams, but is renewed by dissolution from the floating oil. The soluble compounds are also susceptible to evaporation from the floating oil, which typically occurs at a faster rate than dissolution. The soluble fraction compounds have relatively short residence times in water and sediments (Hayes et al. 1992) and can be reduced to below detection levels in a few days or weeks, depending on site-specific conditions.

Diesel components that are lighter than water and have low solubility tend to spread on the surface and form a thin film or sheen less than 0.1 mm thick. As the diesel spreads, it is more susceptible to destruction by evaporation, dissolution, and photodegradation but is also more likely to contact and attach to suspended sediments and shorelines. Most of the spilled diesel would flow with the stream until it reached Iliamna Lake and dissipated. The pour point of diesel (the temperature below which the oil will not flow) is approximately -7°C (20°F); thus, if the spill occurs during cold weather, the diesel would be less likely to spread and would instead form globs or strings and become suspended within the water column. For example, a 1999 cold-weather diesel spill in the Delaware River resulted in more than 90% of the diesel forming globules that were not visible from the surface (Overstreet and Galt 1995).

Oil dispersed in the water column can adhere to fine-grained suspended sediments that settle and deposit on stream edges and bottoms in low-energy areas. Depending on the source of the diesel, there may be a significant portion of compounds that are heavier than water and therefore sink, sorb to sediments, and persist longer than the dissolved fraction. In wetlands or pools and slack water areas of streams, a large percentage of spilled diesel can be deposited in the sediments.

When spilled on ice, diesel is viscous and forms tar-like accumulations on the surface. Lighter diesel components can penetrate the ice, become trapped within the ice structure, and be released as the ice melts. If the spill is trapped below the ice, as is more likely with buried pipelines, it would spread and stick to the underside of the ice in thin layers. Because cold temperatures reduce the solubility of diesel components, less would be dissolved in the stream water (NOAA and API 1994). As the ice breaks up and melts, the diesel would be released from the ice and mix with the stream water.

Because of its low viscosity (except in cold weather), diesel spilled onto the land tends to be rapidly absorbed by soil so that an above-ground spill on land could soon resemble an underground spill. In this area, where the groundwater surface tends to be shallow, spilled diesel would flow on top of the groundwater and a fraction would dissolve in that groundwater. It would then flow down-gradient to any nearby stream, possibly passing through wetlands on the way. Upon reaching a stream, it could pass into the channel through the gravels in which salmon, trout, and Dolly Varden spawn. In some locations, it might flow to Iliamna Lake and pass through a deltaic spawning beach used by sockeye salmon. Diesel-contaminated soil could episodically contaminate water when the water table rises following rain or snow melt. The extent to which fish eggs or fry are exposed by this route would depend on the specific structure of the spill site. Given the abundance of streams, wetlands, and shallow groundwater in the area crossed by the diesel pipeline, some variant of this exposure route is likely. However, saturated soils and particularly those that are frozen could result in overland rather than groundwater flow of diesel fuel.

The primary cause of toxicity to aquatic organisms in oil spills is direct exposure to the dissolved fraction. Exposure via this route would occur immediately following a direct spill to a stream or wetland as the oil dissolved, resulting in an acute exposure. Longer exposures to dissolved oil could result from slow releases of oil from terrestrial spills, flows from oiled wetlands, or the gradual dissolution of oil sorbed to sediments or plant materials. Oil spills can indirectly expose aquatic organisms to low dissolved oxygen as microbes decompose the oil.

Which of these transport and exposure processes would occur in a diesel spill depends on the spill location. The number and nature of water body crossings are the same as for the other pipelines (Section 11.2).

11.5.2.2 Transport and Fate

In the diesel pipeline failure scenarios, a pipeline failure would result in release of diesel directly into either Chinkelyes or Knutson Creek at mean streamflows (Table 11-7). The spill at Knutson Creek would release 12,000 L of diesel into approximately 1.6 million L of stream water, resulting in a 1:130 dilution. At Chinkelyes Creek, the spill would release approximately 30,000 L of diesel into 1.5 million L of stream water, resulting in a 1:49 dilution. At a typical diesel density of 850 g/L, this would result in 6,500 and 17,000 mg diesel/L water in Knutson and Chinkelyes Creeks, respectively. Both of these dilutions are less than the minimum aqueous volume required to get below the saturation of the diesel, if the dissolved hydrocarbons are well-mixed. This conclusion is based on calculation of the minimum volume of water required for diluting each component to a concentration below saturation. For benzene, the minimum volume of water required for dilution below saturation is 169 to 225 L benzene/L diesel; all other components would require higher dilutions. Thus, it is reasonable to assume that at both spill locations the diesel would be at saturation (i.e., at concentrations between 1.89 and 7.81 mg/L) in the receiving waters. Concentrations in the Iliamna River would be lower due to depletion of benzene. The benzene concentration would fall below its Raoult's saturation limit, resulting in a diesel concentration of 1.7 to 7.3 mg/l and a saturation of 92 to 94%.

11.5.3 Exposure-Response

Diesel is considered to be one of the most acutely toxic petroleum products (NOAA 2006), but its composition is variable. Although a model exists for estimating the acute aquatic toxicity of petroleum products from their chemical composition (Redman et al. 2012), the composition of diesel that would be piped to the mine is unknown. For example, the compositions of water-soluble fractions of two brands of Alaskan diesel fuel were found to be C4–C6 non-aromatic hydrocarbons (0.4–1.2 mg/L), benzene (0.03–0.2 mg/L), toluene (0.03–0.2 mg/L), and C2 benzenes (0.005–0.1 mg/L) (Guard et al. 1983). Given this variance in composition, data from laboratory tests and field studies of various whole diesel oils are used in this section to indicate the range of toxic effects observed in response to different exposures.

11.5.3.1 State Standards

According to Alaska water quality standards (ADEC 2011), total aqueous hydrocarbons in the water column may not exceed 15 μg/L and total aromatic hydrocarbons in the water column may not exceed 10 μg/L. The standards state (ADEC 2011): "There may be no concentrations of petroleum hydrocarbons, animal fat, or vegetable oils in shoreline or bottom sediments that cause deleterious effects to aquatic life. Surface waters and adjoining shorelines must be virtually free from floating oil, film, sheen, or discoloration."

11.5.3.2 Laboratory Tests

Laboratory tests of the toxicity of petroleum and its derivative fuels to aquatic organisms are performed with either an oil-water dispersion or a dissolved solution, called the water-soluble fraction. Dispersions are created by adding oil to water at prescribed ratios and mixing. The vigor and duration of mixing is variable, ranging from gentle mixing with a stirring rod to extended mixing with a magnetic stirrer. The resulting dispersion may have an oil layer on the surface as well as suspended oil droplets, although most tests attempt to avoid suspended material. The oil layer may be left in the test container, but more often the aqueous material is drawn off for the test. Results may be expressed as mg diesel/L or volume percent diesel. Water-soluble fractions are created by mixing oil and water to create a nominally saturated solution. The aqueous solution is drawn off and should be filtered to remove any suspended oil droplets. It is then diluted in water to create the test media. Results may be expressed as mg hydrocarbons/L or percent water-soluble fraction. In theory, one could also use toxicity data for each of the component chemicals in diesel fuel and estimate the combined effect based on individual effects, but that approach was judged to be impractical given uncertainties about diesel fuel composition in the scenarios and the paucity of toxicity data.

Potentially relevant results of tests of diesel dispersions and water-soluble fractions are summarized in Table 11-8. Results range over 4 orders of magnitude, and are highly variable even within an individual species or test type. This range results from differences in test procedures and diesel fuel compositions. Tests with biodiesel, synthetic diesel, sub-organismal endpoints, salt water, and dispersants were not included.

11.5.3.3 Analogous Spills: Diesel in Streams

Diesel spills into streams and wetlands are not uncommon, but their biological effects are seldom determined and published. Relevant diesel spill case studies are summarized in Table 11-9 and discussed in the text below. None of these studies were conducted in the Bristol Bay region, so they provide only a general indication of the nature and duration of effects expected from an instream diesel spill. We found no publications describing biological effects of diesel spills in relevant wetland habitats.

Multiple diesel spills have been associated with construction of the Trans-Alaska Pipeline, but biological effects were studied only for a 1972 spill from a broken underground pipeline that released 3,750 L to Happy Valley Creek (during spring streamflows of 14 m^3/s). Biological effects of the spill were studied downstream in the Sagavanirktok River (Nauman and Kernodle 1975, Alexander and VanCleve 1983). Invertebrate abundance declined by 89% after the spill (Nauman and Kernodle 1975), and stonefly and caddisfly nymphs were eliminated from the stream (Alexander and VanCleve 1983). Recovery was not reported.

A pipeline spill into Camas Creek, Montana, of oil that "most strongly resembled diesel fuel" resulted in low abundance and low richness of the invertebrate community with few mayfly, stonefly, and caddisfly taxa (Van Derveer et al. 1995). After remediation that included stream diversion and extensive removal of contaminated soil below the spill and recovery for approximately 1 year, taxa richness and abundance at the spill site were 60 to 70% of the upstream reference site, whereas at sites farther downstream from the remediation activities taxa richness and abundance were less than 15% and 10% of the reference site levels, respectively.

A tanker truck wreck in Trinity County, California, resulted in the flow of approximately half of a 15,000-L tank of diesel fuel into Hayfork Creek, a tributary of the Trinity River (Bury 1972). The oil was spilled on land and reached the stream after 36 hours. An area 1 to 2.5 miles below the spill was surveyed, because it had been previously studied. Numerous dead organisms were collected, including 4,469 vertebrates (rainbow trout and other fishes, tadpoles, snakes, turtles, and a bird) and uncounted thousands of macroinvertebrates. Recovery was not monitored.

A 1980 pipeline break released 340 m^3 of Number 2 fuel oil to a small tributary of Mine Run Creek, which ultimately flows to the Rapidan River, Virginia (Bass et al. 1987). The operator reported collecting 240 m^3 of oil. Monitoring was initiated 4 months after the spill, so acute effects were not observed. Standing crop, density, and diversity of macroinvertebrates were reduced in Mine Run Creek downstream of the tributary, and caddisflies were particularly affected. Effects were still observed at 16 months, when the study ended.

Table 11-8. Toxicity of diesel fuel to freshwater organisms in laboratory tests.

Species	Life Stage[a]	Test Endpoint	Concentration	Source—Notes
Water-Soluble Fraction				
Rainbow trout	Free-swimming embryos	9-day LC_{50}	8 mg/L	Schein et al. 2009—total dissolved hydrocarbon concentration
Rainbow trout	2 months after yolk resorption	48-hour LC_{50}	2.43 mg/L	Lockhart et al. 1987—total hydrocarbon concentration
Daphnia magna	1st instar	48-hour EC_{50}	6.7%	Giddings et al. 1980—percent water soluble fraction
Microcystis aeruginosa	Culture	4-hour carbon fixation	100%	Giddings et al. 1980—significant inhibition as percent water soluble fraction
Selenastrum capricornutum	Culture	4-hour carbon fixation	100%	Giddings et al. 1980—significant inhibition as percent water soluble fraction
Pseudokirchneriella subcapitata	Cultures	96-hour IC_{50}	58.7%	Pereira et al. 2012—inhibition of growth as percent water soluble fraction
Aqueous Dispersion				
Coho salmon	Juvenile	96-hour LC_{50}	10,299 mg/L	Wan et al. 1990—soft water
Coho salmon	Fry	96-hour TLm	2,870 mg/L	Hébert and Kussat 1972
Pink salmon	Juvenile	96-hour LC_{50}	74 mg/L	Wan et al. 1990—soft water
Rainbow trout	Juvenile	96-hour LC_{50}	3,017 mg/L	Wan et al. 1990—soft water
Rainbow trout	Fry	14-day LC_{50}	44.9 mg/L	Mos et al. 2008
Rainbow trout	Swim-up fry	72-hour LC_{50}	133.52 mg/L	Khan et al. 2007
Rainbow trout	Juvenile	96-hour LC_{50}	31 (6.6–65) mg/L	API 2003—mean and range of three tests
Fathead minnow	Juvenile	96-hour LC_{50}	57 mg/L	API 2003
Daphnia magna	Juvenile	24-hour LC_{50}	1.78 mg/L	Khan et al. 2007
Daphnia magna	Unspecified	96-hour LC_{50}	20.0 mg/L	Das and Konar 1988
Daphnia magna	Juvenile	48-hour LC_{50}	36 (2–210) mg/L	API 2003—mean and range of 12 tests
Chironomidae	Larvae	96-hour LC_{50}	346 mg/L	Das and Konar 1988
Selenastrum capricornutum	Culture	72-hour EL_{50}	20 (1.8–78) mg/L	API 2003—mean and range of seven results from three endpoints (inhibition of cell density, biomass, or growth) and three tests

Notes:

[a] As described by the authors.

LC_{50} =median lethal concentration; EC_{50} = median effective concentration; IC_{50} = median inhibitory concentration; TLm = equivalent to LC_{50}; EL_{50} = median effective level.

Table 11-9. Cases of diesel spills into streams. For comparison, the diesel pipeline failure scenarios evaluated here would release 30 and 8 m^3 of diesel into receiving streamflows of 1.8 and 3.4 m^3/s for spills into Chinkelyes Creek and Knutson Creek, respectively.

Case	Diesel Released (m^3)	Receiving Streamflow (m^3/s)	Observed Effects
Happy Valley Creek, AK	3.7	14	Significant declines in the abundance and species richness of invertebrates
Camas Creek, MT	Unknown	0.42	Low invertebrate abundance and richness
Hayfork Creek, CA	15	4.1	Large kill of vertebrates and invertebrates
Mine Run Creek, VA	240	1.2	Reduced invertebrate abundance and diversity
Reedy River, SC	3,600	6.4	Near-complete fish kill
Cayuga Inlet, NY	26	1.8	Fish kill and reduced abundance, reduced invertebrate abundance and species composition
Westlea Brook, UK	9.8	1.34	Fish kill, invertebrates severely affected
Hemlock Creek, NY	0.5	0.76	No significant effects on invertebrates

Notes:

[a] Mean flow from NHDPlus v2; others as reported by the authors.

In 1996, a pipeline ruptured and released 22,800 barrels (3.6 million L) of diesel into the Reedy River, South Carolina (Kubach et al. 2011). That spill resulted in a severe fish kill for 37 km downstream to the confluence with a reservoir. Recovery of the fish community, based on non-metric multidimensional scaling, occurred after 52 months.

In 1997, a train wreck spilled an estimated 26,500 L of diesel into Cayuga Inlet, a tributary stream of Cayuga Lake, New York (Lytle and Peckarsky 2001). Despite containment efforts, a kill occurred, which reduced fish (including rainbow trout) abundance by 92% and invertebrate abundance by 90%. Invertebrate density recovered within 1 year, but species composition had not recovered after 15 months.

In 2005, 9,800 L of diesel spilled into Westlea Brook in Wiltshire, UK (Smith et al. 2010). Due to its urban location, response was rapid, and approximately 7,000 L were recovered. However, the spill killed approximately 2,000 fish and a few frogs and birds. Invertebrate surveys showed that macroinvertebrates were severely affected and impacts were discernible for 4 km. Recovery occurred within the 13.5-month sampling period for all but the most affected site.

A tank of home heating oil (described as similar to diesel) leaked 500 L and an unknown amount entered Hemlock Creek, New York (Coghlan and Lund 2005). Three days after the spill, a survey of benthic invertebrates below the spill site found no significant reduction in the Hilsenhoff index (Coghlan and Lund 2005). The authors concluded that their techniques were sufficiently sensitive and no significant effects resulted from this small spill.

11.5.3.4 Analogous Spills: Crude Oil in Salmon Spawning Streams

The Exxon Valdez oil spill infiltrated the beaches of tidal Alaskan streams that provide spawning habitat for pink salmon (Rice et al. 2007). Water draining over the buried oil dissolved hydrocarbons, exposing salmon eggs and resulting in embryo histopathology and mortality for at least 2 years after the spill. The type of oil spilled and the circumstances of the spill are different from the diesel pipeline failure scenarios, but the studies described by Rice et al. (2007) demonstrate that oil buried near spawning habitats can be a source of potentially toxic exposures for years.

11.5.4 Risk Characterization

Toxicological risk characterization is performed primarily by calculating risk quotients based on the ratios of exposure levels to aquatic toxicological benchmarks (Box 8-3). However, it also includes consideration of actual diesel spills, the potential for remediation and recovery, site-specific factors, and the overall weight of evidence.

To characterize risks from a potential diesel spill, we weighed four lines of evidence based on different exposure estimates and sources of exposure-response relationships. The first two lines of evidence relate modeled estimates of dissolved hydrocarbon concentrations to laboratory test results for dissolved fractions of diesel oil and to state water quality standards. Because the diesel pipeline failure scenarios are sufficient to saturate the two potential receiving streams, we assume dissolved concentrations equal the solubilities of the Alaskan diesels (1.9 and 7.8 mg/L). Estimated concentrations in the Iliamna River are a little lower (1.7 and 7.2 mg/L) due to limited concentrations of soluble chemicals in diesel. These exposure levels are similar to the two median lethal concentration (LC_{50}) toxicity values for rainbow trout (2.43 and 8 mg/L) (Table 11-8) and far higher than the state standard (0.015 mg/L). Based on these estimates of soluble hydrocarbon concentrations, invertebrate kills would be highly likely and some salmonid mortality would be expected in the diesel pipeline failure scenario at either location.

The next line of evidence relates exposure (expressed as the amount of oil added to the stream) to laboratory test results for diesel dispersed in water. This line of evidence is based on the assumption that diesel added to a flowing stream is equivalent to diesel added to water and stirred. Exposure levels within the receiving water would be 17,000 mg/L for Chinkelyes Creek, 1,500 mg/L for the Iliamna River, and 6, 500 mg/L for Knutson Creek (Table 11-7). The laboratory LC_{50} tests for diesel dispersions are shown in Table 11-8, and strongly suggest that an oil spill would result in acute lethality of fish and invertebrates, even if turbulent mixing in a stream is not as efficient as stirring. In addition, tests of the alga *Selenastrum capricornutum* found that multiple growth and production endpoints were reduced by 50% at 20 mg/L (API 2003), which is also well below the estimated exposure.

The published history of freshwater diesel spills provides the final line of evidence. Diesel spill volumes at the two locations considered in these diesel pipeline failure scenarios—30 m^3 at Chinkelyes Creek and 12 m^3 at Knutson Creek—fall within the range of the cases described in Table 11-9 that caused effects on stream and river biotic communities. In addition, the sizes of the receiving streams in these failure scenarios and those in the case studies are similar. If we calculate a crude index of exposure by dividing the amount of diesel spilled by streamflow, values for the two scenarios (17 and 3.5) fall in the middle of the range of cases (0.26 to 560).

Only the case of a very small spill (less than 500 L into Hemlock Creek, NY) caused no significant biological effects. Other diesel spills caused fish and invertebrate kills and reduced invertebrate abundance and diversity. Invertebrate community effects persisted for several months to more than 3 years. Exposures and effects may be more persistent in Alaska's cold climate, but the only Alaskan study did not monitor recovery. Based on past diesel spills in streams, the diesel spills evaluated in this assessment—and any other spill that released more than a trivial amount of diesel to a stream—would be expected to cause an immediate loss of fish and invertebrates. The community would be likely to recover within 3 years, but the time to recovery in Bristol Bay streams is uncertain.

11.5.4.1 Weighing and Summarizing the Lines of Evidence

The diesel pipeline failure probability used in this assessment is based on one line of evidence, the record of actual oil pipelines. However, the predicted effects of a diesel spill are based on four lines of evidence. All lines of evidence lead to the conclusion that a diesel spill into a stream would result in an invertebrate and fish kill and reductions in abundance and diversity (Table 11-10). In the diesel pipeline failure scenarios evaluated here, the lengths of affected stream would be roughly 22 km (Chinkelyes Creek and the Iliamna River) or 2.6 km (Knutson Creek). Because these distances are short relative to oil degradation rates, effects would be likely to extend to Iliamna Lake. Effects in the lake are not estimated here, but are unlikely to extend far beyond the area of input due to dilution. In Knutson Creek, however, flow to Knutson Bay could result in mortality of congregated spawning salmon, their eggs, and other fish attracted by salmon eggs as a food source (Appendices A and B). Based on the monitoring of diesel spills in streams, effects on stream communities would be likely to persist for one to several years. Although each line of evidence has associated uncertainties and weaknesses (Section 11.5.5), they all support these general conclusions.

The weighing of these lines of evidence is summarized in Table 11-10, using the same methods described in Section 11.3.4.4. Overall, available lines of evidence for effects of a diesel spill are supportive of the hypothesis that acute toxic effects would occur following a diesel pipeline failure (Table 11-10). The quality of the exposure-response information is good (+) for all routes of exposure based on reported observations in case studies, because the information is realistic; the quality of information is considered good (+) for exposure via dissolved and hydrocarbons based on laboratory acute tests, because the information reflects multiple tests. The quality of the exposure information for the dissolved and dispersed hydrocarbons is considered ambiguous (0) because of the uncertain relationship between the laboratory preparations and modeled stream exposures. The quality of the exposure-response information is considered very good (++), because it is based on the Alaska water quality standard, an official standard. The analogous spills, as a whole, are considered very strong (++) evidence that a diesel spill would cause toxic effects in streams.

Table 11-10. Summary of evidence concerning risks to fish from a diesel spill. The risk characterization is based on weighing four lines of evidence for different routes of exposure. All evidence is qualitatively weighed (using one or more +, 0, - symbols) on three attributes: logical implication, strength, and quality. Here, all lines of evidence have the same logical implication—that is, all suggest a diesel spill would have adverse effects. Strength refers to how strongly the line of evidence indicates effects, and quality refers to the quality of the evidence sources (i.e., data quality and relevance to the diesel pipeline failure scenario).

Route of Exposure Source of Evidence (Exposure/E-R)	Logical Implication	Strength	Quality		Result
			Exposure	E-R	
Dissolved hydrocarbons Model/laboratory acute tests	+	+	0	+	Modeled dissolved diesel concentrations are clearly lethal to invertebrates and approximately lethal to trout.
Dissolved hydrocarbons Model/laboratory–based standard	+	++	0	++	Modeled dissolved diesel concentrations greatly exceed State standard.
Dispersed hydrocarbons Diesel-to-water ratio/laboratory acute tests	+	++	0	+	Diesel oil/water ratios in the spills and in tests suggest lethality to invertebrates and trout.
All routes in actual spills Amount spilled/observed effects	+	++	+	+	Diesel spills in other streams cause acute biological effects.
Summary Weight of Evidence	+	++	0	+	The effects by four lines of evidence are consistent and the observed effects are strong. The greatest uncertainty is the relation of laboratory to field exposures.

Notes:
E-R = exposure-response relationship.

The specific effects of a diesel spill on salmonid populations would depend on the individual receiving waters. Streams along the transportation corridor that could receive a spill are described in Section 10.1. Chinkelyes Creek receives on average roughly 9,000 spawning sockeye salmon and flows to the Iliamna River, which receives on average more than 100,000 sockeye spawners (Table 10-2). Knutson Creek receives 1,500 sockeye spawners and flows to Knutson Bay, which receives an average of 73,000 beach spawning sockeye (Table 10-2). Not all of those salmon spawn below the stream crossing, but these values indicate that a non-trivial number of spawners and their potential production are at risk. In these scenarios, a spill would likely disrupt spawning if it occurred during the spawning season and would potentially kill adults. In other seasons, it would likely kill fry, and would certainly kill invertebrates on which salmon fry and all stages of other salmonids depend.

11.5.4.2 Duration of Risks

Diesel and natural gas pipelines would be retained after mine closure as long as fuel was needed at the mine site (e.g., for monitoring, water treatment, and site maintenance). Therefore, the diesel pipeline risks would continue indefinitely.

11.5.4.3 Remediation

Remediation of freshwater oil spills is discussed in detail in a review by the National Oceanic and Atmospheric Administration (NOAA) and American Petroleum Institute (API) (1994). For diesel spills in small rivers and streams, remediation via booms, skimming, vacuum, berms, and sorbents results in the least environmental impact. Diesel is difficult to remediate by conventional techniques because its components seep into soil, dissolve in water, or evaporate relatively quickly, making it is less containable than typical crude oil. Also, booms, although useful, are imperfect tools for containing floating oil. Booms were deployed after the diesel spill in Cayuga Inlet (Table 11-9), but within 24 hours a slick was reported on Cayuga Lake, 16 km downstream (Lytle and Peckarsky 2001). Even when recovery of diesel fuel was rapid and approximately 70% effective, as in the Westlea Brook spill (Table 11-9), the rapidly dissolved component was sufficient to cause severe acute effects (Smith et al. 2010).

There has been relatively little study on remediation of oil spills in freshwater wetlands. For diesel, the NOAA and API (1994) review recommends natural recovery, sorbents, flooding, and low-pressure cold-water flushing as least adverse options. Wetlands also have been remediated by burning, which can remove floating oil and destroy oiled vegetation that is likely to die from effects of the oil. Burning can cause severe but localized and short-term air pollution and, if improperly controlled, can result in fires that spread beyond the oiled area. However, burning does not destroy the dissolved fraction, which would move to streams or the lake and is primarily responsible for aquatic toxicity.

Cold winter weather complicates remediation of diesel spills (NOAA and API 1994). Spills into water at temperatures below the oil's pour point can result in the formation of viscous tar-like particles that are difficult to recover. Ideally, a spill onto ice could congeal on the surface where it might be relatively easily recovered if action is prompt; however, diesel oil can penetrate ice, and solar absorption by the oil can result in freeze-thaw cycles that create a complex material. Spills that flow under ice deposit on the undersurface. Standard procedures for oil remediation do not address those conditions.

11.5.5 Uncertainties

Based on weighing multiple lines of evidence, it is certain that a diesel pipeline spill into a stream would cause acute toxic effects. However, the following uncertainties apply to individual pieces of evidence.

- The composition of diesel oil is highly variable. As a result, the fate and toxicity of diesel spills are inherently uncertain unless the specific source is known and analyzed; the source does not change over time; and any physical, chemical, and biological tests are performed with that specific oil. This uncertainty cannot be resolved without case-specific studies of a sort that are not normally performed. This and other uncertainties concerning test results could cause errors of at least one order of magnitude in the risks estimated from laboratory toxicology.
- Measurement of petroleum hydrocarbons in water is performed using a variety of methods. Because the results of hydrocarbon analysis are method-specific, significant uncertainty can be introduced when these results are compared to benchmarks generated using different analytical methods. This contributes to the overall uncertainty of toxicity test results.
- Invertebrate and fish losses are likely if a diesel spill occurs at a stream, but the magnitude and nature of these losses would be highly uncertain. Some mortality would occur for some species, but the species and number of organisms affected cannot be specified. This uncertainty would take a

major case-specific research program to resolve. The inability to exactly define the expected ecological effects occurs in all risk assessments, but is worse for the diesel spill than for other contaminants such as copper.

- The ability of the laboratory toxicity tests to predict responses to diesel in the field is highly uncertain due to the variety of preparation methods, the simplicity of laboratory exposures relative to the complexity of oil spills in streams, and the lack of field validation studies.
- Variation in sensitivity to diesel among species appears to be high relative to other aquatic pollutants. Remarkably, even in the same test series, different salmon species range in sensitivity over two orders of magnitude (Table 11-8).
- Spills into wetlands are likely to have severe and persistent effects due to low rates of flow, but no relevant studies of diesel spills in freshwater wetlands are available to confirm even that very general hypothesis.
- The applicability of previous diesel spills considered in Table 11-9 to streams in the Bristol Bay region is uncertain, given that all of the spills occurred elsewhere. However, the effects observed in the one Alaskan case are not dissimilar from those in temperate regions. The most likely differences are slower loss of oil and longer recovery times. Therefore, effects are likely to be more severe in Alaska than in the temperate cases.
- The principle uncertainty in this analysis is the number and location of spills into aquatic ecosystems, given the probability of a pipeline failure. We can say with some certainty that a diesel spill of a non-trivial volume into a stream would have adverse ecological effects. We can also say that a spill is likely, based on the record of oil pipelines in general and large recent spills from oil pipelines (e.g., into the Kalamazoo River, as described in Section 11.1). However, we cannot predict with any certainty where such as spill may occur.
- Although the diesel spill cases suggest that streams are likely to recover within 3 years, time to recovery is seldom reported. Where it has been reported, it apparently depends on the conditions and the recovery metric used, and ranges from a year to several years.