

A.4.0 Seabed Substrates

A.4.1 Description

Most of the seafloor around Amchitka Island has little or no sediment because it is swept bare by currents. The shallows south of the island have extensive kelp beds, which retard the current. If there is sediment, contaminants released into it may bind to the sediment, reducing their release to the sea but increasing the exposure of sediment-dwelling biota. Knowledge about the type of seabed substrate around the predicted release locations is necessary to model the subsequent transport of radionuclides and exposure of biota.

A.4.2 Current Knowledge

There are very few sand beaches on Amchitka Island. The island is bordered on the north by the Rat Island's Escarpment, where the Bering Sea floor drops rapidly to ~1,500 meters (m). The tidal beach is typically covered with cobbles and small boulders. The south side of the island is bordered by the Aleutian Slope, which drops gradually to the oceanic trench.

A general description of the seabed by Lebednik and Palmisano (1977) states that no mud bottoms were observed in many dives to a depth of 30 m; however, sand, gravel, and cobble bottoms do occur. In addition, there are extensive kelp beds south of the island, and kelp requires a rocky substrate. Organisms that prefer a hard, rocky bottom, such as sea urchins and sea cucumbers, are abundant around Amchitka Island, while organisms that prefer a sandy or muddy bottom, such as king crabs, are rare (Merrell, 1977). Detailed information about the seabed at the predicted locations of radionuclide releases has not been obtained, but it seems unlikely that there are extensive kelp beds. Assumptions made on the potential substrates are described below.

The possible presence of any sediment is of interest because radionuclides can adsorb to sediment particles and be removed from solution or suspension in the groundwater as it passes through to the overlying seawater. However, to ensure a conservative estimate of concentrations in seawater, the risk model does not include a factor for removal of radionuclides from water by sorption to sediment.

Lebednik and Palmisano (1977) present information that kelp is widely observed on the south side of Amchitka from near the shoreline to a depth of about 25 m. For convenience, a depth of 75 ft was

used to calculate the edge of the kelp zone because the map used (USGS, 1975) has bathymetry in feet rather than meters. For risk assessment purposes, it is assumed that heavy growths of kelp on the seabed retard the flow of seawater. Kelp is assumed to be found at Milrow. To calculate exposures from the zone where kelp grows, it was assumed that all of the seabed at depths down to 75 ft is populated by kelp, sea urchins, and other invertebrates, as well as sea otters that feed on the sea urchins. Further, in the absence of other data, it is assumed that the near-shore current is retarded by the kelp by three-fold (Jackson and Winant, 1983). The distance from the shoreline to the 75-ft depth at Milrow is shown in Table A-2.

A.4.3 Discussion of Uncertainties

The nature of the seabed around Amchitka is known (Lebednik and Palisano, 1977). What is not known, and therefore an uncertainty, is the exact nature of the seabed at the exact potential groundwater release locations. Factors that affect the risk assessment are interactions of kelp with water to retard the current and interactions between groundwater and sediment that potential radionuclides would have to pass through before being diluted in the huge volume of seawater above the ocean floor.

The retardation of the current by kelp at Amchitka is estimated from measurements in a California kelp bed. It is assumed that the kelp at Amchitka interacts the same quantitatively. Inclusion of a lower current because of kelp at Milrow resulted in a shorter and wider plume predicted by ocean dispersion modeling. However, the modeled presence of kelp (i.e., by using a lower current velocity) had no effect on the overall risk from the mean radionuclide flux (Section 5.8). The maximum risks in Scenarios 1 and 4 (mostly fish consumption, without and with kelp, respectively) are the same, as are the maximum risks in Scenarios 2 and 5 (mostly marine mammal consumption, without and with kelp, respectively) and Scenarios 3 and 6 (consumption of commercial catch, without and with kelp, respectively). Therefore, uncertainty about the effects of kelp beds on the current is not an important factor in the screening risk assessment.

It is possible that radionuclides issuing from the sea floor could pass through sediment before reaching the seawater column, and in doing so, could be bound to sediment particles. Thick sediment beds are not reported at Amchitka Island (Lebednik and Palisano, 1977), so interactions of groundwater with sediment are expected to be minimal. If sediment beds were to occur, they would decrease the concentration of radionuclides in seawater by binding the radionuclides, causing an

overestimate of the concentrations in marine food species. Therefore, the modeled human exposure is higher when sediment is excluded than if sediment is present, and excluding sediment interactions is conservative.

A.4.4 Implementation

It is assumed that adsorption of radionuclides to sediment is negligible because there is little sediment and to ensure a conservative estimate of concentration in seawater. Extensive kelp beds, which retard the current and, thereby, reduce the dilution of released radionuclides, are assumed in one of the exposure scenarios.

A.5.0 Transport by Currents

A.5.1 Description

Contaminants released from the seabed are moved by the ocean currents and diluted (see the discussion of dilution in the next section). The direction and extent of transport and the rate of dilution are determined by currents.

A.5.2 Current Knowledge

The following discussion addresses many details that determine the location and speed of the ocean currents. The major topics are the oceanographic setting, which greatly influences the direction and speed of the ocean currents; the pathways followed by major currents near Amchitka, and farther away in the Pacific Ocean and the Bering Sea; and the expected effect of the currents on the distribution of materials released into the water near Amchitka.

A.5.2.1 Oceanographic Setting

The Aleutian Ridge is an elongated, curved rim that rises above the seafloor, extends westward from the Bering Shelf, and separates the Pacific Ocean on the south from the Bering Sea on the north. Along the ridge are several rises above sea level that make up the Aleutian Islands (Figure 1 in the main text). Amchitka Island, one of the Rat Islands situated near the center of the Aleutian chain, is a narrow, elliptically shaped land mass oriented SSE – NNW along its major axis (Figure 1 in the main text). Amchitka Pass, the opening between Amchitka and its eastern neighbor, Amitignak Island, has a maximum depth of 1,800 m (Roden, 1995), which is almost 75 percent deeper than any of the passes located to the east. In contrast, Oglala Pass, which separates Amchitka from Rat Island on the west, has a shallow, 100-m bench. An additional feature distinguishing Amchitka and the Rat Islands from the rest of the Aleutians is Bowers Ridge, a northward extension of the Aleutian Ridge. Due to the region's bathymetric complexity, a number of convoluted, highly variable currents exist in the area surrounding Amchitka.

A.5.2.2 Current Pathways

Amchitka Pass

Affecting circulation around Amchitka are two large-scale currents, Alaskan Stream and North Aleutian Ridge, that flow west on the south side and east on the north side of the Aleutian Arc, respectively (Figure A.4). Water from the upper 1,500 m of the Alaskan Stream enters Amchitka Pass with a volumetric transport of 4.1×10^6 cubic meters per second (m^3/s). Once in the pass, currents follow a variety of trajectories, depending upon season and varying geostrophic potentials, resulting in a net contribution of $2.1 \times 10^6 \text{ m}^3/\text{s}$ of water to eastward-flowing Bering Sea water (Reed and Stabeno, 1994). The following composite of mesoscale flow in Amchitka Pass is derived from descriptions in McAlister and Favorite (1977), Reed and Stabeno (1994), Stabeno and Reed (1994), and Okkonen (1996). Water flowing through the pass, but not directly to the Bering Sea, moves to its western side, from which it follows one of at least three possible pathways: westward to the north side of Amchitka; southward out of the pass and then west paralleling the southern shore of Amchitka; or in a large, counterclockwise eddy bounded by north- and south-flowing currents. Notably, the pattern of circulation in Amchitka Pass deviated significantly from mid-July through mid-October 1987 as net flow alternated from north to south for intervals lasting up to 3 weeks. Okkonen (1996) demonstrated that this reversal in net flow resulted from an eddy spun off the Alaskan Stream near the southern end of the pass.

Pacific Coast

There have been few measurements describing currents near the Amchitka shore. A single buoy moored to monitor tidal flows at $51^{\circ}33' \text{ N } 178^{\circ}51' \text{ E}$, a point off the south shore of Amchitka, indicates a clockwise rotary current that attains an average maximum velocity of 36 centimeters per second (cm/s) (U.S. Department of Commerce, Coast and Geodetic Survey, 1995). When tidal currents on the Pacific side of Amchitka are moving westward, it is likely that flow bending around the southeastern tip of the island is drawn into the same westward path. The path of a drifter buoy tracked in 1993 (Reed and Stabeno, 1994) shows the direction of flow also can be drawn eastward, away from the southeastern coast of Amchitka (Figure A.4). During periods when the rotary current is moving in directions other than west, the water moving south from the pass may either cycle through a tidal eddy off the island's southern coast or be directly drawn eastward back into the southern arc of the gyre in Amchitka Pass.

Oglala Pass and the North Coast

The net direction of currents in Oglala Pass is north, northeast (Stabeno and Reed, 1994), and flow from tidal currents moving along the south coast probably merge into this pathway. Data showing the direction of flow near the north coast of Amchitka are sparse. However, during winter 1968, a parachute drifter buoy and dye study tracked for only 5 hours in the "channel" north of Amchitka showed a current moving counterclockwise (McAlister et al., 1968). Based on water stratification caused by salinity, density, and temperature, Reed and Stabeno (1994) showed currents along the north side of the Aleutians, although convoluted and weak, moved to the east between 179° and 171° West. Therefore, it is highly likely that some water is transported to easterly moving north shore currents from the northeast bound portion of current in Oglala Pass. Prior to passing Semisopchnoi Island, the remaining northeast bound flow combines with an eastbound current (McAlister and Favorite, 1977) that either escapes north to the Bering Sea or rejoins the western arc of the gyre or circular oceanic surface current that is produced in Amchitka Pass.

A.5.2.3 Particle Dispersal

Most of the water near Amchitka Island eventually travels northward to the Bering Sea. Because the magnitude and direction of local currents are so variable, it is difficult to predict the rate of dispersal off the Aleutian Shelf for a particle located near the island. However, current velocities vary little through the water column near shore or in Amchitka Pass. Water in these areas is well mixed (Reed and Stabeno, 1994) and is not driven by density, salinity, or temperature differences; thus, flow is driven mainly by tidal currents rather than gradients in physical properties of water. For this risk assessment, it is assumed that radionuclides released near Amchitka, especially from Cannikin and Long Shot, are transported to the Bering Sea.

Measured characteristics for currents near Amchitka are shown in Table A-3, and a composite of known and likely flow trajectories is illustrated in Figure A.4.

The current velocities listed include ranges and maximum values. As a conservative estimate, the current along the north coast of Amchitka will be assumed to move at 32 cm/s (middle of the range provided), and the current along the south coast will be assumed to move at 30 cm/s (arbitrary reduction from 36 cm/s).

Table A-3
Characteristics of Currents Affecting Flow
Near Amchitka Island

Current	Flow (m ³ /s)	Velocity (cm/s)	Net Direction
Alaskan Stream	28 × 10 ⁶	40 to 65	West
Amchitka Pass ^a	4.1 × 10 ⁶	40 max	North
North Aleutian Ridge	20 × 10 ⁶	20 to 40	East
South Semisopochnoi	Not known	25	South, Southeast
North Coast	Not known	25 to 40	East
Oglala Pass	Not known	10	North, Northwest
South Coast	Not known	36	West

^aNet volume entering Bering Sea as a result of gyre ~ 2.1 × 10⁶ m³ s⁻¹.

Source: Summarized from McAlister and Favorite (1977), Warren and Owens (1988), Roden (1995), Reed and Stabeno (1994), Stabeno and Reed (1994), and U.S. Department of Commerce, Coast and Geodetic Survey (1995).

A.5.3 Discussion of Uncertainties

There is sufficient information about ocean currents in the vicinity of Amchitka Island to describe current patterns around the predicted locations of the groundwater releases. The risk assessment model is based on a synthesis of available knowledge, and the directions and speeds of nearshore currents have been deduced from that synthesis. General knowledge of the currents is necessary to understand the size and direction of the plumes. However, more precise knowledge of the directions and speeds of currents is likely not necessary. The risk assessment model assumes that the plumes are contained within the assumed exposure volume, which is a fishing zone defined by the 200-m isobath, an area as much as 9 km to 15 km offshore and an area in which the predicted plumes occupy a small part. The risk assessment model is not sensitive to the precise location of each plume within the fishing zone, as long as the plume is not carried outside the fishing zone by changes in the direction or speed of the current. Given the large size of the fishing zone and the relatively small size of plume sizes, it is unlikely that variations in the direction or speed of currents would take the plumes out of the fishing zone.

A.5.4 Implementation

The available information about near-shore currents was used to evaluate the movement of radionuclides from the release area. It was assumed that near-shore currents parallel the island shoreline and move at rates of 32 cm/s on the north (Bering Sea) side of the island and 30 cm/s on the south (Pacific Ocean) side.