Appendix F

An Analysis of Potential Bedload Sediment Effects on Andadromous Fish in the Klamath Basin

F.1 Introduction

This appendix describes channel conditions and assesses changes to channel bed elevations, substrate, and related anadromous fish habitat under the Proposed Project and alternatives described in Section 2 Project Description.

F.2 Methods

The effects analysis relied on model simulations using the one-dimensional Sediment and River Hydraulics (SRH-1D) model (Huang and Greimann 2010) to estimate changes in bed elevation and substrate in the mainstem Klamath River in response to reservoir sediment release and renewed sediment supply from upstream sources. One-dimensional modeling is transect based, depth averaged, and assumes steady or unsteady flow in primarily one direction. The model simulated changes in bed grain size in the following four size classes: fine sediment (median substrate size [D_{50}] less than 0.063 mm), sand (0.063 to 2 mm), gravel (2 to 64 mm), and cobble (64 to 256 mm). The modeling approach examined short-term (2-year) changes by month under various scenarios involving two consecutive wet water years (i.e., wet simulation), two consecutive median water years (median simulation), and two consecutive dry years (dry simulation). The modeling approach also evaluated longer-term changes (5, 10, 25, and 50 years) using a range of flows taken from historical hydrology. Long-term simulations were not conducted for the Klamath River upstream of Iron Gate Dam, since bed gradations at the end of short-term simulations likely represent conditions that will persist through time and vary as a function of hydrology (USBR 2012; D. Varyu, pers. comm., January 4, 2011). The effects determination used conclusions from the modeling simulations and knowledge of habitat requirements of affected fish species to determine how changes in bed elevation and substrate would potentially impact aquatic habitat (e.g., pools and spawning gravel).

Reservoir sediment release combined with renewed sediment supply from upstream sources will affect spawning habitat over the short and long term. In the short term, fine sediment deposition in the interstitial spaces within spawning gravel could reduce survival of salmonids from egg deposition to emergence by impeding intragravel flow, preventing exchange of nutrients and dissolved oxygen from the water column to embryos, and impede emergence of alevins (Chapman 1988, Bjornn and Reiser 1991). Studies indicate sediment up to 10 mm in grain size can impede intragravel flow and block emergence (Kondolf 2000). A review by Kondolf (2000) found that 10 to 40 percent sediment ranging in grain size from 2 to 10 mm within spawning gravels corresponded to 50% survival-to-emergence of various salmonid species. Bjornn and Reiser (1991) summarized the effects of increasing levels of sediment with grain size less than 6.35 mm in the bed on salmonid incubation and found embryo survival-to-emergence largely unaffected at levels less than 20%. Levels more than 30% showed minor effects on embryo survival (90%) but greater effects on survival-to-emergence (10 to 60%).

The median bed grain size and percent sand predicted by SRH-1D was used to estimate the potential effects of the Proposed Project and alternatives on salmonid spawning success in specific reaches under short-term and long-term scenarios. For the purposes of the effects analysis, a channel bed comprised of a D_{50} grain size suitable for spawning (e.g., 16 to 70 mm for Chinook salmon and 10 to 46 mm for steelhead) with less than

20% sand was considered suitable habitat for salmonid spawning (Kondolf and Wolman 1993). A channel bed with D_{50} outside the observed spawning gravel size ranges and comprised of more than 20% sand was considered unsuitable habitat. Changes in substrate composition occurring as a result of dam removal that changed habitat from suitable to unsuitable was considered an adverse impact on salmonids.

F.3 Area of Analysis

The Area of Analysis includes the bed and banks of the Klamath River downstream of the California-Oregon state line, including Iron Gate, Copco No. 1, and Copco No. 2 reservoirs. Areas of the Upper Klamath Basin in Oregon are discussed in this section as they pertain to potential impacts to bedload, channel conditions, and aquatic habitat in California.

No detailed bathymetry or sediment sampling results were available for the small (approximately 73 acre-feet) Copco No. 2 Reservoir due to the absence of accumulated sediment deposits (USBR 2011). This condition likely results from the presence of the larger, upstream Copco No. 1 Dam that was completed seven years prior to Copco No. 2 Dam, cutting off upstream sediment supply to the Copco No. 2 Reservoir. Estimates of the particle trapping efficiency of Copco No. 2 Reservoir over a range of grain sizes suggest that no particle trapping would occur in this reservoir for particles smaller than 0.2 millimeters (silt) and 1.0 millimeters (clay). Regular scour along the thalweg would limit any potential coarse sand and larger substrates that may be trapped in Copco No. 2 Reservoir to quiescent areas along the channel margins and areas nearest the dam face.

The assessment includes the following reaches of the Klamath River defined by changes in physiography, presence of the facilities included in the Lower Klamath Project, and tidal influence:

1. Hydroelectric Reach from the upstream extent of J.C. Boyle Reservoir to Iron Gate Dam, including the following:
   a. J.C. Boyle, Copco No. 1, Copco No. 2, and Iron Gate reservoirs
   b. J.C. Boyle Bypass and Peaking reaches
   c. Copco No. 2 Bypass Channel;
2. Klamath River downstream of Iron Gate Dam;
3. Klamath River Estuary; and
4. Pacific Ocean nearshore environment.

F.3.2 Hydroelectric Reach

The Hydroelectric Reach includes the 21-mile riverine section between J.C. Boyle Dam (RM 229.8) and the upstream end of Copco No. 1 Reservoir (RM 208.3) and the 1.4-mile riverine reach between Copco No. 2 Dam (RM 201.5) and the upstream end of Iron Gate Reservoir (RM 200.0).

Little to no sediment is supplied to the Klamath River from the basin upstream of Keno Dam (USBR 2012). Upper Klamath Lake, with its large surface area, traps nearly all sediment delivered from upstream tributaries. Tributary and streamside sources within the reaches from Keno Dam to Iron Gate Dam supply approximately 24,200 tons of coarse sediment per year (1.2% of the cumulative average annual basin-wide coarse sediment delivery) (Stillwater Sciences 2010a).

The four Lower Klamath Project developments, in combination with upstream lakes (e.g., Klamath Lake) and reservoirs, trap all coarse sediment produced from upstream source areas, which encompasses predominantly young volcanic terrain with very low erosion rates. The four Lower Klamath Project reservoirs currently store 13,150,000 cubic yards of sediment (3,605,000 tons) (USBR 2012), with Copco No. 1 Reservoir storing the largest amount and J.C. Boyle Reservoir storing the least (Table F-1). Most of the stored sediment is fine, with 85% silt and clay size particles (less than 0.063 mm) and 15% sand or coarser particles (greater than 0.063 mm) (GEC 2006, Stillwater Sciences 2008, USBR 2012).

Table F-1. Estimated Volume (yd^3) and Weight (tons) of Sediment Currently Stored within Hydroelectric Reach Reservoirs.

Reservoir	Sediment Volume (yd^3)	Sediment Dry Weight (tons)
J.C. Boyle	1,000,000	287,000
Copco No. 1	7,440,000	1,884,000
Copco No. 2	0	0
Iron Gate	4,710,000	1,434,000
Total	**13,150,000**	**3,600,000**

Source: USBR 2012

Sediment trapping in Lower Klamath Project reservoirs results in coarsening of the channel bed downstream from the dams (PacifiCorp 2004, USBR 2012). Tributary sediment supply helps reduce the bed coarsening process by delivering gravel, sand, and fine sediment to the Klamath River channel (PacifiCorp 2004).

F.3.3 Klamath River Downstream of Iron Gate Dam

F.3.3.1 Lower Klamath Project

The reach from Iron Gate Dam to Cottonwood Creek (RM 193.1 to RM 185.1) is characterized by coarse cobble-boulder bars immediately downstream from the dam transitioning to a cobble bed with pool-riffle morphology farther downstream near Cottonwood Creek (PacifiCorp 2004, Stillwater Sciences 2010a). The reach from Cottonwood Creek to the Scott River (RM 185.1 to RM 145.1) is a confined channel with a cobble-gravel bed and pool-riffle morphology (PacifiCorp 2004). The median bed grain size ranges from 45 to 50 mm. Bar substrates fine in the downstream direction, with median sizes of 49 mm and 25 mm at the upstream and downstream ends, respectively. Downstream from the Scott River, the Klamath River is typically cobble-gravel bedded with pool-riffle morphology (PacifiCorp 2004). PacifiCorp (2004) also noted increasing quantities of sand and fine gravel on the bed surface with distance downstream of the Scott river confluence, likely reflecting the supply of finer sediment from tributaries.

Because approximately 98 percent of the sediment supplied to the mainstem Klamath River is delivered from tributaries downstream of the Cottonwood Creek confluence (Stillwater Sciences 2010a), the effects of sediment trapping by the Lower Klamath Project reservoirs on downstream channel conditions is limited to a relatively short longitudinal distance. Analysis of the area and number of gravel bars downstream from Iron Gate Dam suggests that the influence of the Lower Klamath Project developments on these alluvial features, which are sources of salmonid spawning gravel, is limited to the reach from Iron Gate Dam to Cottonwood Creek (PacifiCorp 2004).

F.4 No Project Alternative

F.4.1 Hydroelectric Reach

Under the No Project Alternative, the four Lower Klamath Project developments would continue to trap fine and coarse sediment. Approximately 100,600 yd^3/yr (151,000 tons/yr, assuming a sediment density of 1.5 tons/yd) of sediment is delivered to the Klamath River between Keno and Iron Gate dams (Stillwater Sciences 2010a), all of which would deposit within the Lower Klamath Project reservoirs. USBR (2012) estimates these reservoirs would store 23,500,000 yd^3 of sediment (coarse and fine) by 2061.

Under the No Project Alternative, anadromous fish would not have access to this reach, as is currently the case. Effects of sediment deposition would be limited to riverine (redband trout and Lost River and Shortnose suckers) and non-native reservoir fish.

F.4.1.1 Redband Trout

Redband trout are found within the Hydroelectric Reach, migrating between tributaries and reservoirs to complete their life cycle (Hamilton et al. 2011). The No Project Alternative would not change bedload sediment dynamics and would not result in significant effects to redband trout.

F.4.1.2 Lost River and Shortnose Suckers

Federally endangered Lost River and shortnose suckers are found within the Hydroelectric Reach. However, there is little or no successful reproduction of either species downstream from Keno Dam, and habitat in these reaches does not substantially contribute to conservation goals or recovery (Hamilton et al. 2011). The No Project Alternative would not change bedload sediment dynamics, and would not result in significant effects to Lost River or Shortnose suckers.

F.4.1.3 Non-native Reservoir Fish

The No Project Alternative would not change bedload sediment dynamics and would not result in significant effects to non-native fish within the reservoirs.

F.4.2 Klamath River Downstream of Iron Gate Dam

Under the No Project Alternative, the four Lower Klamath Project developments would continue to interrupt bedload supply and transport necessary for long-term maintenance of aquatic habitats. Trapping of sand, gravel, and coarser sediment supplied from sources upstream of Iron Gate Dam would not result in any change to the existing channel bed downstream from Iron Gate Dam (USBR 2012). As occurs under existing conditions, the coarse bed material is relatively immobile, resulting in channel features that are unnaturally static and provide lower value aquatic habitat (Buer 1981).

Spawning habitat would continue to be sparsely distributed and of low quality. The coarsened channel bed gradually fines downstream as mobile coarse sediment (including spawning gravel) is supplied by tributaries (Hetrick et al. 2009). These effects of the Lower Klamath Project developments on channel bed coarsening are substantially reduced downstream of the Cottonwood Creek confluence due to the proportional increase in mobile coarse sediment from Cottonwood Creek and other downstream tributaries. (PacifiCorp 2004).

F.4.2.1 Fall-Run Chinook Salmon

The distribution of fall-run Chinook salmon would continue to be limited by Iron Gate Dam. Under the No Project Alternative, the substrate immediately downstream from Iron Gate Dam would remain coarsened. There would be no change in stream bed elevation or in habitat composition.

F.4.2.2 Spring-Run Chinook Salmon

Habitat relating to bedload movement within the current distribution of spring-run Chinook salmon under the No Project Alternative would remain the same as under current conditions, and thus the effects on this species under the No Project Alternative would be the same as under current conditions.

F.4.2.3 Coho Salmon

Coho salmon use the Klamath River as far upstream as Iron Gate Dam, but most spawning occurs in tributaries. The No Project Alternative would maintain the coarsened, relatively immobile substrate in the mainstem channel, limiting coho salmon spawning habitat as described above for fall-run Chinook salmon.

F.4.2.4 Summer Steelhead

The habitat changes relating to bedload movement under the No Project Alternative would not overlap with the distribution of summer steelhead (NRC 2004). Therefore, the effects on this species under the No Project Alternative would be the same as under current conditions.

F.4.2.5 Winter Steelhead

Winter steelhead are currently distributed throughout the Klamath River upstream to Iron Gate Dam, but spawn and rear in tributaries (FERC 2007). There is no record of winter steelhead spawning in the mainstem Klamath River, which is used mainly as a migration corridor for adults and juveniles (NRC 2004). Therefore, the effects on this species under the No Project Alternative would be the same as under current conditions.

F.4.2.6 Green Sturgeon

The habitat changes relating to bedload movement under the No Project Alternative would not overlap with the habitat of green sturgeon. Therefore, the effects on this species under the No Project Alternative would be the same as under current conditions.

F.4.3 Klamath River Estuary

As discussed above, the effects of dams on channel conditions in and downstream of the Hydroelectric Reach would be substantially reduced downstream from the Cottonwood Creek confluence, and largely absent downstream from the Shasta River confluence (RM 179.5). There would be no effects to aquatic species in the Klamath River Estuary under the No Project Alternative.

F.4.4 Pacific Ocean Near Shore Environment

As discussed above, the effects of dams on channel conditions in and downstream of the Hydroelectric Reach would be substantially reduced at the Cottonwood Creek confluence, and largely absent downstream from the Shasta River confluence (PacifiCorp 2004). There would be no effects to aquatic species in the Pacific Ocean nearshore environment under the No Project Alternative.

F.5 Proposed Project

F.5.1 Hydroelectric Reach

Reservoirs in the Hydroelectric Reach currently store 13,150,000 yd^3 (3,605,000 tons) of sediment (Table F-1) (USBR 2012). No detailed measurements (bathymetry or sediment sampling results) are available for the smaller (approximately 73 acre-feet) Copco No. 2 Reservoir. Sediment sampling was attempted in Copco No. 2, but no samples were collected due to the absence of accumulated sediment deposits (USBR 2011). This condition likely results from the presence of the larger, upstream Copco No. 1 Dam that was completed seven years prior to Copco No. 2 Dam, cutting off upstream sediment supply to the Copco No. 2 Reservoir. Model simulations indicate that 36 to 57 percent (5.3 to 8.6 million yd^3) of sediment stored in J.C. Boyle, Copco No. 1, and Copco No. 2 reservoirs would erode during the first year following dam removal, depending on the water year type (dry, median, or wet) (Figure F-1). Sediment retained on floodplains and terraces within the Lower Klamath Project reservoirs after the first year would be eroded more slowly through hillslope and fluvial processes (Stillwater Sciences 2008). With successful revegetation in accordance with the Reservoir Area Management Plan (Appendix B: *Definite Plan − Appendix H*), reservoir sediments that remain in long term storage above the high water mark of the Klamath River channel would experience limited erosion.

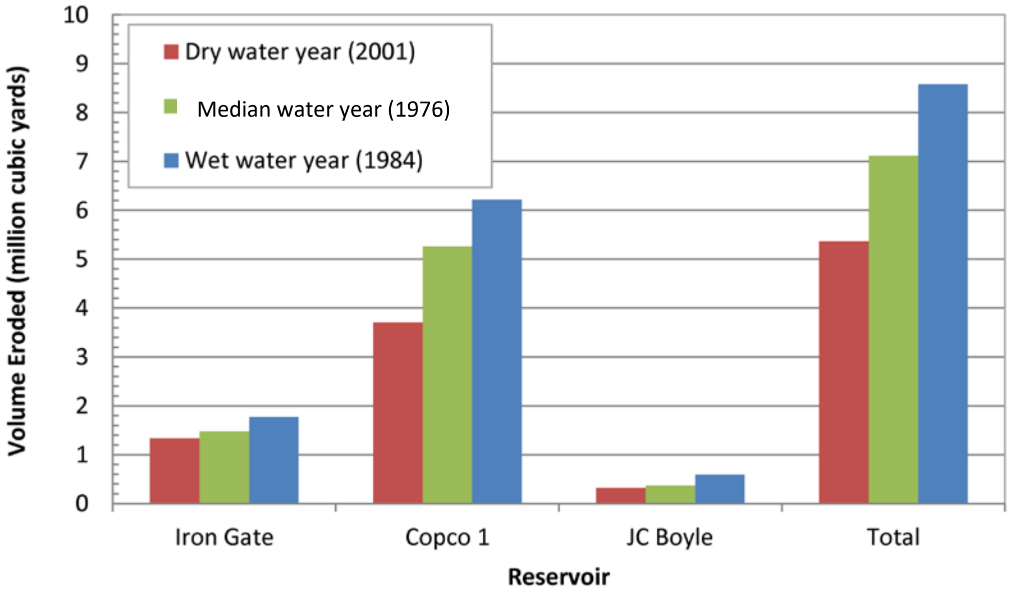

Figure F-1. Cumulative Sediment Volume Eroded from Reservoirs in the Hydroelectric Reach during Drawdown (USBR 2012).

F.5.1.1 Changes in Bed Elevation

SRH-1D model simulations indicate substantial decreases in bed elevation within the reservoirs during drawdown, which stabilize as the river channel within the former reservoir reaches returns to historical (i.e., pre-dam) bed elevations (USBR 2012; B. Greimann, pers. comm., December 23, 2010). In all simulations, the greatest decrease in bed elevations occurs through the Copco No. 1 Reservoir (10 feet of erosion), followed by J.C. Boyle Reservoir (three to four feet), and Iron Gate Reservoir (three feet) (Figure F-2 and Figure F-3). Little or no bed elevation change is anticipated to occur in Copco No. 2 reservoir due to the lack of sediment storage. Drawdown of J.C. Boyle, Copco No. 1, Copco No. 2, and Iron Gate reservoirs and erosion of the accumulated sediment is expected to result in the river channels within reservoirs reaching their historical elevations within six months. Fluvial geomorphic processes would restore these sections of river channel to a pool-riffle morphology, like that existing in the reach downstream from Iron Gate Dam (PacifiCorp 2004).

The river reaches from the upstream end of Copco No. 1 Reservoir to J.C. Boyle Dam and from the upstream end of Iron Gate Reservoir to Copco No. 2 Dam show little change in bed elevations during the wet and dry simulations (Figure F-2 and Figure F-3). Both simulations indicate minimal deposition between Iron Gate Reservoir and Copco No. 2 Dam, and little change in the other riverine reaches (Figure F-2 and Figure F-3). Model simulations also indicate little to no change in channel conditions upstream of J.C. Boyle Reservoir (Figure F-2 and Figure F-3).

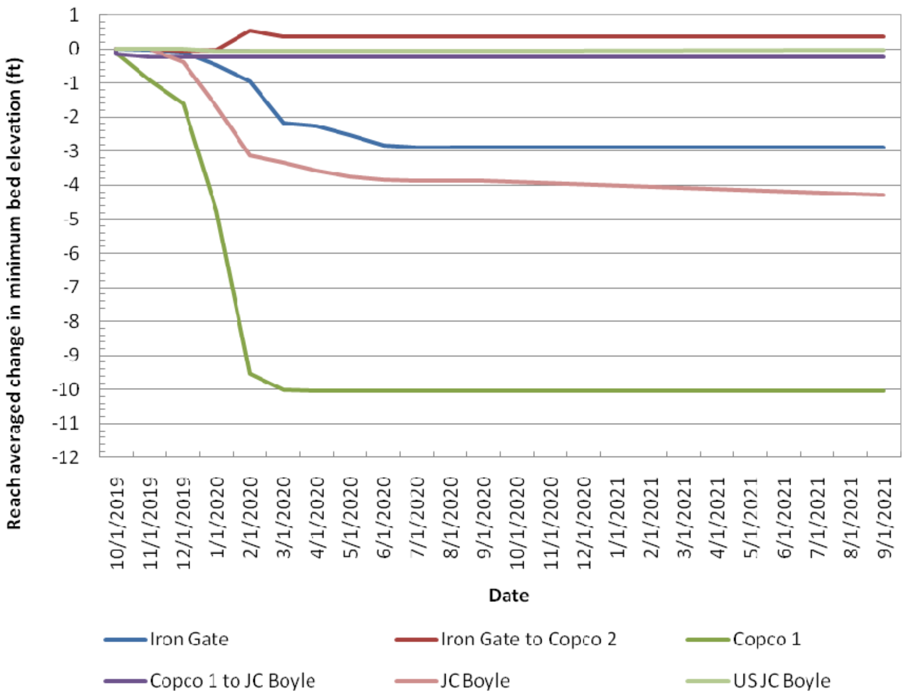

Figure F-2. Reach-Averaged Change in Bed Elevation in the Hydroelectric Reach during a Wet Year (USBR 2012).

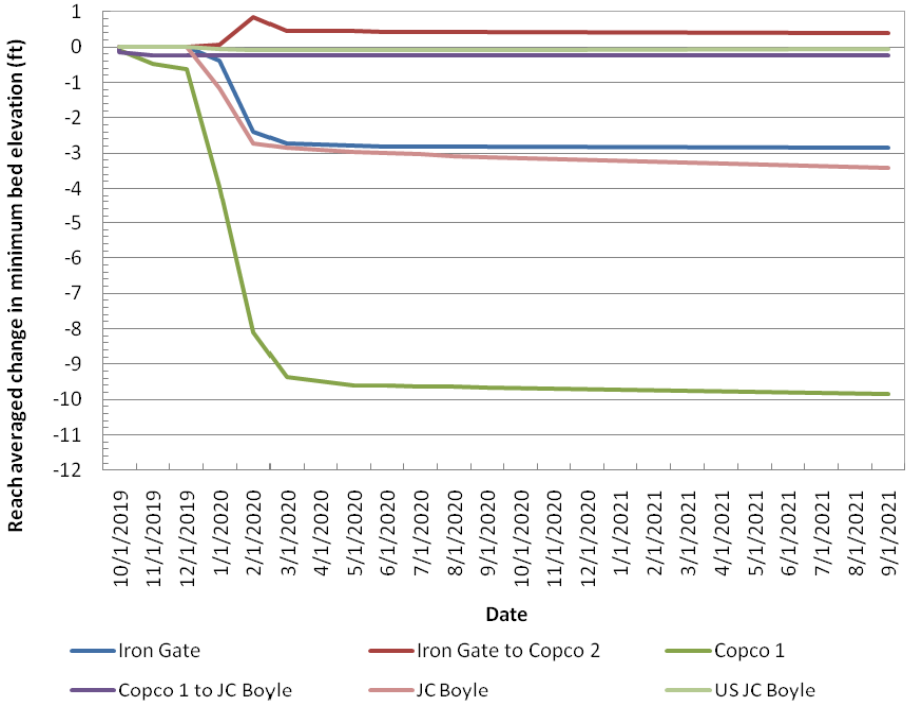

Figure F-3. Reach-Averaged Change in Bed Elevation in the Hydroelectric Reach during a Dry Year (USBR 2012).

F.5.1.2 Changes in Bed Substrate

SRH-1D model simulations for the first two years following dam removal indicate decreases in fine sediment composition and increases in median grain size within the reservoirs. These changes stabilize as the channel bed returns to historical (pre-dam) elevations. The proportion of fine sediment decreases from 50 to 80% to near zero within two months after drawdown. The sand proportion initially increases to 30 to 50% then decreases to 10 to 25%. The proportion of gravel mostly increases to 20 to 35%, and the proportion of cobble increases to 50 to 70%. These estimated changes in sediment composition vary depending on the reservoir and water year type (i.e., wet, median, or dry) (Attachment F-1, Figures F1-1 to F1-9). Median grain sizes increase from less than 1 mm to small cobble (64 to 128 mm) (Figure F-4, Figure F-5, and Figure F-6) (USBR 2012). The dry year scenario results in finer median grain sizes, but substrate is expected to eventually reach median grain sizes similar to those occurring under the wet and normal scenario (USBR 2012).

The simulations indicate similar changes in the D_{16} (16% of all particles are less than 0.063 mm) during drawdown. The model simulations analyze D_{16} as a measure of the finer fraction of the grain size distribution that could affect the quality of salmonid spawning gravel and survival-to-emergence. The D_{16} typically remains sand size or finer (less than 2 mm) sediments under the dry and median water year type simulations in the J.C. Boyle and Iron Gate reservoir reaches (Figure F-4 and Figure F-6) (USBR 2012).

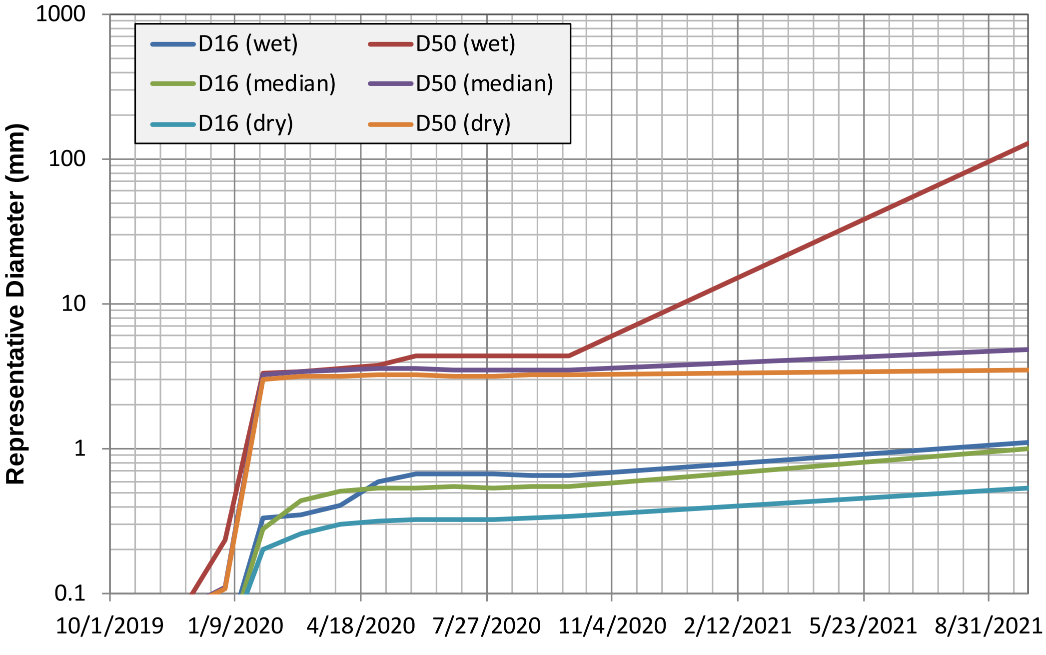

Figure F-4. Reach-Averaged D_{16} and D_{50} in the J.C. Boyle Reservoir Reach Following Dam Removal (based on simulation results provided by USBR, March 2012).

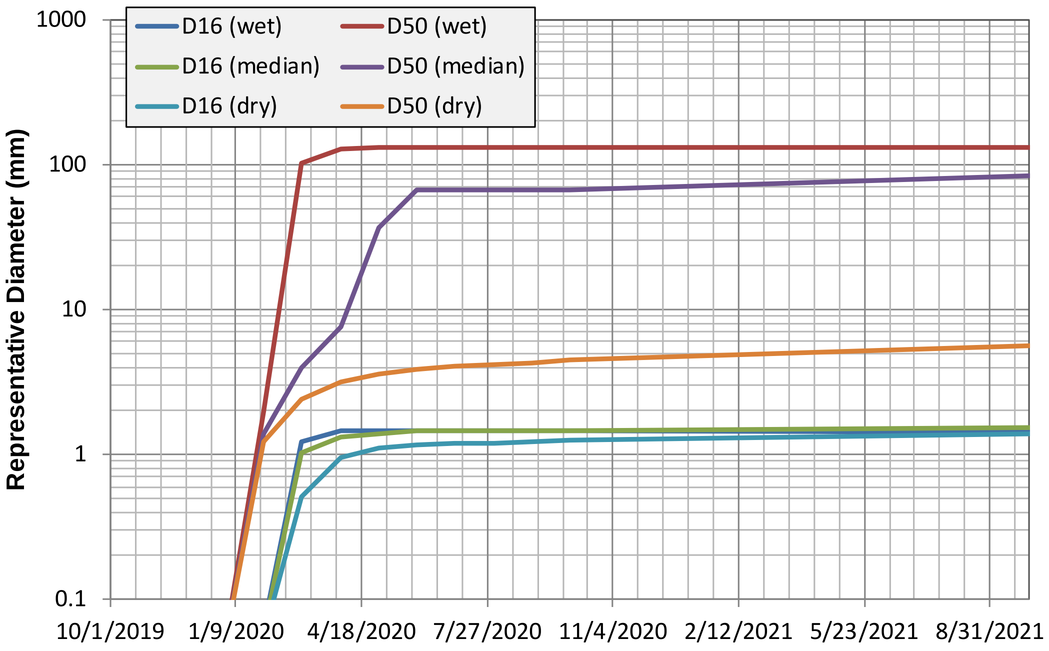

Figure F-5. Reach-Averaged D_{16} and D_{50} in the Copco No. 1 Reservoir Reach Following Dam Removal (based on simulation results provided by USBR, March 2012).

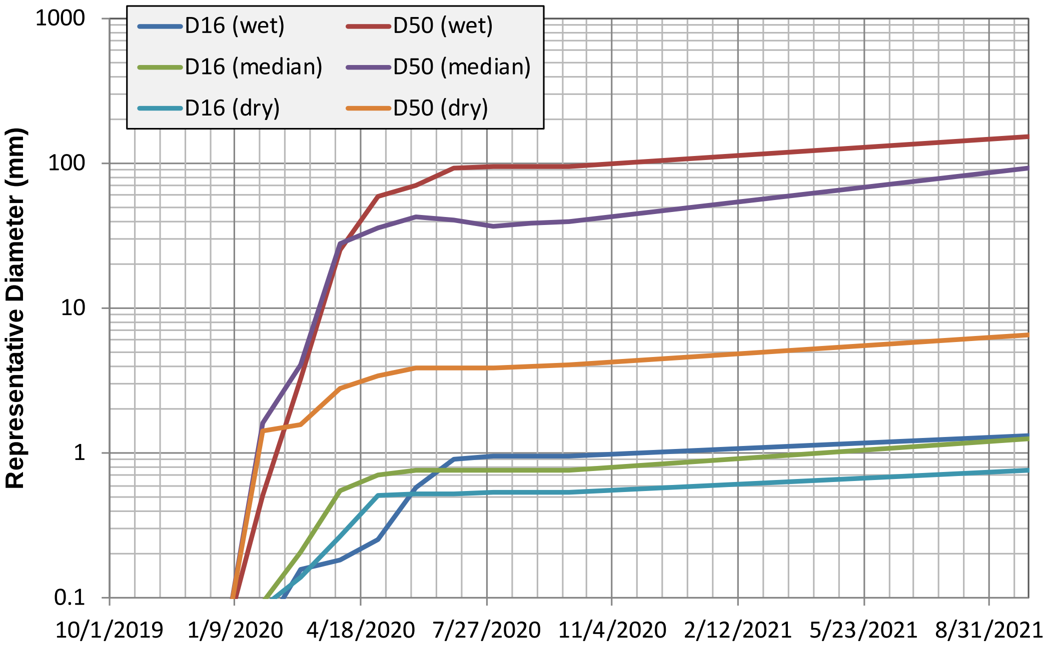

Figure F-6. Reach-Averaged D_{16} and D_{50} in the Iron Gate Reservoir Reach Following Dam Removal (based on simulation results provided by USBR, March 2012).

The river reaches upstream of J.C. Boyle Reservoir and from Copco No. 1 Reservoir to J.C. Boyle Dam show little change in bed composition during drawdown. There is little or no change in bed material in response to drawdown upstream of J.C. Boyle Reservoir and from J.C. Boyle Dam to Copco No. 1 Reservoir, regardless of water year type (Attachment F-1, Figures F1-10 to F1-15). These reaches are currently predominantly (90%) cobble, with small fractions of gravel and sand. This composition is maintained throughout the short-term (2-year) model simulation.

The short-term model simulations indicate decreases in the combined proportion of sand and finer sediment in the river reach from Copco No. 2 Dam to Iron Gate Reservoir. The wet, median, and dry simulations indicate decreases in the proportion of sand and finer sediment to approximately 20, 30, and 35%, respectively, (Figure F-7 and Figure F-8).

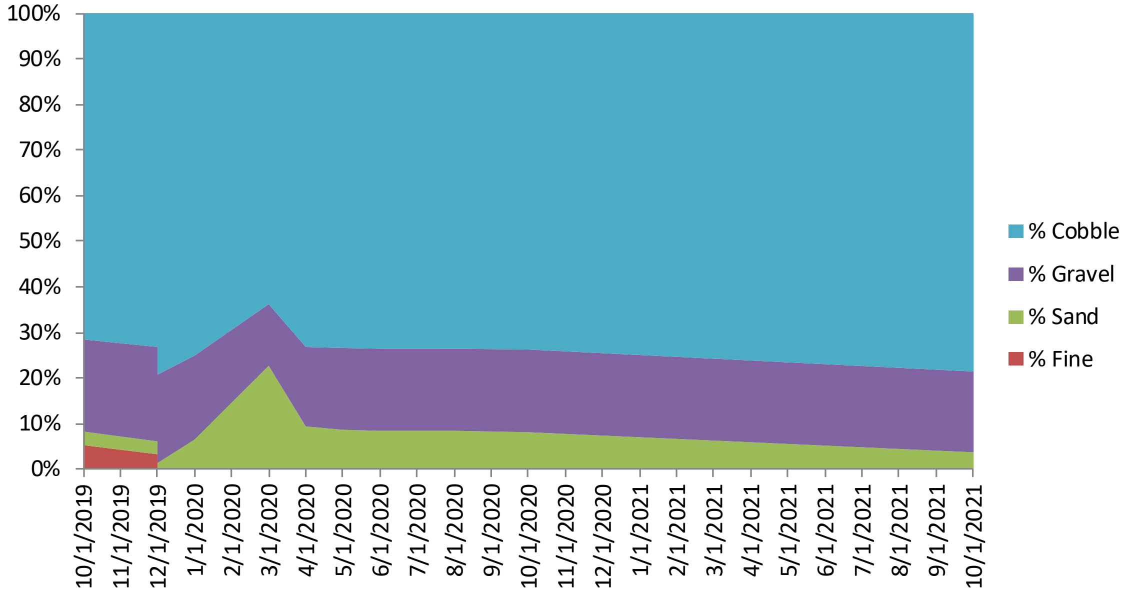

Figure F-7. Simulated Bed Composition from Copco No. 2 Dam to Iron Gate Reservoir for Two Successive Wet Water Years during and after Drawdown (based on simulation results provided by USBR, March 2012).

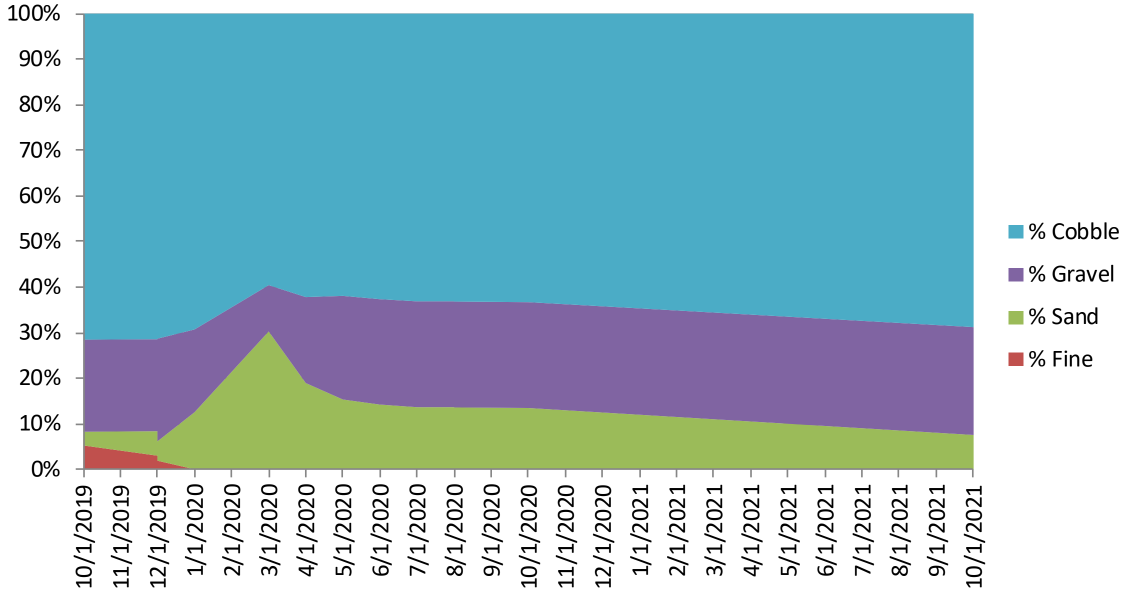

Figure F-8. Simulated Bed Composition from Copco No. 2 Dam to Iron Gate Reservoir for Two Successive Median Water Years during and after Drawdown (based on simulation results provided by USBR, March 2012).

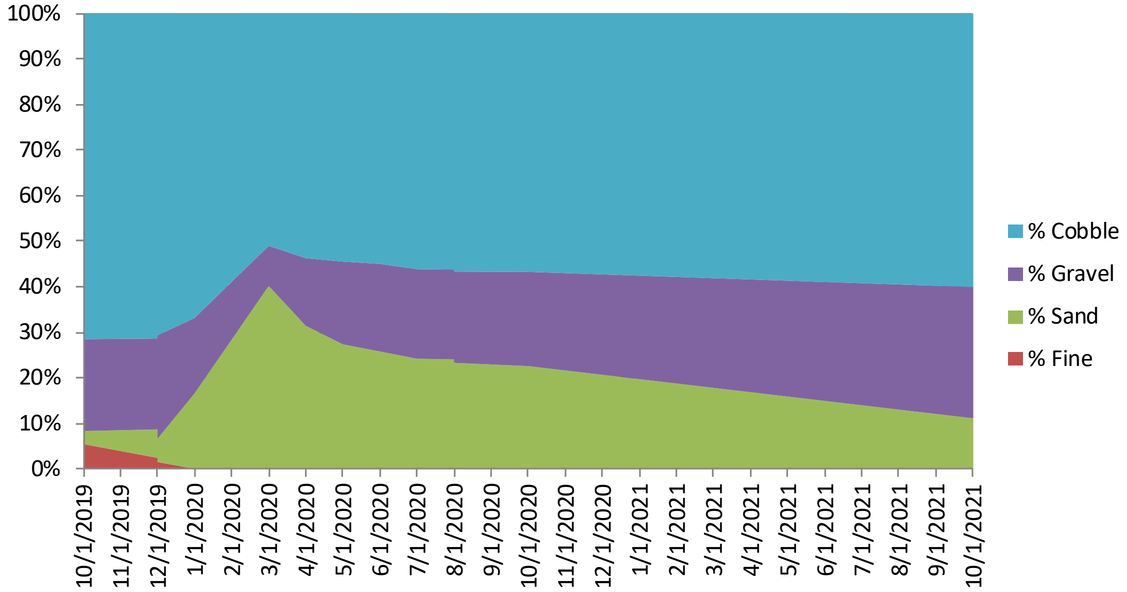

Figure F-9. Simulated Bed Composition from Copco No. 2 Dam to Iron Gate Reservoir for Two Successive Dry Water Years during and after Drawdown (based on simulation results provided by USBR, March 2012).

Fall-Run Chinook Salmon

The Proposed Project Could Have Effects on Pool-Riffle Habitat

The Proposed Project would erode sediment from reservoirs within the Hydroelectric Reach and result in a small amount (less than 0.5 feet) of deposition in river reaches between reservoirs (Figure F-2 and Figure F-3). The return of riverine processes in reservoir reaches would likely establish a channel with historical (pre-dam) bed elevations and composition within six months, likely resulting in and maintaining pool-riffle morphology similar to the reach downstream from Iron Gate Dam (PacifiCorp 2004). This would likely create holding and rearing habitat for anadromous salmonids within the Hydroelectric Reach. Removal of the dams would provide Chinook salmon access to these habitats in upstream reaches.

The Proposed Project Could Have Effects on Spawning Habitat

The Proposed Project would likely increase median substrate sizes in the Hydroelectric Reach. SRH-1D model simulations indicate that the median grain size would range from coarse gravel (16–32 mm) to small cobble (64–128 mm) during the first fall-run Chinook salmon spawning season following dam removal (Figure F-4, Figure F-5, and Figure F-6). These grain sizes are suitable for Chinook salmon spawning (Kondolf and Wolman 1993). River reaches between reservoirs would provide suitable spawning gravel for fall-run Chinook salmon (Attachment F-1, Figures F1-10 to F1-15). The proportion of sand in the bed may remain high in former reservoir reaches (Figure F-9, Attachment F-1, Figures F1-1 to F1-9), which could impact spawning (Chapman 1988).

Spring-Run Chinook Salmon

Spring-run Chinook salmon distribution extends from the mouth of the Klamath River upstream to its confluence with the Salmon River (Stillwater Sciences 2010b). Most spawning and rearing take place within the Salmon and South Fork Trinity rivers. The current distribution of spring-run Chinook salmon does not extend as far as the Hydroelectric Reach. Spring-run Chinook salmon would likely expand their range in response to dam removal and benefit from this action in the same manner as fall-run Chinook salmon. Because spring-run Chinook salmon generally do not spawn in the mainstem, the benefits of increased coarse sediment supply and finer channel substrate in the mainstem Klamath River downstream of Iron Gate Dam would be less than that for fall-run Chinook salmon.

Coho Salmon

The Proposed Project would restore access for coho salmon to the mainstem Klamath River and its tributaries upstream of Iron Gate Dam, increasing available rearing and spawning habitat. The changes to pool and spawning habitat described above for fall-run Chinook salmon may also provide suitable conditions for coho salmon holding, spawning, and rearing. Coho generally do not spawn in the mainstem Klamath River, but would benefit from having access to tributaries upstream of Iron Gate Dam.

Summer Steelhead

Summer steelhead distribution extends from the mouth of the Klamath River upstream to Empire Creek (RM 168.4) and may be rare above Seiad Creek (RM 131.9) due to seasonally high water temperatures (NRC 2004). With the removal of the dams, summer steelhead would be able to re-establish throughout much of their historical range, including the mainstem and tributaries within the Hydroelectric Reach and the upper basin (Hamilton et al. 2005). Under the Proposed Project, increased coarse sediment supply and finer channel substrate in the mainstem Klamath River downstream of Iron Gate Dam would improve spawning habitat, and improved pool habitat would benefit rearing summer steelhead.

Winter Steelhead

Winter steelhead generally spawn and rear in tributaries (FERC 2007). There is no record of winter steelhead spawning in the mainstem Klamath River, which is used mainly as a migration corridor for adults and juveniles (NRC 2004). With the removal of the dams, winter steelhead would be able to re-establish throughout much of their historical range, including the mainstem and tributaries within the hydroelectric reach and the upper basin (Hamilton et al. 2005). Under the Proposed Project, improved pool habitat would benefit rearing winter steelhead.

Green Sturgeon

Green sturgeon are distributed from the mouth of the Klamath River upstream to the Salmon River (RM 66.3). Green sturgeon have been observed occasionally migrating into the Salmon River. Most spawning and rearing takes place within the lower mainstem Klamath and Trinity rivers. Changes in bedload sediment under the Proposed Project are not anticipated to affect green sturgeon.

Redband Trout

Within the Hydroelectric Reach, redband trout migrate between tributaries, free flowing Lower Klamath Project reaches, and reservoirs to complete their lifecycle (Hamilton et al. 2011). The Proposed Project would eliminate reservoir habitat, returning sections of the Hydroelectric Reach currently inundated by reservoirs and riverine sections between reservoirs to a pool-riffle morphology. Although most redband trout are anticipated to continue to spawn in tributaries, after dam removal, spawning gravel in all sections of the Hydroelectric Reach would be within the range usable for redband trout, but the amount of sand within the bed within former reservoir sections might inhibit spawning success in the short term. Riverine sections between reservoirs would be expected to contain gravel with very little sand, suggesting high-quality spawning habitat would become available within a few years following dam removal. The initial movement of coarse and fine sediment after drawdown would likely create unfavorable conditions for redband trout within the mainstem Klamath River, but these conditions would be short term. Buchanan et al. (2011a) estimate that 43 miles of additional riverine habitat would be available to resident redband trout as a result of the Proposed Project.

Lost River and Shortnose Suckers

Federally endangered Lost River and shortnose suckers occur within the Hydroelectric Reach. The Proposed Project would eliminate reservoir habitat. All individual suckers occurring within these reservoirs would likely be lost within dam removal year 2; however, these individuals are not considered to substantially contribute to the achievement of conservation goals or recovery, since little or no reproduction occurs downstream from Keno Dam (Buettner et al. 2006), and there is no potential for interaction with upstream populations (Hamilton et al. 2011). Although both species are fully protected species under California Fish and Game Code, Section 2081.11 was added to the Fish and Game Code under Assembly Bill Number 2640 (Wood 2018) to allow CDFW to authorize the take of both sucker species resulting from impacts attributable to the decommissioning and removal of the Lower Klamath Project facilities, consistent with the Proposed Project. Changes in bedload sediment under the Proposed Project are not anticipated to affect Lost River and shortnose suckers.

Non-native Reservoir Fish

As discussed above, the Proposed Project would eliminate reservoir habitat as dams are removed. Changes in bedload sediment under the Proposed Project are not anticipated to affect non-native reservoir fish.

F.5.2 Lower Klamath River: Downstream from Iron Gate Dam

The Klamath River channel downstream of Iron Gate Dam would be affected by sediment eroded from reservoirs and by restoring sediment delivery from upstream areas. Eighty-five percent of the sediment stored within Lower Klamath Project reservoirs is silt and clay size (less than 0.063 mm), with 15% sand or coarser (greater than 0.063 mm) (GEC 2006, Stillwater Sciences 2008, USBR 2012). Most sediment eroded from the reservoirs would therefore be silt and clay, with smaller fractions of sand (0.063 to 2 mm), gravel (2 to 64 mm), and cobble (64 to 256 mm) (GEC 2006, Stillwater Sciences 2010c, USBR 2012) (Table F-2). Silt and finer sediment, which comprise a large proportion of the stored sediment volume, would likely be transported in suspension and would travel to the ocean shortly after being eroded from the reservoir deposits (GEC 2006). Coarser (greater than 0.063 mm) sediment would travel downstream more slowly, attenuated by channel storage and the frequency and magnitude of mobilizing flows. The amount of sand transported in suspension would vary with flow, with greater proportions of sand in suspension at higher flows. Table F-2 reports the total amount of sediment that would be eroded from Lower Klamath Project reservoirs and delivered to the Klamath River downstream of Iron Gate Dam. The amount of sediment released to the reaches downstream of Iron Gate Dam will generally be lower than the amount of sediment eroded from each reservoir due to sediment deposition in the reaches between the existing dams and within the former reservoir areas.

Table F-2. Estimated Mass (tons)[1] of Reservoir Sediment Released Below Iron Gate by Size for Wet, Median, and Dry Water Year Types During the First Year After Dam Removal.

Sediment Size	Wet	Median	Dry
Silt (<0.063 mm)	2,352,233	1,808,719	1,238,525
Sand (0.063 to 2.0 mm)	185,797	276,558	124,371
Gravel (2 to 64 mm)	37,942	18,213	1,116
Cobble (64 to 256 mm)	5,889	1,513	76
Total	**2,581,862**	**2,105,002**	**1,364,089**

Source: USBR 2012

[1] Dry weight

F.5.2.1 Downstream Extent of Effects

The effects of sediment delivery from reservoirs and upstream areas will likely extend to the Cottonwood Creek confluence (USBR 2012). Reach-averaged stream power (based on channel width, depth, and slope) decreases from Iron Gate Dam to Cottonwood Creek and then increases downstream of Cottonwood Creek (Figure F-10). The increase suggests that short-term and long-term coarse sediment deposition is unlikely downstream of Cottonwood Creek. Using Cottonwood Creek as the downstream extent of effects related to increased coarse sediment supply, eight miles of channel could potentially be affected by sediment delivery from reservoirs and upstream areas. The affected channel length is four percent of the total 190-mile Klamath River channel length downstream of Iron Gate Dam. The channel bed downstream of Cottonwood Creek is expected to be more mobile due to the additional supply and transport of sand.

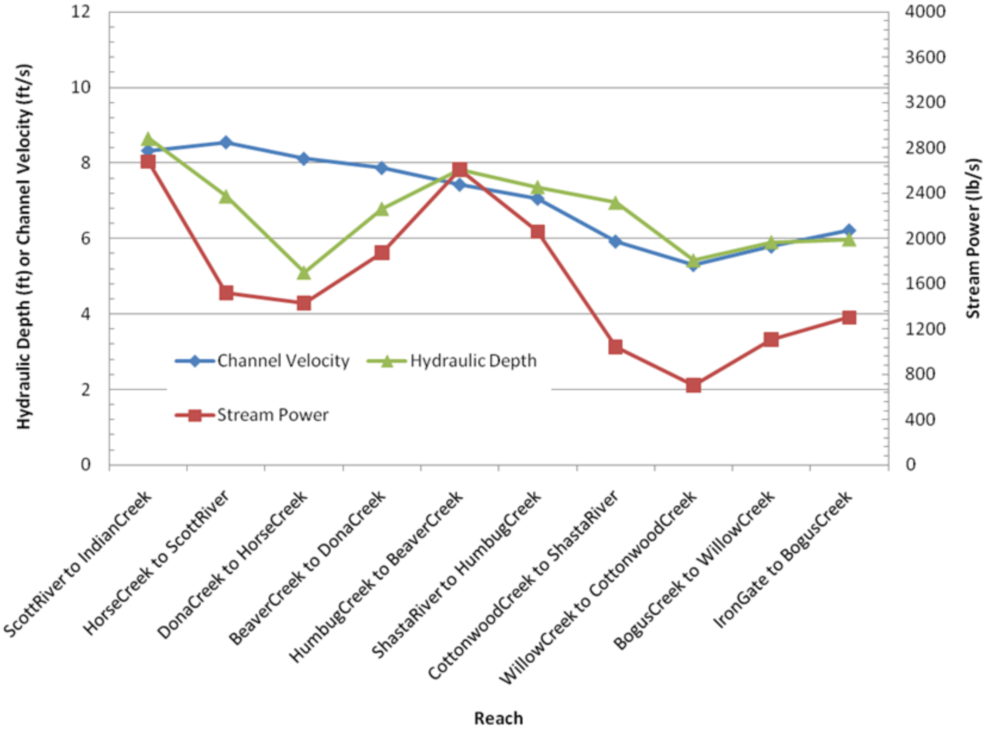

Figure F-10. Reach-Averaged Channel Velocity, Hydraulic Depth, and Stream Power Downstream from Iron Gate Dam during a 2-Year Peak Flow (USBR 2012).

F.5.2.2 Changes in Bed Elevation

Short-term (2-year) model simulations indicate no significant deposition between Iron Gate Dam and Bogus Creek (RM 192.6), up to about 0.9 feet of reach-averaged deposition between Bogus Creek and Willow Creek (RM 188.0), and up to about 0.4 feet of deposition from Willow Creek to Cottonwood Creek (USBR 2012) (Figure F-11, Figure F-12, Figure F-13). Model simulations indicate that reaches located farther downstream will change little (< 0.5 ft). Eight miles of the Klamath River mainstem channel could potentially be affected by sediment release and resupply, representing 4 percent of the total mainstem channel length downstream of Iron Gate Dam (190 miles). Bed elevations over the long-term (from 5 to 50 years) would adjust to a new equilibrium in response to the restored sediment supply from upstream areas. Model simulations predict 2 to 3 feet of aggradation between Iron Gate Dam and Cottonwood Creek over the next 50 years (USBR 2012).

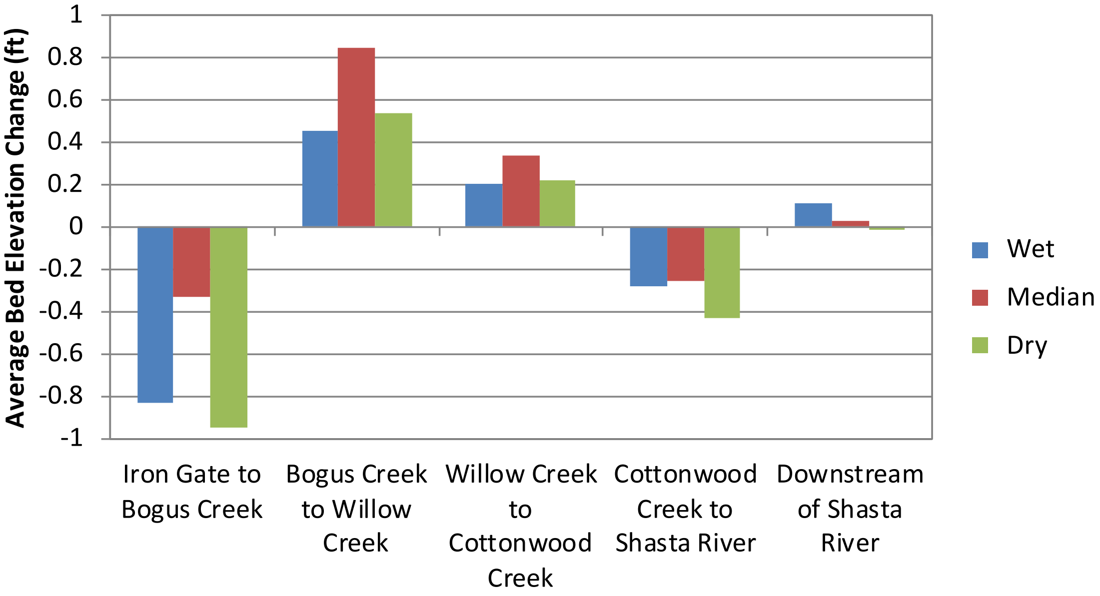

Figure F-11. Reach-Averaged Bed Elevation Change for Two Successive Wet, Median, or Dry Water Years Following Dam Removal (based on simulation results provided by USBR, March 2012).

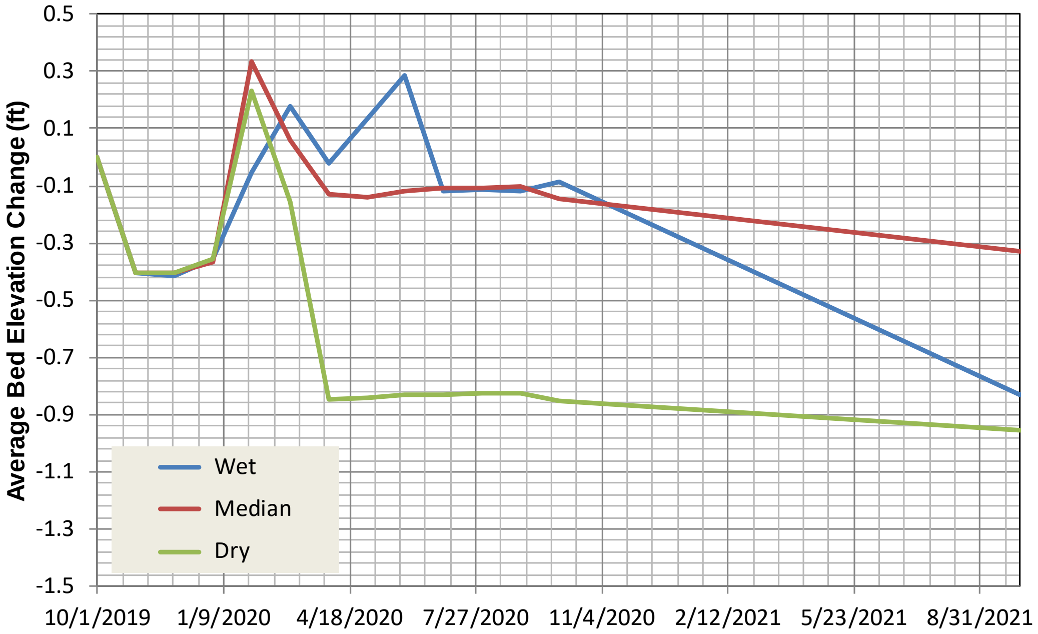

Figure F-12. Reach-Averaged Bed Elevation Change for Two Successive Wet, Median, or Dry Water Years following Dam Removal from Iron Gate Dam to Bogus Creek (based on simulation results provided by USBR, March 2012).

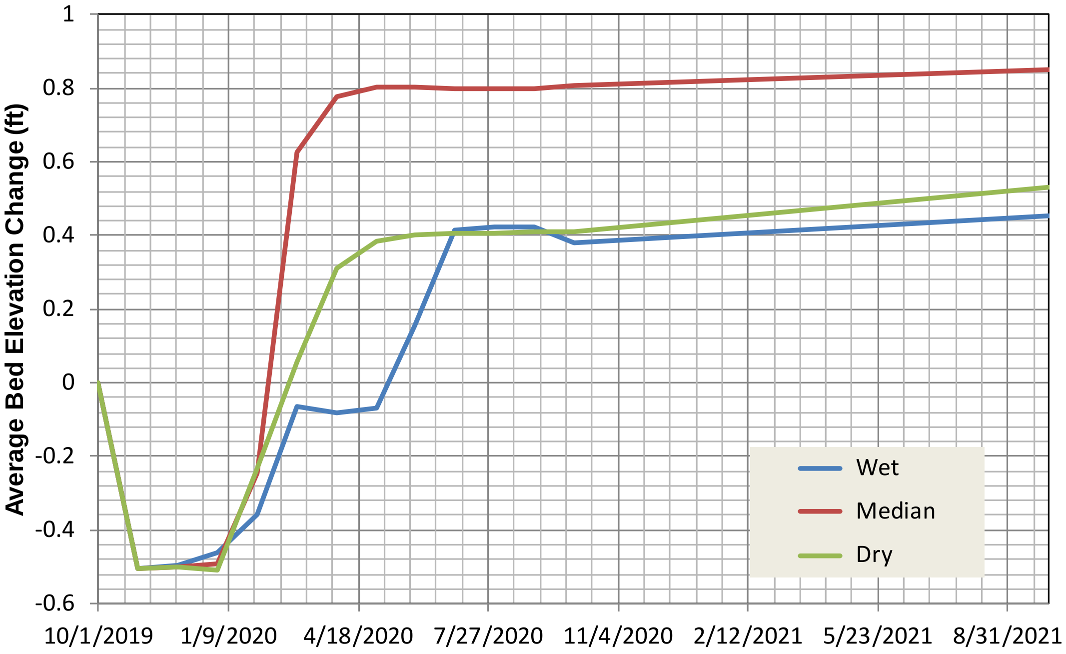

Figure F-13. Reach-Averaged Bed Elevation Changes for Two Successive Wet, Median, or Dry Water Years following Dams Removal from Bogus Creek to Willow Creek (based on simulation results provided by USBR, March 2012).

F.5.2.3 Changes in Bed Substrate

In the short-term (2 years following drawdown), model simulations indicate sediment delivery from reservoirs and upstream areas would increase the proportion of sand in the channel bed and decrease median grain size (USBR 2012). Under wet, median and dry simulations, sand within the bed in the reach from Iron Gate to Bogus Creek would increase to 30 to 35 percent by March to June of the drawdown year, gradually decreasing to 10 to 20 percent by September two years later. Median grain size would fluctuate slightly before stabilizing to approximately the initial condition of 100 mm (Figure F-14, Figure F-15, Figure 16, and Figure F-17). Model simulations indicate a decrease in median grain size (from an initial value of approximately 80 mm down to 40 to 65 mm) and an increase in the proportion of sand (up to 40 percent) in the reach from Bogus Creek to Willow Creek (Attachment F-1 Figures F1-16 to F1-19). Model simulations indicated an increase in the proportion of sand (up to 35 percent) and a decrease in median grain size (from an initial value of approximately 65 mm down to 38 to 45 mm) in the reach from Willow Creek to Cottonwood Creek (Attachment F-1, Figures F1-20 to F1-23).

The probability of transporting fine sediment out of the reach from Iron Gate Dam to Bogus Creek depends on flow magnitude and duration. USBR (2012) estimated that a flow of 6,000 cfs would be necessary to flush sands and fine material from the bed following dam removal. This flow is approximately equal to the 2-year flood (50 percent probability of occurring in a given year) at Iron Gate. If the dams are removed during a median or dry year, the probability that sand and finer sediment would be flushed from the bed is 50 percent by the end of the first year following removal, 75 percent by the end of second year following removal, and over 95 percent by end of the fifth year following removal.

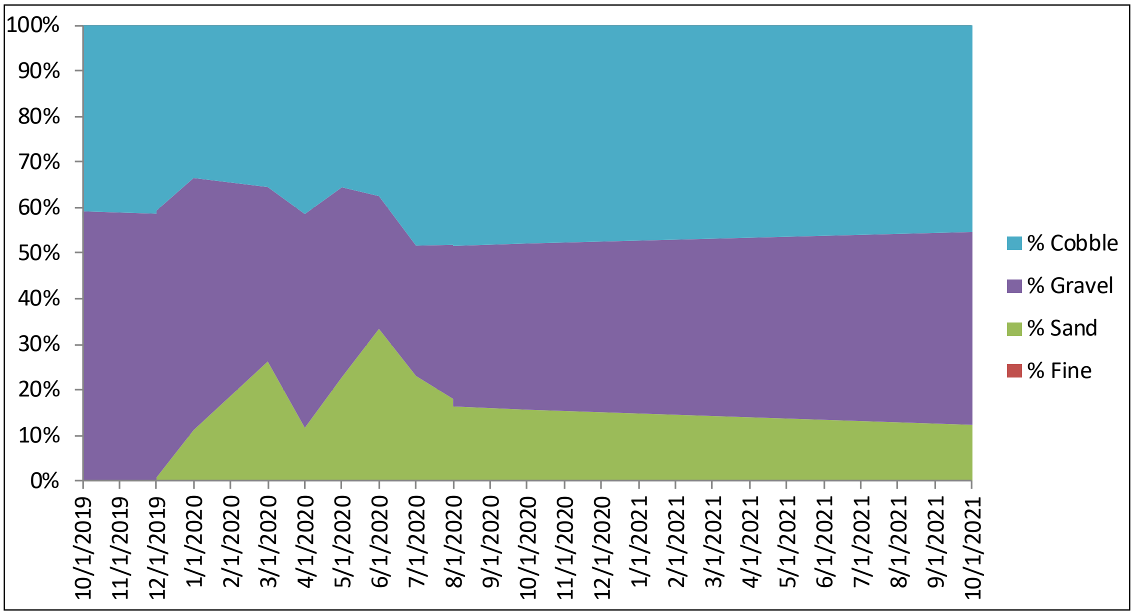

Figure F-14. Simulated Bed Composition from Iron Gate Dam to Bogus Creek for Two Successive Wet Water Years Following Dam Removal (based on simulation results provided by USBR, March 2012).

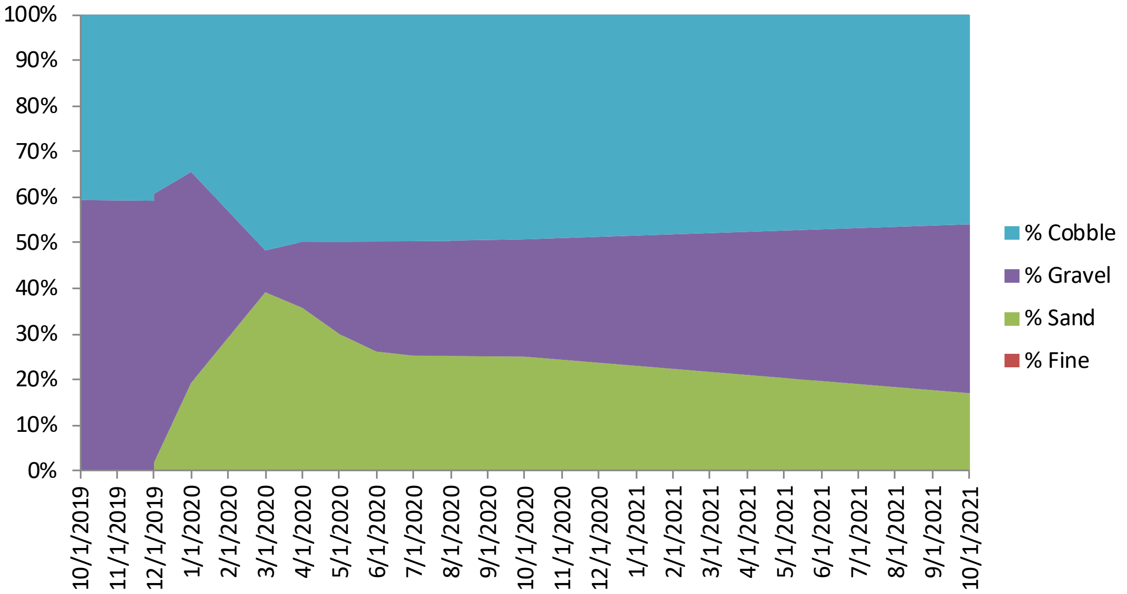

Figure F-15. Simulated Bed Composition from Iron Gate Dam to Bogus Creek for Two Successive Median Water Years Following Dam Removal (based on simulation results provided by USBR, March 2012).

Figure F-16. Simulated D_{50} (mm) From Iron Gate Dam to Bogus Creek for Successive Wet, Median, and Dry Water Years Following Dam Removal (based on simulation results provided by USBR, March 2012).

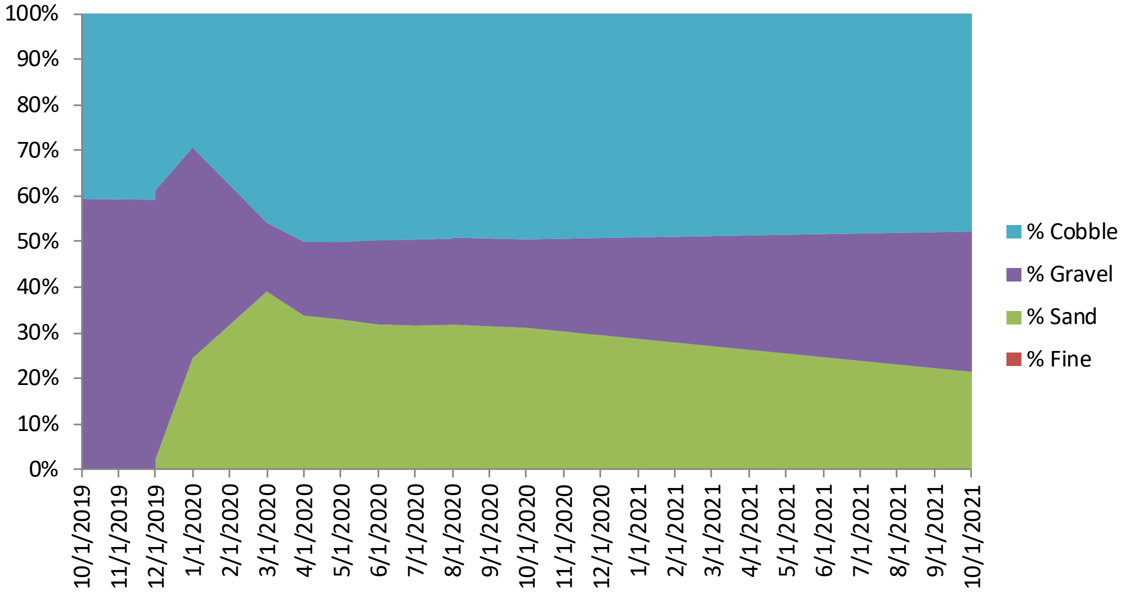

Figure F-17. Simulated Bed Composition from Iron Gate Dam to Bogus Creek for Two Successive Dry Water Years Following Dam Removal (based on simulation results provided by USBR, March 2012).

Longer-term (5, 10, 25, and 50 years) model simulations indicate increases in the proportion of sand to 5 to 22 percent and decreases in D_{50} to approximately 50 to 55 mm

(Attachment F-1, Figures F1-24 to F1-30) after five years. These changes stabilize and continue through year 50. Model simulations indicate no long-term changes in bed composition or substrate size in the mainstem Klamath River downstream from Cottonwood Creek (USBR 2012).

Under the Proposed Project, the channel bed elevations would increase in response to increased sediment supply. Flows required to mobilize the channel bed would decrease. USBR (2012) estimated the magnitude and return period of flows required to mobilize sediment downstream from Iron Gate Dam, 10 years after dam removal, using reach-averaged predicted grain sizes from long-term SRH-1D simulations. The estimates indicate that under the Proposed Project, the threshold for bed mobilization from Bogus Creek to Willow Creek and from Willow Creek to Cottonwood Creek would range from 3,000 to 7,000 cfs (1.5- to 2.5-year return period) and 5,000 to 9,000 cfs (1.5- to 3.2-year return period), respectively. These mobility thresholds are lower than under current conditions and the No Project Alternative. Downstream from the Shasta River, there would be no difference in flow magnitudes required for bed mobilization between the Proposed Project and current conditions or the No Project Alternative.

Bedload sediment effects on aquatic species

Fall-run Chinook Salmon

The Proposed Project Could Have Short-term Effects on Spawning Habitat

The proportion of sand in the channel bed will likely be higher during the first four months following dam removal than under existing conditions. More interstitial sand in the Klamath River channel upstream of the Cottonwood Creek confluence could reduce embryo survival-to-emergence in these reaches (Chapman 1988). The approximately 8-mile affected channel length encompasses only four percent of the current total Klamath River channel length. These effects would be most apparent in successive median or dry years following dam removal, but less apparent in successive wet years.

USBR (2012) estimated that a flow of 6,000 cfs would be necessary to flush sands and fine material from the bed following dam removal. This flow is approximately equal to the 2-year flood (50 percent probability of occurring in a given year) at Iron Gate. If the dams are removed during a median or dry year, the probability that sand and finer sediment would be flushed from the bed is 50 percent by the end of the first year following removal, 75 percent by the end of second year following removal, and over 95 percent by end of the fifth year following removal. Flume experiments (Wooster et al. 2008) found that the amount of fine sediment infiltrating into a static channel bed during sediment pulses decreased with depth below the surface, with significant deposition observed to a shallow depth (i.e., a thickness less than the diameter of the D_{90} grain size). The results suggest that fine sediment infiltration into the gravel bed (and potential spawning gravel) following dam removal would likely be short-lived due to bed mobility and sediment transport during subsequent high flows (Stillwater Sciences 2008).

Short-term (two-year) sediment aggradation following dam removal may be substantial between Iron Gate Dam and Willow Creek (Figure F-12 and Figure F-13). Deposition in these reaches is expected to temporarily bury redds and associated eggs to depths that would adversely affect alevin emergence. The depth of sediment deposition in reaches downstream of Willow Creek likely would not affect survival-to-emergence.

The proportion of sand in the channel bed would be higher during the first and potentially the second years following dam removal than under current conditions (Figure F-14,

Figure F-15, Figure F-17). Salmonids select spawning habitat that maximizes egg survival and are adapted to natural geomorphic processes that alter these habitats from year to year. Adults returning during the first and second years following dam removal would spawn in the reach from Iron Gate Dam to Cottonwood Creek if suitable habitat is present. If no suitable habitat exists, adults may spawn in downstream reaches or newly accessible upstream reaches with suitable habitat. Because of these behavioral adaptations, eggs from fall-run Chinook salmon returning during the first and second years following dam removal would likely be unaffected by the geomorphic changes described above.

Any fall-run Chinook salmon eggs deposited in the reach from Iron Gate Dam to Willow Creek during the Fall prior to dam removal would likely experience high mortality. More successful survival-to-emergence would occur downstream of Cottonwood Creek. These potential negative impacts affect a small proportion of the total habitat available in the mainstem Klamath River downstream of Iron Gate Dam and do not affect habitat in tributaries. Finally, these effects will likely occur only during the first and possibly the second years following dam removal.

The Proposed Project Could Have Long-term Effects on Spawning Habitat

Model simulations indicate that five years after dam removal, the proportion of sand in the bed would be less than 15 percent and the median grain sizes will decrease from existing conditions to near 55 mm in all reaches from Iron Gate Dam to Cottonwood Creek (Attachment F-1, Figures F1-24 to F1-30) (USBR 2012). Less than 15 percent sand in spawning gravel is not expected to substantially reduce survival-to-emergence, and 55 mm gravel is suitable for Chinook salmon spawning (Kondolf and Wolman 1993). Long-term changes in bed elevation and substrate size are expected to improve spawning habitat and benefit fall-run Chinook salmon.

The Proposed Project Could Have Short-term Effects on Pool Habitat

The Proposed Project may result in sediment deposition in pools and other slack water habitat features used for adult holding or juvenile rearing in the 8-mile reach downstream from Iron Gate Dam. These effects on the depth and area of available pool habitat are likely to be most apparent in the 5.1-mile reach from Iron Gate Dam to Willow Creek (Figure F-11 and Figure F-12). The SRH-1D model estimates reach-average changes in bed elevation and substrate size but cannot simulate these changes at the scale of individual geomorphic features (e.g., pools) or the spatial distribution of these changes within a reach (USBR 2012). Flume experiments conducted by Stillwater Sciences (2008) found that a coarse-bedded channel with pool-riffle morphology, similar to that found in the Klamath River below Iron Gate Dam, would maintain pool topography during transient sediment deposition in response to a pulse of increased sediment delivery. Pools are erosional features that typically evacuate sediment before other morphologic units (e.g., riffles). Pool depths would likely return to depths observed prior to dam removal after the initial sediment wave resulting from dam removal passes (Stillwater Sciences 2008). These effects would be most apparent in the 5.1-mile length of channel between Iron Gate Dam and the Willow Creek confluence (Figure F-11). The affected channel length encompasses less than three percent of the current total Klamath River channel length. The fall-run Chinook salmon life stages that use pools (e.g., adults, juveniles, and fry) will utilize other suitable habitats. These results suggest that the effects of the Proposed Project on pool habitat would likely be short term.

The Proposed Project Could Have Long-term Effects on Pool Habitat

In the long-term (from 5 to 50 years) after the initial wave of sediment from the Proposed Project passes downstream, bed elevations would adjust to a new equilibrium in response to sediment supply from upstream areas (sediment that was formerly trapped by dams within the Hydroelectric Reach). The river would likely revert to and maintain a natural pool-riffle morphology, with pool frequency, size, and depth similar to current conditions.

Spring-Run Chinook Salmon

Spring-run Chinook salmon would likely distribute upstream of Iron Gate Dam under the Proposed Project. Chinook salmon may be affected by short- and long-term effects on pool habitat, as described above for fall-run Chinook salmon. Spring-run Chinook salmon are not expected to spawn in the mainstem channel.

Coho Salmon

The Proposed Project Could Have Short-term Effects on Spawning Habitat

Most coho salmon spawn in tributaries to the Klamath River. Most rearing occurs on these tributaries as well, although some coho juveniles may rear in the mainstem when conditions in the tributaries become unsuitable. The effects of the Proposed Project on bed elevations and grain size would likely eradicate any coho salmon eggs that were spawned on the mainstem above Willow Creek in the year preceeding dam removal (as described above for fall-run Chinook salmon). The effect is expected to be small because most coho salmon spawning occurs in the tributaries. In the years following dam removal, no effect is expected because coho salmon would be able to behaviorally adapt (e.g., disperse to other suitable spawning habitat) in response to changes in bed elevation and grain size.

The Proposed Project Could Have Long-term Effects on Spawning Habitat

Model simulations indicate that the proportion of sand in the bed would be less than 15 percent and median grain sizes would decrease in all reaches from Iron Gate Dam to Cottonwood Creek five years after dam removal (Attachment F-1, Figures F1-24 to F1-30) (USBR 2012). The decrease in median substrate size may increase the availability and quality of mainstem spawning habitat for coho salmon, although most coho spawning is still anticipated to occur in tributaries. The increase in sand composition within spawning gravel is not expected to substantially reduce survival-to-emergence (Chapman 1988).

The Proposed Project Could Have Short-term Effects on Pool Habitat

The effects on coho salmon resulting from short-term pools filling in the mainstem channel would be minor and short term for the same reasons described above for fall-run Chinook salmon.

The Proposed Project Could Have Long-term Effects on Pool Habitat

The effects on coho salmon resulting from long-term pool filling in the mainstem would be negligible because the river would likely revert to and maintain a natural pool-riffle morphology, with pool frequency, size, and depth similar to current conditions.

Summer Steelhead

Summer steelhead currently occupy the Klamath River downstream of Empire Creek (RM 168.4). This run of steelhead spawns in tributaries, although some fish may rear in the mainstem. Based on the current distribution, short-term changes in bed elevation and grain size are not expected to affect summer steelhead, and long-term benefits are similar to those described above for coho salmon.

Winter Steelhead

Winter steelhead adults and juveniles occupy the Klamath River upstream to Iron Gate Dam, using the mainstem primarily as a migration corridor (NRC 2004). Like summer steelhead, spawning occurs in tributaries (NRC 2004). Changes in bed elevation and grain size would not impact spawning habitat or incubation, and would have minimal effect on rearing habitat as described above for fall-run Chinook salmon and summer steelhead.

Northern Green Sturgeon

Northern Green Sturgeon currently occupy the Klamath River from the mouth upstream to Ishi Pishi Falls (Moyle 2002, FERC 2007), with some observed migration into the Salmon River. As discussed above, effects of the Proposed Project on bed elevations and grain size in response to increased sediment supply and transport likely extend down to the Cottonwood Creek confluence. The Proposed Project would likely not affect Northern Green Sturgeon.

F.5.3 Klamath River Estuary

Effects of the Proposed Project on bed elevations and grain size related to increased sediment supply will likely extend only to the Cottonwood Creek confluence (RM 185.1). Therefore, the Proposed Project is unlikely to have an effect on bed elevations, grain size, and associated aquatic habitats in the Klamath River Estuary.

F.5.4 Pacific Ocean Near Shore Environment

Effects of the Proposed Project on bed elevations and grain size related to increased sediment supply will likely extend only to the Cottonwood Creek confluence (RM 185.1). Therefore, the Proposed Project is unlikely to have an effect on bed elevations, grain size, and associated aquatic habitats in the Pacific Ocean nearshore environment.

F.6 Partial Removal Alternative

The Partial Removal Alternative would remove enough of each dam to allow free-flowing river conditions and volitional fish passage at all times. Under the Partial Removal Alternative, portions of each dam would remain in place along with ancillary buildings and structures such as powerhouses, foundations, tunnels, and pipes. Under this alternative, embankment/earth-filled dam and concrete dam structures would be removed similar to the Proposed Project, allowing release of sediment stored in the reservoirs. Effects to channel bed elevation, grain size, and associated impacts to aquatic habitat under the Partial Removal Alternative are expected to be the same as those for the Proposed Project.

F.7 Continued Operations with Fish Passage

Under the Continued Operations with Fish Passage Alternative, fish passage structures would be installed at each dam to allow for upstream fish passage. No portion of the dams would be removed under this alternative and sediment would continue to be stored behind Lower Klamath Project dams, similar to the No Project Alternative. Effects to channel bed elevation, grain size, and associated impacts to aquatic habitat under the Continued Operations with Fish Passage Alternative are expected to be the same as those for the No Project Alternative.

F.8 Two Dam Removal Alternative

This scenario has not been modeled, but the effects to channel bed elevation, grain size, and associated impacts to aquatic habitat are expected to be similar but of lesser magnitude than those occurring under the Proposed Project.

F.9 Three Dam Removal Alternative

This scenario has not been modeled, but the effects to channel bed elevation, grain size, and associated impacts to aquatic habitat are expected to be similar but of lesser magnitude than those occurring under the Proposed Project.

F.10 No Hatchery Alternative

This scenario has not been modeled, but the effects to channel bed elevation, grain size, and associated impacts to aquatic habitat are expected to be the same as those occurring under the Proposed Project.

F.11 References

Bjornn, T. C., and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83–138 in W.R. Meehan, editor. Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication No. 19, Bethesda, Maryland.

Buer, K. 1981. Klamath and Shasta rivers spawning gravel enhancement study. Department of Water Resources, Northern District, Red Bluff, California.

Chapman, D. W. 1988. Critical Review of Variables Used to Define Effects of Fines in Redds of Large Salmonids. Transactions of the American Fisheries Society 117: 1–21.

FERC (Federal Energy Regulatory Commission). 2007. Klamath Hydroelectric Project (FERC Project No. 2082-027). Final environmental impact statement for hydropower license. FERC, Office of Energy Projects, Washington, D.C.

GEC (Gathard Engineering Consulting). 2006. Klamath River dam and sediment investigation. Technical Report. Prepared by GEC, Seattle, Washington.

Hamilton, J. B., G. L. Curtis, S. M. Snedaker, and D. K. White. 2005. Distribution of anadromous fishes in the Upper Klamath River watershed prior to hydroelectric dams—a synthesis of historical evidence. Fisheries 30: 10–20.

Hamilton, J., R. Quinones, D. Rondorf, K. Schultz, J. Simondet, and S. Stresser. 2011. Biological synthesis for the secretarial determination on potential removal of the lower four dams on the Klamath River. Draft report. Prepared by the Biological Subgroup for the Secretarial Determination Regarding Potential Removal of the Lower Four Dams on the Klamath River.

Hetrick, N. J., T. A. Shaw, P. Zedonis, and J. P. Polos. 2009. Compilation of Information to inform USFWS Principals on technical aspects of the Klamath Basin Restoration Agreement relating to fish and fish habitat conditions. Arcata Fisheries Technical Report TR 2009-11. U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, California.

Huang, J. V., and B. Greimann. 2010. User's Manual for SRH-1D 2.5 (Sedimentation and River Hydraulics—One Dimension, Version 2.5). U.S. Bureau of Reclamation, Sedimentation and River Hydraulics Group, Technical Service Center, Denver, Colorado.

Kondolf, G. M. 2000. Assessing salmonid spawning gravel quality. Transactions of the American Fisheries Society 129: 262–281.

Kondolf, G. M., and M. G. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research 29: 2,275–2,285.

Montgomery, D. R., and J. M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin 109: 596–611.

Moyle, P. B. 2002. Inland Fishes of California. University of California Press, Berkeley, California.

NRC (National Research Council). 2004. Endangered and threatened fishes in the Klamath River Basin: causes of decline and strategies for recovery. The National Academies Press, Washington, DC. http://www.nap.edu/catalog.php?record_id=10838.

PacifiCorp. 2004. Final Technical Report, Klamath Hydroelectric Project, (FERC Project No. 2082): Water Resources. PacifiCorp, Portland, Oregon.

Stillwater Sciences. 2008. Klamath River dam removal study: sediment transport DREAM-1 simulation. Technical Report. Prepared by Stillwater Sciences, Berkeley, California for California Coastal Conservancy, Oakland, California.

Stillwater Sciences. 2010a. Anticipated sediment release from Klamath River dam removal within the context of basin sediment delivery. Prepared by Stillwater Sciences, Arcata, California for California Coastal Conservancy, Oakland, California.

Stillwater Sciences. 2010b. Potential responses of spring-run Chinook salmon downstream from Iron Gate Dam to No-Action and Dam-Removal alternatives for the Klamath Basin. Prepared by Stillwater Sciences, Arcata, California for U.S.D.I. Bureau of Reclamation in support of the Biological Subgroup for the Klamath Basin Secretarial Determination. Arcata, California.

Stillwater Sciences. 2010c. Potential responses of coho salmon and steelhead downstream from Iron Gate Dam to No-Action and Dam-Removal alternatives for the Klamath Basin. Prepared by Stillwater Sciences, Arcata, California for U.S. Bureau of

Reclamation in support of the Biological Subgroup for the Klamath Basin Secretarial Determination. Arcata, California.

USBR. 2011. Sediment chemistry investigation: Sampling, analysis, and quality assurance findings for Klamath River Reservoirs and Estuary, October 2009 – January 2010. Prepared by Bureau of Reclamation, Mid-Pacific Region, Branch of Environmental Monitoring, MP-157.

USBR (U.S. Bureau of Reclamation). 2012. Hydrology, Hydraulics and Sediment Transport Studies for the Secretary's Determination on Klamath River Dam Removal and Basin Restoration. Technical Report No. SRH-2011-02. Prepared for Mid-Pacific Region, Bureau of Reclamation, Technical Service Center, Denver, Colorado.

Wooster J. K., S. R. Dusterhoff, Y. Cui, L. S. Sklar, W. E. Dietrich, and M. Malko. 2008. Sediment supply and relative size distribution effects on fine sediment into immobile gravels. Water Resources Research 44, W0324, doi:10.1029/2006WR005815.

Attachment F-1

Potential Effects of Dam Removal on Channel Bed Elevations, Grain Size, and Related Anadromous Fish Habitat Impacts in the Hydroelectric Reach of the Lower Klamath River from Iron Gate Dam to the Cottonwood Creek Confluence

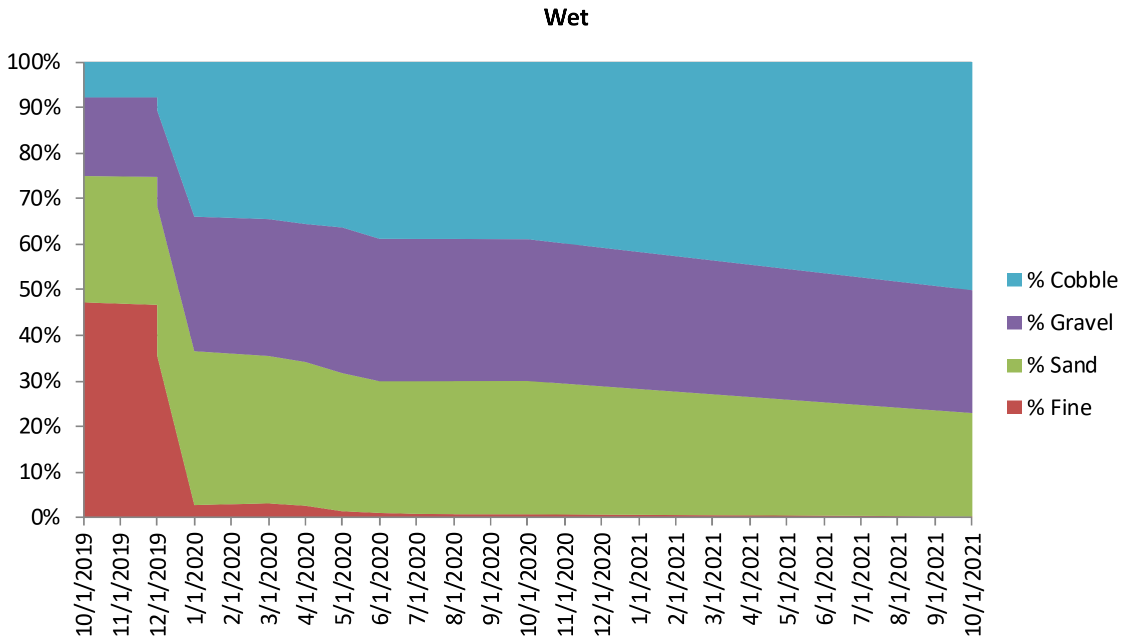

Figure F1-1. Simulated Bed Composition for J.C. Boyle Reservoir for Two Successive Wet Water Years Following Dam Removal. Based on simulation results provided by USBR, March 2012.

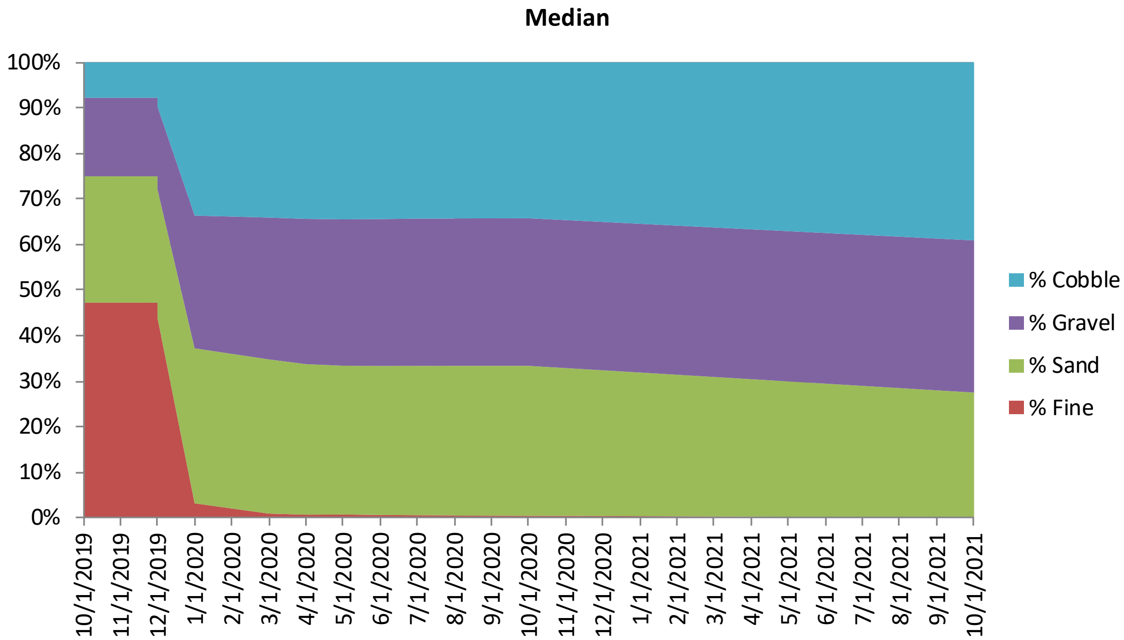

Figure F1-2. Simulated Bed Composition for J.C. Boyle Reservoir for Two Successive Median Water Years Following Dam Removal. Based on simulation results provided by USBR, March 2012.

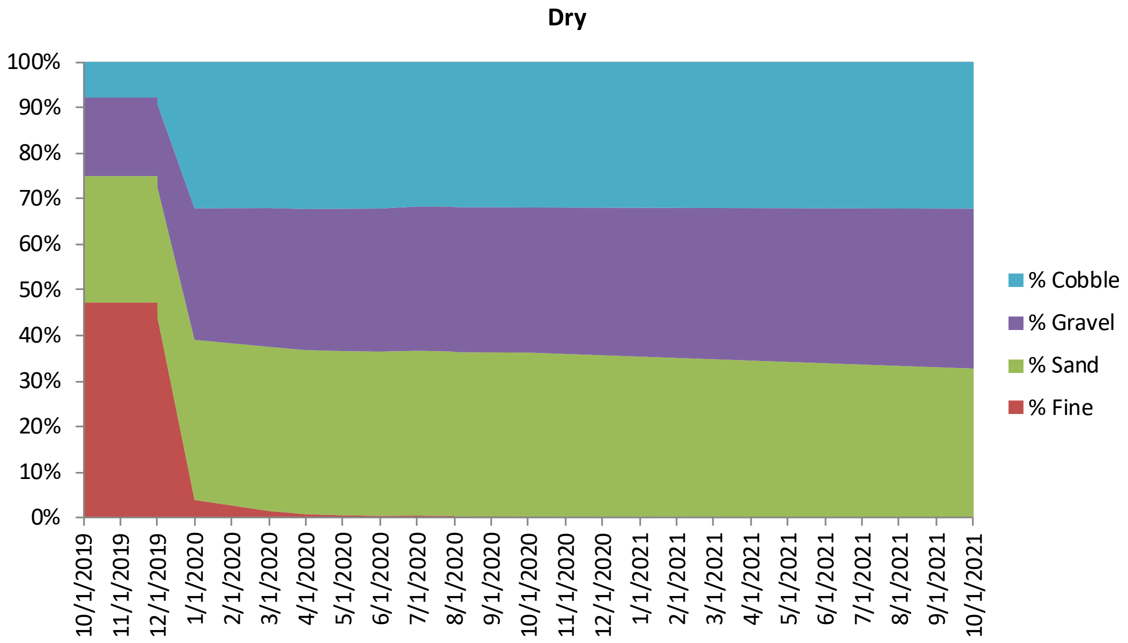

Figure F1-3. Simulated Bed Composition for J.C. Boyle Reservoir for Two Successive Dry Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

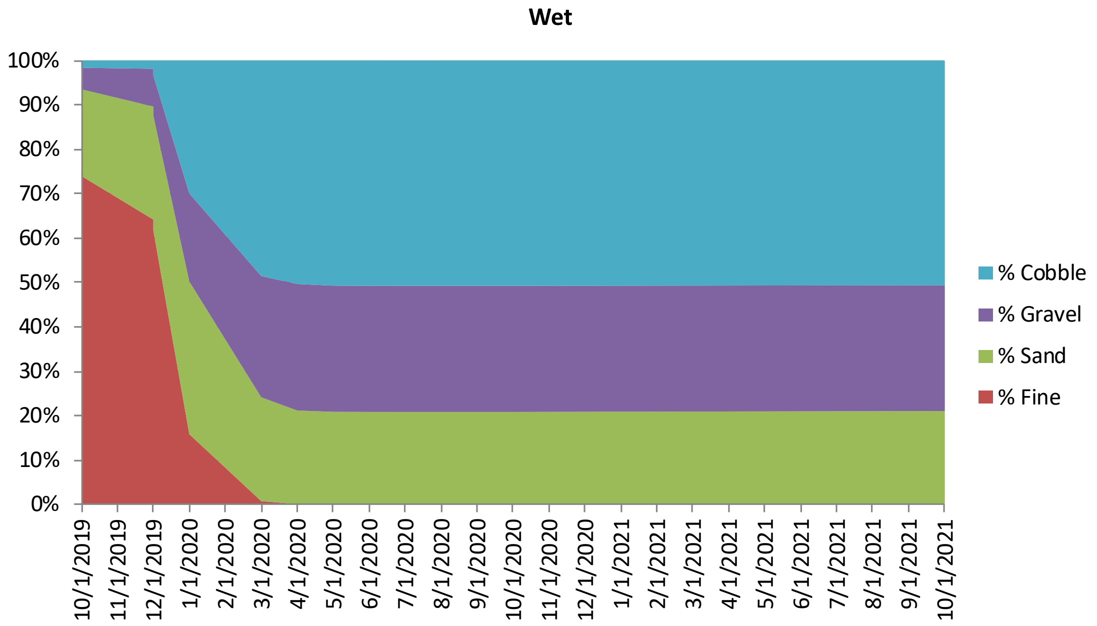

Figure F1-4. Simulated Bed Composition for Copco No. 1 Reservoir for Two Successive Wet Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

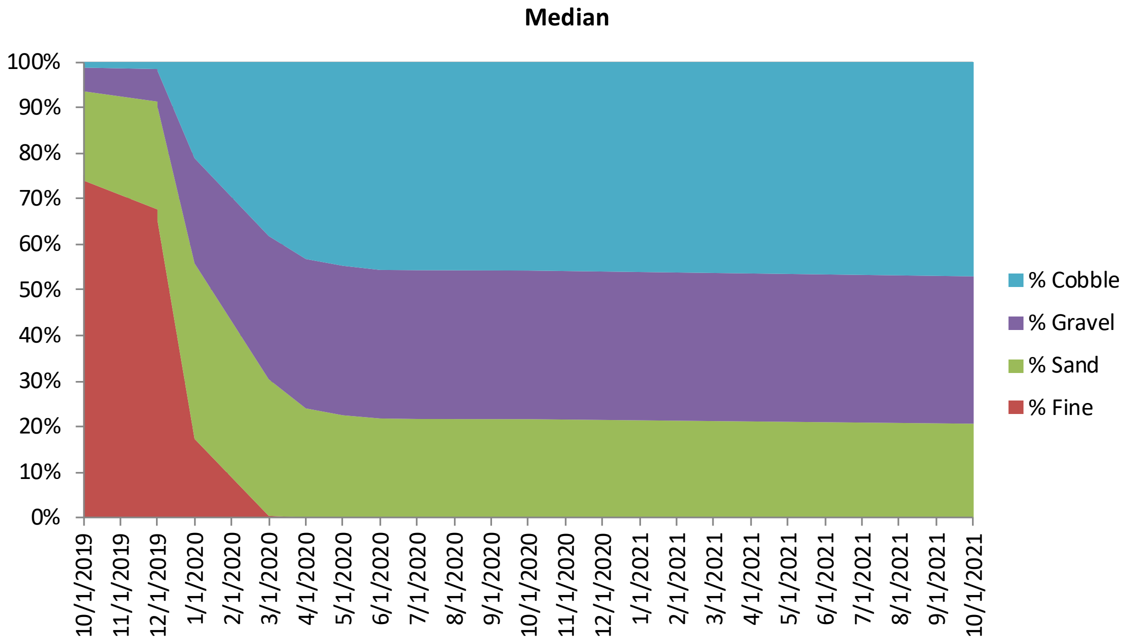

Figure F1-5. Simulated Bed Composition for Copco No. 1 Reservoir for Two Successive Median Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

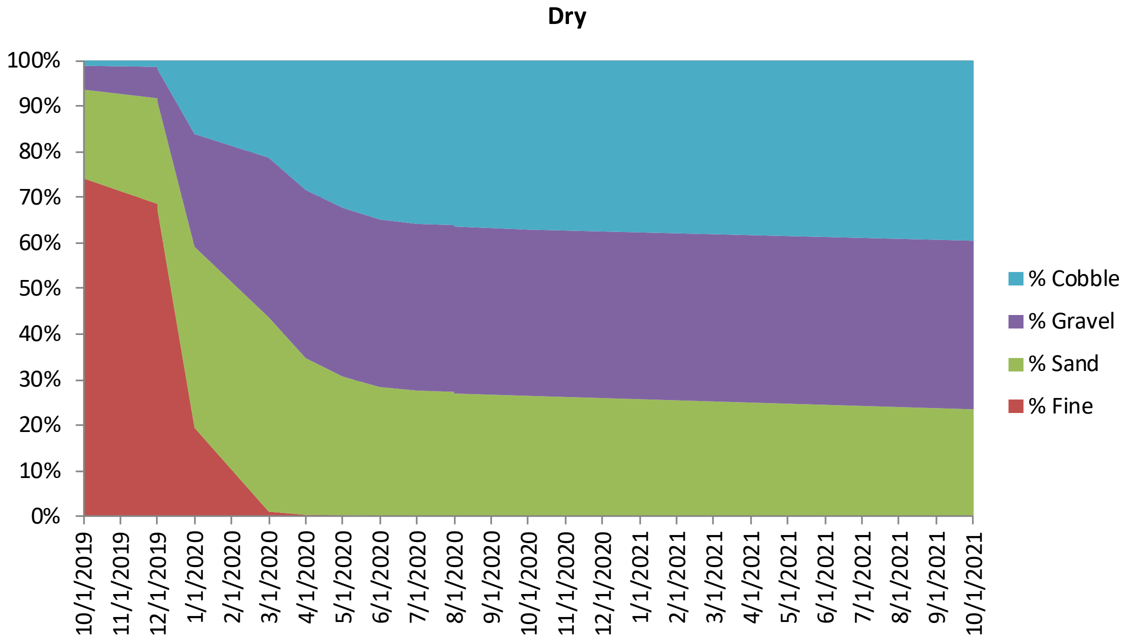

Figure F1-6. Simulated Bed Composition for Copco No. 1 Reservoir for Two Successive Dry Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

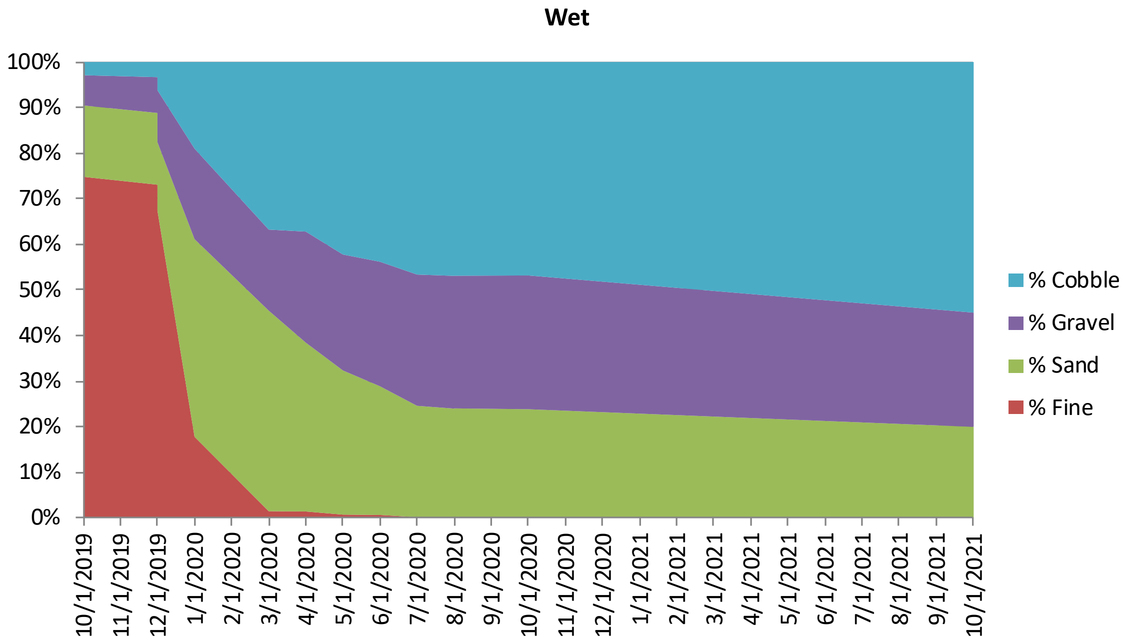

Figure F1-7. Simulated Bed Composition for Iron Gate Reservoir for Two Successive Wet Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

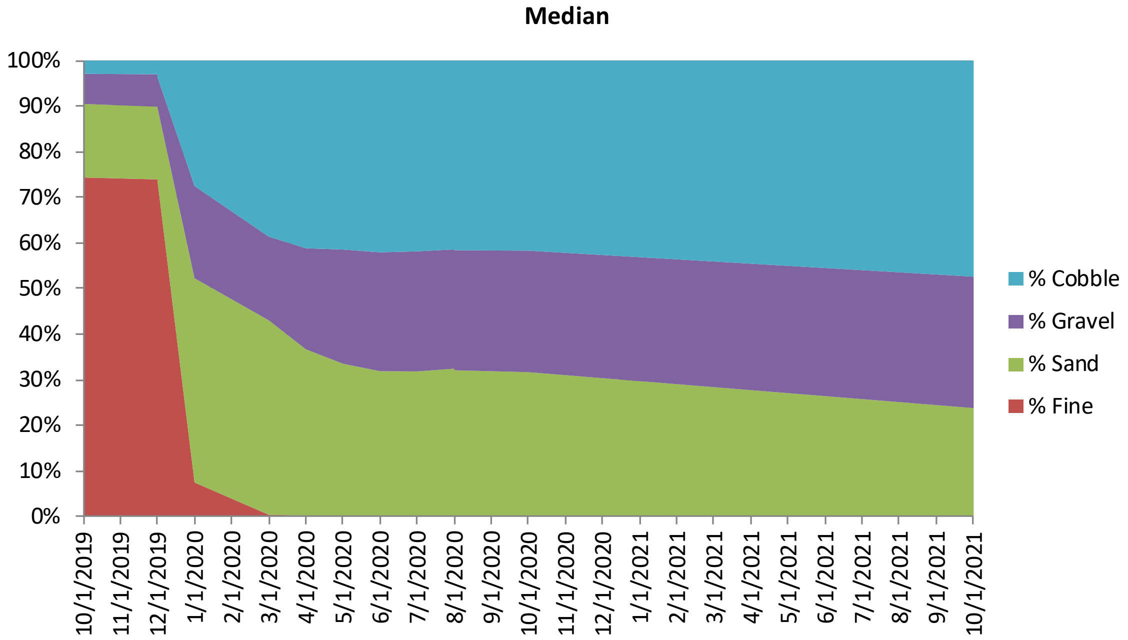

Figure F1-8. Simulated Bed Composition for Iron Gate Reservoir for Two Successive Median Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

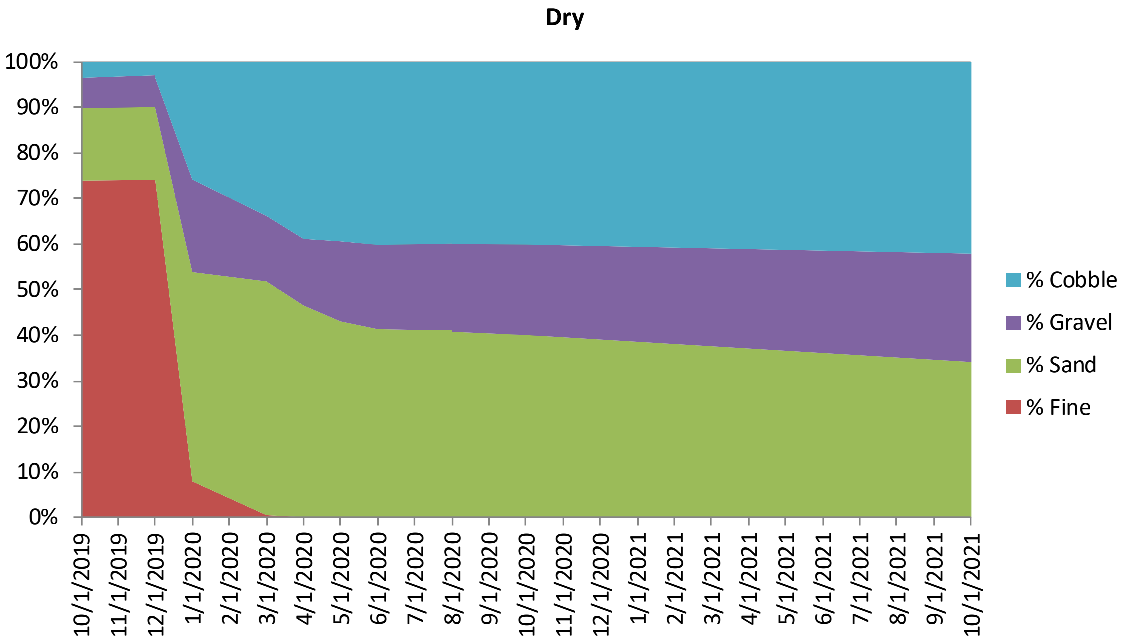

Figure F1-9. Simulated Bed Composition for Iron Gate Reservoir for Two Successive Dry Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

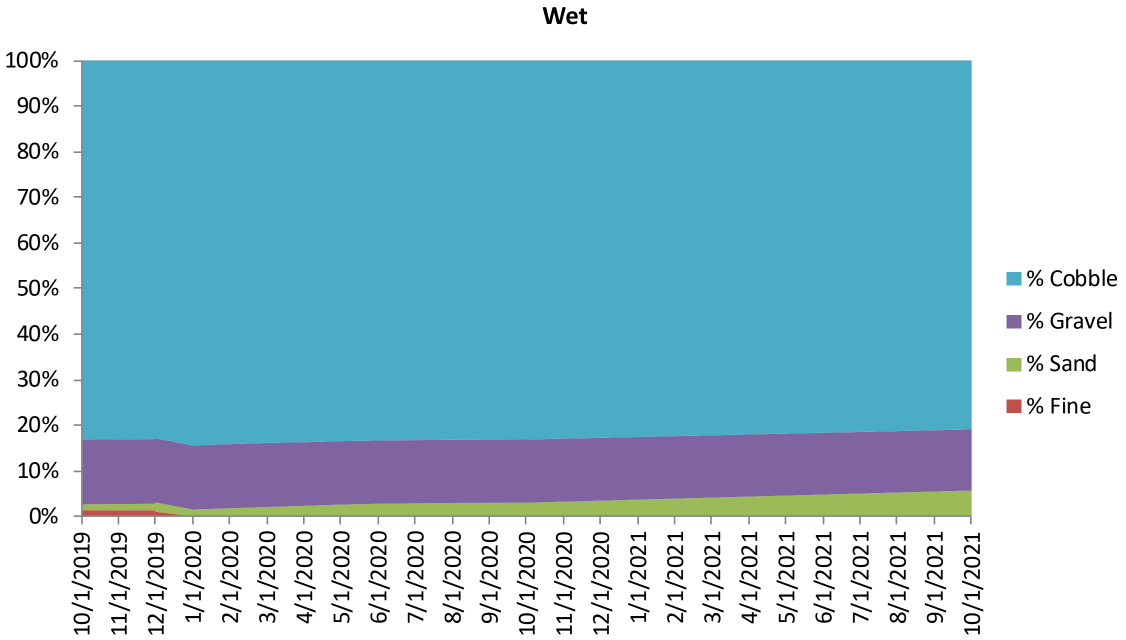

Figure F1-10. Simulated Bed Composition Upstream of J.C. Boyle Reservoir for Two Successive Wet Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

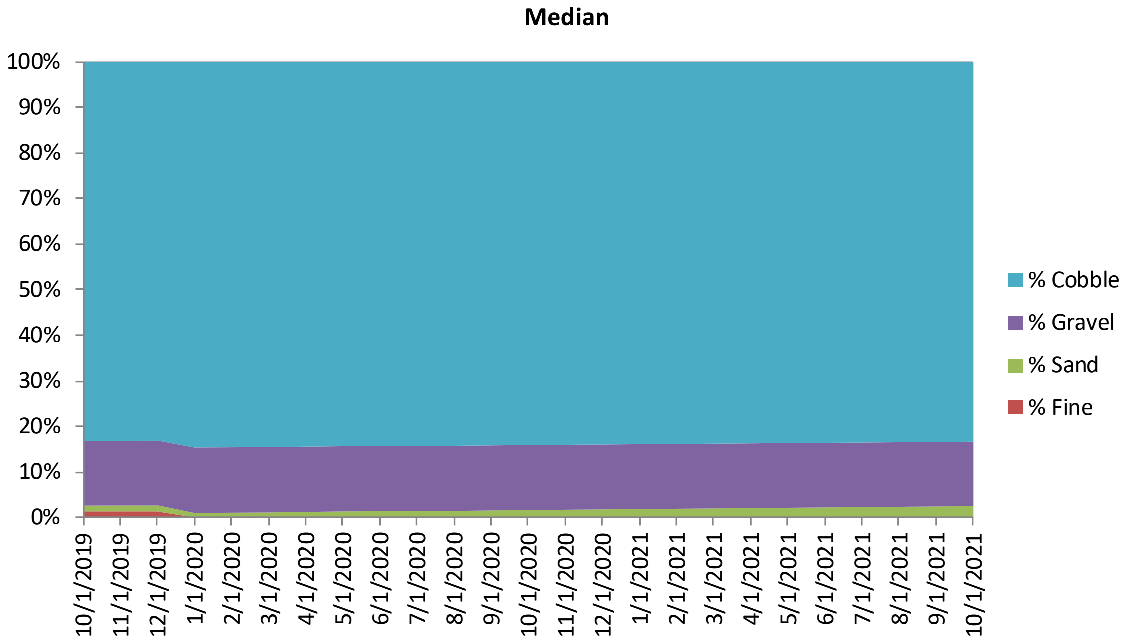

Figure F1-11. Simulated Bed Composition Upstream of J.C. Boyle Reservoir for Two Successive Median Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

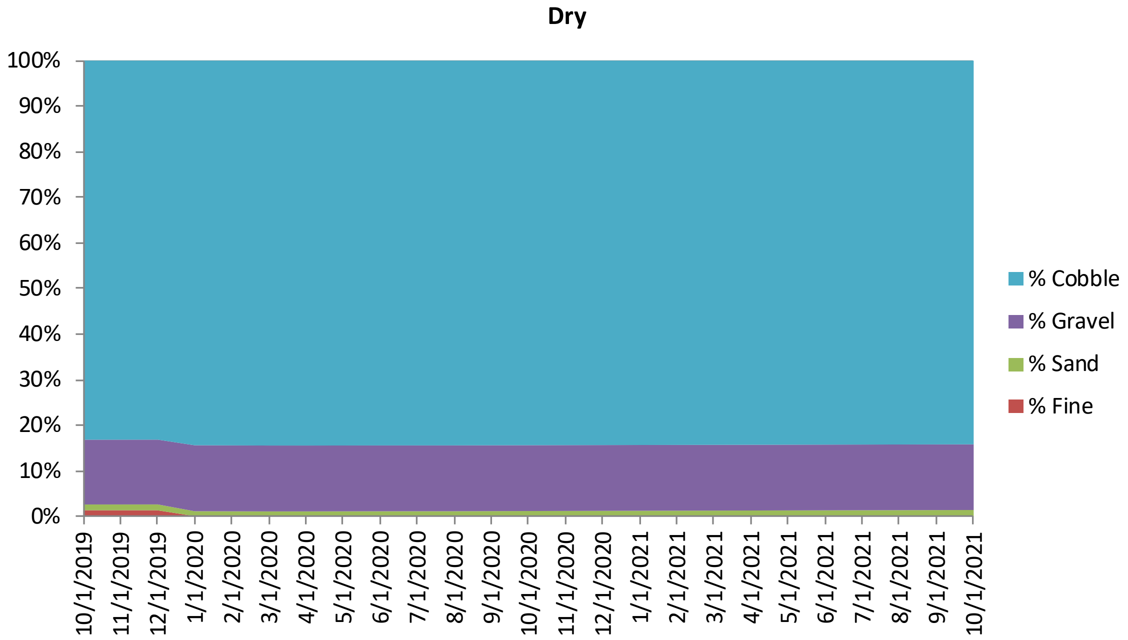

Figure F1-12. Simulated Bed Composition Upstream of J.C. Boyle Reservoir for Two Successive Dry Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

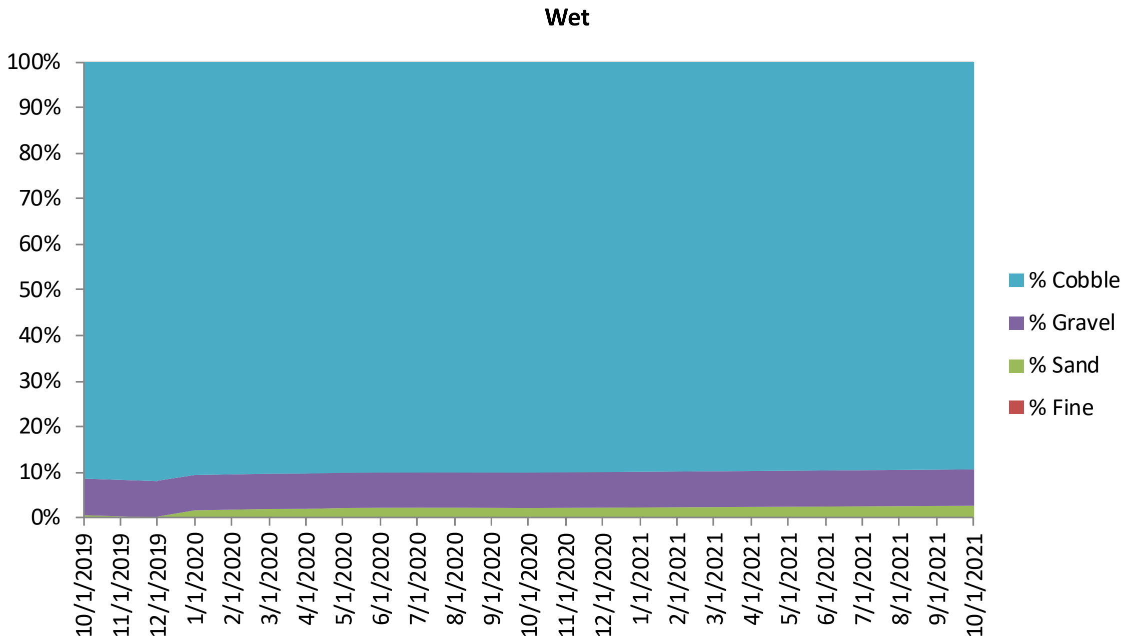

Figure F1-13. Simulated Bed Composition from J.C. Boyle to Copco No. 1 Reservoirs for Two Successive Wet Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

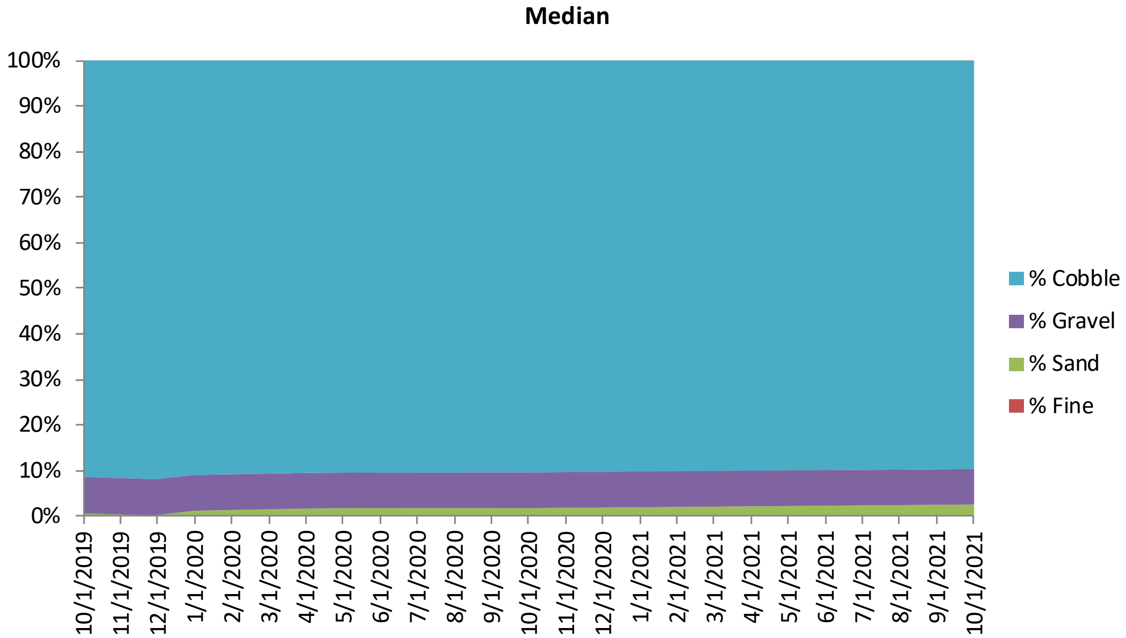

Figure F1-14. Simulated Bed Composition from J.C. Boyle to Copco No. 1 Reservoirs for Two Successive Median Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

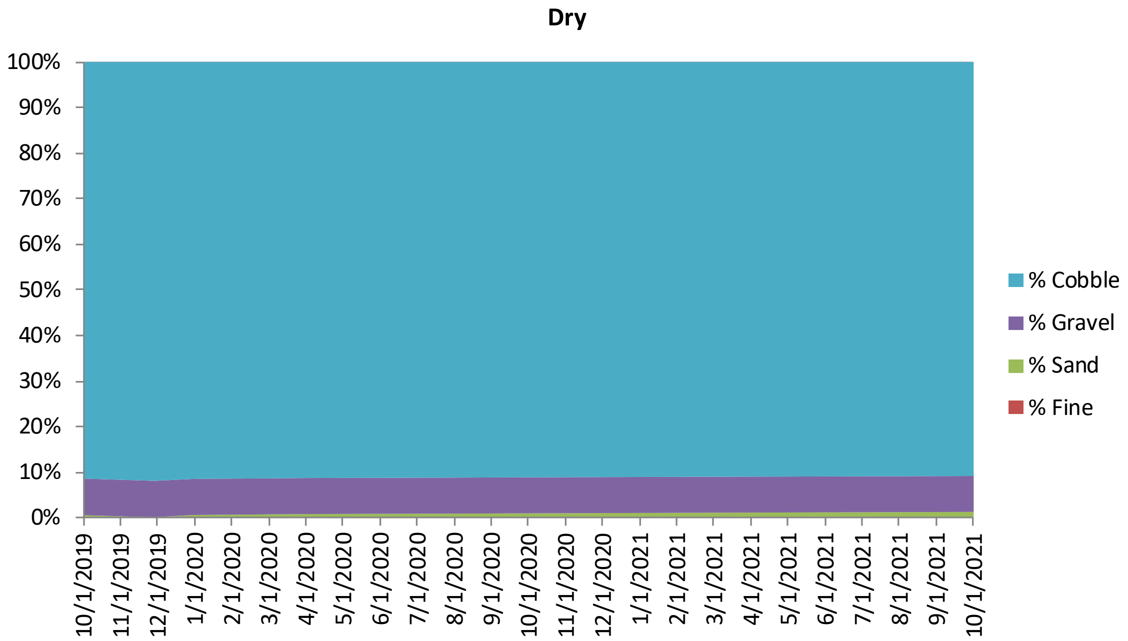

Figure F1-15. Simulated Bed Composition from J.C. Boyle to Copco No. 1 Reservoirs for Two Successive Dry Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

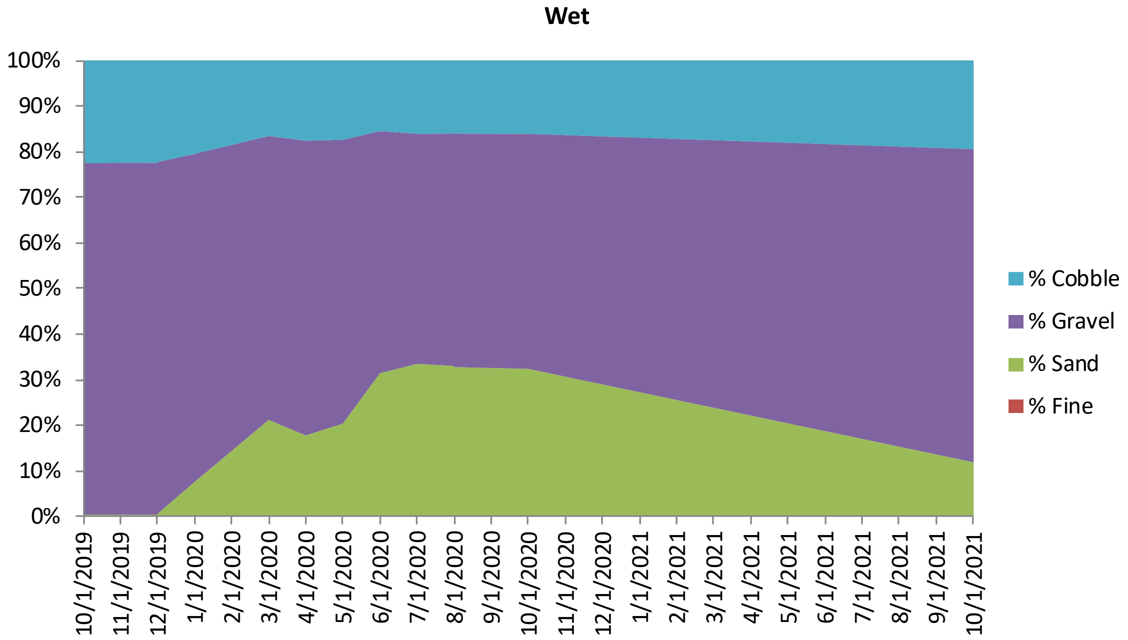

Figure F1-16. Simulated Bed Composition from Bogus Creek to Willow Creek for Two Successive Wet Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

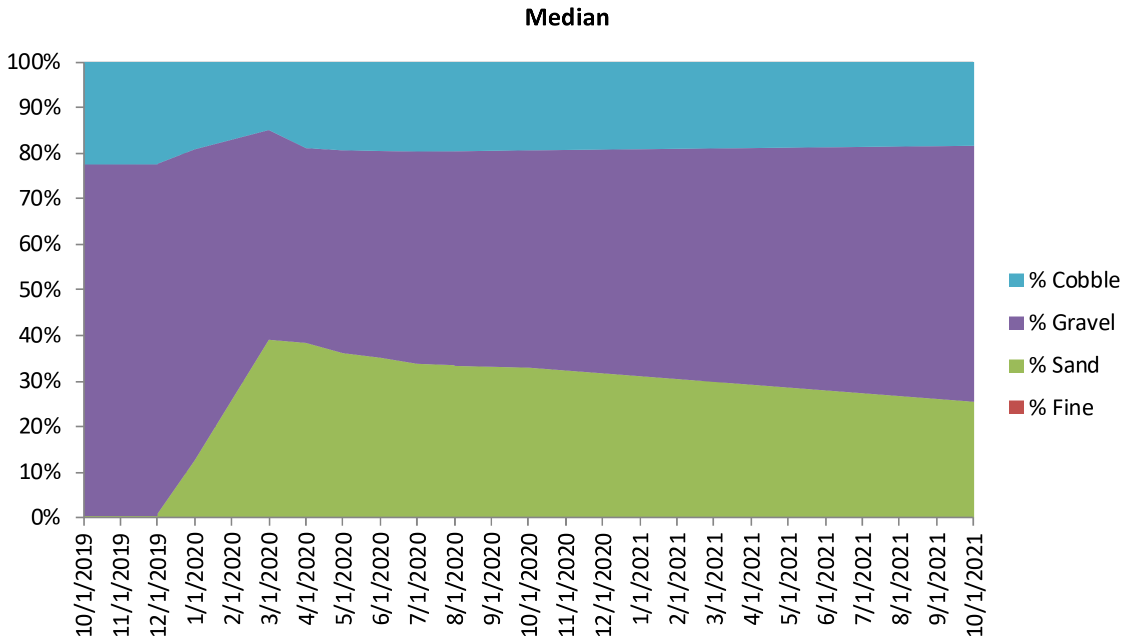

Figure F1-17. Simulated Bed Composition from Bogus Creek to Willow Creek for Two Successive Median Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

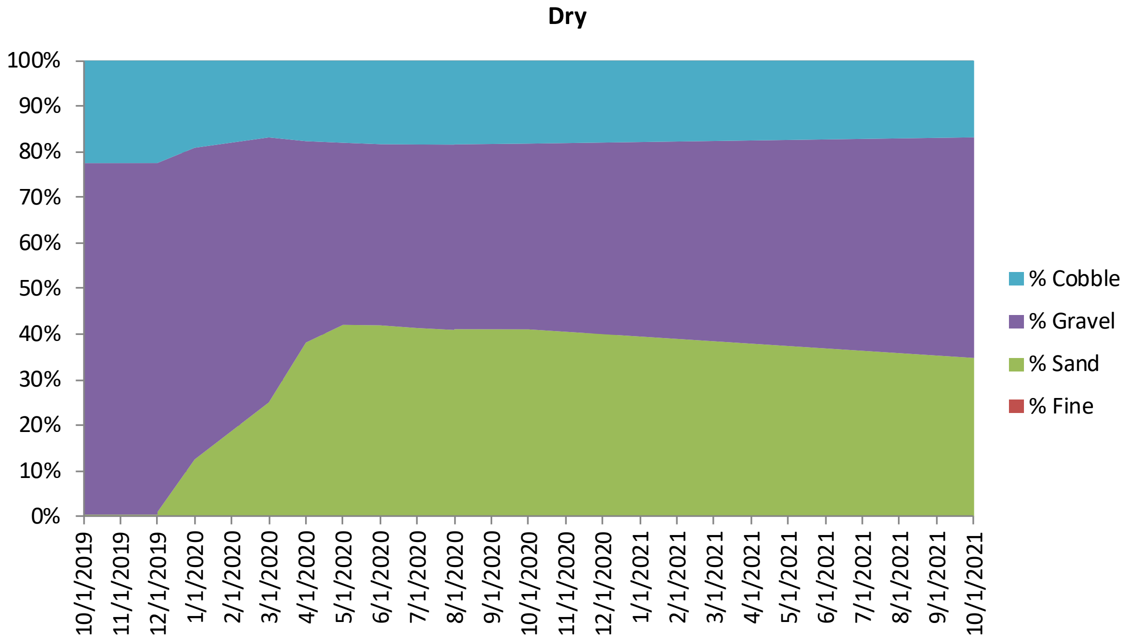

Figure F1-18. Simulated Bed Composition from Bogus Creek to Willow Creek for Two Successive Dry Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

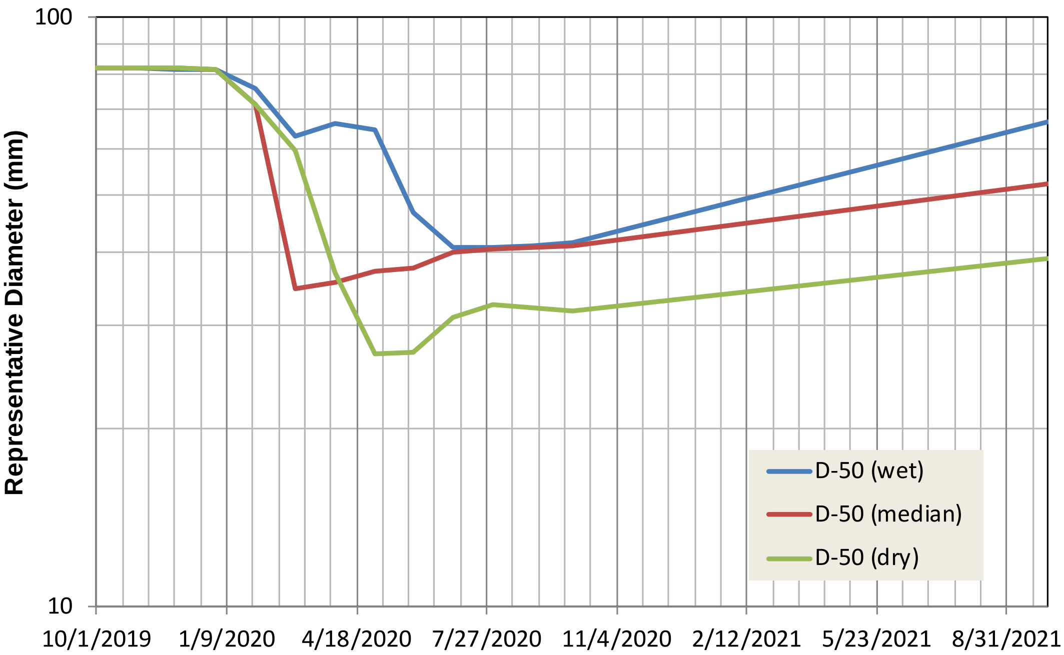

Figure F1-19. Simulated Bed Substrate Size from Bogus Creek to Willow Creek for Successive Wet, Median, and Dry Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

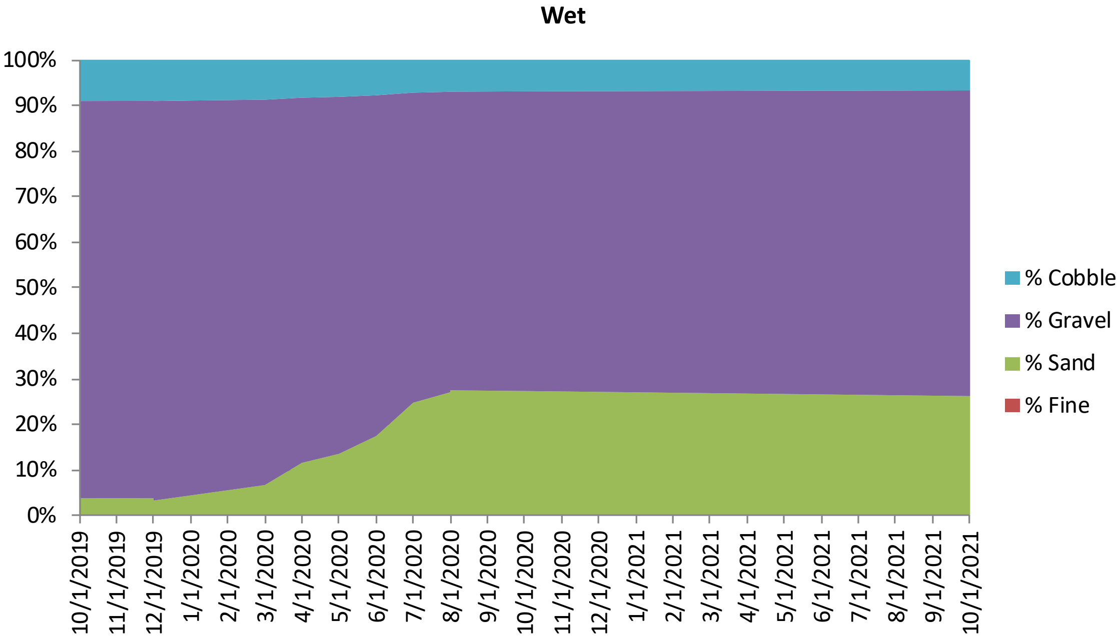

Figure F1-20. Simulated Bed Composition from Willow Creek to Cottonwood Creek for Two Successive Wet Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

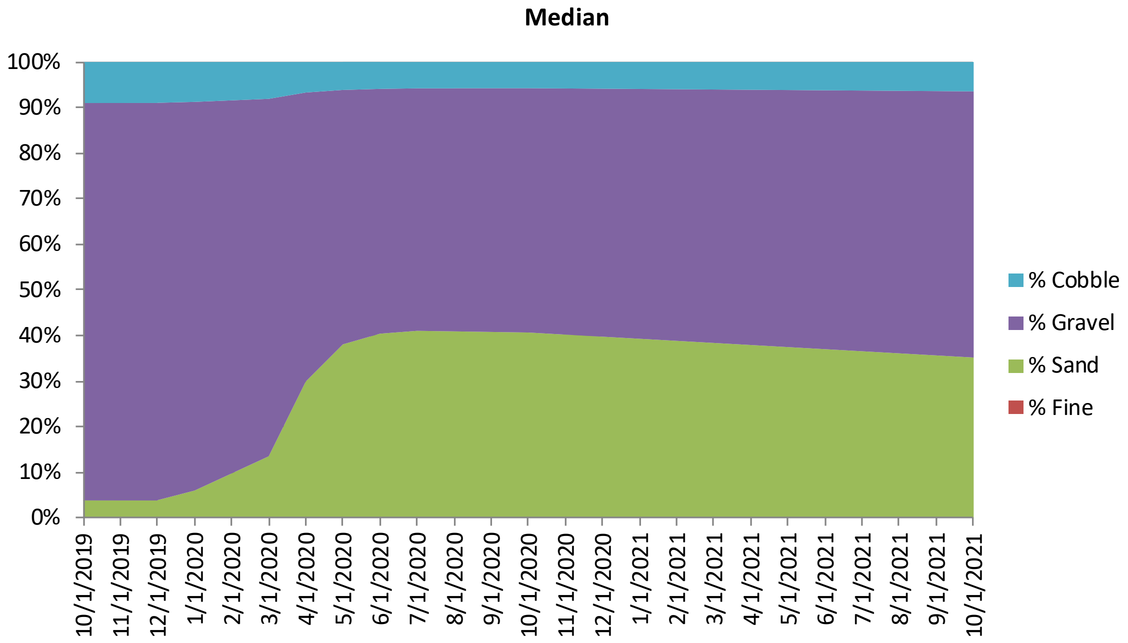

Figure F1-21. Simulated Bed Composition from Willow Creek to Cottonwood Creek for Two Median Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

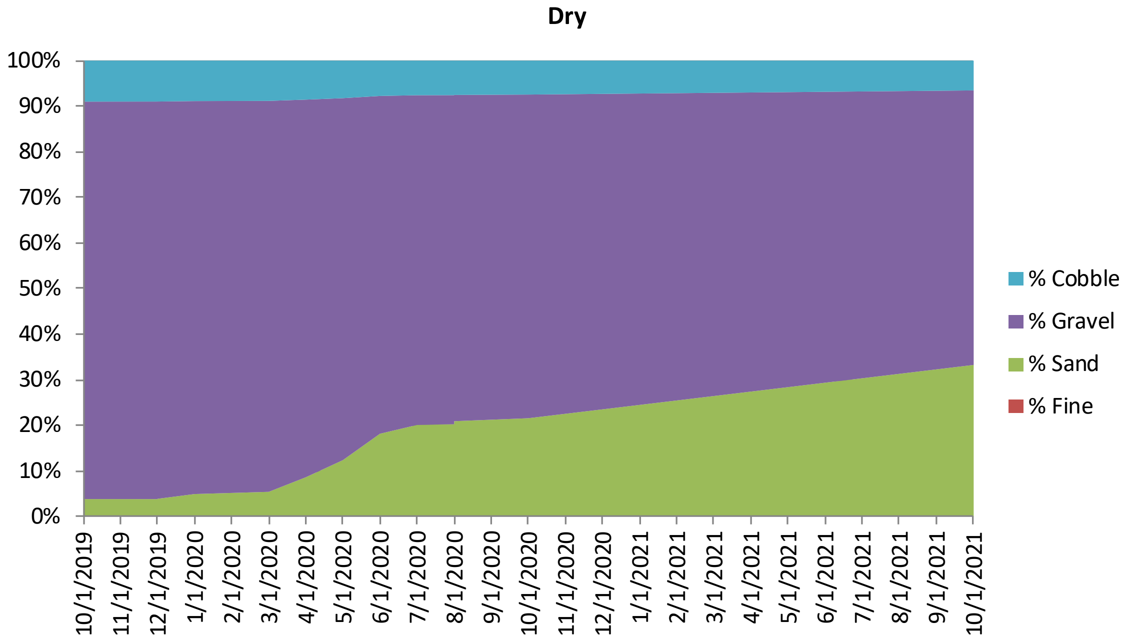

Figure F1-22. Simulated Bed Composition from Willow Creek to Cottonwood Creek for Two Dry Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

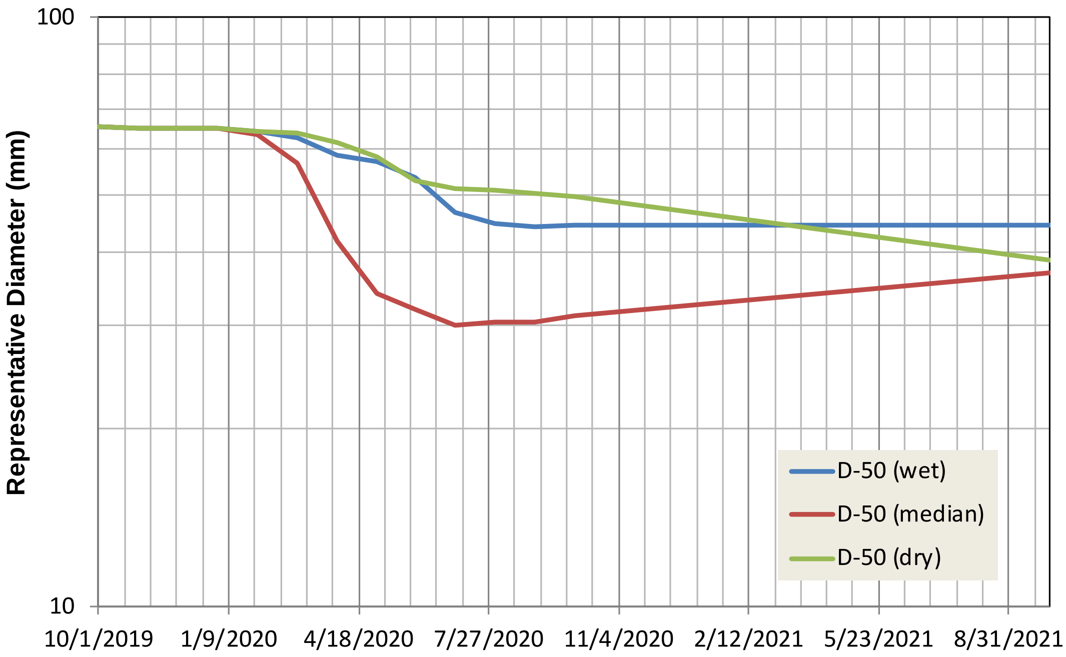

Figure F1-23. Simulated Bed Substrate Size from Willow Creek to Cottonwood Creek for Successive Wet, Median, and Dry Water Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

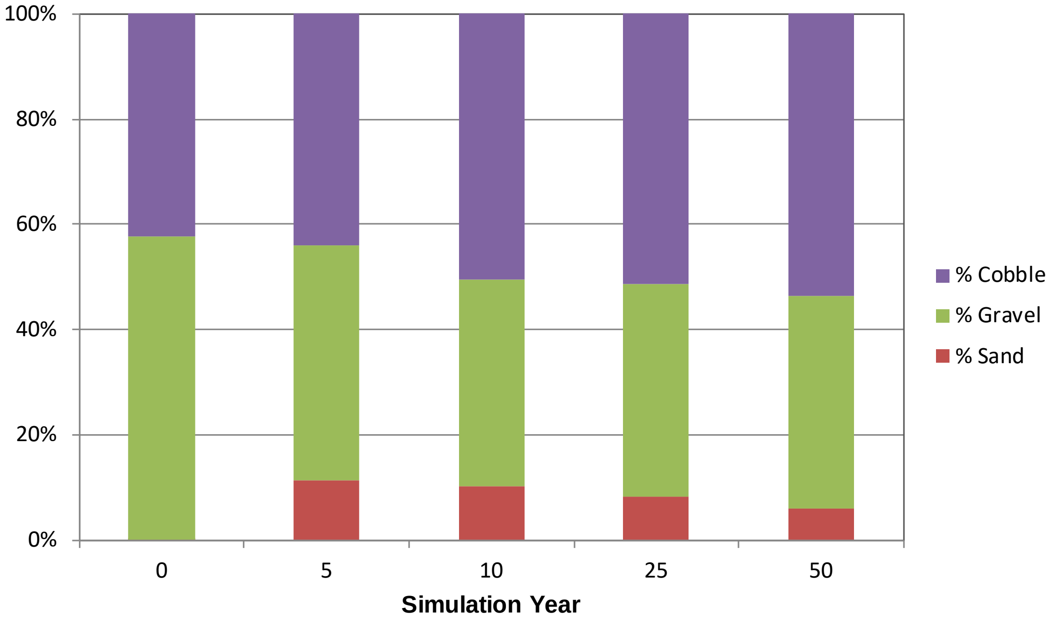

Figure F1-24. Simulated Bed Composition of Iron Gate Dam to Bogus Creek Reach 5, 10, 25, and 50 Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

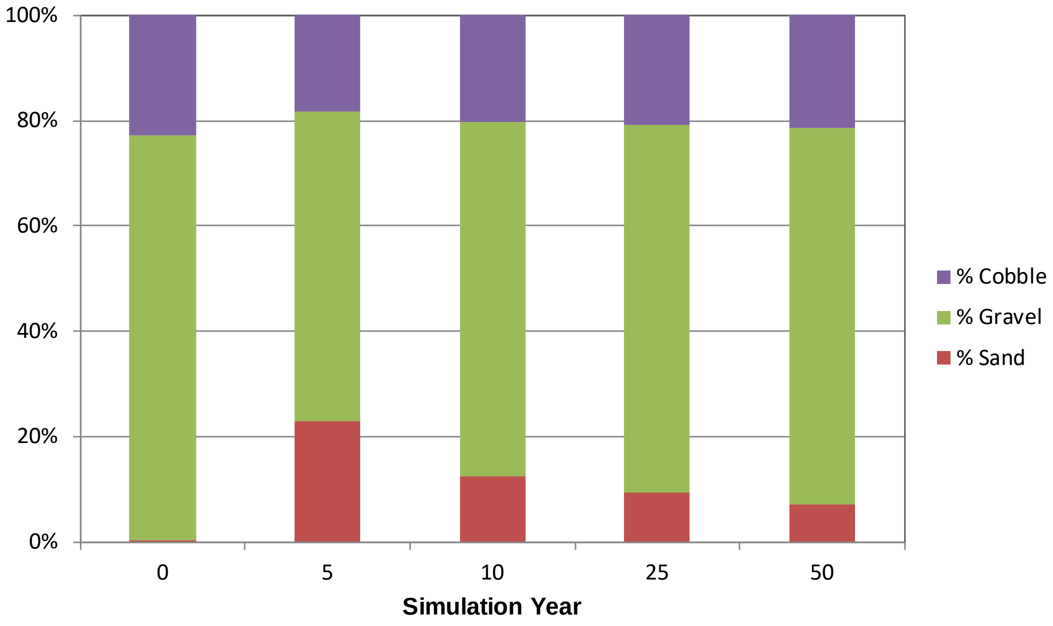

Figure F1-25. Simulated Bed Composition of Bogus Creek to Willow Creek Reach 5, 10, 25, and 50 Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

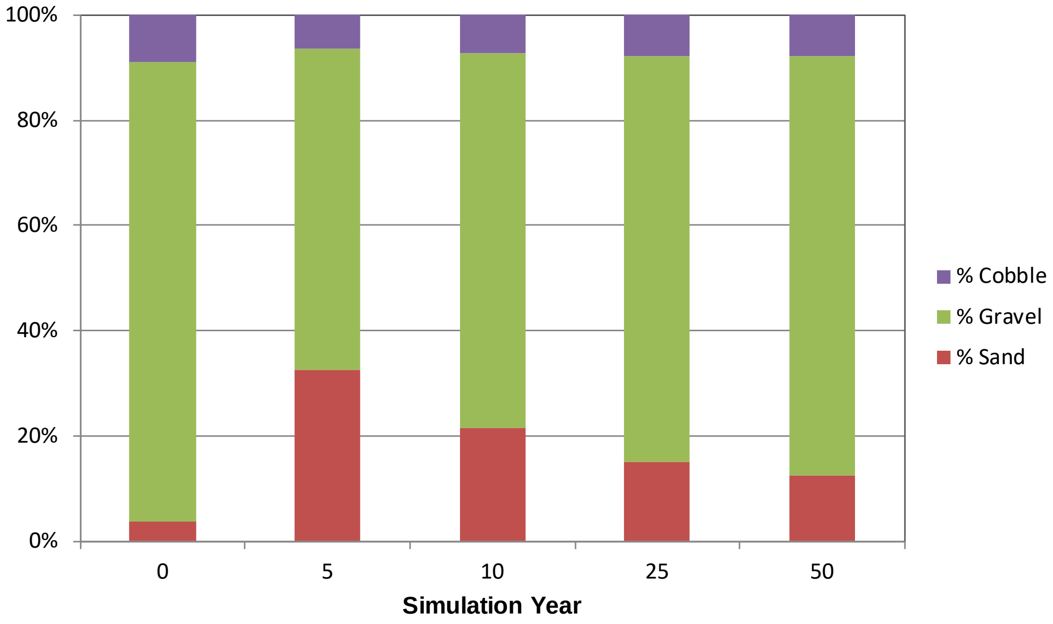

Figure F1-26. Simulated Bed Composition of Willow Creek to Cottonwood Creek Reach 5, 10, 25, and 50 Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

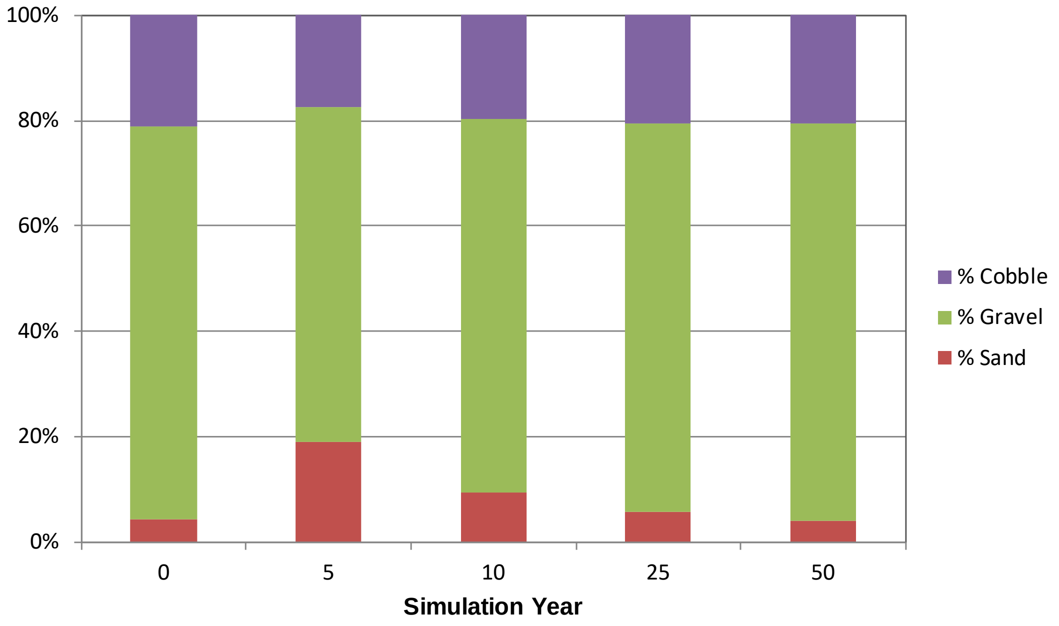

Figure F1-27. Simulated Bed Composition of Cottonwood Creek to Shasta River Reach 5, 10, 25, and 50 Years Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

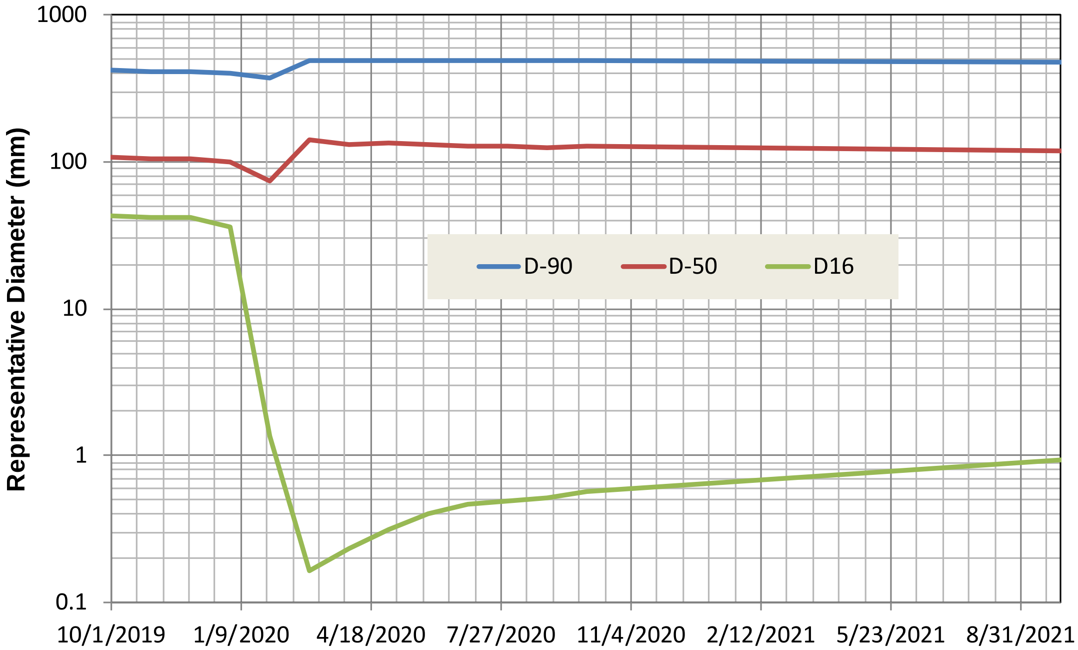

Figure F1-28. Simulated Bed Substrate Size from Iron Gate Dam to Bogus Creek Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

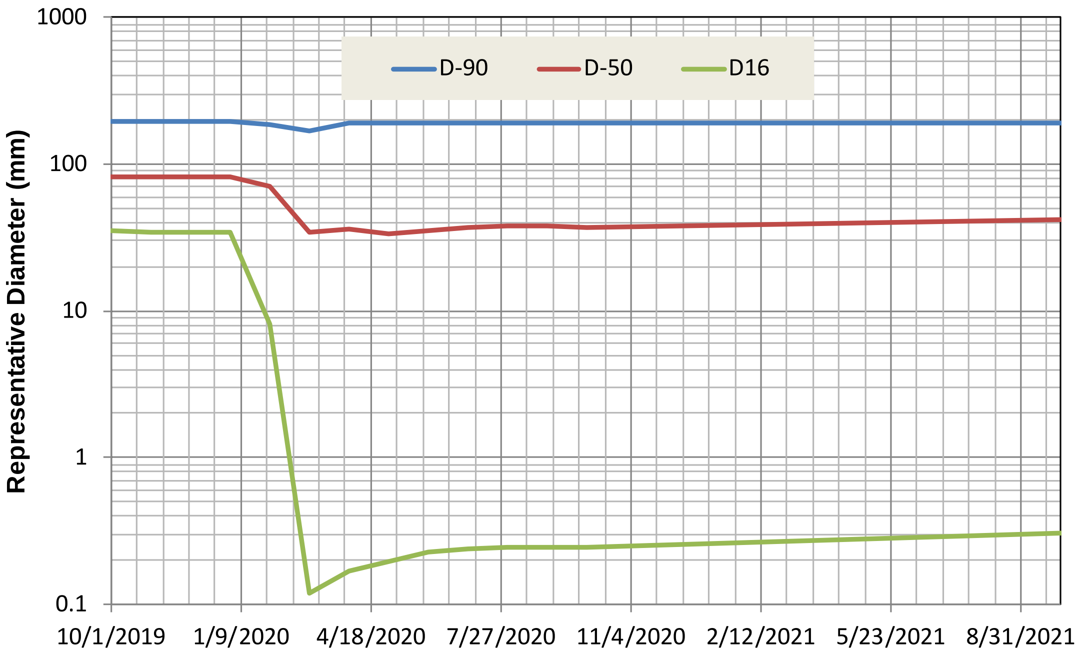

Figure F1-29. Simulated Bed Substrate Size from Bogus Creek to Willow Creek Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.

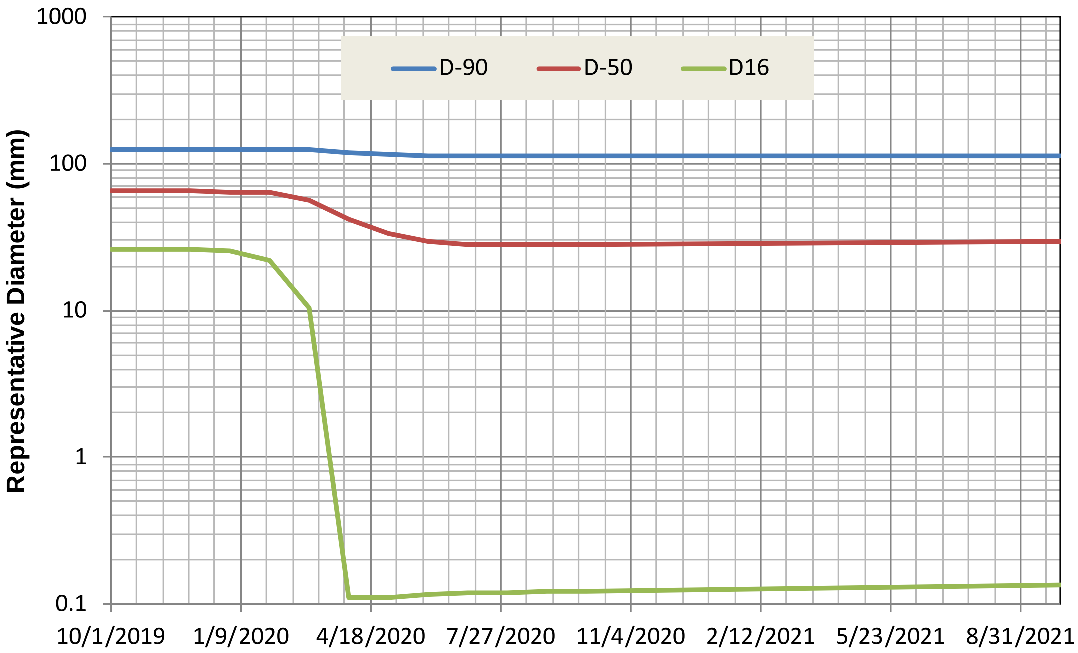

Figure F1-30. Simulated Bed Substrate Size from Willow Creek to Cottonwood Following Dam Removal. Based on simulation results provided by Reclamation, March 2012.