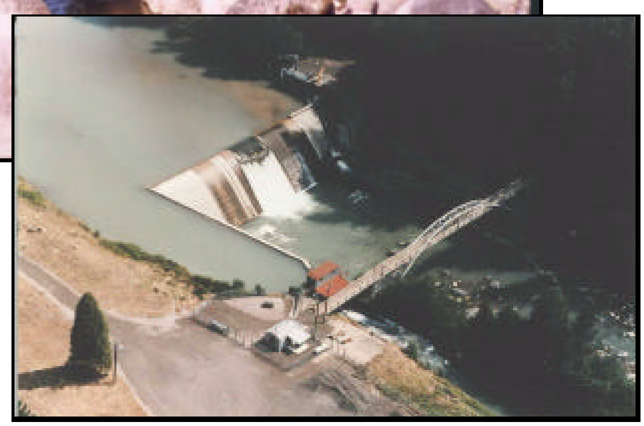
**PRELIMINARY FINAL**

# Evaluation of Geomorphic Effects of Removal of Marmot and Little Sandy Dams and Potential Impacts on Anadromous Salmonids



*Prepared for:*

**Portland General Electric**
121 SW Salmon Street
Portland, OR 97219

*Prepared by:*

**Stillwater Sciences**
2532 Durant Avenue, Suite 201
Berkeley, CA 94704
(510) 848-8098

**March 2000**

## Table of Contents

## List of Figures



## List of Tables

## EXECUTIVE SUMMARY

This report evaluates the geomorphic effects of removing Marmot Dam, on the Sandy River, Oregon, and Little Sandy Dam, on the Little Sandy River, and the potential associated effects on anadromous salmonid habitats and populations. These dams will be removed as part of the decommissioning of Portland General Electric's Bull Run Hydroelectric Project. Removing these dams will improve habitat connectivity for aquatic organisms and restore natural streamflow regimes to reaches currently downstream of the dams. Discussion of the effects of removing these dams on habitat connectivity and flows is provided in the Draft Environmental Assessment for the Bull Run Project and is not covered in detail in this report. Evaluation of sediment-related impacts should be considered in the context of the substantial long-term improvements in access and habitat conditions that dam removal will create. The assessment of Marmot Dam removal presented below includes comparison of the relative effects of four alternatives for removing the dam. The four alternatives, each of which differs in the amount of sediment released downstream, are as follows:

- Alternative A: Remove all sediment to a point 5,500 ft (1,680 m) upstream of Marmot Dam;
- Alternative B: Single-season dam removal with minimal sediment removal;
- Alternative C: Removal of top of dam in Year 1, complete dam removal in Year 2 with sand layer excavation to a point 2,700 ft (830 m) upstream of Marmot Dam;
- Alternative D: Remove sediment to the bottom of the sand layer and to a point 2,700 ft (830 m) upstream of Marmot Dam.

Primary concerns related to the removal of Marmot Dam include direct and indirect effects of exposure to increased suspended sediment concentrations, disturbance or elimination of habitat due to sediment transport and deposition, and impairment of adult salmonid passage in the vicinity of Marmot reservoir and in the Sandy River delta.

### Summary of Existing Conditions in the Sandy River Basin

The Sandy River drains into the Columbia River and is located about 30 mi (48 km) east of Portland, Oregon on the western slopes of the Cascade Range. Marmot Dam is located on the Sandy River at River Mile (RM) 30, and the impoundment formed by the dam is currently filled to near the dam's crest with approximately 980,000 $yd^3$ (750,000 $m^3$) of sediment. The sediment accumulation behind the dam consists of approximately two-thirds coarse sediment (> 2 mm in diameter) and one-third fine sediment (< 2 mm). Marmot Dam provides upstream and downstream fish passage and diverts up to 600 cfs from the Sandy River between the dam and the confluence with the Bull Run River. Little Sandy Dam is located 1.7 mi (2.7 km) upstream of the confluence with the Bull Run River. Little Sandy Dam diverts up to 800 cfs (22.6 cms) from the Little Sandy River and does not have fish passage facilities. Approximately 4,500 $yd^3$ (3,400 $m^3$) of mostly coarse (>2 mm) sediment is stored behind Little Sandy Dam.

The Sandy River basin supports populations of the following anadromous salmonid species: chinook salmon (spring- and fall-run), steelhead (winter- and summer-run), coho salmon, and coastal cutthroat trout. Except for summer steelhead, all of these salmonid populations have special status under the federal Endangered Species Act. Spring chinook salmon, winter and summer steelhead, and coho salmon spawn primarily upstream of Marmot Dam. Primary rearing areas for these species are also likely upstream of the dam, although they may also rear downstream of Marmot Dam. Fall chinook salmon spawn primarily downstream of Marmot Dam, and winter steelhead spawn downstream as well.

The ongoing influence of past laharic events (volcanic mudflows), Mt. Hood glaciers, and the basin's underlying lithology result in naturally high sediment loading in the Sandy River. For the purposes of geomorphic analysis, the Sandy River was differentiated into the following reaches that could be affected by dam removal:

- **The reservoir-influenced reach** (RM 32–30) of the Sandy River extends upstream of Marmot Dam, where the river is affected by the backwater effect and grade control of the dam.

- **Reach 1** (RM 30–RM 28.5) extends from Marmot Dam to the upstream end of the Sandy River gorge.

- **Reach 2** (RM 28.5–24.5) is the Sandy River gorge.

- **Reach 3** (RM 24.5–RM 18.5) extends from the downstream end of the gorge (near Revenue Bridge) to the Bull Run River confluence at Dodge Park.

- **Reach 4** (RM 18.5–RM 6) extends from the Bull Run confluence (Dodge Park) to Dabney State Park. Reach 4 contains the primary spawning and rearing area for fall chinook salmon (in the mainstem Sandy River), from Oxbow Park to Dabney Park, and spawning and rearing habitat for winter steelhead.

- **Reach 5** (RM 6 –RM 0) from Dabney State Park to the confluence with the Columbia River.

The 1.7-mi (2.8-km) reach downstream of Little Sandy Dam, extending to the confluence with the Bull Run River, is largely bedrock constrained and has a steep channel with coarse substrates. The lower Little Sandy River currently provides poor habitat for salmonids and other aquatic organisms because over 90% of baseflows are diverted, and access to the Little Sandy River upstream of the dam is currently blocked because Little Sandy Dam does not have fish passage facilities.

## Potential Geomorphic and Biological Impacts Associated with Removal of Marmot Dam

Stillwater Sciences evaluated the potential impacts to channel morphology and anadromous salmonid habitat resulting from sediment release and erosion of sediment currently stored in Marmot reservoir for each of the four alternatives for removal of Marmot Dam. An important component of this effort was numerical modeling, which provides reach-scale predictions of sediment deposition, transport time, and suspended sediment concentrations from the reservoir reach downstream to the mouth of the Sandy River. Model results are subject to uncertainty, although several sensitivity analyses (e.g., of variable hydrologic conditions and rates of reservoir erosion) were conducted to bracket this uncertainty. Geomorphic and biological impacts were assessed based on the modeling results combined with field reconnaissance, aerial photograph interpretation, literature review, and professional judgement. Modeling was completed for dam removal alternatives B through D. (No sediment modeling was conducted for Alternative A because nearly all sediment would be excavated and removed from the reservoir.)

### Alternative A: Remove all sediments to a point 5,500 ft upstream of Marmot Dam

This alternative entails excavation of approximately 980,000 $yd^3$ (750,000 $m^3$) of sediment and concurrent removal of the dam in one season.

*Upstream impacts and channel adjustment in the reservoir-influenced reach*
Dam removal and excavation of the reservoir sediment would permanently alter channel morphology and habitat characteristics in the reservoir reach. The gradient of this reach would increase to the pre-dam gradient of about 0.006, compared to the current gradient of about 0.002, resulting in increases in bed particle size and loss of the spawning habitat that currently exists for fall chinook salmon in this reach. Impacts to salmonid populations resulting from the changes to this reach are expected to be minor.

*Downstream sediment deposition: Reaches 1–5*
Overall, this alternative would be expected to result in the least amount of sediment transport and deposition downstream and, therefore, the least impact to downstream channel morphology and aquatic habitats of the proposed dam removal alternatives.

*Impacts of downstream suspended sediment and turbidity*
Excavation of sediment from the reservoir could result in substantial increases in suspended sediment concentration and turbidity downstream of the dam during the construction season due to mobilization of fine sediments in the reservoir deposit, although the potential magnitude of such increases has not been modeled. Increased total suspended sediment (TSS) concentration downstream of Marmot Dam during the summer and early fall construction period could adversely affect adult and juvenile salmonids present in the lower river, particularly species expected to be holding, migrating through the lower river, spawning, or rearing.

### Alternative B: Single-season dam removal, minimal sediment removal

This alternative entails removal of Marmot Dam and associated facilities in one season, with removal of only a minimal amount of sediment as required for construction activities. Approximately 980,000 $yd^3$ (750,000 $m^3$) of sediment, consisting of approximately 35% sand (and finer) and 65% gravel (and coarser) would be released downstream following dam removal. The volume of sediment transported downstream would be greatest under Alternative B compared to other alternatives. The greatest magnitude and duration of sediment deposition and associated impacts to salmonids are therefore expected under this alternative (except for impacts related to summer and fall TSS levels, which would likely be greatest for alternatives that entail extensive sediment excavation, especially Alternative A).

*Upstream impacts and channel adjustment in the reservoir-influenced reach*
Under this alternative, sediment stored behind Marmot Dam would be released downstream following dam removal, and the slope in the reservoir reach would gradually flatten out and return to that of the pre-dam channel bed over a period of several years, with the greatest change occurring in the first year following removal. During the adjustment period, the channel in the reservoir reach is expected to be highly unstable and mass wasting of banks may occur. After the first several years, however, the rate of erosion would be low and instability would be reduced. Bank slumping could create barriers to upstream migration of adult salmonids, especially under low flow conditions. The likelihood that barriers to migration will form in this reach is uncertain, but if a barrier did form, it could adversely affect salmonids that spawn in the upper

watershed and must pass through this reach to arrive at their spawning grounds, including spring chinook, winter and summer steelhead, and coho.

*Downstream sediment deposition: Reaches 1-5*
Modeling indicates that, in the first year following removal, coarse sediment would quickly form a debris fan in the portion of Reach 1 immediately downstream of the dam, with small amounts of deposition predicted further downstream in Reach 1 and in Reach 3. In subsequent years, additional sediment would move out of the reservoir and downstream from the debris fan, resulting in a gradual increase in deposition thickness of coarse sediment further downstream in Reach 1, reaching a maximum of about 3 ft (1 m) on a reach-averaged basis. Coarse sediment is predicted to travel quickly through most of the Sandy River gorge (Reach 2), which has a steep gradient and high confinement, with aggradation increasing in the downstream end of the gorge and the upstream end of Reach 3 from Years 1 through 10 following dam removal. Aggradation is predicted to gradually build to a maximum predicted thickness of about 5–6.5 ft (1.5–2 m) in the upper portion of Reach 3 (6–8 mi [9–13 km] downstream of the dam), where the channel widens and decreases in gradient.

In Reach 1, sediment deposition and resulting channel instability would result in the loss of nearly all salmonid habitat values for several years following dam removal. This reach is not known to be heavily used for spawning by any salmonid species, although some spring chinook spawning does occur here. Habitat suitable for juvenile rearing of coho, spring chinook, and steelhead is present, although the majority of rearing habitat for these species is believed to occur in the upper watershed.

Changes in habitat conditions following dam removal are expected to be minimal in Reach 2. In Reach 3, sediment deposition is expected to be greatest in the upstream end of the reach (i.e., at the outlet of the gorge). The magnitude of this impact is expected to be small because little spawning is thought to occur in this reach under current conditions. Limited coarse sediment aggradation is predicted in the lower portion of Reach 3 and downstream of the Bull Run River confluence (in Reach 4); aggradation in these reaches is not likely to be distinguishable from natural depositional processes.

Modeling of sand transport predicts sand aggradation of up to about 1.3 ft (0.4 m) in Reach 5, which has a very low gradient, with the greatest aggradation expected to occur in the first year following removal of Marmot Dam and in the lower 2 mi (3 km) of the reach. This roughly corresponds to the location of the gravel/sand transition area in the Sandy River. The magnitude of sand aggradation in Reach 5 is difficult to predict because of the complex hydraulics created by the backwater effect of the Columbia River and the uncertainty of the combined flow conditions in the Columbia and Sandy rivers following dam removal. Substantial aggradation in this reach could result in creation of barriers to adult salmonid migration, especially under low flow conditions. No sand aggradation is predicted further upstream, although it is likely that some infiltration of sand into the channel bed interstices and transient sand deposition will occur in upstream reaches.

*Impacts of downstream suspended sediment and turbidity*
After the dam is removed and the channel begins to incise into the reservoir deposit, sand and fine sediment will be mobilized from the reservoir deposit, traveling downstream mostly as suspended load and creating elevated TSS concentrations. The magnitude of sand transport out of the reservoir is expected to be largest in the first winter following dam removal, although sand transport out of the reservoir would likely continue for approximately a decade following dam removal. For Alternative B, release of fine

sediment (< 2 mm) from the reservoir would result in increased TSS concentration (relative to reference conditions) during high flow conditions occurring from November through June. Predicted TSS concentration following dam removal is not predicted to change relative to the assumed reference condition during July through October. TSS levels associated with dam removal are predicted to be relatively low because the fine sediment in the reservoir deposit is armored by a coarser surface layer and would therefore be released gradually, rather than as one large pulse. Modeling indicates that, between Marmot Dam and the Bull Run confluence, peak TSS of about 500 ppm would occur in the first winter following dam removal.

The potential impacts of the predicted increase in TSS concentration on adult and juvenile salmonids are highly uncertain. For juvenile salmonids, the predicted increase in TSS concentration could result in short-duration physiological stress, reduced feeding rate and reduced growth rate during extreme TSS peaks associated with high flow events.

**Alternative C: Removal of top of dam in Year 1, complete dam removal in Year 2 with sand layer excavation up to a point 2,700 ft upstream of Marmot Dam.**

This alternative entails removal of Marmot Dam over a 2-year period, with excavation of most of the sand portion of the reservoir sediment deposit to be conducted during the second year. In the first year, the top part of the dam would be removed, allowing a portion of the upper gravel layer of the reservoir deposit to be transported downstream while retaining most of the sand layer behind the dam. In the second year, remaining sediment in the reservoir would be excavated to the bottom of the sand layer, up to a point 2,700 ft (830 m) upstream of Marmot Dam, and then the rest of the dam would be removed. After this time Alternative C can be considered the same as Alternative D in terms of downstream transport patterns and remaining sediment volume in the reservoir.

Numerical modeling was used to test the effects of lowering Marmot Dam by different amounts in Year 1 on sediment transport patterns and to estimate downstream deposition patterns under these scenarios. This modeling indicated that the optimal level of lowering under this alternative appears be to about 30 ft (9 m), in terms of balancing retention of the sand layer versus allowing sufficient downstream gravel transport to facilitate excavation in the summer following dam lowering.

*Upstream impacts and channel adjustment in the reservoir-influenced reach*
Between lowering of the dam in Year 1 and complete removal in Year 2, fish passage would need to be provided over the dam and portions of the reservoir-influenced reach would not be usable for salmonids because of downstream sediment transport (and associated instability) and mechanical excavation. After excavation of the sand layer during the second construction season and removal of the rest of the dam, reservoir erosion patterns, the duration of unstable conditions in the reservoir reach, and the potential for formation of barriers to migration would be the same as under Alternative D.

*Downstream sediment deposition: Reaches 1-5*
Modeling results show that if the top 30 ft (9 m) of Marmot Dam were removed, approximately 25% of the reservoir sediment would be transported downstream in Year 1 under average hydrologic conditions, consisting mostly of gravel but including a small sand component. This result is similar to the amount of reservoir erosion predicted in Year 1 under Alternative B, and downstream deposition patterns and anticipated impacts to salmonids and salmonid habitats are therefore predicted to be similar under

Alternatives B and C in Year 1. In subsequent years, aggradation in downstream reaches, and associated salmonid impacts, would be less than Alternative B because of the excavation of reservoir sediment. Following removal of the rest of the dam and excavation of sediment up to 2,700 ft (830 m) upstream, downstream transport and deposition patterns would be similar to Alternative D, although the overall magnitude of coarse sediment aggradation would be slightly greater under Alternative C because of downstream transport of sediment in Year 1.

*Impacts of downstream suspended sediment and turbidity*
Downstream transport of sand from the reservoir and excavation of the sand layer would result in increased turbidity and suspended sediment concentrations. The magnitude of downstream sand transport, downstream sand deposition, TSS, and associated impacts to salmonids in Year 1 is predicted to be similar to the amount predicted under Alternative B. Downstream sand transport, TSS (including excavation-related turbidity in Year 2), and associated salmonid impacts after Year 1 would be similar to Alternative D.

### Alternative D: Removal of sediments to the bottom of the sand layer and to a point 2,700 ft upstream of Marmot Dam

This alternative entails removal of the dam, canal, and fish ladder in one season and concurrent removal of accumulated sediments from the dam to a point about 2,700 ft (830 m) upstream. This would allow excavation of most of the fine sediment in the reservoir, as under Alternative C, and of the majority of the overall amount of sediment in the reservoir.

*Upstream impacts and channel adjustment in the reservoir-influenced reach*
After sediment excavation, the channel would adjust towards the pre-dam gradient as the remaining material in the reservoir is transported downstream, including into the reach that had been excavated. The duration of this adjustment period under Alternative D is expected to be longer than Alternative A, shorter than Alternative B, and similar to Alternative C. Compared to Alternative B, there is a lesser magnitude of channel and bank instability expected during the adjustment period, and the risk of impairment of fish passage during this adjustment period (e.g., through channel instability) is considered to be reduced due to the relatively small volume of sediment remaining after excavation.

*Downstream sediment deposition: Reaches 1-5*
Downstream transport of the sediment remaining in the reservoir following sediment excavation and dam removal would initially result in deposition in the downstream portion of the reservoir (from which sediments would have been previously excavated), rather than in Reach 1. The magnitude of sediment deposition and associated impacts to salmonids and salmonid habitats in Reaches 1–4 is expected to have a smaller magnitude and shorter duration than under Alternatives B and C, although sediment deposition in Reach 1 could result in the loss or degradation of salmonid habitats. The potential for substantial changes in channel morphology or blockage of side-channel areas in Reaches 3 and 4 is low under Alternative D. Because most sand would be removed from the reservoir by excavation, sand deposition in Reach 5 is expected to be less than Alternative B, and the risk of sediment accumulation sufficient to block fish passage is likely minimal.

*Impacts of downstream suspended sediment and turbidity*
Sediment excavation from the reservoir area may result in substantial increases in turbidity and TSS

concentrations downstream of the dam during the summer and fall construction period. The magnitude of this turbidity and TSS increase cannot be modeled but may be similar to those described for Alternative A.

Although a large amount of the sand in the reservoir would be excavated under Alternative D, some sand would likely remain in the channel bed and in the reservoir deposit following dam removal. In the first year following dam removal, downstream transport of this sediment is predicted to result in magnitudes of sand aggradation and TSS that are similar to those described for Alternative B. Overall, however, increases in suspended sediment concentrations following dam removal under Alternative D are expected to be lower in magnitude and shorter in duration than under Alternative B and similar to Alternative C.

### Summary of Impacts of Removing Marmot Dam and Potential Population Responses

In this section, the predicted geomorphic and physical habitat responses described above for the various dam removal alternatives are qualitatively linked with the potential impacts they would have on populations of anadromous salmonids in the Sandy River basin. Assessment of potential impacts and population responses was based on linking conclusions about geomorphic impacts with information about life history, distribution and habitat for each of the anadromous salmonid species and runs in the Sandy River basin. For a variety of reasons, as described in this report, assessing population impacts is difficult. This discussion is included in the report as an aid to conceptualizing the relative potential impacts of the alternatives for removal of Marmot Dam on salmonid population dynamics in the Sandy River basin in order to assist selection of a preferred alternative for dam removal as part of the project decommissioning process.

Key conclusions about potential impacts are summarized below and in Table ES-1:

- Removal of Marmot Dam could result in the following types of impacts: potential impairment of passage in Reach 1 and the reservoir reach (spring chinook, coho, winter steelhead, cutthroat trout), filling of pools that may be used for adult holding in Reaches 2 and 3 (spring chinook, summer steelhead), coarse sediment deposition and sand infiltration in potential spawning areas in Reaches 3 and 4 (fall chinook, winter steelhead), sediment deposition in rearing habitat in Reaches 1, 3 and 4 (all species), reduction in food supply downstream of the dam (all species), and blocked passage in Reach 5 (all species). The likelihood of each of these impacts occurring at sufficient magnitudes to adversely affect salmonid populations under the various dam removal alternative are summarized in Table ES-1.

- Spring chinook, winter steelhead, coho salmon, and cutthroat trout are expected to benefit from improved adult upstream passage conditions, reduced mortality of juveniles (especially fry) during downstream migration, and restoration of the natural hydrologic regime between Marmot Dam and the Bull Run River.

- Loss or degradation of habitats for some species may occur, although such impacts are not expected to affect any key habitat areas. For example, habitats in Reach 1 that appear to support limited spawning and rearing under current conditions will likely be eliminated following dam removal, but these areas are not likely important to salmonid populations in the basin given their short length and the presence of other reaches with more extensive habitats.

- Juveniles and adults in the Sandy River downstream of Marmot Dam could be adversely affected by increases in total suspended sediment concentration (TSS) associated with (1) sediment excavation during the summer and fall work period, and/or (2) downstream fine sediment transport from the reservoir following dam removal, with TSS increases predicted to occur during periods with higher flows. The potential impacts of increases in TSS concentration on adult and juvenile salmonids are highly uncertain but could include reduced juvenile growth rates, reduced food supply, physiological stress, impaired adult homing, and possibly mortality of fish present in the lower river. The likelihood of TSS-related impacts under the various removal alternatives is summarized in Table ES-1.

**Table ES-1. Summary of key potential impacts on anadromous salmonid populations and habitats expected under the four alternatives proposed for removal of Marmot Dam.**

| Impact | Species and Runs Affected | Alternative A | Alternative B | Alternative C | Alternative D |
|---|---|---|---|---|---|
| Permanent loss of low-gradient spawning habitat in reservoir reach | spring chinook<br>fall chinook | would occur | would occur | would occur | would occur |
| Short-term blockage of adult passage in reservoir reach and/or Reach 1 (due to sediment deposition and/or channel destabilization) | spring chinook<br>coho<br>winter steelhead<br>summer steelhead | very unlikely | possible | unlikely | very unlikely |
| Loss or degradation of pool habitat, and side-channel habitat through burial in Reach 1 | spring chinook<br>coho<br>winter steelhead<br>summer steelhead | no impact | very likely | very likely | possible |
| Loss of suitable pool habitat for adult holding because of partial infilling of pools in Reach 2 | spring chinook<br>summer steelhead | no impact | possible | unlikely | very unlikely |
| Loss or degradation of spawning habitat in Reach 3 due to sand infiltration and burial or scour of redds. | fall chinook<br>winter steelhead | no impact | likely | possible | unlikely |
| Loss or degradation of potential rearing habitat in Reach 3 due to sand infiltration and burial of low-velocity rearing habitats | all species and runs, especially fall chinook and winter steelhead | no impact | likely | possible | unlikely |
| Loss or degradation of spawning habitat in Reach 4 due to sand infiltration and burial or scour of redds | fall chinook<br>winter steelhead | no impact | possible | unlikely | very unlikely |
| Loss or degradation of potential rearing habitat in Reach 4 due to sand infiltration and burial of low-velocity rearing habitats | all species and runs, especially fall chinook and winter steelhead | no impact | unlikely | very unlikely | very unlikely |
| Loss or degradation of spawning habitat in Reach 5 due to sand infiltration and burial or scour of redds | fall chinook<br>winter steelhead | no impact | unlikely | very unlikely | very unlikely |
| Loss or degradation of potential rearing habitat in Reach 5 due to sand infiltration and burial of low-velocity rearing habitats | all species and runs, especially fall chinook and winter steelhead | no impact | very unlikely | very unlikely | very unlikely |

| Impact | Species and Runs Affected | Alternative A | Alternative B | Alternative C | Alternative D |
|---|---|---|---|---|---|
| Reduced growth rates due to reduced macroinvertebrate food supply because of burial or scour | all species and runs | no impact | unlikely | very unlikely | very unlikely |
| Impairment of passage through Reach 5 due to sand deposition | all species and runs | no impact | possible | possible | possible |
| Exposure to increased TSS concentration downstream of Marmot Dam during sediment excavation (July through October) | juveniles (all species and runs except cutthroat trout) | would occur | unlikely | would occur (Year 2) | would occur |
| | (adult) fall chinook spring chinook coho summer steelhead cutthroat trout | would occur | unlikely | would occur (Year 2) | would occur |
| | adult winter steelhead | unlikely | unlikely | unlikely | unlikely |
| Potential stress or injury resulting from exposure to increased TSS concentration downstream of Marmot Dam after removal | all species and runs | unlikely | possible | possible | possible |

## Impact Assessment of Little Sandy Dam Removal

Approximately 4,500–9,400 $yd^3$ (3,400–7,200 $m^3$) of sediment are stored behind Little Sandy Dam and would be released downstream into the Little Sandy River following its removal. This sediment consists of mostly gravel (50–60% of the total) and sand (35–45%), with small amounts of cobble and silt (Squier Associates 2000). The sediment stored behind Little Sandy Dam is less than 1% of the volume of sediment accumulated behind Marmot Dam, and no sediment transport modeling was conducted for Little Sandy Dam.

Although sediment release from Little Sandy Dam may result in some changes to habitat conditions, dam removal and discontinuation of flow diversions will substantially improve conditions for anadromous salmonids and other native aquatic organisms in the Little Sandy River by restoring natural flows in the lower Little Sandy River and restoring habitat connectivity with the upper basin. These habitat benefits are expected to far outweigh any adverse sediment-related effects in the Little Sandy River.

Following removal of Little Sandy Dam, sediment stored behind the dam would be expected to initially move into the reach immediately downstream of the dam (extending about 0-0.3 mi [0-0.5 km] downstream), causing coarse sediment aggradation that varies in magnitude with local shear stress conditions. Gravel deposited downstream of the dam would likely initially be highly mobile and therefore unsuitable for spawning, although small increases in spawning habitat may occur in the long term in this reach. Sediment transport capacity is high in this reach, and downstream movement of this sediment would likely be relatively rapid.

Further downstream (0.3-1.7 mi [0.5-2.7 km] downstream of Little Sandy Dam), the gradient and confinement of the Little Sandy River increase, creating high shear stresses and sediment transport capacity, and channel morphology that appears highly resilient to changes in sediment and water supply. Sediments released from behind the dam are expected to travel quickly through this reach, with some localized coarse sediment aggradation, and into the Bull Run River, and adverse impacts to salmonid habitat in this reach are not expected. Overall, sediment release from Little Sandy Dam is expected to have limited geomorphic effects on the downstream channel because of the small amount of sediment stored behind the dam, the composition of the sediment, and the steep gradient, high confinement, and short distance of this reach. The effects of restoring natural flows to the lower Little Sandy River will likely be more morphologically important, and may include mortality of riparian vegetation that has encroached into the channel and increased mobility of bed sediments.

## Potential Contingency Measures Associated with Removal of Marmot Dam

Because of the uncertainties involved in predicting the impacts of removing Marmot Dam on anadromous salmonids and other aquatic organisms, particularly for removal options in which greater amounts of sediment would be released, development of contingency plans to mitigate some potential impacts may be merited. Three primary areas of potential impacts representing high enough risk to resources of concern, particularly listed salmonids, to merit development of contingency plans have been identified: (1) fish passage problems caused by headcutting or bank failure in the reach upstream of Marmot Dam and/or by aggradation immediately downstream of the dam; (2) impaired salmonid access to side-channel habitats and/or tributaries in Reaches 3 and 4; and (3) fish passage problems caused by sand deposition in the Sandy River delta (i.e., the downstream portion of Reach 5). The potential need for these contingency measures would vary depending on the alternative selected for removal of Marmot Dam, and details would be developed by PGE subsequent to further agency consultation.

# 1. INTRODUCTION

The Bull Run Hydroelectric Project is located in the Sandy River basin, which drains into the Columbia River and is located about 30 mi (48 km) east of Portland, Oregon on the western slopes of the Cascade Range (Figure 1). Portland General Electric (PGE), the holder of Federal Energy Regulatory Commission (FERC) license no. 477 for the Bull Run Hydroelectric Project, has elected to pursue decommissioning rather than relicensing of the project.

PGE's Bull Run project consists of Marmot Dam, Little Sandy Dam, associated flumes and canals, Roslyn Lake, and the Bull Run powerhouse. Marmot Dam is located on the Sandy River at River Mile (RM) 30 and has an upstream drainage area of about 260 $mi^2$ (680 $km^2$). This dam was originally completed in 1913; the original wood crib, rock-filled structure was replaced in 1989 by a 47-ft (14-m) high concrete dam. Marmot Dam is equipped with a fish ladder for upstream passage and a juvenile bypass facility for downstream passage. Approximately 980,000 $yd^3$ (750,000 $m^3$) of sediment are stored behind Marmot Dam (Squier Associates 2000). The impoundment formed by Marmot Dam is currently filled with sediment, and coarse and fine sediment is transported over the dam. Little Sandy Dam is a 16-ft (5-m) high concrete dam completed in 1912 on the Little Sandy River, a tributary to the Bull Run River with a drainage area of 25 $mi^2$ (65 $km^2$). This dam is located 1.7 mi (2.7 km) upstream of the mouth of the Little Sandy River and diverts up to 800 cfs (22.6 cms) from the upper 22.3 $mi^2$ (58 $km^2$) of the Little Sandy River basin. Little Sandy Dam does not have fish passage facilities and blocks access to approximately 6.5 mi (10.5 km) of habitat that were historically accessible to anadromous salmonids (ODFW 1997a). Little Sandy Dam impounds a small reservoir with a low storage capacity; approximately 4,500 $yd^3$ (3,400 $m^3$) of mostly coarse (>2 mm in diameter) sediment is stored behind the dam. The City of Portland also operates two dams on the Bull Run River that supply water to the City (Figure 1).

PGE requested Stillwater Sciences to evaluate the geomorphic and biological effects of removing Marmot and Little Sandy Dams as part of decommissioning the Bull Run Hydroelectric Project. The primary focus of this study has been on predicting downstream sediment transport and deposition associated with the release of stored sediment under various dam removal alternatives and identifying potential impacts on anadromous salmonids and their habitat. The assessment of potential biological impacts has focused on anadromous salmonid species currently known to occur in the Sandy River basin: chinook salmon (spring-run and fall-run), steelhead (winter-run and summer-run), coho salmon, and coastal cutthroat trout. Potential impacts on salmonids related to changes in flow regime and improved fish passage have also been addressed, but in a more limited fashion. While this is a preliminary final report, it is being circulated at this time to inform agencies and other interested parties about the technical studies performed by Stillwater Sciences for PGE as part of the project decommissioning process.

PGE engineers, in consultation with the interested agencies and other member of the Bull Run Working Group, developed four alternatives for removal of Marmot Dam, each of which differs in the amount of sediment released downstream. Stillwater Sciences' analysis includes comparison of the potential geomorphic and biological impacts of these dam removal alternatives. These alternatives are described briefly below (additional details on the engineering methods proposed for each of these dam removal alternatives are provided in the Draft Project Decommissioning Report [PGE 2000a]):

- **Alternative A - Remove all sediment to a point 5,500 ft (1,680 m) upstream of Marmot Dam.** This alternative entails excavation of approximately 980,000 $yd^3$ (750,000 $m^3$) of sediment and concurrent removal of the dam in one season. Before removal of the dam, a cofferdam would be built above the dam and a barrier would be installed below Marmot Dam. After removal of the dam (using controlled blasting), the fish ladder, and the old timber crib dam, sediment would be excavated. Excavation would occur by transfering the stream from side to side as required to facilitate use of heavy equipment to remove sediment.

- **Alternative B - Single-season dam removal with minimal sediment removal.** This alternative entails removal of Marmot Dam and associated facilities in one season, with removal of sediment only as required for construction activities. As with Alternative A, a cofferdam would be built above the dam and a barrier would be installed below the dam to facilitate removal of the dam, but no sediment would be excavated from upstream of the cofferdam. Approximately 980,000 $yd^3$ (750,000 $m^3$) of reservoir sediment would be released downstream following removal of the cofferdam (the actual amount released downstream may be somewhat smaller because some sediment would be excavated to facilitate construction work and some sediment may remain in place within the reservoir reach).

- **Alternative C - Removal of top of dam in year 1, complete dam removal in year 2 with sand layer excavation to a point 2,700 ft (830 m) upstream of Marmot Dam.** This alternative entails removal of Marmot Dam over a 2-year period, with excavation of most of the sand portion of the reservoir sediment deposit to be conducted during the second year. In the first year, the top part of the dam would be removed. In the second year, sediment in the reservoir would be excavated to the bottom of the sand layer and the rest of the dam would be removed. The amount of sediment that would be transported downstream under this option would depend on the flows occurring in the first winter following removal of the top of the dam and before the bottom portion is removed.

- **Alternative D - Remove sediment to the bottom of the sand layer and to a point 2,700 ft (830 m) upstream of Marmot Dam.** This alternative entails removal of the dam, canal, and fish ladder in one season and concurrent removal of accumulated sediments from the back of the dam to a point about 2,700 ft (830 m) upstream. Under this alternative, approximately 75% of the reservoir sediment would be excavated (about 730,000 $yd^3$ [560,000 $m^3$]), including most of the fine sediment (i.e., sand and silt). The remaining reservoir sediment (about 250,000 $yd^3$ [190,000 $m^3$]), most of which is believed to consist of coarse material, would be available for downstream fluvial transport.

As part of the decommissioning of the Bull Run project, Little Sandy Dam will be removed during a low-water season using controlled blasting and conventional air hammers and excavating equipment. No cofferdam will be used, and 6 months will be required to complete removal work. All sediment that is accumulated behind the dam will be transported downstream following removal of Little Sandy Dam.

The following sections describe our analytical approach and methods, the current condition of the watershed, and the potential impacts of dam removal. In Section 2, we describe the methods used in the numerical modeling of sediment transport and the overall geomorphic and habitat analysis. In Section 3, we discuss the existing ecological conditions of the Sandy River basin. In Section 4, we describe the potential impactsof removal of the Bull Run project on stream channel geomorphology, anadromous fish habitat, and anadromous fish populations. Some of the potential impacts of dam removal identified in Section 4 might be mitigated by implementing certain contingency measures, which are briefly discussed in Section 5.

# 2. APPROACH TO ASSESSMENT OF POTENTIAL GEOMORPHIC AND BIOLOGICAL IMPACTS OF DAM REMOVAL

Stillwater Sciences' evaluation of the geomorphic and biological effects of removal of Marmot Dam consists of three major components: (1) numerical modeling to estimate sediment transport and deposition dynamics downstream of the dam for various removal alternatives; (2) interpretation of model results, field reconnaissance, aerial photograph interpretation, and review of available reports and surveys to predict potential geomorphic changes in the Sandy River following dam removal, and (3) discussion of potential impacts of the geomorphic changes associated with dam removal on salmonid habitats and populations in the Sandy River basin. The geomorphic assessment evaluated anticipated changes in channel morphology upstream and downstream of the dam, including changes related to deposition of sediment released from the reservoir and changes in channel gradient and the time period within which these changes will likely occur. The biological assessment evaluates the potential effects of sediment release and alteration of channel morphology on anadromous salmonids and their habitat. In addition to the analysis of Marmot Dam, we also evaluated potential geomorphic and biological effects of removing Little Sandy Dam. The methods used in these assessments are discussed in further detail below.

## 2.1 Numerical Modeling to Predict Characteristics of Sediment Transport Following Dam Removal

Stillwater Sciences developed one-dimensional numerical models of fine and coarse sediment transport to quantify the routing of sediment from behind Marmot Dam downstream through the Sandy River. The numerical modeling allows comparative assessment of sediment transport characteristics under different dam removal methods and river conditions. This modeling effort applies published sediment transport equations to assess the release of coarse and fine sediment from Marmot Reservoir to downstream reaches of the Sandy River following dam removal. Model results include predictions of the time required for sediment to be cleared from the reservoir area, time required for sediment to travel out of various subreaches of the Sandy River, thickness of downstream sediment deposits in various reaches, and total suspended sediment concentrations following dam removal. Because coarse and fine sediment transport occur over different time scales (years vs. days) and in different modes (bedload vs. suspended load), transport of fine sediment (including sand) was modeled separately from coarse sediment (gravel and larger). A technical report describing the numerical modeling, including the governing equations for the models, is provided in Stillwater Sciences (2000). This modeling effort has been peer-reviewed by several experts in sediment transport modeling (see Appendix A).

The modeling incorporated four basic types of input data: (1) channel gradients, based on a longitudinal profile of the Sandy River from 3 mi (4.8 km) upstream of Marmot Dam (RM 33) downstream to the Columbia River (RM 0); (2) channel widths, measured by Stillwater Sciences in the field and from aerial photographs; (3) sediment characteristics of the reservoir deposit behind Marmot Dam, based on sampling by Squier Associates (2000); and (4) daily discharge values from the USGS gage just upstream from

Marmot Dam (station number 1413700).

Numerical modeling was completed for three of the four alternatives for removal of Marmot Dam: it that alternative calls for all sediment to be excavated prior to dam removal; therefore, very little reservoir sediment would be released. In addition, no numerical modeling was conducted to assess sediment release following removal of Little Sandy Dam because of the relatively small amount of material stored behind Little Sandy Dam.

Questions that were explored with the numerical models for different dam removal alternatives include:

- How would sediment (both suspended and bedload) travel over the coarse alluvial and bedrock channel bed of the Sandy River?
- How would transport distance from the dam affect suspended sediment concentrations and the deposition of coarse and fine sediment following dam removal? Is there a distance downstream at which no detectable changes would be expected?
- Would substantial bed aggradation occur following dam removal, or is the sediment transport capacity in reaches downstream of Marmot Dam high enough that little aggradation would be expected to occur? If aggradation does occur, how long would it last and in what reaches would it be most prominent?
- How would discharge conditions during and following dam removal affect downstream sediment transport and deposition characteristics?

While numerical modeling is able to predict sediment transport rates and cross-section and reach-averaged depths of sediment deposits, current state-of-the-art modeling typically cannot predict complex three-dimensional geomorphic responses over long stretches of river, such as depositional patterns in channel cross section, local changes in sediment particle size distribution, infiltration of sand into the channel bed, or changes in the mobility of the existing channel bed downstream of Marmot Dam.

### 2.1.1 Sand model

Stillwater Sciences developed a one-dimensional model of sand transport from reservoir deposits based on Brownlie's bed material equation (Brownlie 1981). Brownlie's equation was developed for sand-bedded rivers but was used here because no sediment transport equations exist to calculate sand transport in a bedrock or coarse-sediment-dominated river. We hypothesize that this approach provides reasonable estimates of potential sand transport rates provided that appropriate roughness adjustments are included. In applying Brownlie's equation of sediment transport and friction, the roughness height was modified to account for the bedrock, boulders, and gravels in the bed of the Sandy River (in cases where the channel is not fully covered by sand). Some basic assumptions of this model include:

- sand transport can be represented as transport over a rough bedrock surface (i.e., the existing gravel bed of the Sandy River remains immobile with respect to sand transport);
- silt is transported as suspended load and will not be deposited in the channel bed;
- sediments are not cohesive; and
- the rate of sediment release from the reservoir is completely dependent on the transport capacity of gravel from the reservoir (i.e., data on sand transport out of the reservoir are derived from the gravel model).

Using the sediment release information generated by the gravel model as input, the sand model predicts thickness of sand deposition on a reach-averaged and cross-section-averaged basis, including changes in deposition thickness through time. The model also predicts suspended sediment concentrations through time along the river's longitudinal profile following dam removal. This information provides a basis for analyzing the effects of acute and chronic exposure to suspended sediment on anadromous salmonids in the Sandy River following dam removal. The sand transport model is written in FORTRAN as a DOS application. Additional technical detail on the methods used in the sand model is provided in Stillwater Sciences (2000).

### 2.1.2 Gravel model

Stillwater Sciences also developed a coarse sediment transport model that is similar to those of Cui et al. (2000) and Cui and Parker (2000), with minor adjustments made to accommodate the specific conditions of the Sandy River and Marmot Dam. The model of Cui et al. (2000) simulated the evolution of gravel pulses in a laboratory flume, and the model of Cui and Parker (2000) extended the former to include abrasion as a factor affecting evolution of gravel pulses to simulate conditions found in natural streams. Hansler et al. (1998) successfully simulated the evolution of a large landslide in the Navarro River, California with an early version of the Cui and Parker (2000) model. The Sandy River gravel model, as well as the models of Cui et al. (2000) and Cui and Parker (2000), are based on Parker's surface-based bedload equation (Parker et al. 1982; Parker 1990a, b; 1991a, b), which calculates sediment transport rate and bedload grain-size distribution if surface grain-size distribution and shear stress are given. Parker's equation has been tested in both laboratory flume (Cui et al. 1996) and natural river situations and has been applied in various simulations of gravel-bed rivers (Cui and Parker 1997, 1998).

The gravel transport model is written in FORTRAN as a DOS application. Reservoir stratification is accounted for by dividing the reservoir deposit vertically into layers and assigning each layer a different grain size distribution, based on the results of sediment coring by Squier Associates. The gravel model predicts change in bed elevation on a reach-averaged and cross-section-averaged basis. The gravel model also predicts sand release from the reservoir (given as a daily average value at the dam site) for use as input data to the sand model. Additional technical detail on the methods used in the gravel model is provided in Stillwater Sciences (2000).

### 2.1.3 Hydrologic scenarios used in numerical modeling

As part of numerical modeling of sediment release following removal of Marmot Dam, Stillwater Sciences evaluated the effects of various flow regimes in the years following dam removal on sediment transport and deposition dynamics. The flows that occur following dam removal, particularly during the first year after removal, will have an important influence on the time required for downstream transport of reservoir sediment, subsequent deposition patterns, and duration of impacts to aquatic organisms. Stillwater Sciences developed scenarios for wet, average, and dry hydrologic conditions for input into the numerical modeling. The hydrologic scenarios account for both peak-flow magnitude and overall water yield, both of which influence sediment transport dynamics. Discharge data used as input for the modeling are from the USGS Sandy River near Marmot gauge (station number 1413700), which is located 0.3 mi (0.5 km) upstream of Marmot Dam, and the Sandy River below Bull Run gauge (station number 14142500), which is located 0.1 mi (160 m) downstream of the Sandy River's confluence with the Bull Run River.

Peak discharges were fit to a Log Pearson III distribution and average annual discharges were fit to a normal distribution in order to predict the return period of future discharges (the exceedance probabilities are equivalent to the inverse of the return period). Based on this analysis, we selected discharge records from representative water years, with exceedence probabilities for both annual peak discharge and average daily discharge corresponding to wet, average, and dry conditions, to use as input for numerical modeling. Selection of water years representative of different hydrologic conditions (wet, average, dry) is described further in Stillwater Sciences (2000).

### 2.1.4 Uncertainties in the numerical modeling

The sediment transport models developed for the Sandy River are state-of-the-art models based on tested sediment transport equations, and the models have been reviewed by experts in the field of sediment transport (see Stillwater Sciences 2000). Some uncertainty is inherent in numerical modeling, however. Many hypotheses are incorporated in the models, both in terms of theoretical development (i.e., reflecting uncertainties in current scientific understanding about the mechanics of sediment transport) and input data. The models are one-dimensional, providing predictions of sediment deposition thicknesses that are averages over the width of the channel cross section and that represent deposition over the existing channel bed. Model predictions do not account for local variations in shear stress caused by features such as deep pools, bedrock outcrops, or large boulders, and the amount of sediment actually deposited may be substantially higher or lower than predicted by the model in localized areas of the channel. The modeling also does not account for certain depositional processes, such as infiltration of fine sediment into the interstices of the channel bed.

The model results are most applicable on a reach-scale and time-averaged basis. Model results reflect a set of hydrologic conditions used as input, which was based on historical flow data from the Sandy River near Marmot gaging station. We modeled a range of hydrologic scenarios, as discussed in Section 2.1.3, to provide insight into the potential effects of different flow scenarios on sediment transport and deposition in the first year following dam removal. Use of a different set of hydrologic conditions would alter certain model predictions, such as the rate of sediment movement out of the reservoir reach. Although the specific hydrologic conditions that occur after dam removal will invariably be different than those used in the model, and extreme flow events were not modeled, the hydrologic scenarios we modeled represent a range of hydrologic conditions that could reasonably be expected to occur in the Sandy River following dam removal.

The gravel and sand models require input parameters on a range of physical characteristics that influence sediment transport in the Sandy River, and these input data contain varying levels of uncertainty. For those input parameters to which the model is most sensitive (i.e., channel gradient, channel width, grain size distribution of the reservoir deposit, and water discharge), we used data collected specifically for this project or that were already available (water discharge). Uncertainty in these data should be relatively small. For other input parameters, such as background gravel and sand transport rates, and abrasion rates in the Sandy River, existing data were not available and new data were not collected for this project. For many of these input parameters, only order-of-magnitude estimates are required for the models, and we therefore used rough assumptions based on our observations of the Sandy River and on published data from elsewhere in the region. Many of the assumptions used in the modeling are conservative with respect to predicted impacts; for example, model runs assume a slightly greater amount of sediment would be released from behind Marmot Dam than volumes estimated by PGE and Squier Associates (2000).

A key uncertainty in the model relates to the expected pattern of sediment release from the reservoir. The model assumes laterally uniform sediment transport out of the reservoir, with sediment mobilization and transport derived from Parker's (1990a) sediment transport equation. Erosion of reservoir sediment would in fact likely result in incision of a channel within the valley walls, although the valley width is relatively narrow in the reservoir reach (see Section 4.1.2 for further discussion of reservoir erosion patterns). In order to address uncertainties in modeling of sediment transport from the reservoir, we performed sensitivity tests to evaluate how different rates of sediment delivery from the reservoir to downstream reaches affect the model results, thereby simulating incision of a channel through the reservoir sediment deposit. We also performed sensitivity analyses examining various hydrologic conditions, various assumptions about the grain-size distribution of reservoir sediment, and variations in downstream channel roughness characteristics. More detailed information on these sensitivity analyses is provided in Stillwater Sciences (2000).

Although the models upon which this effort is based (e.g., Cui et al. 2000, Cui and Parker 2000) have been tested in flumes and in the field, the accuracy of the model developed for dam removal in the Sandy River has not been verified (data collected following removal of Marmot Dam will permit this), and model results should be interpreted accordingly. We have used professional judgement (including input from Dr. William Dietrich [University of California-Berkeley] and Dr. Tom Lisle [USDA Forest Service, Redwood Sciences Laboratory]) and field observations of the Sandy River to interpret model results in terms of expected geomorphic effects in the Sandy River (for example, discussing how predicted reach-averaged deposition patterns may be manifested in the river; see Section 4).

It should be emphasized that this is a state-of-the-art modeling effort, and despite the uncertainties, is unique in its ability to provide predictions of sediment transport and deposition over large temporal and spatial scales and to allow comparison of various dam-removal alternatives. Modeling results are particularly well-suited for comparing impacts expected under the different alternatives. When each dam removal alternative is modeled using identical input data for flows, grain size distribution of reservoir sediment, and other parameters, the results assist evaluation of the relative risks of environmental impacts associated with each alternative.

## 2.2 Geomorphic and Biological Assessment

Stillwater Sciences developed an integrated geomorphic and biological assessment of the effects of removing Marmot and Little Sandy dams on upstream and downstream channel morphologies and aquatic habitats. The assessment of the channel’s geomorphic responses includes evaluation of the effects of releasing sediment from the dams on channel geometry, gradient, bed morphology, and bed particle size characteristics, as well as estimates of the time frame(s) of geomorphic responses. We also evaluate how these geomorphic changes may adversely affect habitat conditions for migration, spawning, incubation, and rearing of anadromous salmonid species, and how salmonid populations may respond to these habitat changes. These evaluations are based on results of numerical modeling, review of existing information on channel morphology and salmonid habitat in the Sandy River basin, analysis of aerial photographs of the Sandy River, and field observations. The following sections elaborate on each of these steps.

### 2.2.1 Review of existing information on geomorphic characteristics and salmonid habitat and populations in the Sandy and Little Sandy rivers

As part of this geomorphic assessment, Stillwater Sciences reviewed existing information related to the geomorphology of the Sandy River and to salmonid issues in the Sandy River basin. The following is a list of key available information that was reviewed and incorporated into the assessment:

- Previous studies of fish habitat in the Sandy River basin (e.g., Craig and Suomela 1940; ODFW 1990, 1997a, 1997b; Cramer et al. 1998);

- Studies pertaining to spawning, habitat use and life history characteristics of salmonids in the Sandy River basin (ODFW 1998a, 1998b; Beak Consultants 1999; PGE 1976, 1980; Cramer and Clark 1988);
- Studies of instream flows and effects on salmonid habitat in the Sandy River basin (e.g., Hardin 1998);
- A Review of Special Status Salmonid Issues for PGE's Sandy River Basin Projects (Stillwater Sciences 1999);
- Watershed analyses of the Upper Sandy and Bull Run basins (USDA Forest Service 1996, 1997);
- Scientific literature on the geology of the Sandy River basin (e.g., Cameron and Pringle 1987, Allen 1989);
- Aerial photography of the Sandy River basin at a 1:6,000 scale, taken in August 1998;
- Data on the volume and particle size distribution of sediment impounded behind Marmot and Little Sandy dams, collected by Squier Associates (2000) as part of decommissioning studies;
- Information on reservoir sediment characteristics from data collected during reconstruction of Marmot Dam in 1989 (Raytheon 1990);
- A longitudinal profile of the Sandy River extending from 3 mi (4.8 km) upstream of Marmot Dam (RM 33) down to the Columbia River (RM 0), developed by PGE and Stillwater Sciences based on photogrammetric methods;
- Hydrologic data from U.S. Geological Survey streamflow gauges (see Table 1 in Section 3.3); and
- Suspended sediment data from the Bull Run River basin (Bull Run River, Fir Creek, North Fork Bull Run, South Fork Bull Run) for the period from 1977-1978 to 1986. (No suspended sediment data that can be used to estimate annual sediment yields are available for the Sandy River.)

### 2.2.2 Field surveys

During August and September 1999, Stillwater Sciences staff conducted field surveys on the Sandy River from about 2.25 mi (3.6 km) upstream of Marmot Dam downstream to the Columbia River. During the field surveys, observations of current channel conditions and hypotheses about potential responses to sediment release from Marmot Dam were developed. These form an important basis of our geomorphic and biological analysis (Section 4).

On 9–11 August 1999, Stillwater Sciences' staff surveyed the Sandy River by boat from downstream of the mouth of Alder Creek (approximately RM 32.3) to a takeout near Marmot Dam (RM 30.1), and from Dodge Park (RM 18.5) to Oxbow Park (RM 11.9). We also accessed the river by foot at the following locations: immediately downstream of Marmot Dam, in a section of the Sandy River gorge, near Revenue Bridge, at the Sandy River's confluence with Cedar Creek, upstream of Dodge Park, at Dabney State Park, and at Lewis and Clark State Park. Objectives of these surveys were as follows: (1) familiarize staff with the geomorphic characteristics and salmonid habitat conditions upstream and downstream of the dam; (2) identify the approximate upstream extent of the influence of Marmot Reservoir based on evidence of aggradation and bedrock controls; (3) collect information to assist design of the reservoir sediment-coring study; and (4) collect geomorphic and biological observations relevant to the dam removal assessment, including information on channel bed particle sizes upstream and downstream of Marmot Dam. Wolman pebble counts were conducted at 11 sites to assess downstream variation in median grain sizes ($D_{50}$). We also made observations about potential changes to habitat conditions critical to spawning, incubation, and rearing of anadromous salmonids. This included observations of the extent of fine sediments in the channel bed and the availability and location of pools, margin habitat, large woody debris, and other salmonid habitat elements.

On 7–10 September 1999, Stillwater Sciences' staff and Tom Lisle of the USDA Forest Service Redwood Sciences Laboratory conducted additional surveys of the Sandy River. The river was surveyed by boat from downstream of Marmot Dam (approximately RM 30) to downstream of Revenue Bridge (approximately RM 24) and from Oxbow Park (RM 11.9) to Dabney Park (approximately RM 6.6). Several reaches of the Sandy River were also accessed by foot, including Dodge Park, Gordon Creek, Lewis and Clark State Park, and the reach of the Sandy River from Highway 84 downstream to the Columbia River (i.e., the Sandy River delta). We also made observations of the Bull Run River at Dodge Park and at the Bull Run powerhouse location. During these surveys, we collected data on geomorphic and ecological characteristics of the Sandy River, including channel cross-sections, substrate characteristics, bedrock controls, bank materials, confinement, and channel morphology. These data provided input for numerical modeling and for our geomorphic and biological assessment.

In addition, Stillwater Sciences staff surveyed the Little Sandy River from the Little Sandy Dam to the Bull Run River in December 1999, one week after a large storm and flood event in the Sandy River basin. Although the magnitude of this flood is not known on the Little Sandy River, where no gaging station currently operates[1], the flood had an approximately 25-year recurrence interval at the USGS Sandy River near Marmot gauge (station number 14137000) and an approximately 50-year recurrence interval at the Bull Run River above Reservoir No. 1 gauge (station number 14138850).

### 2.2.3 Aerial photograph interpretation

Aerial photographs taken in 1998 at a 1:6,000 scale are available for the Sandy River corridor from Marmot dam downstream to the Columbia River. Using these aerial photographs combined with field observation, Stillwater Sciences created a geomorphic map that identifies the distribution and areal extent of active sediment storage sites in the Sandy River downstream of Marmot Dam (see Section 2.2.4); water flow boundaries under various discharge scenarios; and areas of potential geomorphic sensitivities (e.g., side channels). All river miles referred to in this report are based on delineation of river mileages on the geomorphic map. Aerial photographs, in conjunction with field surveys, were also used to estimate channel widths for use in numerical modeling.

### 2.2.4 Sediment storage assessment

To provide a means of comparing the volume of sediment that is currently in active storage in the Sandy River downstream of Marmot Dam with the volume of sediment stored behind Marmot Dam that will be released into the Sandy River under some dam removal alternatives, we developed a rough estimate of in-channel storage between Marmot Dam and the mouth of the Sandy River using the map of active sediment storage sites described above. Active sediment storage sites are channel bed and alluvial features (e.g., mid-channel, alternating, lateral, and point bars) that have little or no vegetation, indicating that they are likely mobilized during moderate floods having a recurrence interval of 1–5 years. Because sediment in such storage sites is expected to be mobile under moderate flows, quantification of active storage volume provides a measure of the amount of sediment available for mobilization and downstream transport in the Sandy River. The active storage volume currently in the channel downstream of the dam can be compared with the amount of sediment stored behind Marmot Dam to provide insight into whether release of sediment from the dam is likely to represent a large or small increase in sediment over what is already present in the Sandy River system.

[1]The USGS Little Sandy near Bull Run gauge (number 14141500) was discontinued in 1997.

Using the aerial photos (supported by field observations), the areal extent of the channel bed and active alluvial features was determined. Active features were then traced onto a gridded sketch vellum in order to estimate their total area. Volume was calculated by assuming an average depth of 8 ft (2.5 m) for active alluvial features and 5 ft (1.5 m) for the channel bed, and volumes were converted to mass using a bulk density of 0.06 t/ft$^3$ (2 t/m$^3$). The average depth estimates are based on corings of the channel bed down to bedrock performed for the City of Portland in the vicinity of the Sandy River's confluence with the Bull Run River (Cornforth Consultants 1999).

### 2.2.5 Conceptual models of salmonid population responses

The final step in our biological assessment involved linking the predicted geomorphica and physical habitat responses to dam removal alternatives with the potential impacts they would have on populations of anadromous salmonids in the Sandy River basin. Conceptual models of salmonid biology were developed for each of the anadromous salmonid species and runs in the Sandy River basin to help summarize existing information and provide a tool for qualitatively assessing potential risks and impacts on population dynamics that are associated with each alternative. Because data on life history, habitat use, habitat conditions, and population dynamics within the Sandy River basin are limited, the conceptual models relied on published data from similar rivers in the Pacific Northwest and on general knowledge of salmonid life history requirements.

The conceptual models were used to link predicted geomorphic and physical habitat changes with likely population responses. Making this linkage is inherently difficult, even in well-studied populations. Given the natural variability in biological responses to habitat changes, the existence of factors outside of the freshwater habitats and outside of the scope of this analysis (e.g., mortality occurring in the Columbia River, estuary and ocean), the limited amount of quantitative data currently available on anadromous salmonid populations and habitat conditions in the Sandy River basin, and the difficulties in predicting future habitat changes under different scenarios or alternatives, the conclusions presented here necessarily contain a high degree of uncertainty. Despite the uncertainty, however, we believe this effort is critical for making the best informed decision about dam removal alternatives. This qualitative assessment provides a framework for dealing with uncertainties involved in predicting the potential impacts of dam removal under the different alternatives.

# 3. EXISTING CONDITIONS IN THE SANDY RIVER BASIN

## 3.1 Watershed Description

The Sandy River and its tributaries drain a 508-mi$^2$ (1,316-km$^2$) basin on the west slope of the Cascade Range in northwestern Oregon (Figure 1). The basin extends approximately 55 mi (89 km) from its headwaters to its confluence with the Columbia River near Troutdale (Columbia River RM 120.5). Principal tributaries to the Sandy River include the Zigzag, Salmon, and Bull Run rivers and Still, Cedar, Gordon, and Beaver creeks. The Bull Run River is the largest tributary to the Sandy River and has a drainage area of approximately 102 mi$^2$ (265 km$^2$) (USDA Forest Service 1997). The climate of the Sandy River basin is characteristic of much of western Oregon, with mild temperatures, wet winters, narrow daily temperature fluctuations, and a long frost-free period (Franklin and Dyrness 1973). Annual precipitation ranges from 40 in (102 cm) near the river's mouth to 110 in (279 cm) near its source on Mt. Hood (ODFW 1990). In the following sections, we discuss the geology, hydrology, and land use history of the basin, and the salmonid species and runs that occur there. We then provide a description of the geomorphic and habitat conditions of each reach of the Sandy and Little Sandy Rivers influenced by the Bull Run project.

## 3.2 Geology of the Sandy River Basin

The geology of the Sandy River basin reflects Tertiary (Miocene and Pliocene) and Quaternary (Pleistocene and Holocene) volcanic events and Pleistocene glaciations. Structurally, the Sandy River basin is located within the Yakima fold belt, which is characterized by a series of east-west by southwest-northeast trending synclines and anticlines, cut diagonally by numerous north-northwest trending fault zones and lineaments (Williams 1982). The upper Sandy River, east of the the town of Brightwood (Figure 1), lies within the High Cascade geologic province, and its morphology reflects the influences of the formation of Mt. Hood (Priest 1982) and Pleistocene glaciation. West of Brightwood, the Sandy River valley is dominated by Quaternary lahar deposits, slopes are less steep, and bedrock of the Western Cascade province underlies this portion of the basin. There are over 31 geologic units in the basin, the most extensive being Pliocene volcanics (basaltic andesite lava flows); the Miocene Rhododendron Formation, which is composed of weak andesitic tuffs and breccias (volcanic rock) and is common in the upper basin; and the Miocene Troutdale Formation, which is a sedimentary formation that is fluvially derived from the erosion of local volcanic rocks and is common in the lower part of the Sandy River basin (USDA Forest Service 1996).

During the Pleistocene epoch, a series of large glaciers extended as far down the Sandy River valley as Brightwood (USDA Forest Service 1996). These glaciers carved a U-shaped valley in the upper part of the basin and deposited terminal and recessional moraines near Alder Creek (Allen 1989). At the last glacial maximum (15,000 years ago), a 1,000-ft (300-m) thick glacier extended about 20 mi (32 km) from Mt Hood down the Sandy River valley. This glacier overflowed into the Little Sandy basin through three saddles in the ridge between the present-day towns of Marmot and Brightwood.

Over the last 500,000 years, Mt. Hood has extruded a series of dacitic lava domes, whose collapse triggered eruptions and at least six volcanic mudflows (lahars). Lahars are mixtures of volcanic debris and water that typically occur as a result of a volcanic eruption in which ejected material melts snow and ice from the slopes of the volcano (in this case Mt. Hood), resulting in a rapidly moving mudflow that can travel substantial distances and bury river valleys (Summerfield 1991). On the Sandy River, lahars traveled as far as the confluence with the Columbia River, leaving terraces up to 500 ft (150 m) high (Allen 1988). Most of the present-day valley-bottom topography is a result of a series of mudflows and pyroclastic flows that occurred during an eruptive period 12,000–15,000 years ago (Allen 1988).

The last two episodes of eruptive activity occurred approximately 1,500 and 200 years ago (the Timberline and Old Maid episodes, respectively), when numerous pyroclastic flows and lahars occurred and built a smooth debris fan on the south and southwest flanks of Mt. Hood. During the most recent (Old Maid) eruptive period, the Sandy River became choked with sediment over 65 ft (20 m) deep that completely buried the pre-eruption valley floor between Sandy and Troutdale. Since then, channels have incised into these deposits, leaving behind several-meter-high terraces with actively eroding banks. In addition, buried old-growth forests are now being fluvially exhumed by the river (Cameron and Pringle 1991). Lahars and sediment-rich floods that flowed to the Columbia River during past eruptive periods built a delta at the mouth of the Sandy River. In 1805 and 1806, likely shortly after the Old Maid event, Lewis and Clark noted braided conditions at the mouth of the Sandy River, indicating very high sediment loading (Cameron and Pringle 1987). The ongoing influence of past laharic events, Mt. Hood glaciers, and the basin's underlying lithology result in conditions of naturally high sediment loading in the Sandy River.

The Bull Run River basin (which is a subbasin of the Sandy River watershed) has experienced some minor glaciation (USDA Forest Service 1997), but less than in the upper Sandy River basin. Except for the very uppermost reaches of the watershed (approximately 10% of the drainage area), the Bull Run basin is in the Western Cascade province. In addition, whereas lahars have left deposits along much of the Sandy River and have had a substantial geomorphic influence, lahars have not occurred in the Bull Run basin (in some areas, lahars originating in the upper Sandy basin may have spilled over into the Bull Run basin). Stratigraphically, the Bull Run basin is underlain by the same competent rock assemblages as the rest of the Sandy River basin (consisting primarily of Pliocene volcanic bedrock in addition to Rhododendron and Troutdale formations) (Peck 1961, USDA Forest Service 1997), although the lack of lahars in valley floors and the lesser glacial influence likely result in lower natural sediment yields in the Bull Run basin.

### 3.2.1 Background sediment flux in the Sandy River

Stillwater Sciences developed rough estimates of background annual sediment flux in the Sandy River, based on literature review, in order to assist in evaluating the potential impacts of reservoir sediment release into the Sandy River. No data on sediment yield are available for the Sandy River, however, so measurements of sediment yield from other rivers in Oregon's western Cascade Range were used. These measurements are highly varied, depending on lithology, glaciation history, land use, and climatic conditions. Swanson et al. (1982) found that in 30 small undisturbed watersheds in the H. J. Andrews Experimental Forest, Oregon, sediment yields averaged 250 tons/mi$^2$yr (98 tonnes/km$^2$yr). Other measurements of sediment flux in undisturbed basins vary between 66 tons/mi$^2$yr (26 tonnes/km$^2$yr) in the H. J. Andrews Forest (Grant and Wolff 1991) and 61–302 tons/mi$^2$yr (24–119 tonnes/km$^2$yr) elsewhere in the western Cascades (Larsen and Sidle 1980). Much higher sediment yields have been measured in intensively managed watersheds, including estimates of 650 tons/mi$^2$yr (255 tonnes/km$^2$yr) in the H.J. Andrews Forest (Swanson and Dyrness 1975), and up to 1,270 tons/mi$^2$yr (498 tonnes/km$^2$yr) elsewhere in the western Cascades (Curtiss 1975, Larsen and Sidle 1980, McBain and Trush 1998).

In the Sandy River basin, sediment yields may be substantially higher on average than in the H. J. Andrews Forest and elsewhere in the western Cascades due to Mt. Hood glaciers, the presence of semi-consolidated lahar deposits, steep topography, and land uses. Swanson et al.'s (1982) average value for the H. J. Andrews Forest of about 255 tons/mi$^2$yr (100 tonnes/km$^2$yr) may therefore be considered a minimum estimate for the Sandy River; average sediment yields may in fact be two to three times higher than this value. Approximately 980,000 yd$^3$ (750,000 m$^3$) of sediment is stored behind Marmot Dam (Squier Associates 2000), which corresponds to 1.2–1.4 million tons (1.1–1.3 million tonnes), assuming a bulk density of 94–106 lb/ft$^3$ (1,500–1,700 kg/m$^3$). These estimates suggest that the reservoir sediments upstream of Marmot Dam (drainage area of Sandy River upstream of Marmot Dam is 260 mi$^2$ [680 km$^2$]) represent a maximum of 20 years of annual average sediment flux yield and possibly much less (the dam has been in place since 1913 and was reconstructed in 1989). This is a simplified comparison that does not account for factors such as the trapping efficiency of Marmot Dam, the bedload vs. suspended load fraction of the sediment yield, and temporal variations in sediment yield, but it does give a rough sense of how the volume of sediment stored behind Marmot Dam compares with background sediment yield in the Sandy River.

## 3.3 Hydrology of the Sandy River Basin

Hydrologic regimes in the Sandy River basin are characterized by low flows in August and September, and by high flows generated by rainfall and rain-on-snow events in winter and snowmelt in spring (Figure 2). Because the headwaters of the Sandy and Zigzag rivers originate from glaciers on the slopes of Mt. Hood at an elevation of about 6,200 ft (1,890 m), flow and sediment loading are greatly influenced by glacial processes and steep unstable slopes (ODFW 1997a). Glacial sediments frequently cause the mainstem Sandy River to remain turbid throughout the summer snowmelt period. The Bull Run River, in contrast, has its source in high mountain lakes and therefore has lower turbidities and would be expected to have lower natural sediment yields.

The U.S. Geological Survey operates streamflow gauges on the Sandy, Little Sandy, and Bull Run rivers; information on some of these gauges is provided in Table 1. Discharge data from the Sandy River near Marmot gauge (station number 14137000) and the Sandy River below Bull Run gauge (station number 14142500) were used in sediment transport modeling, as discussed in Section 2.1.3 above.

**Table 1. Selected U. S. Geological Survey streamflow gauges in the Sandy River basin.**

| Station Name | Station Number | Period of Record | Station Location |
|---|---|---|---|
| Sandy River near Marmot | 14137000 | 1911–present | RM 30.3; 0.3 mi upstream of Marmot Dam |
| Bull Run River near Multnomah Falls | 14138850 | 1966–present | RM 14.8, upstream of Bull Run Reservoir 1 |
| Bull Run River near Bull Run | 14140000 | 1907–present | RM 4.7; 1.8 mi downstream of Bull Run Reservoir 2 |
| Little Sandy River near Bull Run | 14141500 | 1911–1913; 1919–1997 | RM 1.95; 0.25 mi upstream of Little Sandy Dam |
| Sandy River below Bull Run River near Bull Run | 14142500 | 1910–1914; 1929–1966; 1984–present | RM 18.4; 0.1 mi downstream of Bull Run River |

The largest flood event on record in the Sandy River occurred in December 1964, when a peak flow of about 61,000 cfs (1,700 cms) was recorded at the Sandy River near Marmot gauge (station number 14137000). Large floods also occurred in February 1996, when flows reached about 49,000 cfs (1,400 cms; daily average) at the Sandy River near Marmot gauge, and in November 1999, when a peak discharge of 34,400 cfs (970 cms; instantaneous peak) was recorded at the Marmot Dam. Flood frequency gauge analysis using a Log-Pearson type III distribution indicates that the 1964, 1996, and 1999 events had recurrence intervals of nearly 500, 100, and 25 years, respectively. Figure 3 shows a flood frequency curve for the Sandy River near Marmot gauge.

Basin hydrology has been altered by flow regulation and diversion. The City of Portland and PGE own major water development facilities in the basin, both of which are called the Bull Run Project. These facilities include dams on the Sandy, Little Sandy, and Bull Run rivers. Marmot and Little Sandy dams, on the Sandy and Little Sandy rivers, respectively, are part of PGE's Bull Run project and are discussed in Section 1 of this report. Currently, no minimum flows are required downstream of the Little Sandy Dam, and PGE has an agreement with the Oregon Department of Fish and Wildlife (ODFW) to avoid spilling to prevent attraction of anadromous salmonids to the Little Sandy River. PGE (1998a) estimates summer low flow at the mouth of the Little Sandy River at about 5 cfs (0.14 cms) under current diverted conditions, and anadromous salmonid access to the Little Sandy River is likely restricted under such flows. In addition, peak flows downstream of Little Sandy Dam are reduced by up to 800 cfs (22.6 cms), an amount equal to the diversion capacity at this facility.[2] Changes in the high-flow regime caused by the diversion may have altered channel morphology downstream of Little Sandy Dam, as discussed below.

The City of Portland's Bull Run Project, located on the Bull Run River, provides water supply to the City of Portland and generates hydroelectric power that is sold to PGE. The City of Portland's project includes two dams on the Bull Run River, which is the largest tributary to the Sandy River. No minimum flows are currently required at the City's Bull Run Project; consequently, the Bull Run River is dewatered under normal conditions downstream of the City's facilities.

The Marmot Diversion Dam diverts up to 600 cfs (17 cms) from the Sandy River, reducing flow in the mainstem Sandy River downstream of the diversion during all months. Flow diversions at the Marmot facility are subject to minimum flow requirements, which have varied historically. Current minimum flows from Marmot Diversion Dam required by the FERC license are as follows: 200 cfs (5.7 cms) from June 16 through October 15; 400 cfs (11 cms) from October 16 through October 31, and 460 cfs (13 cms) from November 1 through June 15. The required minimum flows average 31 percent of the mean monthly flows and 93 percent of the minimum monthly flows measured 0.3 miles ( 0.5 km) upstream of the diversion from 1912 to 1995 at the USGS Sandy River near Marmot gauge (number 14137000).

USDA Forest Service (1996) compared flows measured upstream of Marmot Diversion Dam at the Sandy River near Marmot gauge (number 14137000) with estimated flows downstream of the dam. This analysis indicates that flow diversions at Marmot Diversion Dam have reduced monthly mean streamflows below the dam by 27–38 percent during wet months (November–May) and 52–69 percent during dry months (June–October). Additional information on basin hydrology can be found in Stillwater Sciences (1999) and in the Preliminary Draft Environmental Assessment (PGE 2000b).

## 3.4 Land Use History and Impacts in the Sandy River Basin

Watershed processes, sediment yield, and salmonid habitat in the basin have been altered by forestry practices, agriculture, flood control projects, and water supply and hydroelectric power development. Approximately 78% of the Sandy River basin is forested, with 75% of the forested lands occurring in the Mt. Hood National Forest (Taylor 1998). Land use in the remaining 22% of the basin, much of which occurs at lower elevations and is in private ownership, includes agriculture, grazing, and residential uses (ODFW 1997a).

### 3.4.1 Potential geomorphic effects of Marmot and Little Sandy dams

Detailed assessment of the current and historical effects of Marmot and Little Sandy Dams on geomorphic processes is beyond the scope of this study, and such effects have not been well documented. It is likely that Marmot and Little Sandy dams have altered natural patterns of sediment and large woody debris transport. The impoundments formed by Marmot and Little Sandy dams are currently filled with sediment.

[2] Diversions at Marmot Dam occur only when flow in the Little Sandy River is less than 800 cfs (22.6 cms) in order to to avoid spilling at Little Sandy Dam.

The time required to fill these dams with sediment is unknown. It is likely that partial trapping of coarse sediment currently occurs upstream of these dams, although coarse and fine sediment transport does occur over these dams during high-flow events. Coarse sediment transport over Marmot Dam likely occurs in most years, while transport over Little Sandy Dam likely only occurs during large high-flow events (i.e., on an approximately decadal time scale) because Little Sandy Dam rarely spills. In the Little Sandy River, sediment transported from upstream may be deposited behind Little Sandy Dam, travel over the dam, or be diverted to the flume. Recently deposited gravels were observed immediately downstream of Marmot and Little Sandy dams following a high-flow event with an approximately 25-year recurrence interval in November 1999. Field surveys of the Sandy and Little Sandy rivers downstream of Marmot and Little Sandy dams, respectively, show no clear evidence of morphologic effects associated with reduced sediment supply in these reaches. Morphologic changes downstream of Little Sandy Dam are likely attributable to reduced flows, as discussed in Section 3.6.2. Analysis of historical aerial photographs would be required to better document the potential morphologic effects of Marmot Dam.

Marmot and Little Sandy dams also may interrupt natural recruitment of large woody debris (LWD) to downstream reaches. PGE maintenance crews currently remove LWD trapped at Little Sandy Dam from the Little Sandy River. Field surveys suggest that large woody debris loading is low downstream of Marmot and Little Sandy dams, which is likely due to a combination of factors. USDA Forest Service (1997) evaluated large woody debris loading in the Little Sandy River downstream of the dam and concluded that low large woody debris loading in the lower Little Sandy River was partly attributable to the channel's confinement, steep gradient, and the practice of removing large woody debris at the dam. In the Sandy River, large woody debris loading is low both upstream and downstream of Marmot Dam (USDA Forest Service 1996).

Operation of the Little Sandy Diversion Dam also likely affects downstream channel morphology and aquatic habitats by reducing the magnitude, frequency, and duration of high-flow events and winter baseflows. Field surveys indicate that these changes in flows may have contributed to encroachment of riparian vegetation into the stream channel downstream of Little Sandy Dam, particularly in the first 0.3 miles (0.5 km) below the dam. This appears to have reduced the width of the active channel and stabilized substrates in areas where willows and alders have established. Flow reductions may also reduce the transport of sediment over Little Sandy Dam, although sediment transport likely does occur during large events that result in substantial spillage over the dam. High flows are not reduced by Marmot Dam.

### 3.4.2 Potential geomorphic effects of other land uses in the Sandy River basin

Timber harvesting and road construction have likely increased sediment inputs to streams in the upper Sandy River basin, where land is predominantly under federal ownership. No data are available with which to quantify the effects of land use on sediment yield in the Sandy River, however. Average road densities on federal lands in the upper Sandy River basin (upstream of the town of Sandy) and Little Sandy River basin are 1.8 mi/mi$^2$ (1.1 km/km$^2$) and 3 mi/mi$^2$ (1.9 km/km$^2$), respectively (USDA Forest Service 1996, 1997). The extent of timber harvesting in the basin has not been quantified, although vegetation data for federal lands indicate that between 1948 and 1996 the percent area occupied by large conifers (>21 in [>50 cm] dbh) declined from 61% to 36% in the Bull Run watershed and from 17% to 7% in the upper Sandy watershed, largely due to timber harvesting (USDA Forest Service 1996, 1997). Since 1892, the area of the Bull Run basin upstream of the City of Portland's water supply project has been largely protected to maintain a source of high-quality drinking water (Taylor 1998), likely resulting in sediment yields characteristic of reference (unmanaged) conditions.

Channel morphologies and salmonid habitat in the upper Sandy River basin (upstream of Marmot Dam) have also been affected by flood control projects; several miles of the Salmon, Zigzag, and Sandy rivers and Still Creek were channelized following the December 1964 flood. Channels were straightened using heavy equipment; boulders, logs, and other flow obstructions were removed; and side channels were blocked by berms created in the channelization process (ODFW 1997a).

The City of Portland's dams on the Bull Run River block delivery of coarse sediment from the Bull Run basin to downstream reaches, potentially affecting channel morphology and salmonid spawning habitat downstream of the dams. Field observations by Stillwater Sciences indicate that the channel of the Bull Run River downstream of the City's dams is sediment-depleted, as evidenced by areas where sediment deposition would be expected but the channel is scoured to bedrock.

## 3.5 Anadromous Salmonids in the Sandy River Basin

The Sandy River basin supports populations of the following anadromous salmonid species: chinook salmon (spring- and fall-run), steelhead (winter- and summer-run), coho salmon, and coastal cutthroat trout. Except for summer steelhead, all of these salmonid populations have special status under the federal Endangered Species Act, as summarized in Table 2. In addition, all of these populations, except for coastal cutthroat trout (which have an uncertain stocking history), have been augmented with hatchery stocks (Table 3). Coho salmon, winter steelhead, and spring chinook salmon continue to be augmented. More detailed discussion of each of these stocks, including life history, current status under the Endangered Species Act, habitat preferences, and hatchery influences, is provided in Stillwater Sciences (1999).

**Table 2. Special-status salmonids in the Sandy River basin.**

| SPECIES | ESU[1] | FEDERAL STATUS | NOTES |
|---|---|---|---|
| Chinook Salmon | Lower Columbia River | Threatened | Listing includes both fall and spring chinook salmon in the Sandy River basin, despite introductions of spring chinook from the Upper Willamette River ESU. Listing excludes spring chinook hatchery stock, which was determined not to be essential for recovery. |
| Coho Salmon | Lower Columbia River/Southwest Washington Coast | Candidate | Listing of this ESU would likely include only later-returning native coho salmon in the Sandy River basin. |
| Steelhead | Lower Columbia River | Threatened | Listing includes later-returning native winter steelhead in the Sandy River basin. Listing excludes early-run hatchery winter steelhead stock in the Sandy River basin. Listing excludes Skamania-origin summer-run steelhead in the Sandy River basin. |
| Coastal Cutthroat Trout | Southwestern Washington/ Columbia River | Proposed Threatened | Proposed listing includes all naturally spawned coastal cutthroat trout occurring downstream of natural barriers in the Sandy River basin. Populations above barriers allowing some downstream migration to occur may warrant listing under the ESA and will be evaluated on a case-by-case basis by NMFS and USFWS. |

1 Evolutionarily Significant Unit

**Table 3. Period of hatchery supplementation and origin of hatchery stocks used to supplement anadromous salmonid populations in the Sandy River basin.**

| SPECIES AND RUN | PERIOD OF SUPPLEMENTATION | HATCHERY STOCK ORIGIN |
|---|---|---|
| Spring Chinook Salmon | early 1900s to 1969 | primarily Sandy River stock |
| | 1977–1978 | Carson stock, Washington |
| | 1973 to present | Willamette River stock |
| Fall Chinook Salmon | early 1950s to 1977 | lower Columbia River tule stock |
| | early 1950s to 1977 | intermittent releases of both Sandy River basin and out-of-basin stocks |
| | 1978 to present | no hatchery supplementation |
| Coho Salmon | 1951 to present | primarily Sandy River stock |
| Winter Steelhead | late 1800s | hatchery supplementation began (unknown origin) |
| | 1950s (?) to present | Two primary hatchery stocks used:<br>• Big Creek Hatchery stock from lower Columbia River near Astoria, Oregon<br>• Eagle Creek National Fish Hatchery stock from Clackamas River basin |
| Summer Steelhead | 1968 to 1975 | probably primarily Skamania Hatchery stock |
| | 1975 to 1996 | Skamania Hatchery stock from Washougal River in southwest Washington |
| Coastal Cutthroat Trout | | no information on hatchery supplementation has been identified |

Distribution and key habitat locations for many anadromous salmonid species in the Sandy River basin are poorly understood, especially with regard to juvenile rearing distributions. Where information is lacking, potential spawning and rearing distribution is described based on availability of suitable habitat as determined by field observations and literature review of salmonid habitat preferences. In general, spring chinook salmon, coho salmon, and steelhead tend to spawn upstream of Marmot Dam, while fall chinook salmon spawn primarily downstream of the dam. Some coho salmon and winter steelhead spawning, however, occurs downstream of the dam, and some fall chinook salmon spawning occurs upstream of the dam. Coho salmon, steelhead, and spring chinook salmon originating from upstream of the dam would be expected to rear primarily in the upper watershed, but may also rear in suitable habitats downstream. Fall chinook salmon would be expected to rear almost exclusively downstream of the dam, as would coho salmon, winter steelhead, and sea-run cutthroat trout that originated downstream of the dam. Distribution, habitat preferences, and locations of key habitat of each anadromous salmonid species present in the Sandy River basin are discussed in the following section and are summarized in Table 4. The life history timing of anadromous salmonid species occurring in the Sandy River basin is shown in Table 5 (downstream of Marmot Dam) and Table 6 (upstream of Marmot Dam). Many aspects of the timing and duration of specific salmonid life history events in the Sandy River remain uncertain.

**Table 4. Primary spawning and rearing locations and habitats for anadromous salmonids in the Sandy River basin.**

| SPECIES AND RUN | PRIMARY SPAWNING LOCATIONS | KEY REARING HABITATS[1] | NUMBER OF YEARS JUVENILES REAR IN STREAM |
|---|---|---|---|
| **UPSTREAM OF MARMOT DAM** | | | |
| Spring Chinook Salmon | Salmon River up to Final Falls, lower 3 miles of Still Creek, Zig Zag River, mainstem upper Sandy River | pools | <1 to 1+ |
| Fall Chinook Salmon | limited spawning observed in 1.6-mi (2.6-km) reach upstream of Marmot Dam and near mouth of Salmon River | margin habitats, pools | <1 |
| Coho Salmon | Salmon River and tributaries below Final Falls, Still Creek, mainstem Sandy River | LWD-formed pools | 1+ |
| Winter Steelhead | Salmon River below Final Falls, Still Creek, other upper basin tributaries | large substrates | 1+ to 3+ |
| Summer Steelhead | mainstem Sandy River and its tributaries | large substrates | 1+ to 3+ |
| Sea-run Coastal Cutthroat Trout | N/A | N/A | |
| **DOWNSTREAM OF MARMOT DAM** | | | |
| Spring Chinook Salmon | immediately downstream of Marmot Dam (Reach 1) | pools | <1 to 1+ |
| Fall Chinook Salmon | mainstem Sandy River from Lewis and Clark State Park to upstream boundary of Oxbow Park; lower tributaries, such as Gordon and Trout Creeks. | margin habitats, pools | <1 |
| Coho Salmon | lower basin tributaries, such as Gordon and Trout creeks (most likely hatchery fish) | LWD-formed pools | 1+ |
| Winter Steelhead | mainstem Sandy River (limited data) | large substrates | 1+ to 3+ |
| Summer Steelhead | N/A | large substrates | 1+ to 3+ |
| Sea-run Coastal Cutthroat Trout[2] | small tributaries | side channels, pools | 2+ to 4+ |

1 Limited data are available describing salmonid rearing distribution in the Sandy River basin; potential presence is assumed based on availability of suitable habitat.

2 Limited data are available describing spawning locations of sea-run coastal cutthroat trout in the Sandy River basin. Based on availability of suitable habitat, it is assumed that small tributaries downstream of Marmot Dam offer likely spawning locations.

**Table 5. Timing of life history stages of anadromous salmonids in the Sandy River basin downstream of Marmot Dam.**

| LIFE STAGE | SPECIES | MONTH | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
| Adult Migration & Holding | Spring Chinook Salmon | | M | M | P | P | M | M | M | P | M | M | |
| | Fall Chinook Salmon | M | M/– | | | | | | M | M | P/M | M | M |
| | Summer Steelhead | | M | M | M | P | P | M | M | M | M | M/– | |
| | Winter Steelhead | M | M | M | M | M/– | | | | | | M | M |
| | Coho Salmon | M | M | | | | | M | P | P | M/P | P | P |
| Spawning | Spring Chinook Salmon[1] | | | | | | | | | | | | |
| | Fall Chinook Salmon | M | M | | | | | | | –/M | P/M | P/M | M |
| | Summer Steelhead[1] | | | | | | | | | | | | |
| | Winter Steelhead | | –/M | M/P | P | P/M | M/– | | | | | | |
| | Coho Salmon[1] | | | | | | | | | | | | |
| Rearing | Spring Chinook Salmon[2] | | | –/X | X | X | X | X | X | X/– | | | |
| | Fall Chinook Salmon | | | –/X | X | X | X | X | X | X/– | | | |
| | Summer Steelhead[2] | X | X | X | X | X | X | X | X | X | X | X | X |
| | Winter Steelhead | P | P | P/M | M | M | M/P | P | P | P | P | P | P |
| | Coho Salmon[2] | X | X | X | X | X | X | X | X | X | X | X | X |
| Outmigration | Spring Chinook Salmon | X | X/– | | X | X | | | | –/X | X | X | X |
| | Fall Chinook Salmon | | | | | –/X | X | X | X | X/– | | | |
| | Summer Steelhead[3] | | | | | | | | | | | | |
| | Winter Steelhead | | | P | P | P | M | M | | | | | |
| | Coho Salmon | | | | M/P | P | P/M | | | | | | |

1 Because there is no documentation of spring chinook salmon, summer steelhead, and coho salmon spawning downstream of Marmot Dam, timing of this life history stage is unknown for the Sandy River basin.
2 Juvenile rearing patterns are poorly understood. Although spring chinook salmon, summer steelhead, and coho salmon are not believed to spawn in the mainstem Sandy River downstream of Marmot Dam, it is possible that juveniles migrate to the mainstem to rear prior to outmigration as smolts.
3 Outmigration of summer steelhead is not well documented in the Sandy River basin.

| | |
|---|---|
| M | **Span of Moderate to Light Activity** |
| P | **Span of Peak Activity** |
| X | **Span of Possible Activity** |

**Table 6. Timing of life history stages of anadromous salmonids in the Sandy River basin upstream of Marmot Dam**

| LIFE STAGE | SPECIES | MONTH | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
| Adult Migration & Holding | Spring Chinook Salmon[1,2] | | | | | Moderate | Peak | Moderate | Moderate | Peak | Moderate | Moderate | |
| | Fall Chinook Salmon | Moderate | Moderate (early) | | | | | | Moderate | Moderate | Moderate | Moderate | Moderate |
| | Summer Steelhead | | | Moderate | Moderate | Peak | Peak | Peak | Peak | Moderate | Moderate | Moderate (early) | |
| | Winter Steelhead | Moderate / Peak | Peak | Peak | Peak / Moderate | Moderate | Moderate (early) | | | | | Moderate (late) | Moderate |
| | Coho Salmon | Moderate | Moderate | | | | | Moderate | Moderate | Peak | Peak | Peak | Peak / Moderate |
| Spawning | Spring Chinook Salmon | Moderate | Moderate | Moderate / Possible | Possible (early) | | | | Moderate | Peak | Peak / Moderate | Moderate | Moderate |
| | Fall Chinook Salmon[3] | Moderate | Moderate | Moderate | Moderate | Moderate (early) | | | | Moderate (late) | Moderate | Moderate | Moderate |
| | Summer Steelhead | Moderate | Moderate (early) | | | | | | | | | | Moderate |
| | Winter Steelhead | | | Moderate / Peak | Peak | Peak / Moderate | | | | | | | |
| | Coho Salmon[4] | Peak | Moderate | | | | | | | | Moderate | Moderate / Peak | Peak |
| Rearing | Spring Chinook Salmon | | | Possible (late) | Possible | Possible | Possible | Possible | Possible | Possible (early) | | | |
| | Fall Chinook Salmon | | | Possible (late) | Possible | Possible | Possible | Possible | Possible | Possible (early) | | | |
| | Summer Steelhead | Possible | Possible | Possible | Possible | Possible | Possible | Possible | Possible | Possible | Possible | Possible | Possible |
| | Winter Steelhead | Peak | Peak | Peak / Moderate | Moderate | Moderate | Moderate / Peak | Peak | Peak | Peak | Peak | Peak | Peak |
| | Coho Salmon | Moderate | Moderate | Moderate | Moderate | Moderate | Moderate | Moderate | Moderate | Moderate | Moderate | Moderate | Moderate |
| Outmigration | Spring Chinook Salmon | Possible | Possible (early) | | Possible | Possible | | | | Possible (late) | Possible | Possible | Possible |
| | Fall Chinook Salmon | | | | | Possible (late) | Possible | Possible | Possible | Possible (early) | | | |
| | Summer Steelhead[5] | | | | | | | | | | | | |
| | Winter Steelhead | | | Peak | Peak | Peak | Moderate | Moderate | | | | | |
| | Coho Salmon | | | Moderate (late) | Peak | Peak | Peak / Moderate | | | | | | |

1 Chinook counted at Marmot Dam in late October and early November may actually be late-maturing fall chinook attracted into the upper basin when flows permit (ODFW 1997a).
2 Passage of spring chinook over Marmot Dam decreases in July and August, probably in response to decreases in flow and increases in water temperature. A second smaller peak of movement over the dam often occurs in September as water temperatures decrease again (ODFW 1997a).
3 Fall chinook salmon runs include an early (hatchery) run, with peak spawning activity September to November, and a late (native) run, with peak spawning activity in November.
4 Coho salmon runs include an early (hatchery) run, with peak spawning activity September to November, and a late (native) run, with peak spawning activity late November through early January.
5 Outmigration of summer steelhead is not well documented in the Sandy River basin.

| | |
|---|---|
| (brick pattern) | Span of Moderate to Light Activity |
| (solid shading) | Span of Peak Activity |
| (diagonal hatching) | Span of Possible Activity |

### 3.5.1 Spring chinook salmon

Spring chinook salmon in the Sandy River basin spawn and rear primarily in the larger tributaries upstream of Marmot Dam, with most spawning occurring in the Salmon River and in lower Still Creek (Figure 4) (ODFW 1997a). Mainstem and side-channel habitats in the Sandy River upstream of Marmot Dam (in particular, upstream of the Salmon River) may also be used for spawning (ODFW 1997a). In addition, spawning has been observed immediately below Marmot Dam, including 30–40 pairs in 1999, and in the reach immediately upstream of the dam (D. Cramer, pers. comm., 2000). Spawning has also been documented in the lower Bull Run and Little Sandy rivers (R2 Resource Consultants 1998a).

Naturally reproducing spring chinook salmon return to the Sandy River from late winter through summer and pass over Marmot Dam from May through October, with peak passage occurring in June and a second smaller peak occurring in September (Tables 5 and 6). Adult spring chinook salmon require large, deep pools with flowing water and suitable temperatures as summer holding habitat during the upstream migration. In many years, about 20% of the spring chinook salmon run that pass over the dam hold in the lower basin for most of the summer (before passing over the dam in September).

Little information is available on rearing habitats used by spring chinook salmon in the Sandy River basin. Extensive use of mainstem reaches and estuaries as rearing habitat typically distinguishes juvenile chinook salmon from coho salmon, steelhead, and sea-run cutthroat trout. Following emergence, chinook fry occupy low velocity, shallow water areas near stream margins, including backwater eddies and areas associated with bank cover such as large woody debris (LWD) (Lister and Genoe 1970, Everest and Chapman 1972, McCain 1992). As fry increase in size, they move to higher velocity, deeper areas further from banks (Hillman et al. 1987, Everest and Chapman 1972, Lister and Genoe 1970). Rearing patterns of spring chinook are variable—they may disperse downstream soon after emergence, as fry; early in their first summer, as fingerlings; in the fall as flows increase; or after overwintering in freshwater, as yearlings (Healey 1991). Information about the life history strategy of spring chinook salmon in the Sandy River basin suggests that downstream migrations occur from the fall of their first year through the spring of the following year, with the majority of outmigration occurring prior to the onset of winter (Cramer et al. 1989; Cramer and Clark 1998; PGE, unpublished data). Juvenile spring chinook salmon may, however, be present in the Sandy River throughout the year (ODFW 1997a).

Juvenile chinook often disperse downstream in the fall from tributaries into mainstem reaches and take up residence in deep pools with large woody debris, interstitial habitat provided by boulders and rubble substrate, and/or along river margins for the winter (Healey 1991, Swales et al. 1986, Levings and Lauzier 1991, as cited in Morgan and Hinojosa 1996). Juveniles that do not disperse downstream generally display high fidelity to their rearing areas and do not appear to make significant movements during the summer (Edmundson et al. 1968). Extended rearing is likely concentrated upstream of Marmot Dam in large tributaries such as Salmon River and lower Still Creek, although a small proportion of juveniles may migrate downstream for rearing. Chinook salmon were not observed during snorkeling surveys conducted in July of 1999 in the mainstem Sandy River, although high turbidity in the mainstem resulted in poor visibility during the survey (O’Neal and Cramer 1999). In the same study, however, juvenile chinook were observed rearing in pools of the Salmon River (O’Neal and Cramer 1999).

Counts of juvenile salmonids passing through the Marmot canal bypass that were conducted for a limited number of days in April, May, and November of 1986 documented large numbers of chinook salmon migrating downstream in November. These fish were likely juvenile spring chinook migrating downstream after rearing through the summer and fall in reaches upstream of Marmot Dam.

The lower Sandy River (downstream of Marmot Dam) is not likely to be extensively used by spring chinook salmon for rearing compared to upstream reaches. Rearing in downstream reaches is likely most important during outmigration. Juvenile chinook feed and grow as they move downstream in spring and summer; larger individuals are more likely to move downstream earlier than smaller juveniles (Nicholas and Hankin 1989). For those fish that may be overwintering in the mainstem, reaches with boulders and coarse substrates would offer refuge from high flows. Reaches 3 and 4 would likely offer the greatest amount of winter habitat. These reaches offer large pool habitats and coarse substrates, and are less confined than reaches upstream (i.e., Reaches 1 and 2). Reach 4 offers a relatively extensive amount of side channel habitat that could also provide refuge from high water velocities during high flows.

### 3.5.2 Fall chinook salmon

The Sandy River has an early and a late run of fall chinook. The early run is comprised primarily of hatchery strays, while the later run is composed of native fish. The former was first observed in 1988 (ODFW 1998a). Late-run wild fall chinook salmon generally spawn in the lower mainstem reaches of the Sandy River, particularly from Lewis and Clark State Park (RM 3) to the upstream boundary of Oxbow Park (RM 14) (Figure 5) (ODFW 1997a, 1998a). Helicopter surveys conducted in 1974 and 1976 upstream of the confluence with the Columbia River (at RM 2.4) to the confluence with Bull Run River (RM 18.5) documented high redd densities. The survey also found minimal spawning in the Sandy River between the Bull Run River confluence and Revenue Bridge (PGE 1980). Fall chinook have also been observed spawning in tributaries downstream of Marmot Dam, including the lower Bull Run River (Beak Consultants 1999, Cramer et al. 1998) and Gordon and Trout creeks (ODFW 1998a).

In addition to the early and late-fall chinook salmon runs, a wild winter-run typically spawns from late-December through January (ODFW 1998a). These chinook spawn in larger tributaries to the lower mainstem, such as Gordon and Trout Creeks (ODFW 1998a, 1997a).

The various stocks of fall chinook salmon in the Sandy River spawn from late September through February (Tables 5 and 6) (ODFW 1997a). These fish enter the river from August through February, with the dominant late-fall native stock typically migrating into the Sandy River in early October, and spawning in November (ODFW 1997a). Small numbers of fall chinook currently pass upstream over the Marmot Dam fish ladder (Kostow 1995). Fish ladder counts at Marmot Dam in 1996 and 1997 documented fall chinook passage over the dam in mid-October (PGE, unpublished data), and spawning of fall chinook has been observed in the 1.6-mile (2.6-km) reach upstream of Marmot Dam (Cramer et al. 1998). Historically, larger numbers of fall chinook salmon were documented to have spawned in large tributaries to the Sandy River upstream of Marmot Dam, as well as in the Bull Run River (ODFW 1997a). Incubation extends through early May in the Sandy River (R2 Resource Consultants 1998a) and emergence likely peaks in April and May.

Juvenile fall chinook salmon use similar habitats as spring chinook, although the length of time spent in these habitats may vary between the two. Following emergence, fall chinook fry typically aggregate in small schools of 20 to 40 fish in low velocity, shallow areas near stream margins, including backwater eddies and areas associated with bank cover such as large woody debris and overhanging vegetation (Lister and Genoe 1970, Everest and Chapman 1972, McCain 1992). Chinook fry may also use pool margins and pool tails associated with bedrock obstructions, rootwads, and overhanging banks. As fry increase in size, they move to higher velocity, deeper areas further from the stream bank (Hillman et al. 1987, Everest and Chapman 1972, Lister and Genoe 1970). Juvenile chinook salmon tend to prefer pool habitats for rearing, especially lateral scour, channel confluence, and mid-channel pools, where they feed on invertebrate drift near the surface (Lister and Genoe 1970, Everest and Chapman 1972, Hillman et al. 1987, McCain 1992). Juvenile chinook feed and grow as they move downstream in spring and summer; larger individuals may be more likely to outmigrate earlier than smaller juveniles (Nicholas and Hankin 1989).

The length of time that juvenile fall chinook salmon rear in the mainstem Sandy and Bull Run rivers is uncertain (Beak Consultants 1999). Juvenile chinook may be present year-round in the Sandy River, although most fall chinook appear to outmigrate in the spring and summer a few months after their emergence (ODFW 1997a, R2 Resource Consultants 1998a, O'Neal and Cramer 1999). Snorkeling surveys conducted in July of 1999 in the mainstem Sandy River found no chinook salmon, although survey conditions were poor due to high turbidity (O'Neal and Cramer 1999).

Little information is available on the rearing distribution of fall chinook salmon in the basin, although most rearing probably occurs downstream of Marmot in the mainstem Sandy River. Juvenile chinook salmon have also been observed rearing in Gordon Creek (ODFW 1998a).

### 3.5.3 Coho salmon

Coho salmon typically spawn higher up in the basin than do chinook salmon, and they often share many of the same spawning tributaries used by steelhead (USDA Forest Service 1996). Adult coho salmon require large, deep pools with flowing water and suitable temperatures for holding during their upstream migration. Presently, most spawning and rearing habitat suitable for coho salmon occurs upstream of Marmot Dam, in tributaries and mainstem side channels (ODFW 1997a).

Historically, wild late-run coho salmon spawned and reared in tributaries throughout the Sandy River basin and in the upper mainstem Sandy River above Marmot Dam (R2 Resource Consultants 1998a). Currently, most coho salmon in the basin represent an early-run hatchery stock; the native late-run Sandy River stock may be extinct or may have been essentially replaced by these early-run fish (ODFW 1990, as cited by R2 Resource Consultants 1998a; Massey and Keeley 1996). These early-run coho generally spawn and rear in tributaries to the Sandy River upstream of Marmot Dam, including Still Creek, the Salmon River and its tributaries, and the mainstem Sandy River upstream of its confluence with the Salmon River (Figure 6) (Taylor 1998, R2 Resource Consultants 1998a, USDA Forest Service 1996, ODFW 1997a). Ground surveys have also documented spawning in tributaries of the Sandy River downstream of Marmot Dam, particularly in Gordon, Cedar, and Trout creeks. Straying of hatchery coho into these three tributaries has been observed, and may account for the high numbers of spawning coho salmon in these streams (ODFW 1998, R2 Resource Consultants 1998a). Surveys conducted from 1990 to 1992 documented greater numbers of coho adults in tributaries of the Sandy River downstream of Marmot Dam than in reaches upstream of the dam (ODFW 1998b).

Coho salmon pass upstream over the Marmot Dam fish ladder from July through February (ODFW 1997a). Peak passage of early-run coho occurs from September through November; the native late-run stock are believed to pass upstream primarily from October through December (ODFW 1997a). Peak spawning occurs from late November to early January (R2 Resource Consultants 1998a, ODFW 1997a).

Following emergence, fry generally aggregate in backwaters, side channels, and other low velocity areas of the stream, especially where there is overhead cover and lower light intensity (Gribanov 1948). As juveniles grow, they shift from lateral habitats into deeper water and show a strong preference for pools, which constitute the most efficient foraging areas available. Riffles, glides, and runs may also be occupied by juvenile coho during the summer, but the densities are usually much lower than those found in pools

(Edie 1975, Everest et al. 1986). Juvenile coho are especially dependent on deep pools in streams with high temperatures and low baseflows in late summer (Nickelson et al. 1979, Peterson and Quinn 1994).

Deep pools (>45 cm) with low velocities (<15 cm/s) and substantial cover in the form of LWD are the most important habitat elements used by juvenile coho in the winter, especially during freshets (Bustard and Narver 1975a, Tschaplinski and Hartman 1983, Swales et al. 1986). Although juvenile coho use pools in all seasons, they especially depend on pools in winter for refuge from high water velocities, displacement by high flows, and cover from predation (Bustard and Narver 1975, Mason 1976, Hartman et al. 1982).

Coho typically migrate downstream in April and May as age 1+ smolts. A smaller portion of the outmigration is made up of age 0+ fry, but these fish are believed to have low probability of surviving to adulthood (Otto 1971, Crone and Bond 1976, Hartman et al. 1982). Juvenile coho have been documented passing over Marmot Dam in March through June at sizes ranging from 75 to 155 mm (Cramer and Clark 1988, Cramer et al. 1989). During winter sampling conducted in December 1988, no coho were captured at the dam. Fry may also pass over the dam throughout the spring.

Juvenile coho rearing is likely concentrated in larger tributaries upstream of Marmot Dam and in mainstem side channels. Rearing in reaches downstream of Marmot Dam may be important during outmigration. Reaches offering deep pools and coarse substrates for cover and refuge from high flows could provide suitable rearing habitat for coho salmon. Side channel habitats in the lower mainstem (particularly between Oxbow Park and Dabney Park) may also be important in rearing.

### 3.5.4 Winter steelhead

Most spawning and rearing of native winter steelhead in the Sandy River basin occurs upstream of Marmot Dam, primarily in the Salmon River and its tributaries, and in Still Creek (Figure 7) (ODFW 1997a). Some spawning also occurs in smaller tributaries and in the mainstem Sandy River and its side channels (ODFW 1997a). Downstream of Marmot Dam, only a limited number of tributaries or side channels are used by winter steelhead for spawning and rearing. Gordon, Trout, and Buck creeks are the most important of these tributaries (ODFW 1997a). A substantial amount of spawning has recently been documented in the lower Sandy River, but little is currently known about winter steelhead in this area of the basin (D. Cramer, pers. comm., 1998).

Winter steelhead adults migrate upstream in the Sandy River from November through May. Most winter steelhead pass over the dam between January and April, with peak passage occurring in March. Spawning of wild winter steelhead extends from early March through late May, with peak spawning occurring from mid-March through mid-May, as shown in Tables 5 and 6 (R2 Resource Consultants 1998a). Emergence of fry from the gravels occurs from June to August. Winter steelhead in the Sandy River basin rear for one to three years before migrating downstream to the ocean. Thus, juvenile steelhead are present in the basin year-round.

Juvenile steelhead appear able to use a wider variety of habitats for rearing than other anadromous salmonids. After emergence, steelhead fry move to shallow, low-velocity habitats such as stream margins and low-gradient riffles, and will forage in open areas lacking instream cover (Hartman 1965, Everest et al. 1986, Fontaine 1988). As fry increase in size, they increasingly use areas with cover and show a preference for higher-velocity, deeper areas nearer the thalweg (Hartman 1965, Everest and Chapman 1972, Fontaine 1988). In the late fall to early winter, steelhead may enter a period of winter inactivity spent hiding in the substrate or closely associated with instream cover (Everest and Chapman 1972, Roelofs 1985). As steelhead grow larger, they tend to prefer habitats with deeper water and higher velocity; and seek out areas with an optimal balance of food supply versus energy expenditure, such as velocity breaks associated with boulders or other large roughness elements adjacent to areas with swift current and high rates of invertebrate drift (Everest and Chapman 1972, Bisson et al. 1988, Fausch 1993).

Although information on juvenile steelhead distribution in the Sandy River basin is limited, rearing likely occurs throughout the basin. Tributaries where spawning occurs are likely utilized by all age classes of juvenile steelhead, while age 1+ and older juveniles may be more abundant in the larger channels. It is likely that the most preferred habitats for steelhead in the mainstem Sandy River are where large boulder substrates provide velocity refuge and optimal feeding conditions. Snorkel surveys conducted in July of 1999, however, indicate relatively light use of the mainstem Sandy River for rearing by juvenile steelhead (O'Neal and Cramer 1999). Higher densities of juvenile steelhead were observed rearing in the lower Little Sandy and Salmon rivers in the same study (O'Neal and Cramer 1999). In the mainstem Sandy River, suitable habitat for older age classes of juvenile steelhead is present in most reaches downstream of Marmot Dam, including the reach immediately downstream of the dam and the reach from the end of the Sandy River gorge (RM 24.5) downstream to Dabney Park (RM 6). The large substrates present in these reaches would provide flow obstructions and feeding opportunities for steelhead during the summer and refuge from high velocity in winter. Side-channel and off-channel habitats would offer refuge during extreme flow events.

### 3.5.5 Summer steelhead

Summer steelhead in the Sandy River basin are currently managed for hatchery production only (ODFW 1997a), although summer steelhead may have historically occurred in the basin. Stocking of hatchery summer steelhead above Marmot Dam has been discontinued and marked hatchery fish are now prevented from ascending the fish ladder to spawn upstream of the dam, but the unmarked progeny of naturally spawning hatchery fish continue to pass upstream of the dam and spawn in the upper Sandy River basin. Little is known about natural production of summer steelhead downstream of Marmot Dam, although given the habitat preferences of these fish, it is unlikely that they spawn in the mainstem Sandy River downstream of Marmot Dam. Summer steelhead migrate into the Sandy River from early winter through spring and pass over Marmot Dam from March through November, with peak passage occurring in May through August (Tables 5 and 6). Adults hold in the river during summer and fall until reaching sexual maturity around mid-winter. Adult summer steelhead require large, deep pools with flowing water and suitable temperatures as holding habitat during the summer and fall (Roelofs 1983).

Summer steelhead, like winter steelhead, typically rear for two to three years before migrating downstream to the ocean. Steelhead likely remain in their natal streams for the first summer after which they may disperse downstream. In the mainstem Sandy River, steelhead rearing habitat would be similar to that described above for winter steelhead.

### 3.5.6 Coastal cutthroat trout

Anadromous (sea-run), freshwater migratory, and resident coastal cutthroat trout are native to the Sandy River basin. Cutthroat trout exhibiting a freshwater migratory life history strategy migrate to larger mainstem river reaches in the spring, summer, and fall growing season and migrate upstream into tributaries for overwintering and spawning. Migratory forms (both sea-run and freshwater migratory forms) are believed to occur primarily in tributaries downstream of Marmot Dam (PGE 1998a), although little or no data are available on the abundance, population trends, and distribution of migratory cutthroat trout in the Sandy River basin (Figure 8). At least two to three dozen sea-run cutthroat trout historically returned each fall to the lower Sandy River hatchery; however, there have been no verified observations of sea-run cutthroat trout in the Sandy River in recent years (R. Hooton, as cited in Johnson et al. 1999; ODFW 1997a). Anecdotal information from anglers suggests that, in the past, sea-run cutthroat trout supported a significant sport fishery in the lower Sandy River basin (Taylor 1998). Resident coastal cutthroat trout are well-distributed in the Sandy River basin, and occur both upstream and downstream of the Marmot and Little Sandy dams.

Cutthroat trout generally spawn and rear in tributary streams (Trotter 1997), with spawning typically occurring between late winter and early spring (ODFW 1997a). In the Sandy River, migratory adult coastal cutthroat trout are present from September through December (PGE 1997). Generally, juvenile cutthroat outmigration occurs primarily from March through May. Tributary reaches used by sea-run cutthroat trout are generally considered to be located upstream of areas used for spawning by coho salmon and steelhead. Like other anadromous salmonids, after emerging from the gravel, cutthroat fry move to low-velocity channel margins, backwaters, and side channels (Moore and Gregory 1988a). As they age and grow, juvenile cutthroat generally move to deeper habitats. Where cutthroat are not spatially or temporally segregated from other salmonid species, they are often displaced from their preferred habitats by larger, more aggressive species, especially steelhead and coho. Juvenile cutthroat prefer to overwinter in low-velocity habitats such as pools and side channels that provide cover such as those having large woody debris (LWD) or undercut banks (Bustard and Narver 1975, Sullivan 1986, Bisson et al. 1988, Heggenes et al. 1991). Older cutthroat tend to prefer habitats with water velocities intermediate between the higher-velocity habitats chosen by juvenile steelhead and the low-velocity habitats used by juvenile coho salmon. Fausch and Northcote (1992) found that pools formed by LWD provided critical habitat for age 2+ and older cutthroat during summer low flows.

Although information on migratory cutthroat trout distribution and habitat use in the Sandy River basin is poorly understood, juvenile cutthroat likely prefer to rear in smaller tributary reaches containing deep pools and adequate cover. Based on information from Willamette River basin tributaries, migratory cutthroat trout in the Sandy River basin likely remain in fresh water for two to four years before first outmigrating to the ocean (Moring and Youker 1979, Nicholas 1978; both as cited in ODFW 1997a). In large streams such as the mainstem Sandy River, cutthroat likely prefer side channels and channel margins as rearing habitat. During winter, cutthroat have been observed (in other river basins) using tributaries with pools and side channels that contain velocity refuge and cover, where they may hide in the interstices of coarse substrates (Lewynsky 1986). In the mainstem Sandy River downstream of Marmot Dam, the reach between Dodge Park (RM 18.5) and Dabney Park (RM 6) is likely to provide the greatest amount of rearing habitat for cutthroat trout because of the presence of side channels and deep pools in this reach.

## 3.6 Reach Descriptions of the Sandy River and Little Sandy River

The geomorphic and salmonid habitat conditions of each reach of the Sandy and Little Sandy Rivers influenced by the Bull Run project are described below. Detailed descriptions include discussion of the following: (1) geomorphic characteristics such as substrate sizes, confinement, gradient, and morphologic type; (2) relative sensitivities of each reach to increases in sediment supply resulting from dam removal; and (3) salmonid habitat characteristics.

### 3.6.1 Reach descriptions of the Sandy River

The Sandy River is characterized by naturally high sediment loading as a result of past laharic events, Mt. Hood glaciers, and lithology. The Sandy River exhibits many characteristics typical of alluvial rivers, including a longitudinal profile that decreases in gradient in a downstream direction (Figure 9), and a decrease in channel bed particle sizes in a downstream direction. Wolman pebble counts conducted by Stillwater Sciences at 11 sites upstream and downstream of Marmot Dam indicate median grain sizes ($D_{50}$) ranging from about 4.7 in (120 mm) (RM 31.8) to about 1.9 in (50 mm) (RM 2.5).

For the purposes of geomorphic analysis, the Sandy River from Marmot Dam downstream to the Columbia River can be delineated into five reaches, with the reach immediately upstream of the dam representing a sixth reach of concern (Figures 9 and 10). The geomorphic characteristics of each of these reaches are summarized in Table 7 and detailed reach-by-reach descriptions are provided below.

**Table 7. Summary of geomorphic characteristics of Sandy River reaches.**

| Reach | Length (mi) | Average width (ft) | Average gradient | Confinement | Morphology | Estimate of active alluvial storage ($yd^3$) | Total length of side channels[1] (ft) |
|---|---|---|---|---|---|---|---|
| Upstream of Marmot dam (RM 32–RM 30) | 1.6–2 | 150 | 0.002 | High | Pool-riffle | 980,000[2] | 0 |
| Marmot Dam to gorge (Reach 1: RM 30–RM 28.5) | 1.5 | 100 | 0.008 | Medium | Forced pool riffle/plane bed | 180,000 | 230 |
| Sandy River gorge (Reach 2: RM 28.5–RM 24.5) | 4 | 100 | 0.01 | High | Step pool | 410,000 | 0 |
| Downstream end of Sandy River gorge to Bull Run River (Reach 3: RM 24.5–RM 18.5) | 6 | 160 | 0.006 | Medium | Forced pool riffle/plane bed | 1,300,000 | 1,640 |
| Bull Run River to Dabney Park (Reach 4: RM 18.5–RM 6) | 12.5 | 230 | 0.0025 | Medium/low | Pool riffle/ plane bed | 4,400,000 | 17,300 |
| Dabney Park to mouth (Reach 5: RM 6–RM 0) | 6 | 330 | 0.0007 | Medium/low | Pool riffle/dune riffle | 2,200,000 | 1,770 |

1 Stillwater Sciences estimated the total length of side channels in each geomorphic reach in order to assist evaluation of current habitat conditions in these reaches and sensitivity to sediment impacts.
2 This volume represents the amount of sediment stored behind Marmot Dam (Squier Associates 2000).

#### *Upstream of Marmot Dam/Reservoir-influenced reach*

The impoundment formed by Marmot Dam has filled to near the dam's crest with sediment and now functions as an alluvial river reach. Compared with upstream and downstream reaches, the reach immediately upstream of Marmot Dam currently has a lower gradient (about 0.002) and smaller bed substrates with a higher percentage of gravels. These differences are a result of the grade control provided by the dam and the backwater effect of the dam's impoundment. The Sandy River upstream of Marmot

Dam is affected by the backwater effect of the dam for a distance of approximately 1.2–2.0 mi (1.9–3.2 km). This estimate is based on field observation and analysis of the Sandy River longitudinal profile by Stillwater Sciences. Evidence of aggradation (buried tree trunks) and substrate characteristics that differ from those upstream and downstream of the dam provide evidence of this backwater effect. The reservoir-influenced reach has pool-riffle/plane-bed morphology, with a higher frequency of pools (Cramer et al. 1998) than upstream and downstream reaches. Substrates in the reservoir-influenced reach consist of cobbles, small boulders, and gravel, and the sand content in the subsurface (i.e., in the sediment that has accumulated in the reservoir) is high.

Approximately 980,000 $yd^3$ (750,000 $m^3$) of sediment are stored behind Marmot Dam (Squier Associates 2000). The grain size distribution of this sediment, which has an important influence on its downstream transport patterns and associated impacts, was determined based on sampling conducted by Squier Associates in October 1999. Sampling of the reservoir sediment consisted of drilling a series of cores into the sediment wedge upstream of the dam and mapping of various sediment units deposited on the bedrock below the old river channel. The reservoir sediment consists of two main units, with the pre-dam channel bed representing a third distinct unit (Figure 11) (Squier Associates 2000). The uppermost unit (Unit 1) is approximately 6–18 ft (2–5.5 m) thick and is composed of a sandy gravel with cobbles and boulders, becoming thicker toward the dam. The next unit (Unit 2) is predominantly fine sediment (silty-sand to sand with gravel, 13–35-ft [4–11-m] thick). Unit 3 represents the pre-dam channel bed and lies below Unit 2. Unit 3 consists primarily of coarse sediment and is 2.5–10 ft (0.8–3 m) thick. The sediment accumulation behind the dam consists of approximately two-thirds coarse sediment (> 2 mm) and one-third fine sediment (< 2 mm). Additional information on the grain-size distribution of these units is provided in Squier Associates (2000) and Stillwater Sciences (2000).

The pool-riffle morphology that characterizes the reservoir-influenced reach provides habitat that is suitable for salmonid spawning, rearing, and holding. Gravel suitable for spawning is relatively abundant in this reach compared with reaches immediately upstream and downstream, likely due to the grade control and backwater effect created by Marmot Dam and the associated low shear stresses. Most of the fall chinook salmon that pass over Marmot Dam likely spawn in this reach (Cramer et al. 1998). Spring chinook also spawn in this reach. Deep pools (< 10 ft [3 m]) are present in this reach and provide habitat suitable for adult holding and summer rearing habitat for chinook salmon, coho salmon, and steelhead.

***Reach 1, Marmot Dam to the upstream end of the gorge (RM 30–RM 28.5)***

This reach is 1.5 mi (2.4 km) long and is bounded by an approximately 65-ft (20-m) high terrace on the southern bank that is actively eroding in places. Reach 1 is characterized by a 0.008 gradient, moderate confinement at bankfull flow, and moderately pronounced forced pool-riffle morphology with a few small lateral cobble/boulder bars. The bed surface consists mainly of cobbles and boulders; gravels are limited. Sand content in the bed subsurface is generally very low. This reach represents a transitional area between the High Cascade and Western Cascade geologic provinces. Bank material is characterized by both Rhododendron formation (relatively competent fractured andesite) and alluvial terraces (which are non-cohesive, consisting primarily of matrix-supported gravels with lenses of conglomerates).

Reach 1 contains two main depositional areas: (1) a large alder-vegetated bar and side channel known as Beaver Island (RM 29.4–29.2) and (2) a large alcove/backwater pool at the downstream end of the reach (RM 28.7). The alder bar/side channel (Beaver Island) is located 0.6 mi (1 km) downstream of Marmot dam, has a LWD jam at its head, and is associated with a local, very coarse sediment deposit that may have been formed during the last lahar event (approximately 200 years ago). The alcove/backwater pool (RM

28.7) is forced by constriction of the channel and a bedrock wall at the head of the gorge and may be a valuable salmonid rearing and holding site. Adjacent to this alcove/backwater pool, the channel contains a LWD jam that was apparently uncovered during the 1964 flood and is referred to as the “1964 jam.” The channel and valley walls become narrower immediately downstream of this LWD jam, marking the beginning of the gorge. As part of the assessment of in-channel sediment storage downstream of Marmot Dam, Stillwater Sciences estimated the amount of active sediment storage in Reach 1 as approximately 180,000 $yd^3$ (130,000 $m^3$); on a linear basis, this corresponds to approximately 120,000 $yd^3$/mi (56,000 $m^3$/km).

A small amount of gravel patches suitable for spawning are present in Reach 1, and spring chinook spawning has been observed in this reach. Overall, however, the channel bed in Reach 1 is dominated by boulder and cobble bed substrates, relatively few depositional areas of gravel suitable for salmonid spawning are present, and the reach likely supports little spawning. The reach does provide suitable rearing habitat for several salmonid species, including side channels and backwaters at the alder-vegetated bar described above (which would be expected to be used by coho salmon), deep pools (which would be used by chinook and coho salmon), and coarse substrates with interstitial spaces that are suitable for chinook salmon and steelhead winter rearing. Deep pools present in this reach also provide adult holding habitat for spring chinook and summer steelhead.

***Reach 2, Sandy River gorge (RM 28.5–RM 24.5)***

The gorge reach is 4 mi (6.4 km) in length and is bounded by 65–100-ft (20–30-m) high bedrock strath terraces[3] with steep hillslopes above. Banks are very competent (usually welded volcanic bedrock of the Rhododendron formation). Reach 2 is characterized by a 0.01 gradient, high confinement, and step-pool morphology with only patchy cobble/boulder deposits and long, deep bedrock pools that are separated by coarse-bedded riffles and boulder rapids. Large (house-sized) boulders are present in the channel, likely originating from the canyon walls. These boulders form momentum defects (i.e., create hydraulic conditions conducive to sediment deposition), but deposition behind them is often limited. In general, few deposition areas are present in this reach: (1) a moderately confined reach approximately 0.9 mi (1.4 km) long is present in the upstream end of Reach 2 (RM 28.5–27.6), where much of the alluvial sediment storage in Reach 2 is concentrated; (2) micro-deposition areas with sand bars are scattered throughout the gorge (sand deposits 0.3–1 foot [0.1–0.3 m] thick have formed at the margins of some bedrock pools); and (3) some cobble/boulder bars are present. Bedrock exposure is more common in the channel bed in this reach than in other reaches of the Sandy River, and the bed is highly armored. Sand content in the bed subsurface is generally very low. The steep gradient and high confinement in this reach create very high shear stresses, resulting in high sediment transport capacity. Active sediment storage in this reach is estimated to be approximately 410,000 $yd^3$ (310,000 $m^3$) (on a linear basis, 100,000 $yd^3$/mi [50,000 $m^3$/km]), much of which is located in the moderately confined section at RM 28.5–27.6; in the rest of the gorge, channel sediment storage is low.

The deep, bedrock scour pools in the gorge are the primary salmonid habitat within the gorge, in particular providing suitable habitat for adult holding during upstream migration. Pools may also be used for juvenile rearing, especially by chinook and coho salmon during the summer, although coho salmon prefer habitats associated with LWD and few such habitats are present in the gorge. Riffles with coarse bed material also may provide rearing habitat for steelhead. Because shear stresses are extremely high in the

[3] Strath terraces are river terraces that are cut into bedrock (rather than into alluvial valley fill) and that may covered by a thin veneer of sediment over the bedrock (Summerfield 1991).

gorge during high flows and refuge habitats (e.g., side channel, vegetated floodplain) are nearly absent, winter rearing is likely limited in this reach. In addition, little or no spawning habitat is present in this reach because of high shear stresses and limited availability of depositional areas.

***Reach 3, Downstream end of gorge (near Revenue Bridge) to Dodge Park (Bull Run River confluence) (RM 24.5–RM 18.5)***

Reach 3, which extends from the downstream end of the gorge (near Revenue Bridge) to the Bull Run River confluence at Dodge Park, is about 6 mi (10 km) in length. This reach widens considerably compared with Reaches 1 and 2 (with an average width of 160 ft [50 m]), has an average gradient of 0.006 (compared with 0.01 in Reaches 1 and 2), and is characterized by forced pool-riffle morphology with many cobble/boulder bars and a cobble/gravel-dominated channel bed. Because the channel and valley bottom widen and gradient decreases downstream of the gorge, sediment transport capacity is lower than in the gorge and potential for sediment deposition increases. Several wide areas with mid-channel bars are present, both upstream and downstream of Revenue Bridge (RM 24.5), and some side channel features are also present. Shear stresses remain relatively high, however, and although average bed particle sizes in this reach decrease compared with Reaches 1 and 2, gravels suitable as spawning substrate are limited, occurring only in scattered patches and pool tail-outs (ODFW 1990, 1997a). The sand content in the bed subsurface is generally higher than in upstream reaches but lower than in downstream reaches. River banks are mostly mudstone bedrock (Troutdale formation), debris fans, and cutbanks of vegetated alluvial features. Active alluvial storage is estimated to be approximately 1,300,000 $yd^3$ (1,000,000 $m^3$) (220,000 $yd^3$/mi [110,000 $m^3$/km]), based on Stillwater Sciences' assessment of in-channel sediment storage. This is substantially higher than in Reaches 1 and 2, reflecting the wider active channel and increased depositional potential in Reach 3.

This reach provides suitable habitat for fall chinook salmon and steelhead (spawning, summer rearing, winter rearing) and coho salmon (summer and winter rearing), as well as a migration corridor for anadromous salmonids that spawn and rear upstream of Marmot Dam. Spawning habitat for chinook salmon and steelhead are available in isolated locations. Stillwater Sciences observed spawning habitat suitable for chinook salmon upstream of Revenue Bridge near the downstream end of the gorge (≈RM 24.4). PGE surveys documented winter steelhead redds downstream of Revenue Bridge and near the confluence of Cedar Creek in 1998; many of these redds were located in side channels (PGE 1998b). Summer rearing habitat is available for chinook and coho salmon in the low-velocity pool and glide habitats, and steelhead summer rearing habitat is abundant in pool, riffle and glide habitats. Substrate used by chinook and steelhead during winter rearing is abundant. Winter refuge habitat is available in side channel, overflow channel and vegetated floodplain habitats.

***Reach 4, Dodge Park to Dabney Park (RM 18.5–RM 6)***

Reach 4 extends from the Bull Run confluence (Dodge Park) to Dabney State Park, a length of 12.5 mi (20 km). This reach has an average gradient of approximately 0.0025, is bounded by high (mostly alluvial) terraces, and is characterized by pool-riffle morphology with many cobble/gravel bars. The channel bed is a mixture of cobbles, gravel, and sand. Sand content in the bed subsurface is generally high, notably increasing at Oxbow Park. River banks generally consist of mudflow deposits (which include unconsolidated silt, sand and conglomerate deposits), vegetated alluvial bars, and competent bedrock originating from Mt. Hood volcanic material. Banks formed of mudflow deposits, which were deposited by runout from the Old Maid and Timberline volcanic events, are 23–30 ft (7–9 m) high along some reaches and may be an important source of fine sediment to the channel under current conditions.

In Reach 4, channel confinement, gradient, and bed particle size decrease further compared with reaches upstream, with these tendencies particularly evident in the reach from Oxbow Park (RM 11.9) to Dabney Park (RM 6.6). Large bars, side channels, overflow channels, and islands are present in larger magnitude and greater frequency. The percent of the active bed and bars covered with sand increases, and in portions of Reach 4 (particularly downstream of Oxbow Park), the active bed is saturated with sand and the potential for additional sand storage in the interstices of coarser sediment is low. Many of the active channel bars are mantled with overbank sand deposits and have side channels. Reach 4 has a large amount of coarse and fine sediment stored in the active and semi-active channels. Stillwater Sciences estimated the volume of sediment stored in active storage sites to be approximately 4,400,000 $yd^3$ (3,400,000 $m^3$) (350,000 $yd^3$/mi [170,000 $m^3$/km]).

This reach provides suitable habitat for chinook, steelhead, and coho salmon, in particular providing substantial spawning habitat for fall chinook salmon and winter steelhead. This reach contains the majority of fall chinook spawning habitat in the Sandy River and the majority of mainstem spawning habitat used by winter steelhead (PGE 1998b), reflecting the increased availability of spawning-sized gravel in this reach. Most of this spawning habitat is located downstream of Oxbow Park (PGE 1998b). Chinook and steelhead spawning has also been observed in tributaries to the Sandy River within this reach, specifically Buck, Gordon, and Trout creeks (ODFW 1997a). In a one-day aerial survey in 1998 of winter steelhead redds in the mainstem Sandy River from Marmot Dam to the Interstate-84 bridge, about 70% of the redds observed were in this reach (PGE 1998b), although it is unknown what percentage of total winter steelhead spawning in the Sandy River basin this represents. Summer rearing habitat is available for chinook and coho salmon in low-velocity pools and glides, and steelhead summer rearing habitat is abundant in pool, riffle and glide habitats. Coarse substrates potentially used by chinook and steelhead during winter rearing are abundant. Winter refuge habitat is available in side channel, overflow channel, and vegetated floodplain habitats. Side channels in this reach likely provide important spawning and summer and winter rearing habitat for salmonids; these types of habitats are particularly suitable for juvenile coho rearing.

***Reach 5, Dabney Park to mouth (RM 6–RM 0)***

Reach 5 is 6 mi (9.6 km) long and is characterized by a 0.0007 gradient (compared with 0.0025 in Reach 4), moderate-to-low confinement at bankfull flow, and dune-ripple morphology with large gravel/sand alternate and medial bars. Many of the active channel bars, some spanning 50% of the channel area, are mantled with overbank sand deposits and have side channels. The channel bed is a mixture of sand and gravel, is highly mobile, and has a very high sand content in the bed subsurface (Stillwater Sciences estimated 60–100% embeddedness). The decrease in bed particle size is a function of decreased channel gradient and confinement. Active sediment storage, estimated at approximately 2,200,000 $yd^3$ (1,700,000 $m^3$) (370,000 $yd^3$/mi [180,000 $m^3$/km]) by Stillwater Sciences, is the highest per unit length of any reach in the Sandy River. This reflects the increased channel width and the decreased sediment transport capacity in this reach compared with upstream reaches.

The Sandy River delta forms the downstream-most portion of Reach 5. In the delta, the channel is sand-bedded and depositional dynamics are strongly influenced by the backwater effect of the Columbia River. Human influences have caused substantial morphologic changes in the Sandy River delta over the last century. In the early 1900s, a channel to the east of what is currently the main channel was the main outlet of the Sandy River to the Columbia River (Craig and Suomela 1940). This channel has been referred to as the Big Sandy Channel and may have become the main channel after a large flood in 1904. At that time, what is now the main channel was a secondary channel that was sealed (aggraded) at its mouth during low flows (Craig and Suomela 1940). Because this resulted in fish passage problems during periods of low flow, a small wooden dam (10-ft [3 m] high) was constructed across the Big Sandy Channel in 1938 in order to divert water into what is now the main channel of the Sandy River, allowing year-round passage for migratory fishes (Craig and Suomela 1940). Dredging of the main Sandy channel at its mouth has also occurred to facilitate fish passage.

This reach contains spawning and rearing habitat in its upstream end, particularly for fall chinook and winter steelhead, and serves as a migration corridor for all fish entering the Sandy River system. The majority of spawning habitat for fall chinook salmon occurs upstream of Lewis and Clark State Park, although overall, this reach supports less fall chinook spawning than Reach 4. Steelhead spawning habitat is also present in isolated locations, although steelhead tend to spawn in smaller channels upstream. The upper portion of this reach provides abundant summer rearing habitat for chinook and coho salmon and steelhead. Winter refuge habitat for all salmonids is also available in side channel, overflow channel and vegetated floodplain habitats, although juvenile coho salmon tend to prefer smaller channels for rearing. In addition, coarse substrate suitable for use by chinook and steelhead during winter is limited. The Sandy River delta is not likely used for extended periods by any salmonid species or lifestage; this area primarily serves as a migration route.

### 3.6.2 Reach descriptions of the Little Sandy River

Little Sandy Dam impounds a small reservoir and has a limited storage capacity. Preliminary estimates by PGE engineers indicated that approximately 4,500 $yd^3$ (3,400 $m^3$) of sediment are stored behind the dam, based on an average sediment accumulation depth of 4 ft (1.2 m), a width of 100 ft (30 m), and a length of 300 ft (90 m). Field observations by Stillwater Sciences suggested a greater volume of sediment accumulation—approximately 9,400 $yd^3$ (7,200 $m^3$)—due to variations in the estimate of the upstream extent of the sediment accumulation. This difference is likely attributable to the different dates on which the estimates were made: PGE’s estimate was made in summer 1999, while Stillwater Sciences’ observations occurred after the November 1999 high-flow event, which appears to have deposited additional sediment behind the dam. The predicted impacts of removal of Little Sandy Dam remain the same, regardless of which estimates of sediment volume is used. Sampling of the sediment deposit behind Little Sandy Dam found that this sediment consists of mostly gravel (50–60% of the total) and sand (35–45%), with small amounts of cobble and silt (Squier Associates 2000). Because of the low elevation of this dam and the filling of the impoundment with sediment, fine and coarse sediment transport likely occur over the dam during spill events; evidence of passage of gravels (up to about 50 mm) was observed downstream of the dam following the November 1999 high-flow event.

The 1.7-mi (2.8-km) reach downstream of Little Sandy Dam is largely bedrock constrained with a steep-sided, V-shaped valley. Stream banks and valley walls are composed of Rhododendron formation bedrock, mantled in some locations with alluvial deposits. The average channel gradient is 0.028, the average active channel width is 47 ft (14.4 m), and about two-thirds of total reach length consists of riffles, cascades, or rapids (the rest consists of pools) (ODFW 1997b). The substrate is composed of boulders, cobbles, and bedrock with few gravels. Previous surveys (ODFW 1997b, Hardin 1998, Craig and Suomela 1940) have noted that spawning substrate is severely limited (or nonexistent) downstream of Little Sandy Dam, which agrees with observations by Stillwater Sciences. For the purposes of this analysis, Stillwater Sciences divided the Little Sandy River below the diversion dam into two reaches. These reaches are shown on Figure 12.

***Upstream of Little Sandy Dam***

The sediment accumulation behind Little Sandy Dam extends upstream for a distance of approximately 300 ft (90 m) and has an average depth of about 4 ft (1.2 m) (maximum depth is about 8 ft [2.4 m]). Further upstream of Little Sandy Dam, the channel is no longer bedrock constrained, causing a change in morphology and increased frequency of gravels, although boulders and cobbles are dominant substrates (ODFW 1997b). Five bedrock falls that act as barriers to fish migration were noted in ODFW habitat surveys (ODFW 1997b). Additional detail on habitat conditions upstream of Little Sandy Dam is provided in ODFW (1997b).

***Little Sandy Reach 1***

The reach from Little Sandy Dam to approximately 0.3 mi (450 m) downstream of the dam is a geomorphically distinct reach. This reach has a step-pool/plane bed morphology, an average gradient of 0.02, and channel bed substrates consisting of cobbles (50% by volume) and gravel (40% by volume) within an immobile framework of boulders (10% by volume). Although gravel is present in the channel bed, mixed in with cobbles, no gravel patches that are suitable for spawning were observed in Reach 1. Reach 1 has a relatively wide valley (up to 500 ft [150 m] wide) constrained by bedrock, with 5-ft (1.5-m) high strath terraces within the valley walls constraining the channel on the southern bank. The active channel has an average width of about 33 ft (10 m), which appears to be less than under unregulated conditions due to encroachment of riparian vegetation onto channel bars. Boulder/cobble bars are densely vegetated with willows and alders. High-water marks from the November 1999 high-flow event were observed on this vegetation 6.6–8.2 ft (2–2.5 m) above the channel bed. This event also appears to have created overbank sand deposits in Reach 1. Large woody debris is infrequent throughout the reach and is mostly deposited on streamside bars; no channel-spanning debris accumulations are present. Removal of LWD that accumulates at Little Sandy Dam by PGE maintenance crews has likely contributed to the low frequency of LWD in Reach 1. Evidence of bank erosion along this reach is provided by exposure of tree roots of Western red cedars growing on 3–5 ft (1–1.5 m) terrace banks, perhaps as a result of aggradation caused by reduced sediment transport capacity.

Pools suitable for steelhead resting during migration are spaced at regular intervals throughout Reach 1 (pool frequency in this reach is 4.3 channel widths/pool). Deep pools (> 10 ft [3 m]) suitable for extended holding, however, are not present. Reach 1 does not currently contain spawning habitat, although increased flows could make some channel-margin areas suitable for steelhead spawning. Reach 1 contains habitat that could be used for summer and winter rearing by steelhead juveniles although under current conditions, summer rearing habitat is limited by low summer instream flows. Interstices within coarse substrate particles, which provide suitable winter rearing habitat for juvenile steelhead (e.g., Everest and Chapman 1972), are abundant in Reach 1.

***Little Sandy Reach 2***

Reach 2 extends from about 0.3 mi (450 m) below Little Sandy dam downstream to the confluence of the Little Sandy with the Bull Run River (1.7 mi [2.8 km] below the dam). This reach has an average slope of approximately 0.028 and is constrained within a narrow bedrock gorge (mostly Rhododendron formation mantled with alluvial terraces). The channel is characterized by step-pool morphology, with boulder-dominated riffles/rapids separating pools and cobble bars that have a surface elevation about 5 ft (1.5 m) above the current active channel bed. Most of the channel bed is mantled by coarse alluvium, although bedrock protrusions are common, localized bedrock knickpoints are present, and some pools lack an alluvial mantle. Gravel deposits are limited in Reach 2, reflecting the high sediment transport capacity in the reach, and mostly occur as patches formed on channel margins, in pool tails, and in association with momentum defects (e.g., boulders, bank irregularities). Although the bed is dominated by coarse sediments, sand deposits were also observed in the channel bed and on low cobble bar surfaces, which were inundated by the November 1999 flood. Valley width averages 82 ft (25 m) (ranging 52–130 ft [16–40 m]), active channel width averages 66 ft (20 m) (ranging 30–72 ft [9–22 m]), and bankfull depth averages approximately 2.6 ft (0.8 m). In addition to sediment supply from upstream and tributary sources, sediment is supplied to this reach by recruitment of boulders from Rhododendron formation cliffs and banks, which are highly erosive in some locations, and Quaternary alluvial terraces that overlie the Rhododendron bedrock along portions of the reach also contribute cobbles to the channel. There are six small debris jams in this reach, and only two logs that span the channel.

The upstream end of Reach 2 (from about 0.3 to 0.6 mi [450 to 950 m] below the dam) represents a transition between Reaches 1 and 2, having a lower gradient (approximately 0.025) than the majority of Reach 2 and small gravel deposits behind boulders. Further downstream, the Little Sandy River steepens and becomes more confined. Several bedrock knickpoints, which are about 100–500 ft (30–150 m) in length and 6.6–13 ft (2–4 m) high, create substantial elevation change in the channel bed. The main fish habitat within this reach is provided by two large pools and one riffle (0.9–1.0 mi [1,500–1,650 m] below the dam). These pools are approximately 100 ft (30 m) in length, have a maximum depth of 6.6–10 ft (2–3 m), and are constricted within bedrock walls.

The basic differences between Reaches 1 and 2 are as follows:

- Reach 1 has a wider valley bottom than Reach 2.
- Reach 1 has a lower gradient (0.02) than Reach 2 (0.028).
- No bedrock scour pools were observed in Reach 1, whereas many are present in Reach 2.
- Sediment stored in the channel bed in Reach 1 appears less mobile in Reach 1 than in Reach 2, possibly reflecting the greater influence of Little Sandy Dam in reducing transport capacity in Reach 1 than in Reach 2, where the channel is steeper and more confined (resulting in greater transport capacity) and tributaries increase discharge magnitudes.
- Large boulders that were likely recruited from channel banks/valley walls are rare in Reach 1 but are frequent in Reach 2.
- Gravel patches (consisting of mobile, well sorted clasts) are not present in Reach 1 but are locally present in Reach 2.
- Sand deposits are less extensive in Reach 1 than in Reach 2, occurring in the latter reach in both the channel bed and as overbank deposits, while mainly being limited to overbank areas in Reach 1.
- LWD frequency is lower in Reach 1 than in Reach 2, although overall, both reaches have little LWD.

# 4. POTENTIAL GEOMORPHIC AND BIOLOGICAL IMPACTS ASSOCIATED WITH REMOVAL OF THE BULL RUN PROJECT

In this section, we discuss the geomorphic and biological impacts of removal of Marmot and Little Sandy dams. For the analysis of Marmot Dam, an important component of this effort was the numerical modeling of downstream sediment transport and deposition (see Section 2). Modeling results (for Marmot Dam), field reconnaissance, aerial photograph interpretation, literature review, and professional judgement were used to provide a complete evaluation of the geomorphic impacts and associated impacts on anadromous salmonid habitats and populations expected under each alternative. Potential impacts associated with the removal of Marmot Dam and Little Sandy Dam are covered in Sections 4.1 and 4.2, respectively.

## 4.1 Comparison of Alternatives for Removal of Marmot Dam

This section compares the potential impacts resulting from sediment release and erosion of sediment currently stored in Marmot reservoir for each dam removal alternative. For Alternatives B, C, and D, this discussion is based primarily on results of the numerical modeling, which provides for each of these alternatives reach-scale predictions of the following: (1) depth of sediment deposition downstream of the dam (differentiated into sand versus gravel components), (2) time required for the coarse sediment and sand to pass through the river system (from Marmot Dam to the Columbia River), (3) erosion patterns of the sediment stored behind Marmot Dam, and (4) suspended sediment concentrations following dam removal[4]. (No modeling was conducted for Alternative A because nearly all sediment would be excavated and removed from the reservoir, although a "reference run" of the model was completed that provides results that may be analagous to Alternative A.) Model results are interpreted in terms of geomorphic and biological effects on a reach-by-reach basis (current geomorphic conditions and anadromous salmonid habitat in each of the geomorphic reaches delineated by Stillwater Sciences are described in Section 3.6).

The details of expected impacts on channel geomorphology and physical habitat under each alternative are presented in Sections 4.1.1 through 4.1.4. These potential impacts are then summarized and linked to potential salmonid population responses in Section 4.1.5.

### 4.1.1 Alternative A: Remove all sediments to a point 5,500 ft upstream of Marmot Dam

This alternative entails excavation of approximately 980,000 $yd^3$ (750,000 $m^3$) of sediment and concurrent removal of the dam in one season. Excavation would occur by transfering the stream from side to side as required to facilitate use of heavy equipment to remove sediment. The analysis presented below assumes that all sediment could be removed in one construction season before the onset of high flows.

***Numerical Modeling Results***

No numerical modeling was conducted for this alternative because almost all of the reservoir sediment deposit would be excavated and removed prior to dam removal. A numerical model run was completed for reference conditions, however, assuming that no dam exists and downstream sediment transport is equivalent to estimated background (natural) conditions, with no release of reservoir sediment. This "reference run" of the model was a necessary component of numerical modeling (see Stillwater Sciences 2000 for technical discussion) and provides a basis for comparison with modeling of Alternatives B–D, in which varying amounts of sediment are released downstream. In the reference run of the model, a small amount of coarse sediment aggradation (and degradation) is indicated in Reaches 3 and 4, even without sediment release from Marmot reservoir (Figure 13). When comparing predicted deposition patterns for Alternatives B–D (based on model results) with Alternative A, this reference model run, which depicts aggradation and degradation in the Sandy River in the absence of sediment release from Marmot Dam, should also be used as a point of comparison.

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[4] Construction activities and downstream sediment release associated with dam removal would result in increases in both turbidity and total suspended sediment (TSS). Turbidity is a measure of the scattering of light and is typically expressed in nephelometric turbidity units (NTUs), while TSS refers to concentration of suspended sediment and is expressed in either ppm or mg/l. Numerical modeling only predicts increases in TSS; potential turbidity increases are discussed in qualitative terms.

***Geomorphic Assessment***

*Upstream impacts and channel adjustment in the reservoir-influenced reach (RM 32-30)*
Geomorphic conditions in the reach upstream of Marmot Dam that is currently influenced by the grade control and backwater effect of the dam would change significantly under all dam removal alternatives. Under current conditions, this reach is relatively low gradient (about 0.002) as a result of the grade control provided by the dam. Following dam removal and excavation of reservoir sediment, this reach will have a gradient similar to the pre-dam channel gradient (about 0.006, as suggested by analysis of a channel profile surveyed by USGS shortly after construction of Marmot Dam [USGS 1915] and PGE photogrammetry data). This channel slope adjustment will increase bed shear stresses and will likely increase bed particle size (in the long term) and alter channel morphology to more closely resemble the forced pool-riffle reaches currently found upstream of the influence of Marmot Dam.

Following excavation of the reservoir sediment, morphologic adjustments in the reservoir reach would be expected, including some deposition of coarse sediment within the reservoir reach from upstream areas. Depending on the excavation design and the composition and slope of the channel and bank, some instability would still be anticipated as the channel adjusts to the restored gradient, although potential channel instability would be less than under other alternatives. In general, the reach above the dam would be expected to return to a functional alluvial river channel more quickly than under other alternatives.

*Downstream sediment deposition: Reaches 1–5*
Under this alternative, almost all of the sediment stored in the reservoir would be excavated and removed from the river before dam removal. Overall, this alternative would be expected to result in the least amount of sediment transport and deposition downstream and, therefore, the least impact on downstream channel morphology and aquatic habitats of the proposed dam removal alternatives.

*Turbidity and suspended sediment*
The excavation operation may result in substantial increases in suspended sediment concentration and turbidity downstream of the dam during the construction season due to mobilization of fine sediments in the reservoir deposit. The magnitude of this turbidity increase was not modeled and would depend on how the excavation is carried out and on flow conditions during the excavation period. This increase in turbidity would be somewhat attenuated downstream of the Bull Run River because of the dilution effect of inflows from the Bull Run River, but construction-related turbidity increases could extend downstream to the confluence with the Columbia River and would likely continue at least for the period of construction. In addition, if the excavated material is stored on-site adjacent to the river, erosion of the disposal pile may deliver additional fine sediment to the channel and increase turbidity during storm events. The increase in TSS concentration resulting from excavation of the entire reservoir deposit under Alternative A would be substantial in magnitude and would extend for the entire construction season. As currently proposed, Alternative A would require excavation in the channel (i.e. in areas not protected by cofferdams) 22 hours per day, 6 days per week, throughout the construction season. This impact would be greatest for Alternative A and least for Alternative B.

Following removal of the dam, exposed sand and fine sediment remaining in the channel (i.e., material that was not excavated) would be transported in suspension downstream as flows increase. Mobilization of this sediment would likely result in only short-duration increases in turbidity and suspended sediment concentrations downstream, particularly in comparison to Alternative B. This is because most sand and fine sediment would have been removed from the reservoir under Alternative A before removal of the dam, assuming that all of the proposed excavation could be completed in one construction season before the onset on high flows.

***Potential Impacts on Anadromous Salmonid Habitat***

*Impacts of Channel Adjustment in the Reservoir Reach*
Under Alternative A, sediment excavation from the reservoir prior to dam removal would alter the habitat characteristics in the reservoir reach. Under current conditions, this reach is low gradient and provides suitable habitat for fall and spring chinook spawning, and rearing of juvenile anadromous salmonids of all species spawning upstream of the dam. After excavation, this reach would be steeper and likely would no longer provide suitable spawning habitat, although juveniles of some species would still be expected to rear in this reach. Because this reach is short and is not considered to provide primary spawning habitat for anadromous salmonids, impacts on salmonid populations resulting from the changes to this reach are expected to be minor.

Following excavation of the reservoir sediment, morphologic adjustments in the reservoir reach would be expected, including deposition of coarse sediment from upstream areas. Depending on the excavation design and the composition and slope of the channel and bank, some instability would still be anticipated as the channel adjusts to the restored gradient. Because nearly all of the sediment would be mechanically removed, there does not appear to be a risk of impairment to fish passage in the reservoir reach under this alternative.

*Impacts of Downstream Sediment Deposition*
Because nearly all of the reservoir deposit would be removed under this alternative, downstream impacts on anadromous salmonids resulting from release of coarse sediment from the reservoir are expected to be minor.

*Impacts of Downstream Suspended Sediment*
Increased TSS concentration downstream of Marmot Dam associated with sediment excavation during the summer and early fall construction period (which would extend from the beginning of July through the end of October) could adversely affect adult and juvenile salmonids present in the lower river. The severity of potential adverse impacts would depend on the magnitude, duration, and timing of any increases in TSS concentrations. Species, runs, and life stages potentially present downstream of the dam during this period include spring chinook (adult and juvenile), fall chinook (adult and juvenile), coho (adult and juvenile), winter steelhead (adult [potential] and juvenile), and cutthroat (adult and juvenile). Potential impacts on anadromous salmonids resulting from increased TSS levels are discussed in Section 4.1.5. Adult spring chinook, fall chinook, summer steelhead, coho (early hatchery run) and potentially winter steelhead could be particularly vulnerable to increases in TSS concentration downstream of the dam during excavation because large portions of these populations could be expected to be holding or migrating through the lower river. In addition, fall chinook salmon spawning and incubation, which could begin as early as September and occurs primarily downstream of the dam, could be impacted by increased TSS concentration downstream. Fall-run chinook salmon juveniles, which rear almost exclusively downstream of the dam, and winter steelhead juveniles, originating from spawning downstream of the dam, would be most vulnerable to increases in TSS concentration during the construction season. Juvenile coho, spring chinook, and summer steelhead rearing in the lower river may also be affected, but the majority of juveniles of these species would be expected to occur upstream of the dam.

### 4.1.2 Alternative B: Single-season dam removal, minimal sediment removal

Under this alternative, only a minimal amount of sediment would be excavated from behind the dam (i.e., only as required to facilitate dam removal activities). Approximately 980,000 $yd^3$ (750,000 $m^3$) of sediment, consisting of approximately 35% sand (and finer) and 65% gravel (and coarser) would be released downstream following dam removal. As discussed above in Section 3.2, rough estimates of background sediment flux in the Sandy River suggest that the volume of sediment released under Alternative B would be on the order of 20 years or less of annual yield; this volume would be released over a period of several years, as discussed below.

***Numerical Modeling Results***

*Modeling of coarse sediment transport*

Figure 14 illustrates model predictions of the downstream movement of coarse sediment out of the reservoir and resulting increases in bed elevation (aggradation) downstream of Marmot Dam, under average hydrologic conditions[5] and over a 20-year period. These model results indicate that, in the first year following removal, coarse sediment would move downstream into the portion of Reach 1 immediately downstream of the dam, creating a debris fan up to a maximum of about 12 ft (4 m) thick, with small amounts of deposition predicted further downstream in Reach 1 and in Reach 3. In subsequent years, additional sediment would move out of the reservoir, resulting in a gradual increase in deposition thickness in Reach 1, reaching a maximum of about 3 ft (1 m) on a reach-averaged basis. The aggradational wave is predicted to travel quickly through most of the gorge (Reach 2), with aggradation increasing in the downstream end of the gorge and the upstream end of Reach 3 from Years 1 through 10. Aggradation is predicted to gradually build to a maximum predicted thickness of about 5–6.5 ft (1.5–2 m) in the upper portion of Reach 3 (6–8 mi [9–13 km] downstream of the dam), where the channel widens and decreases in gradient (Figure 14). In Reach 1, the greatest amount of aggradation would be expected in the early years following dam removal, while in Reach 3, aggradation would be expected to show gradual increases through the first 10 years. After the first ten years, deposition thickness in Reach 3 would gradually decrease as the sediment wave is transported downstream. The model predicts small amounts of aggradation (typically <1.6 ft [<0.5 m]) downstream of the Bull Run River confluence, although this aggradation is similar in magnitude to aggradation predicted in a reference run of the model and is not likely to be distinguishable from natural depositional processes.

Figure 15 shows the predicted change in bed elevation in a longitudinal profile view in the reservoir reach and in Reach 1 following dam removal. This figure shows how, following dam removal, the slope in the reservoir reach would gradually flatten out and return to that of the pre-dam channel bed. Model results show that under average hydrologic conditions, the depth of the sediment deposit in the reservoir would decrease from about 36 ft (11 m) at the time of dam removal to about 30 ft (8 m) after 30 days, 23 ft (7 m) after 60 days, 20 ft (6 m) after one year, 10 ft (3 m) after 5 years, and 3 ft (1 m) after 10 years (Figure 14). The evolution of channel gradient in the reservoir reach and immediately downstream is summarized in Table 8.

[5]See Section 2.1.3 and Stillwater Sciences (2000) for description of the hydrologic conditions that were modeled.

**Table 8. Change in channel bed slope through time near Marmot Dam for Alternative B.**[1]

| Distance (mi)[2] | Initial slope | Slope after 5 days | Slope after 30 days | Slope after 90 days | Slope after 1 year | Slope after 2 years | Slope after 5 years | Slope after 10 years |
|---|---|---|---|---|---|---|---|---|
| –1.0 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.004 | 0.005 | 0.006 |
| –0.5 | 0.002 | 0.002 | 0.002 | 0.007 | 0.007 | 0.009 | 0.007 | 0.006 |
| –0.3 | 0.002 | 0.002 | 0.013 | 0.010 | 0.007 | 0.005 | 0.008 | 0.005 |
| 0.0 | ∞ | 0.019 | 0.014 | 0.009 | 0.011 | 0.005 | 0.008 | 0.006 |
| 0.5 | 0.007 | 0.007 | 0.007 | 0.009 | 0.010 | 0.008 | 0.012 | 0.008 |

1 Bed slopes are typically highest at a given point at the time when the erosion "front" is most active at that location, after which time bed slopes decrease towards the pre-dam channel gradient.

2 0.0 is the location of Marmot Dam. A negative distance indicates a reach upstream of the dam while a positive distance indicates a reach downstream of the dam.

In addition to the total deposition thickness, the annual change in bed elevation is an important component of channel response. In most reaches and years, the model predicts annual changes in bed elevation of less than 1 ft (0.3 m). Figure 16 shows predicted annual change in bed elevation following removal of Marmot Dam, including reductions in bed elevation in the reservoir reach and fluctuations in bed elevation downstream of the dam. Figure 16 shows that in Reach 3, where the largest total magnitude of reach-scale aggradation is predicted (Figure 14), the annual change in bed elevation is typically expected to be less than 1.6 ft (0.5 m). Further downstream, the model predicts annual changes in bed elevation of less than 1 ft (0.3 m); these changes are indistinguishable from the results of the reference run, indicating that no change from natural conditions is predicted.

Modeling also indicates that variations in hydrologic conditions and in assumed grain size distributions for the reservoir deposit would result in differences in the rate of erosion of the reservoir deposit but would cause only slight changes in the predicted spatial and temporal pattern of downstream sediment deposition. Wet conditions would cause sediment to move more quickly out of the reservoir area. This would have the effect of slightly reducing overall aggradation in Reach 1 in the years following removal, altering the temporal pattern of aggradation in Reach 3 (with thicker deposition in the first several years after removal compared with the reference run, but with similar magnitude of aggradation over a 10-year scale), and slightly increasing aggradation in Reach 4 compared to average hydrologic conditions. Dry conditions would reduce the rate of sediment movement out of the reservoir area, but result in similar patterns of downstream aggradation as under average conditions, with aggradation expected to be most evident in Reaches 1 and 3. Stillwater Sciences (2000) provides additional detail on model runs that incorporate variations in hydrology and assumed grain size distributions of the reservoir sediment.

*Modeling of sand transport*

After the dam is removed and the channel begins to incise into the reservoir deposit, sand and fine sediment will be mobilized from the reservoir deposit, traveling downstream mostly as suspended load. Modeling of sand transport indicates that sand aggradation is most likely to occur in the lower 6 mi (10 km) of the Sandy River (Reach 5), and that essentially no aggradation would occur further upstream. Reach 5 has the lowest transport capacity of any reach in the Sandy River, reflecting its greater width and low gradient, and is currently sand-bedded in its lower portion. The model predicts deposition thicknesses of up to about 1.3 ft (0.4 m) in Reach 5 (Figure 17), with the greatest aggradation expected to occur in the first year following removal of Marmot Dam. The deposition thickness could be much greater than this, however, because of the potential backwater effect of the Columbia River. Because the model is unable to account for this backwater effect, we have a low level of confidence in model results in terms of actual magnitude of deposition thickness in Reach 5. Modeling also indicates that the magnitude of sand aggradation would fluctuate both seasonally and between years (Figure 18).

Sand would be metered out of the reservoir area in the years following dam removal, with the magnitude of sand transport depending on the rate of movement of the gravel surface layer out of the reservoir. The rate of sand transport out of the reservoir varies with flows, as indicated by the wet, average, and dry hydrologic conditions that were modeled, and with the assumed grain size distribution of the reservoir deposit (Stillwater Sciences 2000). In all model runs, the magnitude of sand transport out of the reservoir is expected to be largest in the first winter following dam removal, although sand transport out of the reservoir continues for the duration of the model runs. Figure 19 shows predicted sand release following removal of Marmot Dam for Alternatives B and D, based on average hydrologic conditions.

Sand release from the reservoir would not result in large increases in total suspended sediment (TSS). Modeling indicates that, between Marmot Dam and the Bull Run confluence, peak TSS of about 500 ppm would occur in the first winter following dam removal (Figure 20). TSS would generally remain between 100 and 200 ppm during the first two years after removal, with increases above this level associated with high flows during the second winter. Downstream of the Bull Run River, TSS levels would be lower because of the dilution effect of flows from the Bull Run River. TSS levels associated with dam removal are relatively low because of the nature of the sediment deposit, in which fine sediment deposits are armored by a coarser surface layer (Figure 11) and are therefore released gradually, rather than as one large pulse. Background TSS levels in the Sandy River are not known; modeled results should be considered indicative of potential increases in TSS above background levels due to sediment release from Marmot Reservoir.

Model predictions of reservoir erosion patterns contain uncertainties because one-dimensional modeling does not capture processes such as channel incision and lateral migration. In the model, sediment transport out of the reservoir area is driven by shear stress (i.e., as indicated by the Parker [1990a] bedload transport equation) and is assumed to be laterally uniform. Erosion of reservoir sediment would in fact likely result in incision of a channel within the valley walls. In order to account for the uncertainty in the modeling of reservoir erosion patterns and the potential effects of incision, we completed a sensitivity analysis of sand release from the reservoir. This analysis (explained in more detail in Stillwater Sciences 2000) tested the effects of accelerated sediment release (compared with the slower release predicted by the basic model) on downstream deposition patterns and total suspended sediment (TSS) concentrations under Alternative B. This test involved increasing the rate of sand release from the reservoir by an order of magnitude (10-fold) over that which is predicted by the model based on predicted shear stresses in the reservoir reach. Although sand release at such a high rate is extremely unlikely, the results of this test provide an upper bound on downstream sand transport and potential downstream impacts.

This sensitivity analysis suggests that sand release from the reservoir at ten times the expected rate would result in peak TSS of approximately 4,000 ppm in the first winter following dam removal (compared with a maximum of about 500 ppm for basic model runs under this alternative). Otherwise TSS would generally remain between 100 and 400 ppm with levels approaching background conditions during late summer and fall (July through October). In the second winter following dam removal, TSS would increase above 400 ppm during storms, with a maximum of 2,000 ppm, and decline to near-background conditions during late summer and fall. Increasing the rate of sand release by an order of magnitude would also result in additional deposition downstream, including deposition of about 0.7–1.3 ft (0.2–0.4 m) in the downstream end of Reach 4 and maximum aggradation of about 3 ft (1 m) in Reach 5. If sand release occurred faster than predicted by the basic model runs, as described in this sensitivity test, this would increase the magnitude of potential impacts but would shorten their duration, because sand would be transported out of the Sandy River more rapidly.

***Geomorphic Assessment***

In this section, the model results presented above are interpreted for each of the geomorphic reaches, including discussion of the implications of model results for channel morphology and of how actual transport and deposition patterns may differ from model predictions. Alternative B would be expected to result in greater magnitude of downstream sediment deposition and greater geomorphic and biological impacts than Alternatives A, C, and D (except for impacts related to increased TSS concentrations during the summer construction period). Comparisons between Alternative B and Alternatives A, C, and D are provided in the sections addressing those alternatives.

In general, coarse sediment transport may be slower than predicted by the model, because irregularities in channel morphology that are not captured by the model (e.g., large boulders) would tend to increase roughness and decrease sediment transport rates. This could increase deposition in reaches closer to the dam compared with model predictions (e.g., Reaches 1 and 2) and increase the time required for coarse sediment to deposit in downstream reaches (e.g., Reaches 3 and 4). Modeling also predicts that between the dam and Reach 5, sand and finer sediment would be carried in suspension and no deposition would occur. It is possible, however, that during low flows sufficient to mobilize sand, sand could "bleed" from the reservoir deposit and travel downstream as a sheet or carpet. This mechanism of sand transport is not predicted by the model but could occur, potentially resulting in infiltration of sand into coarse-substrate interstices and seasonal, transient sand deposition in pools and other portions of the channel bed. Scour of these transient sand deposits from pools and other portions of the channel bed would likely occur during high flows. This pattern of low-flow sand movement could be most evident in Reaches 1 and 2 but could also extend downstream into Reaches 3, 4, and 5.

*Upstream impacts and channel adjustment in the reservoir-influenced reach (RM 32-RM 30)*
Under Alternative B, the majority of the sediment stored behind Marmot Dam would be transported downstream, and the reach upstream of the dam would adjust towards its pre-dam channel gradient following removal of the dam. As noted in the discussion of Alternative A above, the gradient would increase from about 0.002, which reflects the grade control provided by the dam, to about 0.006, which is an estimate of the pre-dam gradient based on analysis of a channel profile surveyed by USGS shortly after construction of Marmot Dam (USGS 1915) and PGE photogrammetry data. In contrast to Alternative A, however, this gradient adjustment would occur over a period of years as a result of downstream transport of reservoir sediment, rather than occurring as a result of sediment excavation.

During the adjustment period, the channel in the reservoir reach is expected to be highly unstable. As the channel incises to its new gradient, the bed will be highly mobile and mass wasting of banks may occur, especially in the downstream portion where the depth of incision would be greatest and where sand would be a dominant bank component. Chronic ravel may also occur along the banks of the newly incised channel as a result of seepage, which, in combination with gravitational forces (i.e., the relatively low angle of repose of non-cohesive reservoir sediments), would encourage further channel widening (e.g., Crouch and Blong 1989, Howard and McLane 1988, Schumm et al. 1984, Little et al. 1982).

Because the reservoir deposit is composed of non-cohesive sediment (predominantly gravel in the upper layer and sand in the lower layer [Squier Associates 2000]), headcutting and associated knickpoint migration are unlikely to occur. Headcutting and/or knickpoint formation are most likely to develop in cohesive sediments that are difficult to erode and that have a high angle of repose (e.g., Selby 1993, Heede 1976). In the case of a loose gravel deposit, as occurs in Marmot Reservoir, a negative feedback would likely act against potential headcutting, whereby initiation of headcutting would increase gradient and shear stresses, resulting in erosion of any headcut and flattening of the gradient.

Modeling predicts that most reservoir sediment would be transported downstream in the first several years after dam removal, but that some sediment would remain for a decade or more. After the first several years, however, the rate of erosion would be low and instability would be reduced. Reservoir erosion patterns and the rate of channel adjustment would depend upon flow conditions following dam removal. Higher flows in the first years following dam removal would result in more rapid erosion of sediment from the reservoir reach and more rapid stabilization of the channel.

As discussed above, model predictions assume laterally uniform erosion from the reservoir reach. Incision could accelerate both the movement of sediment out the portion of the reservoir that incises and the exposure of the sand layer of the reservoir deposit compared with model predictions. This process would also increase the time required for sediment to be eroded from areas along the margin of the reservoir.

*Reach 1: Marmot Dam to the upstream end of the gorge (RM 30–RM 28.5)*
As discussed above, modeling indicates that under Alternative B, the thickness of sediment deposition following removal of Marmot Dam would be greatest immediately downstream of the dam, where a debris fan could quickly form in the channel at the former dam location. The thickness of the deposit would be expected to decrease as the sediment wave is transported downstream. Model predictions indicate that the debris fan immediately downstream of the dam could have a thickness of 12 ft (4 m) in the first year following removal, under average hydrologic conditions. Deposition further downstream in Reach 1 is predicted to have a thickness of about 3 ft (1 m). This estimate is a reach and cross-section average, and local deposition patterns will vary from these predictions. Deposition may also be greater than model predictions in certain portions of this reach where the channel widens and shear stresses are reduced, including (1) a large alder-vegetated bar and side channel known as Beaver Island (RM 29.4–29.2), where deposition could bury the existing bar, create braided, unstable conditions, and/or block access to side-channel habitat; and (2) a large alcove/backwater pool at the downstream end of the reach (RM 28.7), where deposition could substantially reduce pool depth.

The model predicts that, except for immediately downstream of the dam, most coarse sediment will pass through this reach in less than 10 years. This reach will likely experience some long-term changes in morphology as a result of dam removal, sediment release, and the change in gradient of the upstream reach. For example, in the years following dam removal, aggradation would likely result in plane-bed morphology (Montgomery and Buffington 1993) in this reach, filling of pools with sediment, and increased gradients in the upstream end of the reach. Channel banks extending from Marmot Dam to about 0.4 mi (0.6 km) downstream of the dam are dominated by bedrock and therefore have low susceptibility to erosion from aggradation (which would be large in this sub-reach due to debris-fan formation below the dam). Further downstream in Reach 1, beginning approximately 0.4 mi (0.6 km) downstream of Marmot Dam, the southern bank is composed of non-cohesive, alluvial terrace material, and bed aggradation in this reach could cause localized flow deflection and increased rates of bank erosion. Increased erosion of alluvial terrace banks would contribute sand, gravel, and minor amounts of cobble to the channel, thereby increasing the supply of coarse and fine sediment to this reach and downstream. The magnitude of this effect has not been quantified, although it is not likely to be large because only about 3 ft (1 m) of aggradation are predicted in Reach 1. Even if aggradation is greater than this, the volume of increased sediment from bank erosion would likely be very small compared with the amount of sediment released from behind Marmot Dam under Alternative B, based on our observations.

Model results indicate that sand would be transported in suspension through Reach 1, with no deposition predicted. As discussed above, however, it is possible that sand will "bleed" from the reservoir and travel through this reach as a bedload during low-flow periods, potentially causing transient deposition in the channel bed and infiltration into interstitial spaces. Sand deposition would be most likely in the two locations cited above where the channel widens and shear stresses are reduced (the alder bar/side channel at RM 29.4–29.2 and the large alcove/backwater pool located at the downstream end of the reach).

*Reach 2: Sandy River gorge (RM 28.5–RM 24.5)*
Sediment transport modeling indicates that through most of the gorge reach, no deposition of sand and gravel following dam removal would be expected under Alternative B (Figure 14) or any of the other removal alternatives. This is because the steep gradient and high confinement of this reach create very high shear stresses and high sediment transport capacity. Modeling indicates that deposition would be restricted to the downstream-most portion of the gorge (RM 25–RM 24.5; Figure 14), where the channel gradient decreases (Figure 9) and the channel widens slightly compared with upstream portions of the gorge, representing a transition between conditions in the gorge and in Reach 3.

While the modeling does account for the steep gradient and narrow channel width in this reach, simplifying assumptions about channel morphology are used in the model and the very large boulders present in the reach are not accounted for. Localized deposition could occur in certain locations that are not identified by modeling, and large boulders would tend to reduce the rate of gravel transport through this reach and increase deposition compared with model predictions. Such deposition would be most likely in the following areas, according to field observations: (1) a less-confined channel segment at the upper end of Reach 2 (RM 28.5–27.6); (2) areas with strong momentum defects (e.g., downstream of large boulders or upstream of channel constrictions); and (3) at the margin of some bedrock pools, where localized sand deposits may increase in extent and thickness after removal of the dam. In addition, seasonal deposition of fine and coarse sediment could occur in Reach 2. Gravel deposition would likely occur during individual high flow events in the winter, even if net deposition is small on an annual basis. In addition, sand transport during low flows could cause seasonal deposition of sand in pools. This sediment would be transported out of the reach as flows increased, and decreases in pool depth would be expected to be minor, given the depth and size of the pools in this reach. In general, the likelihood of year-round net deposition in the pools in this reach is limited, because the features that create high scouring capacity through these pools during high flows (e.g., channel constrictions) would not be affected by dam removal.

*Reach 3: Downstream end of gorge (near Revenue Bridge) to Dodge Park (Bull Run River confluence) (RM 24.5–RM 18.5)*
Sediment transport modeling indicates that the upstream portion of Reach 3 has a high potential for coarse sediment deposition following removal of Marmot Dam (Figure 14). This is because valley width increases substantially and channel gradient decreases at the transition from Reach 2 to Reach 3, causing deposition of alluvial sediment. As sediment released from behind Marmot Dam travels downstream, little attenuation of the coarse sediment wave would have occurred by the time it arrives at Reach 3 because of

the high transport capacity of the upstream reach (Reach 2). The greatest amount of deposition is predicted to occur in the upstream end of Reach 3, from approximately RM 24.5 to RM 22 (approximately 5.6–8.1 mi [9–13 km] downstream of the dam) (i.e., from upstream of Revenue Bridge downstream to near the mouth of Cedar Creek). Little deposition is predicted in the downstream portion of Reach 3, near the Sandy River's confluence with the Bull Run River.

The predicted aggradation of 3–6 ft (1–2 m) is a reach-average for the upstream portion of Reach 3 and reflects gradual aggradation over time rather than instantaneous deposition. Modeling indicates that the aggradational wave of coarse sediment would gradually build in Reach 3 in the first 10 years following removal, to a maximum thickness of 6 ft (2 m), and would dissipate between 10 and 20 years following removal (Figure 14). Maximum aggradation therefore would not occur for a number of years until after dam removal and would result from gradual aggradation rather than deposition of a single large pulse of sediment. Therefore, the rate of change in bed elevation would be relatively low (<1.6 ft/yr [< 0.5 m/yr]) (Figure 16). This is important in terms of the biological impacts of the deposition in this reach, which would be greater if the sediment deposition resulted in rapid and frequent changes in bed elevation (scour and fill).

Depositional patterns would not be expected to be uniform across the channel bed, and most deposition would likely be associated with existing alluvial features, causing swelling of these features both laterally and vertically. Variations in depositional patterns could result in localized aggradation of greater than 6 ft (2 m) in areas such as the large alluvial bar and side-channel area located upstream of Revenue Bridge. Several side-channel areas are located in the upstream end of Reach 3, and gravel deposition in these areas could fill these side-channels and/or close off their upstream or downstream ends. Gravel deposition also could increase braiding in depositional areas, potentially creating additional side channels. The presence of large woody debris at the heads of side channels may affect sediment deposition dynamics in these areas, by reducing transport capacity and thereby increasing sand deposition in side channels. Alluvial banks along this reach, which consist largely of Troutdale mudstone, are cohesive but may be susceptible to limited aggradation-induced erosion. Banks consisting of vegetated alluvial features, which are present along portions of Reach 3, are more susceptible to erosion than mudstone banks, although erosion of such features is not likely to be distinguishable from natural bank erosion processes.

These results are based on average hydrologic conditions and reflect the hydrologic input data used in the modeling. The actual transport time of the aggradational wave and deposition magnitude will differ depending on the hydrologic conditions that occur in the years following dam removal. For example, a model run with wetter hydrologic conditions predicted a more rapid arrival of the sediment wave in Reach 3 and more rapid subsequent transport downstream, with a similar maximum magnitude of aggradation (Stillwater Sciences 2000).

*Reach 4: Dodge Park to Dabney Park (RM 18.5–RM 6)*

Numerical modeling predicts that only a small amount of coarse sediment deposition will occur in the reach from Dodge Park to Dabney Park (Figure 14). Deposition of less than 1.6 ft (0.5 m) is predicted, an amount only slightly greater than predicted under reference conditions in Reach 4 (Figure 13). Under natural conditions, the reach downstream of Dodge Park (and particularly downstream of Oxbow Park) has a high potential for deposition of sediment delivered from upstream reaches because channel gradient and confinement are considerably less than in upstream reaches. Sediment transport modeling suggests that most coarse sediment would be deposited upstream of Reach 4 and that sand would travel through this reach in suspension. The timing of sediment transport to this reach and subsequent deposition would vary with flows following removal. Modeling for 20 years with average flows in Year 1 indicates that very small increases in sediment deposition would occur with increasing time after dam removal, with maximum deposition thickness (about 2 ft [0.6 m]) occurring 20 years after removal (Figure 14). This reflects the downstream movement of the sediment wave; as aggradation declines in Reach 3 in years 10 to 20, aggradation slightly increases in Reach 4.

The limited amount of deposition predicted in Reach 4 would most likely occur in existing depositional areas, such as at the heads of bars, potentially resulting in swelling of alluvial features. As in Reach 3, such a depositional pattern is more likely to occur than uniform deposition across the channel bed. No sand deposition is predicted in this reach by modeling, although some sand deposition is likely to occur. Sand deposition would most likely occur on bars, particularly on bars currently mantled with sand, or in side channels, particularly during the receding limb of high-flow events. Transient deposition may also occur in the active channel bed if low and moderate flows are sufficient to mobilize sand from upstream reaches, as described above. These types of deposition would likely be transported out of the reach during subsequent high flows.

Because of abrasion, the time required for coarse sediment to travel to this reach, and the large amount of coarse sediment already stored in this reach, it is possible that deposition of coarse sediment released from Marmot Dam will not be detectable in this reach. As noted above, predicted deposition in Reach 4 is not substantially greater for Alternative B than for a reference run of the model with only background sediment transport conditions. An assessment of alluvial sediment storage estimated that the amount of active sediment (i.e., sediment available for mobilization under moderate flows) stored in Reach 4 is more than 4 times greater than the amount stored behind Marmot Dam. This suggests that whatever fraction of sediment released from the dam that is deposited in Reach 4 is not likely to represent a substantial increase over the volume of sediment currently stored in the reach. The likelihood of aggradation that is sufficient to accelerate bank erosion in Reach 4 appears to be extremely low.

*Reach 5: Dabney Park to mouth (RM 6–RM 0)*
Numerical modeling suggests that sand aggradation of up to 1.3 ft (0.4 m) will occur in this reach following removal of Marmot Dam, but that no coarse sediment aggradation is predicted. This aggradation is predicted to occur mainly in the lower 2 mi (3 km) of the Sandy River (with lesser aggradation in the upper part of the reach). This roughly corresponds to the location of the gravel/sand transition area in the Sandy River (i.e., very little gravel is found in the channel bed downstream of this portion, whereas upstream the bed contains both sand and gravel). Observations in other river systems suggest that the gravel/sand transition zone is typically an area of active deposition. The magnitude of sand aggradation in this reach is difficult to predict because of the complex hydraulics created by the backwater effect of the Columbia River and the uncertainty of the combined flow conditions in the Columbia and Sandy rivers following dam removal. If flows are high in the Columbia River at the same time as sand from Marmot Reservoir is being transported downstream in the Sandy River, this would create a backwater effect in Reach 5 (i.e., gradient and velocity would be reduced), and increased deposition (>1.3 ft [>0.4 m]) could occur. Sand aggradation could be lower than model predictions in Reach 5, however, if deposition occurs in upstream reaches, which is not predicted in basic model runs but which is likely to occur in some localized areas. No coarse sediment aggradation is predicted by the model for this reach, which is reasonable given upstream deposition of coarse sediment, abrasion, the long travel time that would be required for gravel to travel to Reach 5, and field observations that most of the channel is currently sand-bedded in Reach 5.

*Turbidity and suspended sediment*
Model predictions of downstream increases in suspended sediment concentrations following dam removal are described above, in the section on modeling of sand transport.

***Potential Impacts on Anadromous Salmonid Habitat***

*Impacts of channel adjustment in the reservoir reach*
Under this alternative, sediment stored behind Marmot Dam would be released downstream and the reach upstream of the dam would adjust to its pre-dam gradient over a period of years. As described for Alternative A above, this adjustment would result in the conversion of what are currently low-gradient habitats to higher-gradient habitats. As a result, the quality and/or quantity of currently existing spawning habitats would be reduced. This would affect primarily fall chinook salmon, which spawn in limited numbers upstream of the dam. Also, rearing habitat suitability for spring chinook, coho and summer steelhead would be reduced, but suitability for winter rearing of spring chinook salmon and steelhead, which utilize interstitial spaces in coarse substrates, may increase in the long-term (after the channel adjusts to the new gradient and cobbles and boulders become more abundant).

The channel in the reservoir would continue to adjust to the removal of the dam over a period of several years, but some sediment would remain for a decade or more. During this period (especially the first few years following dam removal), channel instability and input of sand from bank erosion and mass wasting would likely make this reach unsuitable for salmonid spawning or rearing. Redds constructed in this reach would be highly vulnerable to burial and scour, resulting in low survival-to-emergence. Considering the short length of this reach and that most salmonid spawning occurs further upstream or downstream, the adverse impact of this temporary loss of habitat and permanent habitat conversion is expected to be minor.

During the channel adjustment period, sediment deposits in the channel that are formed by bank slumping may pose barriers to upstream migration of adult salmonids, especially under low flow conditions. The likelihood that barriers to migration will form in this reach is uncertain and varies between species and runs. Species and runs that would be most affected by impairment of passage include spring chinook, winter and summer steelhead, and coho. The potential for impaired upstream passage for each spawning run is discussed in Section 4.1.5. Blockage or impairment of downstream passage could affect downstream dispersal and outmigration of spring chinook, summer and winter steelhead, and coho.

*Impacts of downstream sediment deposition*
Downstream of the dam, sediment deposition would be greatest in Reaches 1 and 3 and at the downstream end of Reach 2. For several years following dam removal (expected to be less than a decade), sediment deposition and resulting channel instability in Reach 1 would result in the loss of nearly all salmonid habitat values. This reach is not known to be heavily used for spawning by any salmonid species and, based on field work completed for this assessment, does not appear to provide a substantial amount of spawning habitat, although some spring chinook spawning does occur here. Habitat suitable for juvenile rearing of coho, spring chinook, and steelhead is present. Also, channel braiding and channel instability during the adjustment period following dam removal may hinder upstream migration of adult salmonids and downstream movement of juveniles, especially during low flow conditions. As discussed above, impairment of upstream migration would primarily affect spring chinook, coho, and steelhead. Impairment of downstream migration during low flow periods would primarily affect spring chinook salmon (which may be more likely to pass through this reach during early fall when flows are typically low).

In Reach 2, changes in habitat conditions following dam removal are expected to be minimal. Pools suitable for adult holding habitat are not likely to substantially fill with sediments, and pools are of sufficient depth that, even if some sediment deposition occurs, they would remain usable by salmonids. Sand may be deposited during low flows, but deposition is not expected to substantially decrease pool depth or volume.

In Reach 3, sediment deposition is expected to be greatest in the upstream end of the reach (i.e., at the outlet of the gorge). The magnitude of this impact is expected to be small because little spawning is thought to occur in this reach under current conditions (some fall chinook spawning has been observed upstream of Revenue Bridge and winter steelhead spawning has been observed in side channels near Cedar Creek). This reach also provides suitable summer and winter rearing habitat for fall chinook salmon and steelhead, and suitable summer rearing habitat for chinook, coho, and steelhead. Sediment deposition in this reach may reduce or degrade spawning habitat by: (1) burying spawning riffles, (2) reducing flow depth, (3) burying redds, (4) increasing the frequency and depth of scour, and/or (5) reducing substrate permeability. Loss of spawning habitat, destruction of redds, or reduced survival-to-emergence in this reach would primarily affect fall chinook and winter steelhead. Other anadromous salmonid species are not expected to spawn in this reach. Filling of pools and side channels and deposition of sand into the channel bed would reduce rearing habitat quality for coho, winter and summer steelhead, and spring chinook from the upper watershed, and fall chinook and winter steelhead produced in this reach. The majority of juvenile winter and summer steelhead, and spring chinook, however, are believed to rear upstream of Marmot Dam, and the majority of juvenile fall chinook and winter steelhead produced in the mainstem downstream of the dam are expected to rear in Reaches 4 and 5.

In Reach 4, the depth of coarse sediment deposition is expected to be minor and concentrated at the heads of bars, in side channels, and at the mouths of streams where substantial debris fans occur. Reach 4 contains the primary spawning and rearing area for fall chinook salmon (in the mainstem Sandy River) and important spawning and rearing habitat for winter steelhead; coho and winter chinook spawn and rear in tributaries to this reach. Juveniles of all species produced upstream of the dam may also rear in this reach. Deposition of sand and coarse sediment in this reach may affect salmonid spawning and incubation by burying redds, reducing substrate permeability (if large amounts of sand accumulate in the channel bed), increasing the depth and frequency of scour, and blocking access to spawning tributaries. Deposition may affect rearing habitat by eliminating access to side channels, blocking access to non-natal tributaries that may be suitable for rearing, and impairing juvenile dispersal or emigration from tributaries to the mainstem. Based on the model results, effects on spawning substrates and interstitial spaces used for rearing are expected to be minor (especially given the high sand content of the bed subsurface under current conditions) and the potential for elimination of side channel habitats or blockage of access to tributary habitats is considered to be small (due to the amount of time required for sediment to arrive to this reach, abrasion of sediment prior to its arrival, and the volume of sediment currently stored in this reach).

Little coarse sediment deposition is predicted to occur in Reach 5, but substantial sand deposition can be expected. This reach is used primarily as a migration corridor by most anadromous salmonids in the Sandy River, but it is also used by fall chinook and winter steelhead for spawning and presumably rearing. Substantial aggradation in this reach could result in creation of barriers to adult salmonid migration, especially under low flow conditions, which could affect all anadromous salmonids entering the river. Aggradation could also impair juvenile outmigration. In addition, deposition of sand may adversely impact fall chinook spawning and incubation by: (1) burying redds, (2) increasing the frequency and depth of scour, and (3) reducing substrate permeability.

*Impacts of downstream suspended sediment*
Potential downstream increase in TSS concentration following dam removal was assessed using the numerical model. For Alternative B, release of sand and finer sediment from the reservoir would result in increased TSS concentration (relative to reference conditions) during high flow conditions occurring from November through June. Predicted TSS concentration does not change relative to the assumed reference condition during the summer and early fall (July through October). Potential impacts of increased TSS concentration on anadromous salmonids are discussed in section 4.1.5.

### 4.1.3 Alternative C: Removal of top of dam in Year 1, complete dam removal in Year 2 with sand layer excavation up to a point 2,700 ft upstream of Marmot Dam

***Numerical Modeling Results***

For Alternative C, we used numerical modeling to test the effects of lowering Marmot Dam by different amounts in Year 1 on sediment transport patterns and to estimate downstream deposition patterns under these scenarios. We carried out the following model runs for Alternative C:

- lowering of Marmot Dam by about 25 ft (7.6 m) in Year 1, and leaving the lower 22 ft (6.7 m) in place until the following year,
- lowering of Marmot Dam by about 30 ft (9.1 m) in Year 1, and leaving the lower 17 ft (5.2 m) in place until the following year, and
- lowering of Marmot Dam by 35 ft (10.7 m) in Year 1, and leaving the lower 12 ft (3.7 m) in place until the following year.

In addition, we modeled the effects of wet, dry, and average water years for dam lowering of 30 ft (9.1 m), using techniques identical to those used to model Alternative B. Basic runs for Alternative C, including modeling of reservoir erosion and downstream deposition, were only extended for one year. After the first year, sediment would be removed up to 2,700 ft (830 m) upstream of Marmot Dam and the rest of the dam would be removed, after which time Alternative C can be considered the same as Alternative D in terms of sediment transport and deposition (see Section 4.1.4 for discussion of Alternative D).

*Modeling of coarse sediment transport*
Modeling results show that if the top 30 ft (9 m) of Marmot Dam were removed, approximately 25% of the reservoir sediment would be transported downstream in Year 1, consisting mostly of gravel but including a small sand component. The thickness of the reservoir deposit would decrease from approximately 36 ft (11 m) at the time of dam removal to about 20 ft (6 m) after 1 year under average hydrologic conditions (Figure 21, 22). This result is similar to the amount of reservoir erosion predicted in Year 1 under Alternative B, in which the entire dam would have been removed in Year 1. Likewise, there is little difference in the amount of lowering of the sediment between removal of 30 ft (9 m) and 35 ft (10.7 m) of the dam after 1 year. If the dam is lowered only 25 ft (7.6 m), however, less than 20% of the total reservoir sediment would be eroded downstream, and the height of the sediment is reduced to 21 ft (6.5 m) after 1 year, about 2 ft (0.6 m) less than the other scenarios. Hydrologic conditions would also affect the removal of sediment immediately upstream of the dam. One year after a 30-ft lowering, the depth of the sediment deposit is predicted to be 22 ft (6.7 m) and 14 ft (4.4 m) under dry and wet conditions, respectively, versus 19 ft (5.9 m) under average hydrologic conditions.

As noted above, modeling of sediment deposition downstream of Marmot Dam was only carried out for the first year following dam lowering, because in subsequent years this alternative would resemble Alternative D. The greatest amount of aggradation is predicted immediately downstream of the dam (approximately 9 ft [3 m]), as sediment is eroded from the reservoir and a debris fan forms in the first 0.6 miles (1 km) below the dam. Further downstream, modeling predicts that under average hydrologic conditions, downstream deposition thickness would generally be less than 2 ft (0.6 m), regardless of the level of dam lowering, with the largest amount of aggradation in Reach 1 and less aggradation in Reach 3 (Figure 21). Altering the level of dam removal from 25 to 35 ft (7.6 to 10.7 m) would not significantly change the amount of aggradation downstream. Altering the hydrologic regime, however, would affect the amount of downstream aggradation. In a wet water year, maximum aggradation height would be approximately double and much more extensive than normal water year values, whereas under dry conditions in Year 1, there would be little or no aggradation after the first 0.6 miles (1 km) downstream of the dam. In general, the amount of sediment carried downstream in Year 1 with a lowered dam left in place would not likely be substantially larger than what would occur during a natural flood event, and aggradation patterns may be indistinguishable from background patterns.

The degree to which the sand layer would be exposed in Year 1 near the downstream end of the reservoir deposit would depend on the level of dam removal (25, 30, or 35 ft) and hydrologic conditions. There was little difference between lowering the dam 30 ft (9 m) versus lowering the dam 35 ft (10.7 m) during average flow years, but both would expose much more of the sand layer than if the dam was lowered 25 ft (7.6 m). Hydrologic conditions in Year 1 would also influence the portion of the sand layer exposed. Approximately 1,310 ft (400 m) of the sand layer would be exposed under wet conditions in Year 1 versus approximately 705 ft (215 m) under dry conditions in Year 1.

*Modeling of sand transport*

Under this alternative, the magnitude of downstream sand transport is predicted to be about 45,000 $yd^3$ (35,000 $m^3$) for lowering of 30 ft (9 m) and average hydrologic conditions, which is similar to the amount predicted for Year 1 under Alternative B. This includes both the sand fraction of the gravel layer (Unit 1) and sand from the exposed portion of the sand layer (Unit 2). Downstream deposition and TSS patterns are therefore similar to those predicted for Year 1 under Alternative B. Downstream sand transport was not modeled after Year 1 for Alternative C but would be similar to Alternative D.

***Geomorphic Assessment***

*Upstream impacts and channel adjustment in the reservoir-influenced reach (RM 32-30)*

The idea behind development of this alternative was that during the first year, following removal of the top portion of the dam, a substantial amount of the gravel layer in the reservoir (Unit 1) would be transported downstream, while the sand layer (Unit 2) would be retained in place by the lower portion of the dam. During the following construction season, the sand layer would then be excavated and removed. In Year 2, the remaining sediment would be removed up to a point about 2,700 ft (830 m) upstream, after which this alternative would resemble Alternative D in terms of downstream transport patterns and remaining sediment volume in the reservoir.

In this alternative, there would be a trade-off between the amount by which the dam is lowered, the amount of gravel transported downstream in Year 1, and the amount of the sand layer that is exposed in Year 1. That is, the further the dam is lowered, the more gravel transport from Unit 1 occurs, but more of Unit 2 is also exposed. If the dam is only lowered by a small amount, the sand layer is retained in place, but only a small amount of gravel is eroded in Year 1 and a large amount remains to be excavated in Year 2. Based on the modeling scenarios to test varying levels of dam lowering, the optimal level of lowering under this alternative appears be to about 30 ft (9 m), in terms of balancing retention of the sand layer versus allowing sufficient downstream transport to facilitate excavation in the summer following dam lowering.

Model runs indicate, however, that a relatively limited portion of the gravel layer in the reservoir (Unit 1) would be transported downstream in Year 1 following lowering of the dam, even under the maximum lowering scenario (35 ft [10.7 m]) that we modeled. Comparison of model runs for Alternatives C and B indicates that even if the entire dam were removed in one year, the difference in downstream transport after one year would not be substantially different. The modeling suggests that a two-year removal, with sediment excavation in Year 2, would not be expected to work as originally envisioned, because sediment transport would not likely occur in Year 1 in a way that much of the gravel layer would be removed and the sand layer would be retained and could be subsequently removed. For example, wet conditions would be required in Year 1 in order to erode a substantial portion of the gravel layer, thereby facilitating excavation, but substantial sand transport would also occur. Alternative C would therefore not be substantially different than Alternative B, in terms of reservoir erosion in Year 1, or than Alternative D, in terms of the amount of total sediment excavation required.

After excavation of the sand layer during the second construction season and removal of the rest of the dam, this alternative would resemble Alternative D. Reservoir erosion patterns, the duration of unstable conditions in the reservoir reach, and the potential for formation of barriers to migration would be the same as under Alternative D, with a one-year time lag under Alternative C because sediment excavation and complete dam removal would occur over two construction seasons rather than one. In general, the time required for the upstream channel to stabilize would be less than Alternative B. Additional discussion of potential reservoir erosion patterns under Alternative D is provided in Section 4.1.4 below.

*Downstream sediment deposition: Reaches 1-5*

Under this alternative, a portion of the upper gravel layer of the reservoir deposit (Unit 1) would be transported downstream, while most of the sand layer (Unit 2) would be retained behind the dam and mechanically excavated in Year 2, along with remaining gravel overlying the sand layer. The volume of gravel and sand transported in Year 1 will depend on the elevation of the remaining portion of the dam and on the discharge during Year 1. Modeling indicates that approximately 260,000 $yd^3$ (200,000 $m^3$) of mixed sand and gravel could be transported downstream in Year 1 for lowering of 30 or 35 ft (9 or 10.7 m), which is similar to reservoir erosion in Year 1 for Alternative B. As described above, the patterns of downstream sediment deposition resulting from erosion of reservoir sediment in Year 1 are similar for the three dam lowering scenarios. Following removal of the rest of the dam and excavation of sediment up to 2,700 ft (830 m) upstream, downstream transport and deposition patterns would be the same as under Alternative D, although the overall magnitude of coarse sediment aggradation would be slightly greater under Alternative C because of downstream transport of sediment in Year 1. Compared with Alternative B, the following sediment delivery and deposition patterns would be expected under Alternative C:

- In Reach 1, the pattern of coarse sediment deposition in Year 1 would be similar, reflecting the similar volume of downstream sediment transport. Substantial aggradation would occur immediately downstream of the lowered portion of Marmot Dam, in the form of a debris fan. Sediment deposition immediately downstream of the dam during Year 1 could require additional excavation in Year 2 to facilitate removal of the lower portion of the dam. Smaller amounts of aggradation are predicted for downstream portions of Reach 1. In subsequent years, however, aggradation in Reach 1 would be less than Alternative B because of the excavation of reservoir sediment.

- In Reaches 2 through 5, deposition patterns would be similar in Year 1, with only limited deposition because most coarse sediment would remain upstream. In subsequent years, aggradation in downstream reaches, including coarse sediment aggradation in Reach 3 and sand deposition in Reach 5, would be less than Alternative B because of the excavation of reservoir sediment. In addition, because the majority of the sand (and a portion of the gravel) would be removed from the reservoir under Alternative C, the potential for impacts that are not predicted by the model, including localized deposition resulting in blockage of side channels or infiltration of sand into the channel bed, would be less than Alternative B.

*Turbidity and suspended sediment*
Construction-related excavation is expected to increase turbidity levels during both construction seasons. During Year 1, increases in turbidity are expected to be similar to that described for Alternative B. During Year 2 (while the sand lens is being excavated), increases in turbidity would likely be similar to that described for Alternative A.

Downstream transport of sand from the reservoir would also result in increased turbidity and suspended sediment concentrations. Modeling indicates that if the top 30–35 ft (9–10.7 m) of the dam are removed, downstream sand transport would be similar to Alternative B, resulting in similar patterns of downstream TSS. In subsequent years, after excavation of sediment to 2,700 ft (830 m) upstream of Marmot Dam, downstream TSS patterns would be similar to Alternative D.

***Potential Impacts on Anadromous Salmonids***

*Impacts of Channel Adjustment in the Reservoir Reach*
During the year between lowering of the dam in Year 1 and complete removal in Year 2, fish passage would need to be provided over the dam. Also, portions of the reservoir-influenced reach would not be usable for salmonids because of downstream sediment transport (and associated instability) and mechanical excavation. After sediment is excavated from the reservoir (during the second year), impacts in the reservoir reach are expected to be similar to those described for Alternative D.

*Impacts of Downstream Sediment Deposition*
As described above, the initial deposition of sediment in Reach 1 is expected to be similar to that for Alternative B, but the reach would return to equilibrium sooner. Anticipated impacts on salmonid habitats, therefore, would be similar to Alternative B during Year 1 but would be reduced in subsequent years. If a temporary fish passage facility is built immediately downstream of Marmot Dam to provide passage between Year 1 and Year 2, coarse sediment aggradation resulting from downstream transport of gravel from the reservoir could damage such a facility. Downstream, both the magnitude and duration of sediment deposition and resulting impacts on salmonids and salmonid habitats would be less than for Alternative B. Because most sand would be removed from the reservoir by excavation, sand deposition in Reach 5 is expected to be less than Alternative B, and the risk of sediment accumulation sufficient to block fish passage would likely be minimal.

*Impacts of Downstream Suspended Sediment*
Under this alternative, total suspended sediment concentration downstream of the dam may increase during the construction period, including during dam removal in Year 1 and during excavation of sediment in

Year 2. Construction-related increases in TSS concentration occurring in Year 1 would be similar to those described for Alternative B. Construction-related increases during Year 2 would be similar to those described for Alternative D.

Following partial removal of the dam, increases in downstream suspended sediment concentration resulting from release of sediment for the reservoir are expected to be similar to those predicted for Year 1 under Alternative B. Impacts on salmonids during the first year following removal, therefore, would be similar to those described for Alternative B.

### 4.1.4 Alternative D: Removal of sediments to the bottom of the sand layer and to a point 2,700 ft upstream of Marmot Dam

Under this alternative, sediment would be excavated from the dam up to about 2,700 ft (830 m) upstream. This would allow excavation of most of the fine sediment in the reservoir and of the majority of the overall amount of sediment in the reservoir. Under this alternative, approximately 250,000 $yd^3$–460,000 $yd^3$ (190,000 $m^3$–350,000 $m^3$), most of which is believed to consist of coarse material, would remain in the reservoir and thus be available for downstream fluvial transport. This range reflects uncertainty in the location of the pre-dam channel bed in the upper end of the reservoir reach and in the upstream extent of the reservoir deposit. Numerical model runs for this alternative assumed that the amount of sediment at the upper end of this range would be transported downstream. If the volume of sediment after excavation is at the lower end of this range (250,000 $yd^3$ [190,000 $m^3$]), the magnitude of downstream deposition may be lower than indicated by the model results presented below.

***Numerical Modeling Results***

In model runs for this alternative, the sediment wedge behind the reservoir at the time of dam removal was assumed (1) to begin about 2,700 ft (800 m) upstream of Marmot Dam, reflecting the excavation of a portion of the reservoir sediment; (2) to have a thickness of about 23 ft (7 m), reflecting the estimated depth of the reservoir deposit at this point; and (3) to have a volume of 460,000 $yd^3$ (350,000 $m^3$), reflecting a conservative estimate of the amount of sediment remaining upstream of the 2,700-ft point. Modeling indicates that the gradient in the reservoir reach flattens out in a short time following dam removal (Figure 24). Modeling also predicts that after one year under average hydrologic conditions, the thickness of remaining sediment would be less than 10 ft (3 m), and after two years, the rate of change in the thickness of remaining sediment would be slow (Figure 23, 24). Downstream transport of this sediment would result in deposition in the downstream portion of the reservoir (from which sediments would have been previously excavated), a very small amount of deposition in Reach 1 (<1.6 ft [< 0.5 m]), no deposition in the gorge (Reach 2), and deposition of less than 3 ft (1 m) downstream of the gorge (Reach 3) (Figure 23). In Reaches 4 and 5, the small amount of deposition indicated by modeling is similar to that predicted by reference runs of the model (as is the case for model runs for Alternatives B and C).

Although a large amount of the sand in the reservoir would be excavated under Alternative D, some sand would likely remain. Our model assumptions are conservative with respect to the amount of sand that may remain in the reservoir, assuming that the sand layer extends slightly further upstream than suggested by Squier Associates (2000). Predicted magnitudes of sand aggradation and TSS are slightly lower than under Alternative B. The model predicts that nearly all sand would be eroded in the first year, with only very small amounts of sand released in subsequent years. This differs from Alternative B, in which larger amounts of sand are transported downstream in the various years following removal.

***Geomorphic Assessment***

*Upstream impacts and channel adjustment in the reservoir-influenced reach (RM 32-30)*
Although modeling assumes that the downstream end of the sediment wedge would have a steep face (Figure 24), sediment excavation could be used to lower the gradient of the downstream end of the sediment wedge. Even without this, the gradient at the downstream end of the sediment wedge would flatten quickly, according to the modeling results, while the overall gradient of the reservoir reach would increase compared with current conditions. As the sediment remaining in the reservoir after excavation is transported downstream (including into the reach that had been excavated), the reservoir reach will experience morphologic adjustments and channel instability. The risk of headcutting during this adjustment period is considered to be minimal, however, because of the non-cohesive nature of reservoir sediments (see Section 4.1.2 for further discussion of headcutting) and the relatively small remaining volume of sediment following excavation (compared with Alternative B). Compared with the other alternatives, the length of time in which the reservoir sediments are unstable and the reservoir reach is adjusting towards a pre-project gradient and channel form under Alternative D is expected to be longer than Alternative A, shorter than Alternative B, and similar to Alternative C.

*Downstream sediment deposition: Reaches 1–5*
The model results described above indicate the predicted pattern of sediment delivery to downstream reaches and sediment deposition under Alternative D. As with Alternative C, the majority of the sand in the reservoir deposit would be excavated prior to dam removal. Under Alternative D, however, a large amount of coarse sediment would also be excavated from the reservoir, whereas under Alternative C, some of this material would travel downstream in Year 1 following lowering of Marmot Dam. The overall magnitude of downstream aggradation would therefore be expected to be slightly smaller under Alternative D than Alternative C.

Compared with Alternative B, Alternative D would result in downstream transport of about 40% of the total sediment volume and about 25% of the sand volume. These comparisons are based on conservative assumptions about the upstream extent of the sand layer (Unit 2) and of the total reservoir deposit; the amount released under Alternative D could therefore be even smaller compared to Alternative B. The following compares sediment delivery and deposition predicted under Alternative D to Alternative B, for each of the geomorphic reaches:

- In Reach 1, coarse sediment deposition would likely be substantially less under Alternative D. Under Alternative B, a debris fan would form in the upstream end of Reach 1 immediately following removal, whereas downstream deposition under Alternative D would initially occur in the excavated portion of the reservoir reach, which would act as somewhat of a buffer for Reach 1. Aggradation would therefore be much lower once the sediment arrived in the upstream end of Reach 1. Further downstream in Reach 1, predicted aggradation would be less than 1.6 ft (0.5 m).

- In Reach 2, no deposition is predicted to occur under Alternative D, as under the other alternatives, except for a small amount at the downstream-most portion of this reach where the gradient decreases. The magnitude of this aggradation is expected to be less than predicted under Alternative B.

- In Reach 3, a smaller magnitude and shorter duration of coarse sediment deposition is predicted to occur under Alternative D, from a maximum aggradation of 5 to 6.5 ft (1.5 to 2 m) under Alternative B to less than 3 ft (1 m) under Alternative D. Coarse sediment aggradation under Alternative D could result in the swelling of alluvial features in Reach 3, but the potential for substantial changes in channel morphology or blockage of side-channel areas is low.

- In Reach 4, modeling predicts that coarse sediment aggradation would be slightly lower and that no sand aggradation would occur under Alternative D. The likelihood that deposition that is not captured by the model will occur, such as localized deposition of sand or gravel on bars or infiltration of sand into the channel bed in Reach 4, is lower under Alternative D than under Alternative B because of the smaller volume of sediment that would be released.

- In Reach 5, the model predicts that the pattern and magnitude of sand deposition would be the same as under Alternative B. As noted above, however, we have low confidence in model predictions of the magnitude of sand deposition in Reach 5 because of the backwater effect of the Columbia River. Because the majority of the sand would be removed from the reservoir under Alternative D, less deposition would be expected to occur under Alternative D than under Alternative B. In addition, impacts that are not captured by model predictions but that may nevertheless occur, such as localized deposition upstream of Reach 5 and infiltration of sand into the channel bed, would be reduced under Alternative D compared with Alternative B.

*Turbidity and suspended sediment*

During the period of sediment excavation from the reservoir area, excavation may result in substantial increases in turbidity downstream of the dam. The magnitude of this turbidity increase cannot be modeled, but turbidity impacts are expected to be similar to those described for Alternative A.

Following excavation of sediment up to 2,700 ft (830 m) upstream and removal of the dam, sand remaining in the channel bed and in the reservoir deposit would be transported in suspension downstream as flows increase. The model results presented above provide estimates of the predicted increases in suspended sediment concentrations as these sediments are mobilized. Increases in suspended sediment concentrations following dam removal under Alternative D are expected to be lower in magnitude and shorter in duration than under Alternative B and similar to Alternative C.

### *Potential Impacts on Anadromous Salmonids*

*Impacts of channel adjustment in the reservoir reach*

Under this alternative, sediment would be excavated to a point 2,700 feet (830 m) upstream of the dam. The remainder of the sediment would be left in place. Following dam removal, the channel would adjust to the restored gradient. Compared with Alternative B, there is a lesser magnitude of channel and bank instability expected during the adjustment period, and the risk of impairment of fish passage during this adjustment period (e.g., through channel instability) is considered to be reduced due to the relatively small volume of sediment remaining after excavation. The length of time in which the reservoir sediments are unstable and the reservoir reach is adjusting towards a pre-project gradient and channel form under Alternative D is expected to be longer than Alternative A, shorter than Alternative B, and similar to Alternative C. As described under Alternatives A and B, habitat characteristics in the reservoir reach would change as the channel adjusts to the restored grade, and redds constructed in the reservoir during the adjustment period would be vulnerable to burial and scour.

*Impacts of downstream sediment deposition*

Under this alternative, much of the sediment remaining in the reservoir would initially be deposited in the downstream portion of the reservoir reach rather than in Reach 1. The magnitude of impacts on salmonids and salmonid habitats in Reach 1, therefore, is expected to be less than under Alternatives B and C. However, it is likely that sediment deposition in this reach would result in the loss or degradation of salmonid habitats and that instability in this reach in the first years following dam removal would make this reach less suitable for salmonid rearing.

As with the other alternatives, no deposition of sediment in Reach 2 is anticipated. Downstream of Reach 2, deposition and resulting impacts on salmonids and salmonid habitats are expected to be less severe than for Alternative B. Since most sand would be removed from the reservoir by excavation, sand deposition in Reach 5 is expected to be less than Alternative B, and the risk of sediment accumulation sufficient to block fish passage is likely minimal.

*Impacts of downstream suspended sediment*

Under this alternative, total suspended sediment concentration downstream of the dam may increase during the construction period. Construction-related increases in TSS concentration would likely be slightly shorter in duration than under Alternative A because of the smaller amount of sediment excavation under Alternative D.

Following dam removal, the predicted increase in suspended sediment concentration is similar to that described for Alternative B during the first year. During the second year, only slight increases relative to reference conditions are predicted.

### 4.1.5 Summary of Impacts and Key Population Responses

This section is intended to provide a summary and synthesis of the potential geomorphic and biological impacts of the different alternatives for removal of Marmot Dam. The key step in this synthesis is linking the predicted geomorphic and physical habitat responses described above for each alternative (Sections 4.1.1–4.1.4) with the potential impacts they would have on populations of anadromous salmonids in the Sandy River basin. The potential geomorphic and biological impacts of removal of Little Sandy Dam are discussed separately in Section 4.2.

All alternatives are expected to have a long-term beneficial effect on anadromous salmonid populations in the basin because they would restore more natural flow regimes and restore unimpaired access to upstream areas in both the mainstem Sandy River and the Little Sandy River. The extent of anadromous salmonid access under current conditions and the expected improvements in access with removal of Marmot and Little Sandy dams are illustrated in Figures 25 and 26, respectively. Improved habitat connectivity and flow conditions should result in improved quality and increased quantity of habitat available to anadromous salmonid populations in the Sandy River basin. These expected benefits are discussed in more detail in the Preliminary Draft Environmental Assessment (PGE 2000b).

This section focuses on how the various dam removal alternatives could, in the short-term, adversely affect population dynamics (population size, variability, etc.) of anadromous salmon, steelhead, and coastal cutthroat trout runs in the Sandy River basin, but does not attempt to develop a detailed, quantitative understanding of population dynamics. The primary intent is to qualitatively assess the general short-term risks to each anadromous salmonid population in the basin in order to assist selection of a preferred alternative for dam removal as part of the project decommissioning process. Of particular interest is whether short-term adverse impacts that may result from implementation of any of the alternatives would outweigh expected long-term benefits to anadromous salmonid populations in the basin.

We have developed conceptual models of salmonid biology for each of the anadromous salmonid species and runs in the Sandy River basin to help summarize existing information and provide a tool for qualitatively assessing potential risks and impacts on population dynamics that are associated with each alternative. Because data on life history, habitat use, habitat conditions, and population dynamics within the Sandy River basin are limited, the conceptual models we developed relied on published data from similar rivers in the Pacific Northwest and on general knowledge of salmonid life history requirements. We have not attempted, however, to summarize or cite all of the relevant literature. The conceptual models explicitly incorporate mechanisms for both density-dependent[6] and density-independent[7] mortality.

The conceptual models are then used to link predicted geomorphic and physical habitat changes with likely population responses. Making this linkage is inherently difficult, even in well-studied populations. Given the natural variability in biological responses to habitat changes, the existence of factors outside of the freshwater habitats and outside of the scope of this analysis (e.g., mortality occurring in the Columbia River, estuary and ocean), the limited amount of quantitative data currently available on anadromous salmonid populations and habitat conditions in the Sandy River basin, and the difficulties in predicting future habitat changes under different scenarios or alternatives, the conclusions presented here necessarily contain a high degree of uncertainty. Despite the uncertainty, however, we believe this effort is critical for making the best informed decision about dam removal alternatives. This qualitative assessment provides a framework for dealing with uncertainties involved in predicting the potential impacts of dam removal under the different alternatives.

The conclusions that are proposed below, using the conceptual model approach, are based on the best available information (as required by NEPA) about geomorphic processes and salmonid habitats and populations in the Sandy River basin. This discussion should thereby aid in differentiating among the alternatives for removal of Marmot Dam and conceptualizing the potential impacts of these alternatives on salmonid population dynamics in the Sandy River basin. This information provides part of the technical foundation for the NEPA process and the Environmental Assessment document.

### *Spring Chinook Salmon*

*Overview of conceptual model*

Removal of Marmot Dam could result in impacts on spring chinook salmon including impaired passage in Reach 1 and the reservoir reach, filling of pools that may be used for adult holding in Reaches 2 and 3,

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[6] Density-dependent mortality occurs when the rate of mortality in a population is influenced by the density of the population. Environmental factors may influence density-dependent mortality by differentially affecting survival as population density changes. This type of influence on mortality results from competition for limited food and space, as when salmonid fry exhibit inter- and intra-specific aggressive behavior in the defense of feeding territories in streams (Chapman 1966, LeCren 1973).

[7] Density-independent mortality occurs when controls on a population are independent of the density of organisms in the population.

sediment deposition in rearing habitat in Reaches 3 and 4, reduction in food supply downstream of the dam, and blocked passage in Reach 5. Spring chinook are expected to benefit from improved adult upstream passage conditions, reduced mortality of juveniles (especially fry) during downstream migration, and restoration of the natural hydrologic regime downstream of Marmot Dam.

Spring chinook salmon typically spawn in larger tributaries upstream of Marmot Dam, particularly in the Salmon River and lower Still Creek, but they have also been observed spawning in Reach 1 and it is possible that they spawn in the reservoir reach. Because they spawn primarily upstream of the dam, spring chinook are vulnerable to impaired passage in Reach 1 and the reservoir reach, but would be expected to benefit in the long term from improved upstream passage conditions once the reach stabilizes. The reaches downstream of the dam are used by adult spring chinook as a migration corridor and for holding in the summer and may be inhabited by juveniles throughout the year. Reaches 2 and 3 contain deep pools that may be important adult holding areas, with Reach 2 appearing to provide higher quality and more extensive holding habitat. Little data are available regarding areas used by rearing juvenile spring chinook in the mainstem Sandy River. Available data suggest that juveniles pass downstream over Marmot Dam from fall (subyearlings) through spring (yearlings), with the majority of juveniles leaving the upper watershed as subyearlings in the fall (Cramer et al. 1989, Cramer and Clark 1998). The lower Sandy River (downstream of Marmot Dam) is not believed to be as important for rearing as the upstream reaches, but juveniles may overwinter in the lower river and may be present in the lower river throughout the year (ODFW 1997a). Reaches downstream of the dam are important during outmigration, as juvenile chinook are known to continue feeding and growing during this period.

Spring chinook are stream-type; that is, they may remain in the river to rear for several months to more than a year. Rearing patterns of spring chinook are variable—they may disperse downstream soon after emergence, as fry; early in their first summer, as fingerlings; in the fall as flows increase; or after overwintering in freshwater, as yearlings (Healey 1991). Juveniles that leave the upper watershed in late fall may continue to migrate to the estuary or ocean or may remain to overwinter in the lower Sandy River. During winter, these juveniles would reside primarily in the interstitial spaces of coarse rocky substrate. With the onset of spring, these juveniles would likely move to pools, where they would reside and feed until their outmigration in spring (probably prior to [or in response to] summer increases in turbidity). Juveniles have also been documented passing downstream over Marmot Dam in spring. These spring migrants likely continue to the ocean, but may feed and rear in the lower river during their outmigration. While rearing, juvenile chinook have been observed to display territoriality in feeding areas (Taylor and Larkin 1986, Reimers 1968).

The life history strategy for stream-type chinook is based upon rearing for an extended period in fresh water, with relatively fewer fish leaving the river but at larger sizes. For stream-type chinook, both spawning gravel limitations and limitations in rearing habitat and food supply are likely to be the most important sources of density-dependent mortality. Lack of available spawning habitat can cause salmon to construct redds on top of previously constructed redds, referred to as “redd superimposition.” Spring chinook, however, spawn primarily upstream of Marmot Dam. The amount of available spawning habitat would therefore not be affected by dam removal. Because spring chinook rear in fresh water for an extended period and are territorial (i.e., compete for food resources), limited food supply, changes to physical habitat that reduce feeding efficiency (such as increased turbidity), and increases in water temperature may decrease growth rates and displace some juveniles to suboptimal habitats.

Based on their life history strategy and available information regarding spring chinook distribution in the Sandy River, we believe that the most important factor affecting density-dependent mortality that may be affected by dam removal is reduced rearing habitat availability. Reduced macroinvertebrate production downstream of the dam may also affect growth and survival. Under all dam removal alternatives, rearing habitat area and quality downstream of the dam are not expected to be substantially reduced and may actually be increased as a result of increased flows and decreased spring and summer water temperatures.

Current potential sources of density-independent mortality that may be eliminated by dam removal include: (1) false attraction of adults to the Bull Run Powerhouse, (2) migration delay at the Marmot Dam fish ladder, and (3) mortality of juvenile downstream migrants (especially fry) at the Marmot Dam juvenile bypass facility. Further discussion of upstream and downstream passage issues are provided by Stillwater Sciences (1999). The main sources of density-independent mortality that could be increased by dam removal are: (1) impairment of passage through Reach 1 and the reservoir reach, (2) impairment of passage through Reach 5, and (3) injury or mortality resulting from acute or chronic exposure to increased TSS concentrations.

Combining our general understanding of potential limiting factors with the predictions of geomorphic and habitat effects in each reach leads to the following more specific conclusions regarding potential impacts on the spring chinook population in the Sandy River basin:

*Sources of density-dependent mortality*

- Coarse sediment and sand deposition may decrease rearing habitat area downstream of the dam in reaches in Reaches 1, 3, and 4. Deposition of coarse sediment and sand in Reach 1, especially under Alternative B, would eliminate winter, spring, and summer rearing habitats throughout this reach for up to a decade. Due to the short length of this reach, this loss is not expected to affect spring chinook population abundance. In Reaches 3 and 4, sand deposition may reduce the amount of interstitial space used for winter rearing and may fill side channels potentially used for spring and summer rearing. Since the extent of use of the lower reach for overwintering is not known, the magnitude of this impact to spring chinook population dynamics is uncertain. Under current conditions, winter rearing is likely restricted to Reach 3 and the upper portion of Reach 4. Downstream of Oxbow Park (i.e., in the lower portion of Reach 4), the channel bed is highly embedded with sand and is not suitable for winter rearing under current conditions. Loss of interstitial habitats is predicted to be greatest in Reach 3 upstream of Revenue Bridge and relatively minor downstream of Revenue Bridge. If spring chinook that migrate from the upper watershed remain to rear in the lower river through the winter and into the following spring and summer, loss of rearing habitat could result in decreased population abundance. If these fall migrants continue to the ocean and do not remain in the river to rear, effects of this loss of rearing habitat would be expected to be minor.

- Sand deposition in Reaches 1, 2, and 3 may reduce pool depths, but loss of pool area and depth in important holding areas is expected to be minor and temporary. Under current conditions, there is limited pool habitat in Reach 1. However, due to the short-length of this reach, loss of these pools is not expected to substantially affect spring chinook holding. Minor sand deposition in pools is expected in Reach 2, which provides more extensive holding areas consisting of very deep (10–20 ft) bedrock pools and is likely the most important reach for adult holding downstream of the dam. Extensive coarse sediment deposition is predicted in the upper portion of Reach 3, which may provide pools suitable for chinook holding. Deposition in these pools is expected to be minor based on observations of large, anthropogenic sediment releases in other river systems, where deposition occurred primarily at existing depositional features (i.e., bars and islands) (W. Dietrich, pers. comm.) As in Reach 2, pools may experience partial filling in the summer and fall during low flows, but would be scoured during high winter and spring flows. Additionally, adult oversummering habitat would benefit from increased summer flows, which would increase pool depth and likely reduce summer water temperature.

- Sand transport and deposition may reduce macroinvertebrate populations downstream of the dam, thereby reducing food supply for rearing salmon. Macroinvertebrate populations could be reduced by reduction in primary productivity (resulting from increased turbidity) and increased frequency, magnitude and duration of disturbance and scour. The potential magnitude of this impact is difficult to determine but is expected to be minor-to-moderate. Under current sediment supply conditions, a large volume of sand is transported through and stored in Reaches 4 and 5, as evidenced by sand deposits on active channel bars and in the active channel bed. Based on current sand loading, disturbance and scour of macroinvertebrates is likely high under current conditions. Release of sand from behind the dam may increase disturbance and scour through this reach, but the effect of this disturbance on the macroinvertebrate production is likely to be small. If macroinvertebrate populations are already low enough to suppress juvenile salmon growth rates, further reductions in food supply would increase density-dependent mortality and reduce recruitment to the population.

*Sources of density-independent mortality*

- Adult passage to the upper Sandy River basin would be improved in the long term by: (1) eliminating the diversion of Sandy River water to the Bull Run River, which may attract adults to the Bull Run River, and (2) eliminating migration delays at the Marmot Dam fish ladder. Following removal of Marmot Dam and stabilization of the reservoir reach and Reach 1, spring chinook salmon would have unrestricted access and passage delays that may currently be caused by the ladder would be eliminated. Adult upstream passage may also benefit from the restoration of natural flows to the lower river following dam removal. If spawning habitat upstream of the dam is not limiting population size, these improvements in upstream passage conditions would be expected to increase population abundance. If spawning habitat is limiting, no population response would be anticipated.

- ODFW and NMFS have identified mortality of juvenile downstream migrants in the Marmot Dam juvenile bypass system as a major concern. Removal of the dam’s diversion would eliminate the need for the juvenile bypass system, and juveniles would pass freely downstream through the current dam site. Elimination of the bypass facility could substantially decrease mortality of fry during downstream migration. If these fry migrants rear successfully in the lower river or estuary and contribute to adult escapement, elimination of the diversion would be expected to increase spring chinook population abundance. If these fry experience low survival rates in the river or estuary, no population response would be anticipated.

- Impairment of adult passage through Reach 1 and in the reservoir reach is unlikely to occur. Spring chinook salmon return to the Sandy River from late winter through summer and pass over Marmot Dam from May through October, with peak passage occurring in June and a second smaller peak occurring in September. The dam would be removed in the period from July 1 through October 31, but the cofferdam would be left in place and passage would be provided until flows reached 1,800 cfs.

At these flows, the channel is expected to adjust quickly and should be fairly stable by the following summer, when the spring chinook typically arrive to the reach. Depending on hydrologic conditions following removal, however, short-term blockages may occur as a result of bank failures during low flows. It is assumed that contingency measures can be implemented to provide passage through reaches where significant bank failures occur, if necessary. It is also assumed that passage can be successfully provided during construction. If blockages do form and contingency measures cannot be rapidly implemented, passage may be blocked or impaired for all or a portion of the upstream migration season. Additionally, if passage cannot be adequately provided during construction, passage may be impaired during the entire upstream migration period.

- Deposition of sand in Reach 5 may reduce water depth and impair adult upstream migration under some flow conditions. Uncertainties exist about the likelihood of a passage barrier forming in this reach, and the degree and duration of passage impairment that would affect the spring chinook population in the basin. Contingency measures (such as dredging) can likely be quickly implemented to re-establish migration should a barrier form. If a barrier does form and contingency measures cannot be rapidly implemented, passage may be impaired for one or more years.

- Sediment excavation from the reservoir may result in substantial increases in turbidity downstream of the dam during the construction season(s) (July through October), particularly under Alternatives A, C, and D. The magnitude and duration of this increase would depend upon the alternative implemented and the measures implemented to control the release of sediment-laden water from the site. The magnitude would be greatest for Alternative A and lest for Alternative B. Adult spring chinook may be present in the river downstream of the dam from February through November, but are most likely to occur from March through October. Since excavation would extend from July through October, adult spring chinook holding downstream of the dam could be exposed to increased TSS concentrations for several months. Juveniles could occur downstream of the dam throughout the year, although their use of rearing habitat downstream of the dam is not known. If juveniles rear downstream of the dam, they would be exposed to elevated TSS concentrations for several months during summer and early fall. The magnitude of this increase has not been determined but could result in impaired homing, physiological stress, and possibly mortality in adults and reduced feeding efficiency, reduced growth rates, and physiological stress in juveniles. If sediment release from the site cannot be controlled during construction, downstream impacts could result in density-independent mortality.

- The most commonly observed effects of exposure to elevated TSS concentrations on salmonids include the following: (1) avoidance of turbid waters in homing adult anadromous salmonids, (2) avoidance or alarm reactions by juvenile salmonids, (3) displacement of juvenile salmonids, (4) reduced feeding and growth rates, (5) physiological stress and respiratory impairment, (6) damage to gills, (7) reduced tolerance to disease and toxicants, (8) reduced survival, and (9) direct mortality. The severity of these effects depends on both the magnitude and the duration of the exposure.

  Newcombe and Jensen (1996) conducted a comprehensive review of the scientific literature on the effects of suspended sediments on numerous fish species. Based on their review, the authors developed an approach to evaluating and describing the severity of ill effects associated with exposure to a range of TSS concentrations. Effects to adult spring chinook are expected to be minor because most adults arrive and hold in the river in spring and summer, when increases in TSS concentration are expected to be minor. Juveniles, however, could occur downstream of the dam year-round associated with release of sediment from Marmot Dam and could be exposed to increases in TSS concentration during winter high flows that mobilize sediment from the reservoir. Based on the Newcombe and Jensen literature review, the predicted magnitude and duration of exposure could result in reduced growth rates in juveniles (McLeay et al. 1987, MacKinley et al. 1987, Noggle 1978, Sigler et al. 1984, Sykora et al. 1972). Depending on the cumulative effects of repeated exposure resulting from successive storm events, low to moderate rates of mortality could also occur. If sand is delivered at the rate used for the sensivity test (i.e., 10 times the predicted rate), predicted increases in TSS concentration could further increase the rate of juvenile mortality.

***Fall Chinook Salmon***

*Overview of conceptual model*

Because fall chinook salmon in the Sandy River spawn and rear almost exclusively in the mainstem downstream of Marmot Dam, this species is probably more vulnerable than other anadromous salmonids to impacts resulting from sediment transport and deposition. Removal of Marmot Dam could result in impacts on fall chinook salmon that include transport and deposition of sand and coarse sediment in Reaches 4 and 5, and increases in suspended sediment concentrations, as described above in Sections 4.1.1 through 4.1.4 and Table 9. Surveys indicate that fall chinook spawn primarily in Reaches 4 and 5. Although no data are available regarding the areas used by rearing juvenile fall chinook in the mainstem Sandy River, it is reasonable to assume that fall chinook rear from the Bull Run River confluence downstream to the mouth of the Sandy River. Fish size at outmigration is not known.

Fall chinook are ocean-type; that is, they migrate from fresh water to the ocean as subyearling smolts. It is likely that a portion of the Sandy River fall chinook population leaves the river as fry (shortly after emergence) or juveniles (following up to several months of rearing) to rear in the Columbia River or estuary while others may continue to rear in the river until smolting.

The life history strategy for ocean-type chinook is based on leaving fresh water in relatively large numbers after only a few months of rearing. For ocean-type fish, spawning gravel limitation is likely to be the most important source of density-dependent mortality Because fall chinook rear in freshwater for a short period and leave by spring or summer and because they are not territorial (i.e., do not compete for food resources), food supply and availability of suitable rearing habitat are not likely to be the most important factor in limiting population abundance. Limited food supply, changes to physical habitat that reduce feeding efficiency (such as increased turbidity), and changes in water temperature, however, may cause reduced growth rates, leading to outmigration at less than optimal size. Juveniles that outmigrate at smaller sizes have been documented as having lower survival to escapement (Havey 1973). Lack of available spawning habitat can result in redd superimposition leading to substantial mortality of eggs and alevins. On the Tuolumne River in California's Central Valley, field studies indicated that 10–25% of fall chinook eggs were lost due to superimposition during a low escapement year and such losses were expected to increase at higher escapements (TID/MID 1992). Severe reduction in food supply could also result in density-dependent mortality. Under all of the dam removal alternatives, fall chinook spawning and rearing habitat area and food supply are not expected to be substantially reduced.

Primary sources of density-independent mortality potentially resulting from dam removal may include (1) reduction in egg survival resulting from infiltration of sand into spawning gravels, and (2) direct mortality or stress resulting from chronic or acute exposure to high suspended sediment concentrations during construction and following dam removal. These impacts could occur in some reaches following removal of Marmot Dam.

Combining our general understanding of potential limiting factors with the predictions of geomorphic and habitat effects in each reach leads to the following more specific conclusions regarding potential impacts on the fall chinook population in the Sandy River basin:

*Sources of density-dependent mortality*

- Sediment deposition is not expected to substantially reduce spawning habitat area. Sediment deposition could reduce spawning habitat area through two mechanisms: (1) direct burial of suitable habitat, and (2) fining of bed substrates, which could result in increased depth and frequency of scour. Deposition of coarse sediment in Reaches 4 and 5 is predicted to be minor in extent and magnitude. Sand deposition is predicted to occur primarily downstream of RM 2, which is downstream of the area documented as being used by fall chinook for spawning. Sand deposition within the spawning reach would likely occur on bars (especially vegetated bars) and low velocity areas (such as side channels). Many active bars in these reaches are currently mantled with sand, and sand patches occur on the active channel bed. Deposition of coarse sediment and in the spawning gravel sand in the reach known to be used for spawning by fall chinook is therefore expected to be minor. As a result dam removal is not expected to reduce spawning habitat area or increase redd superimposition. Because we believe that spawning habitat area limitations and resulting redd superimposition are the primary sources of density-dependent mortality affecting fall chinook populations and because loss of spawning habitat is expected to be minor, we do not expect sediment deposition following dam removal to increase density-dependent mortality of fall chinook under any of the dam removal alternatives. Due to the lack of data on spawning habitat availability in the Sandy River, however, it is not known whether redd superimposition is the primary source of density-dependent mortality in the Sandy River. If other density-dependent mechanisms are more limiting to this population, this conceptual model would need to be revised.

- Sand transport and deposition may reduce macroinvertebrate populations in the rearing reach (Reaches 4 and 5), thereby reducing food supply for rearing salmon. The potential for density-dependent mortality of fall chinook salmon to reductions in food supply is similar to that described above for spring chinook salmon. If spawning habitat availability is the most important source of density-dependent mortality for fall chinook salmon, minor reductions in food supply would not be expected to affect the population. If, however, macroinvertebrate populations are already low enough to suppress juvenile salmon growth rates, further reductions in food supply may increase density-dependent mortality and reduce population size.

- Sand deposition in pools and stream margin habitats, used for rearing, are not expected to reduce rearing habitat area by a sufficient amount to cause density-dependent dispersal or reduce growth rates. Sand deposition in Reach 4 and the upstream end of Reach 5 is expected to be minor and is not expected to substantially reduce availability of rearing habitat. Sand deposition in the lower two miles of Reach 5 could be substantial. Because this reach is shallow and contains little cover, it is not expected to provide important rearing habitat for juveniles, although it may provide some habitat for fry. It is not known what portion of the fall chinook population outmigrates from the Sandy River as fry and what portion remains in the river to rear to smoltification. Fry rearing habitat is not usually limiting for chinook. Reduction in fry rearing habitat area, therefore, is not expected to result in a population response. For larger juveniles known to prefer deep pools, rearing habitat can be limiting. Reduction in deep pool habitat, however, is not expected to be sufficient to result in a population response.

*Sources of density-independent mortality*

- Infiltration of sand into the bed may reduce substrate permeability, and result in reduced survival to emergence. No impact is expected to be detectable downstream of Oxbow Park (i.e., in the most important spawning reach), but permeability may be reduced to some degree in Reach 4 upstream of Oxbow Park. The channel bed in the main spawning reach (from Oxbow Park [RM 14] to Lewis and Clark Park [RM 3]) currently contains large quantities of sand and fine sediment. Field observations suggest that substrates in the channel bed from Oxbow Park to the upstream end of Reach 5 (Dabney Park), are highly embedded with sand, and that from Dabney Park to the delta, much of the bed is matrix supported (i.e., substrate particles are not touching each other but are "floating" in a matrix of sand). Substrate permeability in these reaches is therefore expected to be low under current conditions, and no detectable change is anticipated following dam removal. Sand deposition in this reach is therefore not expected to reduce egg and alevin survival. From upstream of Oxbow Park to the Bull Run River confluence, which is also used by fall run chinook for spawning, the bed contains less sand. In this reach, sand deposition and infiltration into the bed may reduce substrate permeability, thereby potentially reducing survival to emergence. If reduction in permeability is of sufficient magnitude and extent following dam removal, the resulting reduction in survival to emergence could result in density-independent mortality of fall chinook salmon in the Sandy River.

- The potential for sand deposition in Reach 5 to cause impaired upstream passage and resulting density-independent mortality of fall chinook salmon is the same as described above for spring chinook salmon.

- As discussed for spring chinook above, sediment excavation from the reservoir may increase suspended sediment concentration downstream of Marmot Dam during the construction season, particularly under Alternatives A, C, and D. Adult fall chinook spawn almost exclusively downstream of the dam and could be present from August through February, with adult arrival typically peaking in October. If excavation continues through October 31, a large portion of the fall chinook adult arrivals would be exposed to increased TSS concentrations from their arrival to the river until spawning. Juveniles occur in the mainstem river from the onset of emergence through the end of summer. A large portion of the juvenile population therefore could be exposed to increased TSS levels for several months during summer and early fall. The magnitude of this increase has not been determined but could result in impaired homing, reduced spawning success, physiological stress, and possibly mortality in adults and reduced feeding efficiency, reduced growth rates, and physiological stress in juveniles.

- As described for spring chinook, fall chinook may be affected by increased TSS concentrations following dam removal. Adult fall chinook are present downstream of the dam primarily in fall and winter, which coincides with the period of increased TSS concentrations. For the predicted increases, potential impacts on adult fall chinook are sublethal but may include impaired homing and physiological stress. Juveniles are also present downstream of the dam in winter. Potential impacts would be the same as described for spring chinook. If sand is delivered at the rate used for the sensivity test (i.e., 10 times the predicted rate), predicted increases in TSS concentration could result in impaired spawning behavior in adults in addition to the impacts described above. Adult mortality would not be expected at exposures of less than 100 days. For juveniles, potential effects would be the same as described for juvenile spring chinook.

***Coho Salmon***

*Overview of conceptual model*

Removal of Marmot Dam could result in impacts to coho salmon that include potential impairment of passage in Reach 1 and the reservoir reach, filling of pools and side channels used as rearing habitat in Reaches 1 and 4, reduction in food supply supply downstream of the dam, and blockage of passage in Reach 5. The likelihood of these impacts and their potential effect on coho salmon populations are discussed below.

Coho salmon primarily spawn and rear in tributaries to the Sandy River upstream of Marmot Dam, including Still Creek and the Salmon River and its tributaries. Coho also spawn in tributaries downstream of Marmot Dam, particularly Gordon, Trout, and Cedar Creeks, although these fish may be primarily hatchery strays. Little data are available regarding areas used by rearing juvenile coho in the mainstem Sandy River. Information from the juvenile bypass facility at Marmot Dam and limited sampling downstream of the dam suggests that the lower Sandy River (downstream of Marmot Dam) is not likely to be as important for rearing as reaches upstream of the dam. Although data from the juvenile bypass facility are limited, the available data suggest that juvenile coho produced upstream of Marmot Dam remain to rear in the watershed upstream of the dam, and do not migrate to the lower Sandy River for rearing. Coho that pass downstream of the dam as fry or juveniles may rear in the lower river, however, especially if suitable overwintering habitat is not available in the upper watershed. Rearing juvenile coho salmon prefer deep pools with cover provided by LWD and off-channel habitats (including backwaters, beaver ponds, and side channels), especially during high flows. Timber harvest, road construction, and channelization for flood control that have occurred in the upper watershed have likely degraded coho rearing habitat upstream of the dam, potentially forcing juveniles to disperse downstream. Side channel habitats in the lower river may provide suitable winter rearing habitats for coho under high flow conditions, but lack of LWD in the main channel likely reduces its suitability as coho rearing habitat. Areas appearing most suitable for coho winter rearing downstream of the dam are located in Reach 1 (in the vicinity of Beaver Island) and Reach 4 (in side channels).

Coho salmon populations are generally believed to be limited by density-dependent mechanisms related to the availability of freshwater rearing habitat (Allen 1969, McFadden 1969, Larkin 1988, Meehan and Bjornn 1991). Because rearing habitat availability is believed to limit coho production, especially in watersheds lacking in LWD-associated pools, floodplains, side channels, and other low-velocity habitats, rearing habitat availability is likely the most important density-dependent source of mortality in the Sandy River basin. Under Alternatives B, C, and D, but especially under Alternative B, rearing habitat area may be reduced by sand deposition in backwaters and side channels. Severe reduction in macroinvertebrate food supply could also increase density-dependent mortality. Under all alternatives, coho rearing habitat area and food supply are not expected to be substantially reduced. Important sources of density-independent mortality resulting from dam removal could include: (1) impairment of passage through Reach 1 and the reservoir reach, (2) impairment of passage through Reach 5, and (3) injury or mortality resulting from acute or chronic exposure to increased TSS concentrations.

*Sources of density-dependent mortality*

- Sediment deposition in Reaches 1 and 4 may result in loss of floodplain and side-channel habitats potentially used by juvenile coho. Deposition of coarse sediment and sand in Reach 1, expected to be most significant under Alternative B, could result in loss of suitable juvenile coho overwintering habitat for up to a decade. The vicinity of Beaver Island (in Reach 1) provides good quality rearing habitat, with abundant LWD and a large, protected side channel with complex habitat. It is not known whether this reach is used by coho for rearing, but due to its short length in relation to other potential coho habitat in the basin, this loss is not expected to reduce coho population abundance. If, however, Reach 4 does provide important habitat and rearing habitat is limiting to coho salmon, loss of habitat in this reach could cause a small population response. Side channels in Reach 4 may also provide suitable winter rearing habitat. While sand deposition in this reach is expected to be minor, deposition that does occur would be primarily on bar surfaces and in low velocity areas, such as side channels. Due to the relatively small volume of sand stored in the reservoir and the extent of side channel habitat available in Reach 4, loss of side-channel habitat resulting from sediment deposition is expected to be minor, and no detectable population response is expected to occur.

- Sand transport and deposition may reduce macroinvertebrate populations downstream of Marmot Dam, thereby reducing food supply for rearing salmon. The potential for density-dependent mortality of coho salmon due to reductions in food supply is similar to that described above for spring chinook salmon.

*Sources of density-independent mortality*

- Under current conditions, coho salmon may be affected by false attraction to the Bull Run River, migration delays at the Marmot Dam fish ladder, and stress, injury, and mortality while passing through the Marmot Dam juvenile bypass system. These impacts would be eliminated under all dam removal alternatives. Because the majority of naturally produced coho are believed to spawn upstream of the dam, coho could benefit from long-term restoration of unimpaired access. If population abundance is indeed limited by rearing habitat, improved adult upstream passage would not be expected to increase population size. If rearing habitat is not limiting, however, improved passage may increase coho population abundance.

- Depending on hydrologic conditions following dam removal, impairment of adult upstream migration through Reach 1 and the reservoir reach could occur, especially during the first fall and winter following dam removal. Coho salmon pass over Marmot Dam from July through February, with peak passage of the early (Sandy hatchery stock) run occurring from September through November and of the native late run from October through December. The dam would be removed during the period from July 1 through October 31, and the cofferdam would be left in place until flows reached 1,800 cfs. Although the channel is expected to adjust quickly following dam removal, some blockage to upstream movement of salmon could occur if removal of the cofferdam occurs before the end of the coho migration (e.g., in November or December) and is followed by a significant reduction in flows to a level insufficient to transport coarse sediment and remove deposits created by bank failures. Contingency measures can likely be implemented to provide passage through reaches where significant bank failures occur, if necessary. Passage can also likely be successfully provided during the construction season(s). If blockages form and adequate contingency measures cannot be rapidly implemented, coho upstream passage could be blocked or impaired especially during the first winter following removal. The greatest risk of impaired passage would be expected during the period when the native late run are migrating upstream. Also, if passage cannot be adequately provided during the work season(s), upstream movement of both the early and late runs could be adversely affected.

- The potential for density-independent mortality associated with sand deposition in Reach 5 and impairment of upstream migration is the same for coho salmon as described above for spring chinook salmon.

- Coho occur downstream of the dam from July through February with an early (hatchery) run component arriving at the dam primarily in August and September, and a late (native) run component arriving at the dam from October through December. Construction-related TSS, therefore, could affect the entire early run component and the early arrivals of the late run component. Juveniles occur downstream of the dam year round and could be exposed to construction-related increases TSS concentration during summer and fall.

- As described for spring chinook, coho may be affected by increased TSS concentrations following dam removal. Adult coho are present downstream of the dam throughout fall and winter, which coincides with the period of increased TSS concentrations. For the predicted increases, potential impacts on adult coho are the same as described for fall chinook. Juveniles could occur year-round and could be exposed to increases in TSS concentration resulting from winter storms. For juveniles, potential effects would be the same as described for juvenile spring chinook.

***Winter Steelhead***

*Overview of conceptual model*

Removal of Marmot Dam could result in impacts to winter steelhead that include potential impairment of passage in Reach 1 and the reservoir reach, coarse sediment deposition and sand infiltration in potential spawning areas in Reaches 3 and 4, and coarse sediment and sand deposition in pools and side channels that may be used for rearing in Reaches 3 and 4. Dam removal is expected to benefit winter steelhead through restoration of unimpaired access at the dam site, long-term restoration of more natural hydrologic regimes downstream of the dam site, and decreased juvenile mortality associated with downstream migration through the juvenile bypass facilities.

Winter steelhead spawn primarily upstream of Marmot Dam, with most spawning occurring in the Salmon River and its tributaries and in Still Creek. Steelhead also spawn in tributaries downstream of the dam, and spawning has been observed in the mainstem downstream of Marmot Dam. No complete surveys have been conducted downstream of the dam during periods when steelhead would be expected to be present, and their spawning distribution in the lower river is not well understood. No information is available regarding areas used by rearing juvenile steelhead in the mainstem downstream of the dam. Steelhead that pass downstream of the dam as fry and juveniles, as well as juveniles produced in the mainstem and tributaries downstream of the dam may rear in the lower river. Winter steelhead have been documented passing through the Marmot juvenile bypass system from March through June (the only months sampled) at sizes ranging from 2.5 to 8.6 inches (65 to 220 mm). This suggests that at least some of the steelhead leaving the upper watershed (i.e. juveniles that migrate past Marmot Dam at small sizes) continue to rear downstream of the dam. As discussed in the section on coho salmon above, land uses in the upper watershed may have resulted in degreadation of rearing habitat, forcing juveniles to disperse downstream.

Suitable rearing habitat for steelhead is available in Reaches 1, 3, and 4, although naturally high turbidity levels may discourage rearing in the mainstem during summer. While it seems likely that steelhead would rear in the lower river, snorkel surveys conducted during the summer have indicated relatively limited use of the mainstem, at least during this period.

Steelhead exhibit a complex and highly variable life history. Adults may spend up to 3 years in the ocean and are iteroperous (spawning one or more times in successive years before dying). The length of time that juveniles rear in fresh water is also highly variable and can range from one to three years. Juveniles that rear in the mainstem downstream of Marmot Dam would be expected to use low velocity margin habitats as fry and move into higher velocity pool habitats as they grow. In winter, juveniles either remain in their natal streams if adequate habitat exists or disperse to other streams to find suitable winter habitat (Bjornn 1971, Dambacher 1991). Steelhead overwinter in pools, especially low velocity, deeper pools, with large rocky substrate or LWD for cover (Hartman 1965, Swales et al. 1986, Raleigh et al. 1984, Fontaine 1988). During periods of low temperatures and high flows, juveniles may take refuge in substrate interstices and other low velocity areas, such as those associated with LWD and bank margins.

Life history strategies for steelhead are based on rearing for an extended period in fresh water, with relatively few fish leaving the river but at larger sizes. Thus, both spawning gravel limitations and limitations in rearing habitat and food supply are likely to be the most important sources of density-dependent mortality. Because winter steelhead rear in fresh water for an extended period and are highly territorial (i.e., compete for food resources), reductions in food supply, reduction in rearing habitat, changes in physical habitat that reduce feeding efficiency (such as increased turbidity), and increases in water temperature may decrease growth rates and displace some juveniles to suboptimal habitats. Reductions in spawning habitat area downstream of the dam related to sediment deposition following dam removal could also increase density-dependent mortality for those steelhead that spawn downstream of Marmot Dam. We therefore believe that the most important density-dependent factors influencing winter steelhead populations that may be affected by dam removal are spawning habitat area, rearing habitat area, and macroinvertebrate production downstream of the dam. Under all dam removal alternatives, rearing habitat area and quality downstream of the dam are not expected to be significantly reduced and may actually be increased as a result of increased flows and decreased spring and summer water temperatures.

Important sources of density-independent mortality that could be increased by dam removal include: (1) reduction in egg survival resulting from infiltration of sand into spawning gravels, (2) impairment of passage through Reach 1 and the reservoir reach, (3) impairment of passage through Reach 5, and (4) injury or mortality resulting from acute or chronic exposure to increased suspended sediment. Sources of density-independent mortality that would be eliminated by dam removal include: (1) false attraction of adults to the Bull Run Powerhouse, (2) migration delay at the Marmot Dam fish ladder, and (3) mortality of juvenile downstream migrants (especially fry) at the Marmot Dam juvenile bypass facility.

Combining our general understanding of potential limiting factors with the predictions of geomorphic and habitat effects in each reach leads to the following more specific conclusions regarding potential impacts to the winter steelhead population in the Sandy River basin:

*Sources of density-dependent mortality*

- Sediment deposition would likely bury spawning habitat in the upper portion of Reach 3 but is not expected to eliminate spawning habitat in the downstream portions of Reach 3 or in Reach 4.

Deposition of coarse sediment and sand in Reach 3 would likely eliminate spawning habitat upstream of Revenue Bridge (i.e., at the outlet of the gorge). In the lower portion of Reach 3 and in Reach 4, coarse sediment deposition is predicted to be minor in extent and magnitude. Sand deposition is also expected to be minor in these reaches and would occur primarily on bar surfaces (especially vegetated bars) and in low velocity areas (such as side channels) where spawning is unlikely. If the large majority of winter steelhead spawn upstream of the dam or in tributaries downstream of the dam, reduced substrate permeability in this reach would not be expected to result in a population response. If spawning downstream of the dam is significant or represents a separate life history strategy, however, reduced survival to emergence in this reach could reduce steelhead population size, genetic diversity, and resilience to natural and artificial disturbance.

- Coarse sediment and sand deposition in Reaches 1, 3, and 4 may result in loss of main-channel and side-channel habitats that are potentially used for rearing. Deposition of coarse sediment and sand in Reach 1, expected to be most significant under Alternative B, could eliminate habitat suitable for steelhead rearing for up to a decade. This reach provides good quality habitat for summer and winter rearing, with abundant LWD, coarse substrates, deep pools, and a large, protected side channel with complex habitat. It is not known whether this reach is currently used by steelhead for rearing, but due its short length in relation to habitats elsewhere in the basin, this loss is not expected to reduce steelhead population size. In Reach 3, sediment deposition could eliminate summer and winter rearing habitat upstream of Revenue Bridge for a period of years, until the sediment wave is attenuated and sediment delivery to the reach slows. In the lower portion of Reach 3 and in Reach 4, deposition is expected to be minor and is not expected to eliminate substantial areas of rearing habitat. Increases in flows from Marmot Dam to the Bull Run River confluence (Reaches 1, 2, and 3) following its removal are expected to benefit steelhead rearing downstream of the dam through increases in water depths and wetted channel area and reduced temperatures during low flow periods. This could potentially offset potential density-dependent mortality related to loss of rearing habitat.

- Sand transport and deposition may reduce macroinvertebrate populations in Reaches 3, 4 and 5, thereby reducing food supply for steelhead rearing downstream of the dam site. The potential for density-dependent mortality of winter steelhead due to reductions in food supply is similar to that described for spring chinook salmon.

*Sources of density-independent mortality*

- Depending on hydrologic conditions following dam removal, impairment of adult steelhead migration through Reach 1 and in the reservoir reach could occur, especially during the first fall and winter following dam removal. Winter steelhead pass over Marmot Dam from November through May, with most passage occurring from January through April. The dam would be removed during the work season, which extends from July 1 through October 31, and the cofferdam would be left in place until flows reached 1,800 cfs. Although the channel is expected to adjust quickly following dam removal, some blockage could occur if removal of the cofferdam occurs before the end of steelhead migration (e.g., in November or December) and is followed by a significant reduction in flows to a level insufficient to transport coarse sediment and remove deposits created by bank failures. If contingency measures can be implemented to provide passage through reaches where significant bank failures occur, and that passage can be successfully provided during the construction season(s), no impacts to winter steelhead populations are expected. If blockages form and adequate contingency measures cannot be rapidly implemented, however, steelhead upstream migration could be blocked or impaired for the duration of such blockages. Also, if passage cannot be adequately provided during the work season(s), migration may be impaired during these periods.

- Infiltration of sand into the bed may reduce substrate permeability downstream of the dam, thereby reducing egg and alevin survival. As described for fall chinook, no impact is expected to be detectable downstream of Oxbow Park, but reductions in permeability may occur in Reach 4 upstream of Oxbow Park. The spawning distribution of winter steelhead in the mainstem channel is not known but habitat surveys suggest that the most suitable spawning habitat is located upstream of Oxbow Park. In this reach, reduced substrate permeability may reduce survival to emergence. If the large majority of winter steelhead spawn upstream of the dam or in tributaries downstream of the dam, reduced substrate permeability in this reach would not be expected to result in a population response. If spawning downstream of the dam, however, is significant or represents a separate life history strategy, reduced survival to emergence in this reach could reduce steelhead population size, genetic diversity, and resilience to natural and artificial disturbance.

- The potential for density-independent mortality associated with sand deposition in Reach 5 and impairment of upstream migration is the same for winter steelhead as described above for spring chinook salmon.

- As discussed for spring chinook above, sediment excavation from the reservoir may increase suspended sediment concentration downstream of Marmot Dam during the construction season, particularly under Alternatives A, C, and D. Adult winter steelhead could be present downstream of the dam from January through May and therefore would not be exposed to construction-related increases in TSS concentration. Winter steelhead spawn primarily upstream of the dam but also spawn downstream. Since fry emergence extends from June through August and juveniles may be present in the lower river year-round, fry and juveniles could be exposed to increased TSS levels for several months during summer and early fall.

- As described for spring chinook, winter steelhead may be affected by increased TSS concentrations following dam removal. Adult winter steelhead are present downstream of the dam throughout winter, which coincides with the period of increased TSS concentrations. For the predicted increases, potential impacts on adult winter steelhead are the same as described for fall chinook. Juveniles could occur year-round and could be exposed to increases in TSS concentration resulting from winter storms. For juveniles, potential effects would be the same as described for juvenile spring chinook.

***Summer Steelhead***

*Overview of conceptual model*

Impacts to summer steelhead that may result from dam removal are similar to those identified for winter steelhead and spring chinook salmon. These impacts could include potential impairment of passage in Reach 1 and the reservoir reach, sediment deposition in pools used for adult holding, coarse sediment and sand deposition in pools and side channels potentially used for rearing in Reaches 3 and 4, and impairment of passage through Reach 5.

Summer steelhead are not native to the Sandy River, do not have special status under the Endangered Species Act and are managed as a hatchery stock. Hatchery-reared steelhead are currently released only downstream of Marmot Dam. All hatchery steelhead are now marked, and marked adult summer steelhead are sorted at the Marmot Dam fish ladder. Marked hatchery fish are returned downstream, and unmarked fish are released upstream of the dam. Progeny of naturally spawning hatchery fish cannot be identified and are known to spawn in the upper watershed. With the removal of Marmot Dam, both hatchery fish and their unmarked progeny would have access to the upper Sandy River reaches if stocking is continued and and/or an alternative sorting facility is not constructed. Little is known about natural production of summer steelhead in the Sandy River basin, but are believed to spawn primarily upstream of Marmot Dam. Summer steelhead life history is similar to that described for winter steelhead except that adults arrive ~~to~~ at the river sexually immature and hold in deep pools in the river through the summer and fall prior to spawning. Adults pass over Marmot Dam primarily between May and August. The time spent holding downstream of the dam is not known. As with winter steelhead, some juvenile summer steelhead may rear downstream of Marmot Dam.

Because their life history strategy, habitat requirements, and distribution are similar to those of winter steelhead, potential limiting factors are similar between the two runs, except that summer steelhead require summer and fall holding habitat similar to spring chinook salmon. We believe that the most important density-dependent sources of mortality limiting summer steelhead include the availability of: (1) spawning habitat, (2) rearing habitat, (3) food supply, and (4) adult holding habitat. Primary sources of density-independent mortality that could be increased by dam removal include: (1) reduction in egg survival resulting from infiltration of sand into spawning gravels downstream of the dam, (2) impairment of passage through Reach 1 and the reservoir reach, (3) impairment of passage through Reach 5, and (4) injury or mortality resulting from acute or chronic exposure to increased TSS concentrations. Potential effects of dam removal on these sources of density-dependent and density-independent mortality (and on sources of density-independent mortality that would be eliminated) are discussed in the sections above on winter steelhead and, for impacts pertaining to adult holding and upstream migration, in the sections on spring chinook salmon. Overall, impacts associated with sediment release from Marmot Dam are not expected to adversely affect summer steelhead populations in the Sandy River basin, particularly in the context of flow and access improvements.

*Sources for density-dependent mortality*

- Sand deposition in Reaches 1, 2, and 3 may reduce pool depths, but loss of pool area and depth in important holding reaches is expected to be minor and temporary, as discussed above for spring chinook salmon.

- Sediment deposition in Reaches 1, 3, and 4 may result in loss of main channel and side-channel habitats that are potentially used for rearing, as discussed above for winter steelhead. In Reaches 1, 2, and 3 increases to water depths and wetted channel area and decreases to summer and fall water temperatures resulting from increases in flow following dam removal may somewhat offset these losses by improving habitat quality for oversummering juveniles and for adults holding in the lower river.

- Sand transport and deposition may reduce macroinvertebrate populations in reaches that may be used for rearing (Reaches 4 and 5). This could reduce food supply, as discussed above for spring chinook salmon.

*Sources of density-independent mortality*

- The potential for impairment of adult passage for summer steelhead through Reach 1 and the reservoir reach is low, given the timing of upstream migration of summer steelhead. Summer steelhead arrive at the dam primarily from May through August. This is similar to spring chinook salmon (see discussion above). As discussed above, only unmarked summer steelhead are currently allowed to migrate past Marmot Dam.

- The potential for density-independent mortality associated with sand deposition in Reach 5 and impairment of upstream migration is the same for summer steelhead as described above for spring chinook salmon.

- As discussed for spring chinook above, summer steelhead may be affected by construction-related increases in TSS concentration as a result of sediment excavation from the reservoir, particularly under Alternatives A, C, and D. Adult summer steelhead could be present downstream of the dam from February through October, with peak arrival to the dam typically in June and July. Since peak arrival coincides with the onset of excavation, a large number of summer steelhead adults could be exposed to increased TSS levels during upstream migration. The duration of this exposure would depend upon the migration rate of these fish but is expected to be short. As for spring chinook, juveniles could occur downstream of the dam throughout the year, although their use of rearing habitat downstream of the dam is not known.

- As described for spring chinook, effects of increased TSS concentrations associated with transport of reservoir sediment following dam removal would likely be limited for adult summer steelhead. Adult summer steelhead are present downstream of the dam in summer when increases in TSS concentrations are expected to be minor. Juveniles could occur year-round and could be exposed to increases in TSS concentration resulting from winter storms. For juveniles, potential effects would be the same as described for juvenile spring chinook.

***Coastal Cutthroat Trout***

*Overview of conceptual model*

Key impacts to coastal cutthroat trout that may result from dam removal include elevated suspended sediment concentrations in Reaches 3, 4 and 5; blockage of passage in Reach 5; and impairment of passage in Reach 1 and the reservoir reach. Dam removal may benefit cutthroat trout by increasing flows and improving access to upstream reaches, thereby improving habitat connectivity between upstream and downstream populations.

Coastal cutthroat trout are likely the most widely distributed salmonid in the Sandy River basin, consisting of populations of resident (non-migratory), fluvial (migrating solely within river systems), and possibly sea-run (migrating between marine environments to feed and grow and freshwater environments to spawn) fish. Both fluvial and sea-run populations of migratory coastal cutthroat trout have been historically observed in the Sandy River, but sea-run cutthroat have not been documented in many years. Migratory coastal cutthroat trout in the Sandy River basin are currently thought to occur primarily downstream of Marmot Dam, spawning and rearing in tributaries and using the mainstem Sandy River during seasonal migrations, although their use of mainstem habitats in the lower river is poorly understood. Little or no juvenile rearing is expected to occur in the mainstem Sandy River. Adults of migratory populations typically migrate from smaller tributaries by late May and return upstream to overwinter and spawn in the late summer or fall of the same year . Migratory populations of cutthroat trout could be vulnerable to potential impacts of dam removal due to their use of mainstem habitats during seasonal migrations.

Coastal cutthroat trout spawn primarily in smaller tributaries upstream of spawning areas utilized by coho salmon and steelhead. Cutthroat trout are relatively poor competitors when in sympatry with other salmonids, and interspecific competition may limit cutthroat trout populations in tributaries (Trotter et al. 1993, Trotter 1997). For overwintering habitat, cutthroat trout are expected to prefer deep pools associated with complex woody debris for cover in smaller tributary reaches (Bisson and Sedell 1984).

*Sources of density-dependent mortality*

No density-dependent factors that may be affected by dam removal are expected to limit cutthroat trout carrying capacity in the mainstem Sandy River downstream of the dam.

*Sources of density-independent mortality*

- As discussed for spring chinook above, sediment excavation from the reservoir may increase suspended sediment concentration downstream of Marmot Dam during the construction season, particularly under Alternatives A, C, and D. Migratory populations of coastal cutthroat trout may be affected by construction-related increases in TSS concentration. Migration timing for cutthroat varies from stream to stream, and no information is available regarding migration timing or habitat utilization of adult cutthroat trout in the Sandy River. In general, fluvial cutthroat leave spawning tributaries in the spring to feed and grow in mainstem habitats (much like use of marine environments by anadromous forms), and return in the fall to overwinter and spawn. Cutthroat could therefore be present in the mainstem during dam removal activities in the early fall. The duration of this exposure would depend upon the migration timing and the extent to which migratory forms utilize the Columbia and Sandy rivers. Juvenile coastal cutthroat trout are not expected to use mainstem habitats for rearing throughout the year, although their use of rearing habitat downstream of the dam is not known.

- As with other salmonid species, cutthroat could be affected by increases in TSS concentration. Adult cutthroat would be present in the mainstem in spring and fall. During spring, anticipated increases in TSS concentration are minor. In fall, impacts on cutthroat trout would likely be similar to those described for fall chinook.

- As discussed for other salmonid species above, deposition of sand in Reach 5 may reduce water depth and impair adult upstream migration under some flow conditions. It is assumed that contingency measures (such as dredging) can be implemented to reestablish migration should a barrier form. If contingency measures cannot be implemented, passage of migratory and sea-run cutthroat trout could be blocked for one or more years.

- Depending on hydrologic conditions following dam removal, impairment of adult cutthroat passage through Reach 1 and the reservoir reach could occur, especially during the first fall and winter following dam removal. This would not be expected to have substantial effects on cutthroat trout in the basin, however, as sea-run cutthroat have not been observed passing over the dam in many years and habitat connectivity is expected to be re-established after a short time.

- As discussed for other salmonid species, fry and juveniles passing downstream of the dam may be injured or killed in the juvenile bypass system. Adult cutthroat may also migrate or disperse downstream through the bypass, through the ladder, or over the spillway, which may cause injury or mortality. These adults may also be injured or killed. Removal of the dam and diversion would eliminate this source of mortality and would improve habitat connectivity. This increase in connectivity may increase genetic exchange between upstream and downstream populations, and could provide for increased diversity of life history patterns within migratory populations.

**Table 9A. Coarse sediment aggradation locations, magnitudes, and duration for Alternatives B, C, and D, as predicted by numerical modeling for average hydrologic conditions.**[1] *(Footnotes follow Table 9B)*

| Reach | Location within Reach | Deposition Thickness | Reference Run[2] | Alternative B | Alternative C[3] | Alternative D |
|---|---|---|---|---|---|---|
| **COARSE SEDIMENT DEPOSITION** | | | | | | |
| Reach 1 | RM 30–29 | average depth (ft) | 0.75 | 7 (entire period) | 7 | 1.5 (Year 1–10) |
| | | maximum depth (ft)[4] | 1 | 12 (Day 5) | 14 | 4 (Year 3) |
| | RM 29–28.5 | average depth (ft) | undetectable | 3 (Year 0–5) | 1 | undetectable |
| | | maximum depth (ft) | | 4 (Year 2) | 1.5 | |
| Reach 2 | RM 28.5–28 | average depth (ft) | undetectable | 1.5 (Year 2–4) | 1.0 | undetectable |
| | | maximum depth (ft) | | 2.5 (Year 5) | 1.5 | |
| | RM 25–24.5 | average depth (ft) | undetectable | 3 (Year 1–20) | minor | 1.5 (Year 3–7) |
| | | maximum depth (ft) | | 5 (Year 5) | | 3 (Year 3) |
| Reach 3 | RM 24–22 | average depth (ft) | 0.5 | 3 (Year 1–20) | 0.5 | 1 (Year 1–10) |
| | | maximum depth (ft) | 2.5 | 6.5 (Year 7) | 1.1 | 3 (Year 1) |
| | RM 21–19 | average depth (ft) | 0.3 | 0.5 (Year 1–20) | 0.2 | 0.2 (Year 1–10) |
| | | maximum depth (ft) | 1 | 1.5 (Year 10) | 1.2 | 1 (Year 1) |
| Reach 4 | RM 16–13 | average depth (ft) | 0.2 | 0.3 (Year 1–20) | 0.2 | 0.3 (Year 0–10) |
| | | maximum depth (ft) | 1.6 | 2.1 (Year 20) | 0.6 | 1.3 (Year 10) |
| Reach 5 | RM 6–0 | minor deposition under all alternatives | | | | |

**Table 9B. Sand aggradation locations and magnitudes for Alternatives B, C, and D during the first two years after dam removal as predicted by numerical modeling for average hydrologic conditions[1]**

| Reach | Location within Reach | Deposition Thickness | Reference Run[2] | Alternative B | Alternative C[3] | Alternative D |
|---|---|---|---|---|---|---|
| **SAND DEPOSITION** | | | | | | |
| Reaches 1–4 | | minor deposition under all alternatives | | | | |
| Reach 5 | RM 6–2 | All alternatives are similar to the reference run | | | | |
| Reach 5 | RM 2–0 | average depth (ft)[4] | 0.3 | 0.3 | 0.2 | 0.3 |
| | | maximum depth (ft) | 1.3 | 1.4 | 0.7 | 1.3 |

1 Modeled deposition thicknesses represent cross-section and sub-reach averages. Magnitudes and timing of aggradation reflect a given set of hydrologic input data. Model predictions are subject to uncertainty, as discussed in Section 2.1.4.
2 A "reference run" assessing background sediment transport conditions in the Sandy River, with no release of reservoir sediment was completed as part of the numerical modeling. Results of the reference run provide a basis for comparison with Alternatives B, C, and D and may be analagous to Alternative A, under which all sediment would be excavated prior to dam removal.
3 Year 1 only, after Year 1, Alternative C would be similar to Alternative D.
4 The maximum depth represents one point within the given subreach.

**Table 10. Summary of key impacts on anadromous salmonids and their habitats expected under the four alternatives proposed for removal of Marmot Dam.**

| Impact | Species and Runs Affected | Alternative A | Alternative B | Alternative C | Alternative D |
|---|---|---|---|---|---|
| Permanent loss of low-gradient spawning habitat in reservoir reach | spring chinook<br>fall chinook | would occur | would occur | would occur | would occur |
| Short-term blockage of adult passage in reservoir reach and/or Reach 1 (due to sediment deposition and/or channel destabilization) | spring chinook<br>coho<br>winter steelhead<br>summer steelhead | very unlikely | possible | unlikely | very unlikely |
| Loss or degradation of pool habitat, and side-channel habitat through burial in Reach 1 | spring chinook<br>coho<br>winter steelhead<br>summer steelhead | no impact | very likely | very likely | possible |
| Loss of suitable pool habitat for adult holding because of partial infilling of pools in Reach 2 | spring chinook<br>summer steelhead | no impact | possible | unlikely | very unlikely |
| Loss or degradation of spawning habitat in Reach 3 due to sand infiltration and burial or scour of redds. | fall chinook<br>winter steelhead | no impact | likely | possible | unlikely |
| Loss or degradation of potential rearing habitat in Reach 3 due to sand infiltration and burial of low-velocity rearing habitats | all species and runs, especially fall chinook and winter steelhead | no impact | likely | possible | unlikely |
| Loss or degradation of spawning habitat in Reach 4 due to sand infiltration and burial or scour of redds | fall chinook<br>winter steelhead | no impact | possible | unlikely | very unlikely |
| Loss or degradation of potential rearing habitat in Reach 4 due to sand infiltration and burial of low-velocity rearing habitats | all species and runs, especially fall chinook and winter steelhead | no impact | unlikely | very unlikely | very unlikely |
| Loss or degradation of spawning habitat in Reach 5 due to sand infiltration and burial or scour of redds | fall chinook<br>winter steelhead | no impact | unlikely | very unlikely | very unlikely |
| Loss or degradation of potential rearing habitat in Reach 5 due to sand infiltration and burial of low-velocity rearing habitats | all species and runs, especially fall chinook and winter steelhead | no impact | very unlikely | very unlikely | very unlikely |
| Reduced growth rates due to reduced macroinvertebrate food supply because of burial or scour | all species and runs | no impact | unlikely | very unlikely | very unlikely |
| Impairment of passage through Reach 5 due to sand deposition | all species and runs | no impact | possible | possible | possible |

| Impact | Species and Runs Affected | Alternative A | Alternative B | Alternative C | Alternative D |
|---|---|---|---|---|---|
| Exposure to increased TSS concentration downstream of Marmot Dam during sediment excavation (July through October) | juveniles (all species and runs except cutthroat trout) | definite | unlikely | definite | definite |
| | (adult) fall chinook spring chinook coho summer steelhead cutthroat trout | definite | unlikely | definite | definite |
| | adult winter steelhead | unlikely | unlikely | unlikely | unlikely |
| Potential stress or injury resulting from exposure to increased TSS concentration downstream of Marmot Dam after removal | all species and runs | unlikely | possible | possible | possible |

## 4.2 Impact Assessment of Little Sandy Dam Removal

As noted above, approximately 4,500–9,400 $yd^3$ (3,400–7,200 $m^3$) of sediment are stored behind Little Sandy Dam and would be released downstream into the Little Sandy River following its removal. This value represents a relatively small volume of sediment, equivalent to less than 1% of the volume of sediment accumulated behind Marmot Dam. Uncertainty regarding the volume of sediment behind the dam therefore does not affect the analysis of potential effects of removing Little Sandy Dam and releasing sediments downstream. Reaches that may be affected by sediment release from Little Sandy Dam include the following: (1) immediately upstream of Little Sandy Dam, (2) from Little Sandy Dam to the mouth of the Little Sandy River, and (3) the Bull Run River below the mouth of the Little Sandy River. Effects are not likely to be detectable in the Sandy River below its confluence with the Bull Run River, which is about 2.7 mi (4.4 km) downstream of the Little Sandy River's confluence with the Bull Run River.

***Geomorphic and Biological Impacts***

*Potential impacts to Little Sandy Reach 1 (0-0.3 mi [0-0.5 km] downstream of Little Sandy Dam)*
Removal of Little Sandy Dam will result in movement of the sediment currently accumulated behind the dam downstream into Reach 1. Under full-flow conditions, this reach would have a high sediment transport capacity, resulting in relatively rapid downstream movement of this sediment, depending on the magnitude of high flows in the Little Sandy River following dam removal. In the short term, aggradation in Reach 1 is anticipated, with deposition occurring unevenly depending on local shear stress conditions. Coarse sediment aggradation may cause mortality of alders that have encroached into the channel due to reduced flows. Restoration of natural flow regimes (including high flows and winter baseflows) could also cause scour/dieback of riparian vegetation that has become established in the formerly active channel. Restoration of high flows will also likely promote more frequent mobilization of bed materials that are immobile under the current flow regime, resulting in an overall decrease in median grain size in the channel. Mortality of riparian vegetation (willows and alders) could also contribute to increased mobility of cobble/boulder bars on which willows currently grow, since the stabilizing influence of vegetation roots on substrates would be reduced once the willows die and their roots decay. The small pools in Reach 1 are also likely to infill with coarse sediment. Fine sediment deposits that are currently present in Reach 1 will

likely be transported downstream by restored flows.

*Potential impacts to Little Sandy Reach 2 (0.3-1.7 mi [0.5-2.7 km] downstream of Little Sandy Dam)*
Removal of Little Sandy Dam is expected to have little effect on geomorphic conditions in Reach 2, because the steep gradient and high confinement of this reach create high shear stresses and sediment transport capacity, resulting in channel morphology that appears highly resilient to changes in sediment and water supply. Sediments released from behind the dam are expected to travel quickly through this reach and into the Bull Run River, and restored flows are not expected to result in morphologic changes. Some coarse sediment deposition may occur in the pools located 0.9–1.0 mi (1500–1650 m) downstream of the dam (as well as in the riffle between the pools), decreasing pool depth and volume. Decreases in habitat area in these pools may be counterbalanced to some extent by increased discharge. In addition, localized aggradation may deposit a coarse sediment mantle over bedrock bench areas associated with knickpoints in this reach, and some small deposition sites associated with momentum defects (bedrock outcrops, boulders) could swell with gravel in response to the sediment pulse from the dam, although the duration of these effects will likely be short.

*Potential impacts to Bull Run River*
The Bull Run River appears to be sediment-depleted downstream of the City of Portland's dams, which block downstream delivery of coarse sediment, and gravel augmentation in the Bull Run River has previously been proposed to mitigate the loss of upstream supply (R2 Resource Consultants 1998b). Release of sediment from Little Sandy Dam may therefore have a beneficial effect on the Bull Run River, facilitating deposition in locations that currently lack alluvial deposits or are unsaturated. This effect is likely to be small, however, given the small amount of sediment that will be released from behind Little Sandy Dam. No adverse effects of sediment release from Little Sandy Dam on the Bull Run River are anticipated.

*Impacts of turbidity and suspended sediment*
Because sand comprises 35 to 45% of the reservoir deposit upstream of Little Sandy Dam, removal of the dam and subsequent mobility of the reservoir sediments could increase turbidity and suspended sediment concentrations in the lower Little Sandy and Bull Run rivers. Because the amount of sand stored behind Little Sandy Dam is relatively small, however, turbidity and suspended sediment impacts are expected to be substantially less than under any of the alternatives for removal of Marmot Dam, including Alternative A.

### *Potential Impacts on Anadromous Salmonids*

Assessment of potential impacts on aquatic habitat in the Little Sandy River differs from assessment of impacts in the Sandy River because of the substantial differences in habitat suitability and access under current conditions. The lower Little Sandy River currently provides poor habitat for salmonids and other aquatic organisms because over 90% of baseflows are diverted, and access to the upper Little Sandy River from downstream of the dam is currently blocked because Little Sandy Dam does not have fish passage facilities. In contrast, the Sandy River currently supports good habitat for anadromous salmonids both upstream and downstream of Marmot Dam, and facilities for upstream and downstream passage for these species are provided at Marmot Dam. Although sediment release from Little Sandy Dam may result in some changes to habitat conditions, dam removal will substantially improve conditions for anadromous salmonids and other native aquatic organisms in the Little Sandy River by increasing flows and restoring connectivity with the upper basin. The analysis presented below focuses on potential sediment-related impacts of removing Little Sandy Dam and does not discuss the habitat benefits of restoring flows and access in the Little Sandy River, which, as noted above, are expected to far outweigh any adverse sediment-related effects.

Juvenile steelhead are currently found in the lower Little Sandy River (O'Neal and Cramer 1999), and surveys for this study suggest that steelhead are the anadromous salmonid species most likely to use this reach under full-flow conditions, particularly winter steelhead, given the lack of deep pools suitable for holding by adult summer steelhead. Coho salmon, spring chinook salmon, and cutthroat trout could also use this reach (mainly for rearing) with restored flows.

Migration (which is currently blocked by Little Sandy Dam) is not expected to be adversely affected by sediment release. Because of the relatively low volume of sediment stored behind Little Sandy Dam, it is unlikely that the sediment deposit (or downstream aggradation resulting from sediment release) will create a physical barrier to fish passage following removal of the dam.

Aggradation in Reach 1 may limit its suitability for salmonid spawning in the short term, although as noted above, such habitat is currently limited in this reach. Gravels deposited downstream of the dam will likely initially be highly mobile, potentially causing egg mortality if these gravels are used for spawning. The high sediment transport capacity in this reach will likely transport most substrates suitable for salmonid spawning downstream (and out of the Little Sandy River) within a short period of time following dam removal. Spawning habitat may increase near the downstream end of Reach 1 following dam removal, where deposition of sediments released from the dam (as well as increased flows) may increase the suitability of existing alluvial deposits for spawning. Sediment released from Little Sandy Dam also would not likely substantially affect summer or winter rearing habitat for salmonids in Reach 1. Infilling of pools with coarse sediments may slightly reduce the suitability of these sites as adult holding and juvenile rearing habitat, but the riffle areas that predominate in this reach will likely remain suitable for rearing, even if short-term aggradation occurs.

Sediments released from the dam would not likely affect spawning or rearing habitat for salmonids in Little Sandy Reach 2 in the long term. No suitable spawning habitat currently occurs in the reach, and increases in gravel deposition as a result of the sediment pulse following dam removal would likely be short in duration because of the reach's high gradient. Riffles that are suitable for juvenile steelhead rearing (including coarse substrate interstices used for winter refuge) would not be expected to be susceptible to sediment deposition impacts. In the long term, restoration of LWD transport and supply from the upper basin could increase the potential for gravel deposition and improve habitat conditions in this reach.

# 5. POTENTIAL CONTINGENCY MEASURES ASSOCIATED WITH REMOVAL OF MARMOT DAM

Because of the uncertainties involved in predicting the impacts of removing Marmot Dam on anadromous salmonids and other aquatic organisms, particularly for removal options in which greater amounts of sediment would be released, development of contingency plans to mitigate some of the potential impacts discussed above may be merited. Contingency plans carried out as part of an adaptive management framework would include the following steps: (1) identification of potential impacts prior to initiation of dam removal (i.e., this document and the environmental assessment document); (2) development and implementation of monitoring to evaluate the occurrence and magnitude of actual impacts during dam removal and for a defined period after removal is completed (with the duration of monitoring being guided by modeling results and agency consultation), and (3) implementation of specified mitigation measures if monitoring indicates that pre-determined impact thresholds ("triggers") are being exceeded.

Potential impacts that might require development and implementation of contingency plans can be evaluated through a process involving initial assessment of the range of potential geomorphic and biological effects of the different dam removal alternatives, followed by evaluation of the associated risks (where risk is determined by the expected probability of an impact occurring and the magnitude and duration of adverse effects if the impact occurs). The contingency planning process should focus on potential high risk impacts, and should also account for whether or not certain impacts can be mitigated. For example, impacts such as fine sediment infiltration into spawning gravels may be more difficult to mitigate and therefore less conducive to contingency plan development than impacts related to fish passage, for which contingencies are discussed below.

Three primary areas of potential impacts representing high enough risk to resources of concern, particularly listed salmonids, to merit development of contingency plans have been identified:

- *Fish passage problems caused by headcutting or bank failure in the reach upstream of Marmot Dam and/or by aggradation immediately downstream of the dam.* Erosion of sediment from Marmot Reservoir and sediment deposition immediately downstream of the dam could potentially create a barrier to upstream fish migration under some removal alternatives. Review of scientific literature on headcutting and analysis of the characteristics of reservoir sediment suggest that reservoir headcutting would be unlikely to create a fish passage problem, although there is a possibility of a short-term barrier being created by bank failures upstream of the dam site or coarse sediment being deposited immediately downstream of the dam site, particularly under Alternative B. Regardless of this assessment of the probability of occurrence of headcutting or bank failure, a contingency measure to address potential passage problems following dam removal is merited because the impacts on listed salmonid populations are potentially high if a barrier is created. A contingency plan to address fish passage barriers in the reservoir reach and in Reach 1 could entail frequent monitoring of these reaches and storing of appropriate mechanical excavation equipment near the dam site. Fish passage barriers could therefore be quickly identified and removed using excavation equipment. A contingency plan accounting for headcutting or aggradation could also require developing a procedure for trapping and hauling fish around the reservoir area on short notice should a significant barrier develop. Key issues related to any trap-and-haul program would include the method and location of trapping fish. Fish traps located immediately downstream of the dam site would maximize salmonid access to downstream river habitats but would be subject to substantial risk of being buried or otherwise damaged by the sediment released from the reservoir. Details of this contingency plan would need to be developed by PGE after further agency consultation.

- *Impaired salmonid access to side-channel habitats and/or tributaries in Reaches 3 and 4.* As discussed in Section 4.1 above, sediment released from behind Marmot Dam is expected to result in gravel deposition in Reaches 1 and 3 and sand deposition in Reach 5 (contingency measures for Reach 5 are discussed below). The model does not predict deposition of sand or gravel in Reach 4, but if such deposition did occur in side-channel areas, it could reduce the availability or suitability of these areas as juvenile salmonid rearing habitat. A contingency measure to address the risks associated with potential sediment deposition in Reaches 3 and 4, where most side-channel habitats in the Sandy River are located, could include monitoring a subsample of side-channel habitats and tributary confluences under different flows, before and after dam removal, to document baseline conditions and to assess impacts associated with dam removal. Mitigation actions could consist of limited excavation of sediment deposits to restore access to side-channel habitats or tributary channels (excavation to reverse aggradation throughout side-channel areas is not expected to be warranted; mechanical methods would be confined to limited use to maintain access to side channels). Baseline information and agency consultation could be used to establish the impact threshold, or trigger, for implementing any mitigation actions.

- *Fish passage problems caused by sand deposition in the Sandy River delta (i.e., the downstream portion of Reach 5).* Because of its low gradient and the backwater effect of the Columbia River, the Sandy River delta (Reach 5) could undergo sand aggradation following removal of Marmot Dam, possibly meriting contingency measures to account for potential fish passage problems during low-flow periods. While sediment transport modeling predicts sand deposition of up to 1.3 ft in Reach 5, with fluctuations throughout the year (see Section 4.1), the actual magnitude of deposition remains uncertain because of the potential backwater effect of the Columbia River. A contingency measure to address the risks associated with potential deposition of sand in Reach 5 could include monitoring of channel depths during low-flow conditions in the Sandy River delta area and near the Interstate 84 bridge. Baseline surveys could be conducted to establish specific channel cross sections (tied to a stable benchmark) to be used for subsequent monitoring and to document pre-impact channel depths under low-flow conditions. Mitigation could entail dredging of a deeper channel if monitoring indicated that sand deposition could impair or prevent upstream migration of adult salmonids (i.e., if depths were less than an agreed-upon threshold for maintaining fish migration).

The potential need for these contingency measures would vary depending on the alternative selected for removal of Marmot Dam, and details would be developed by PGE subsequent to further agency consultation. No additional contingency or mitigation measures have been identified at this time. As development of the preferred alternative and agency consultations continue, additional contingency plans or mitigation measures may be developed.

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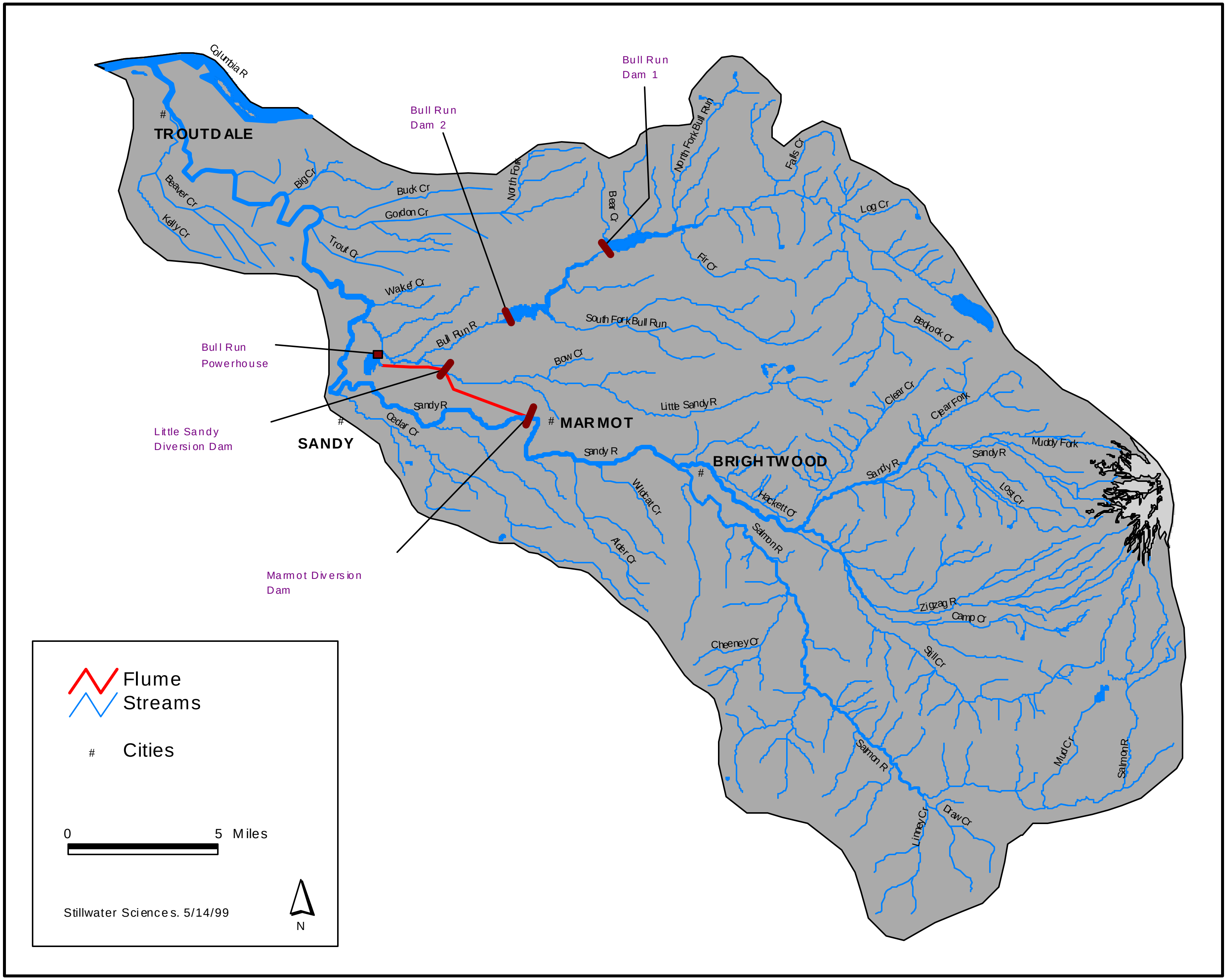
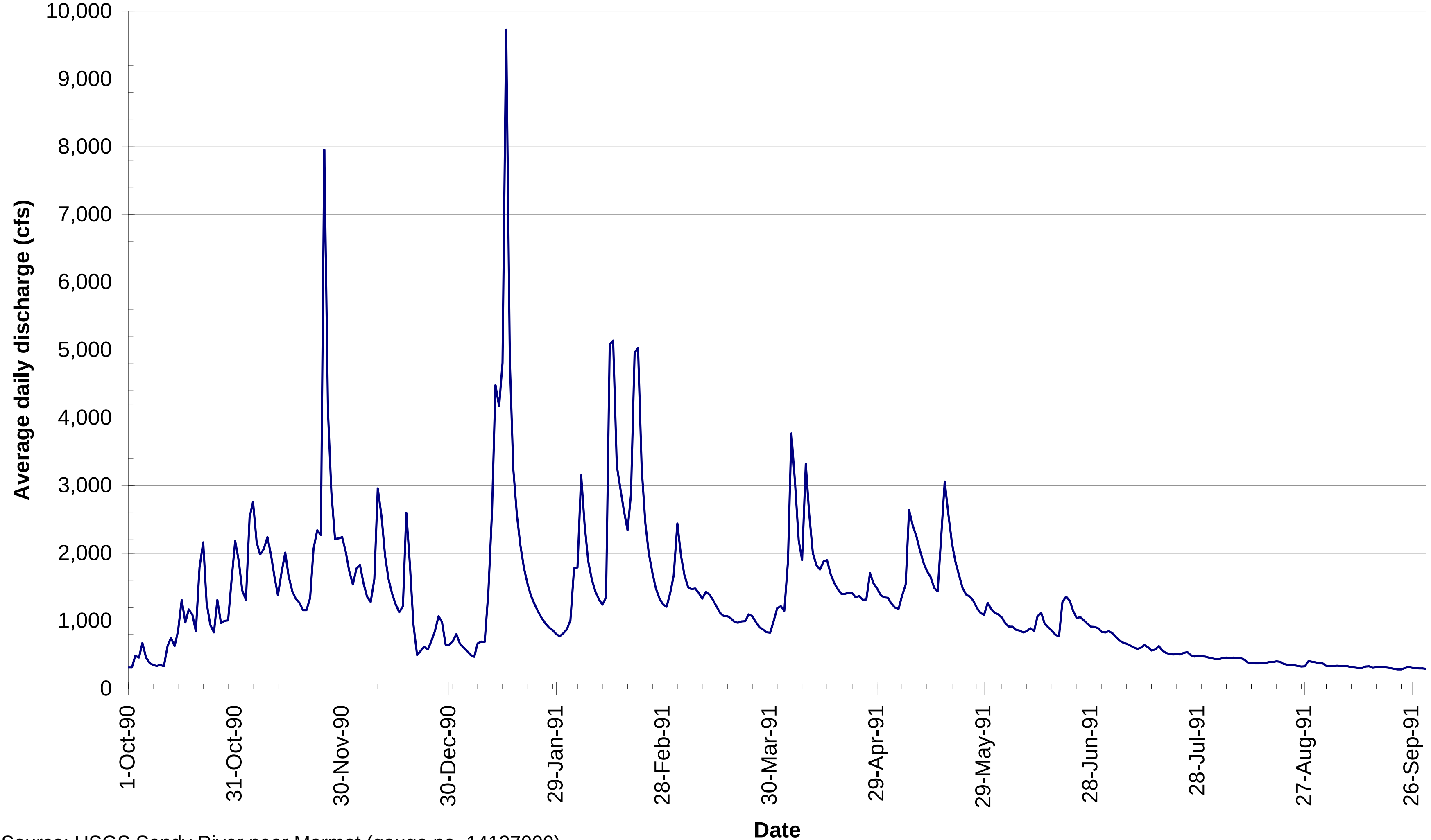



**Figure 1. Map of the Sandy River Basin.**

**Figure 2. Annual hydrograph for a year with average flow conditions (WY 1991), from the USGS Sandy River near Marmot gauge (station number 14137000) .**




Source: USGS Sandy River near Marmot (gauge no. 14137000)

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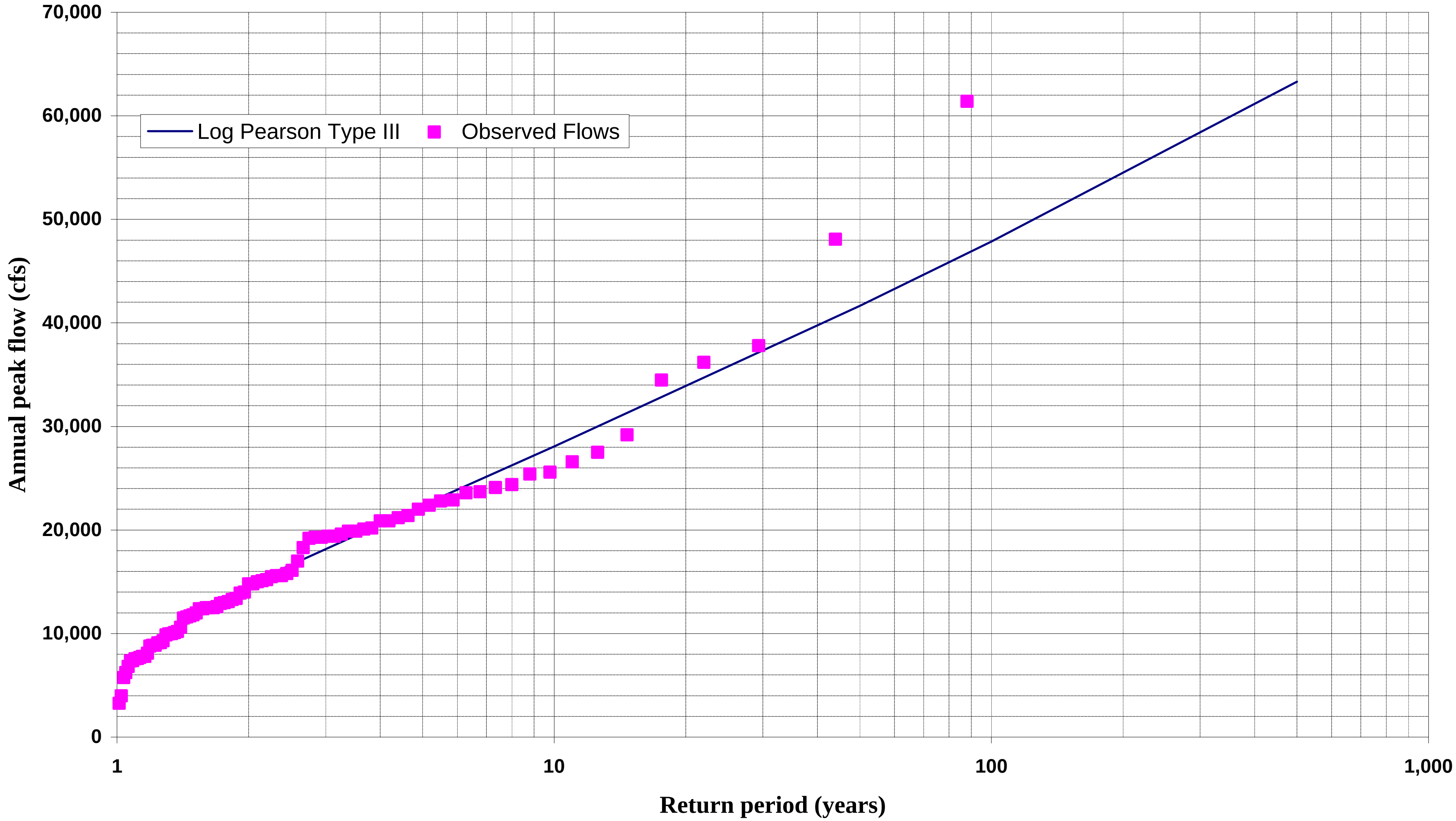
**Figure 3. Flood frequency, Sandy River near Marmot, OR gaging station (Period of Record 1912-1998).**




Source: USGS Sandy River near Marmot (gauge no. 14137000)

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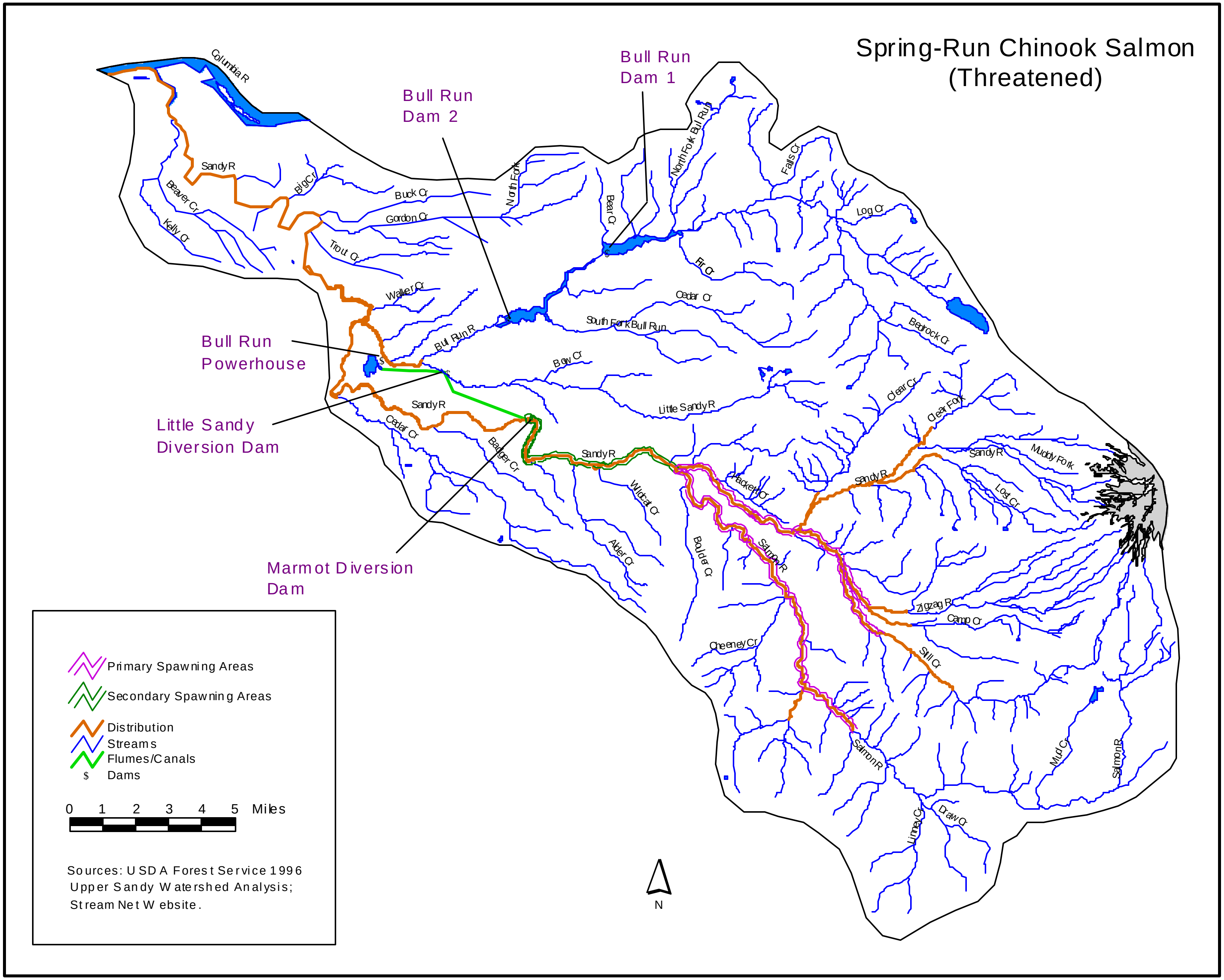



**Figure 4. Fish distribution map: spring-run chinook salmon.**

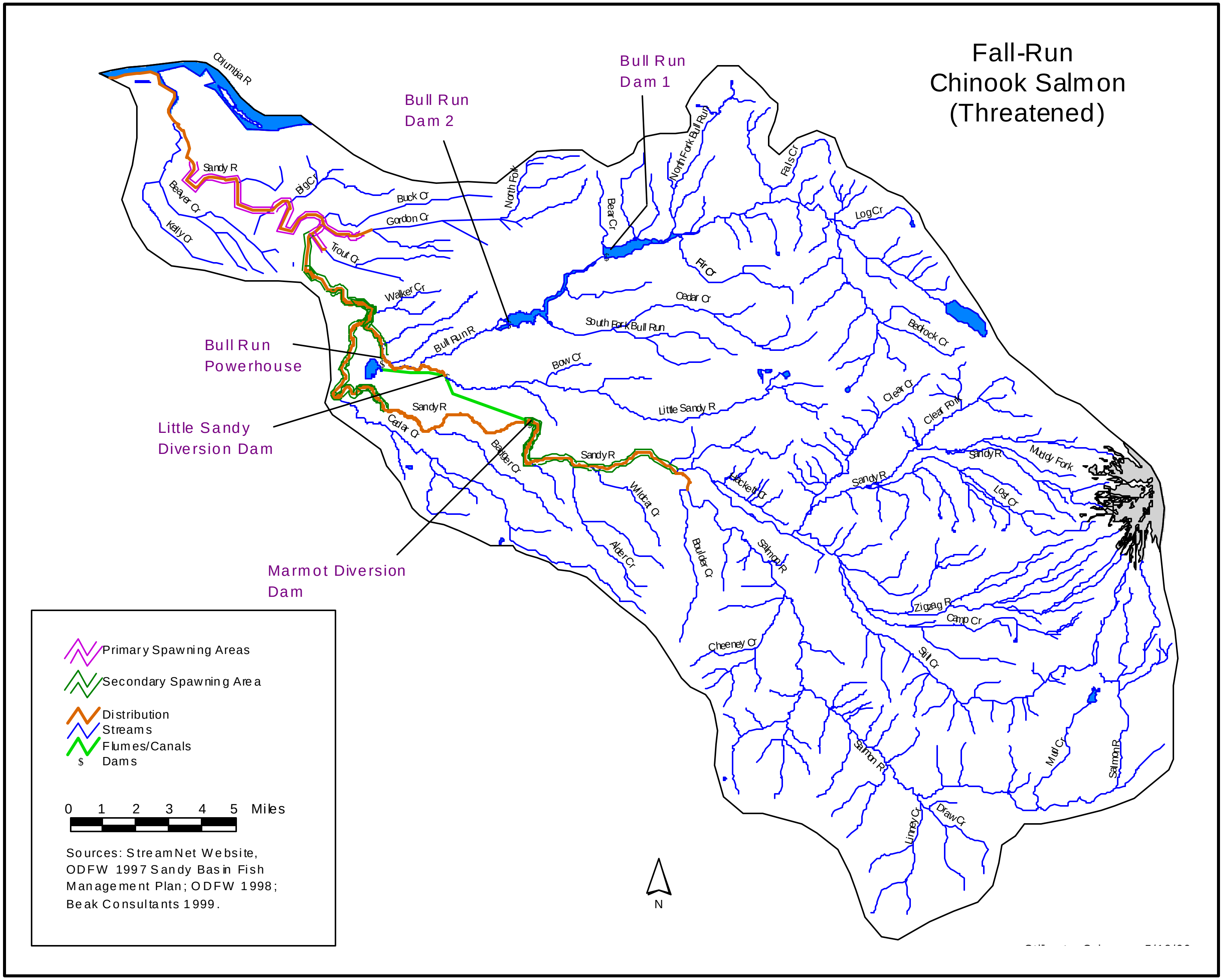



**Figure 5. Fish distribution map: fall-run chinook salmon.**

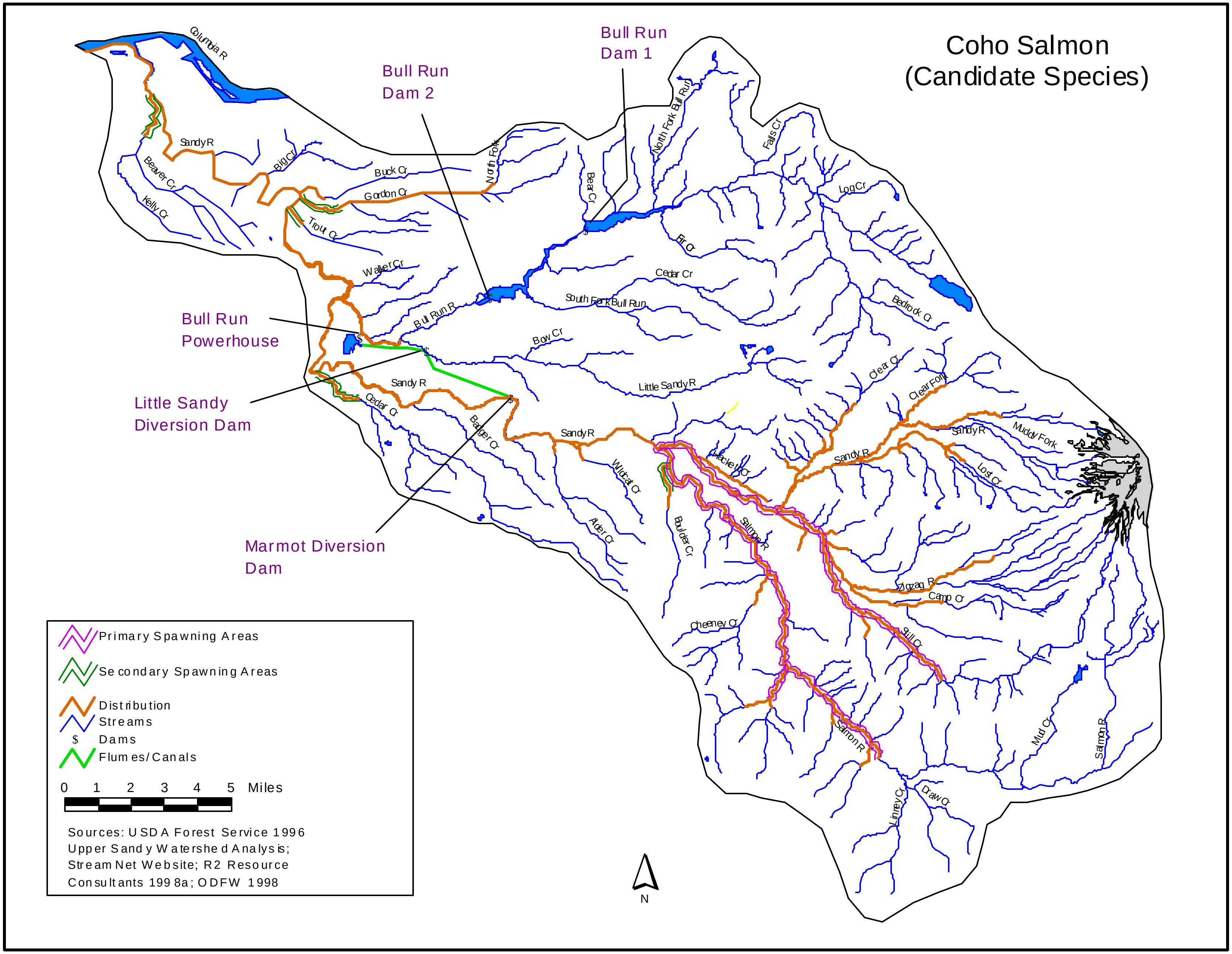
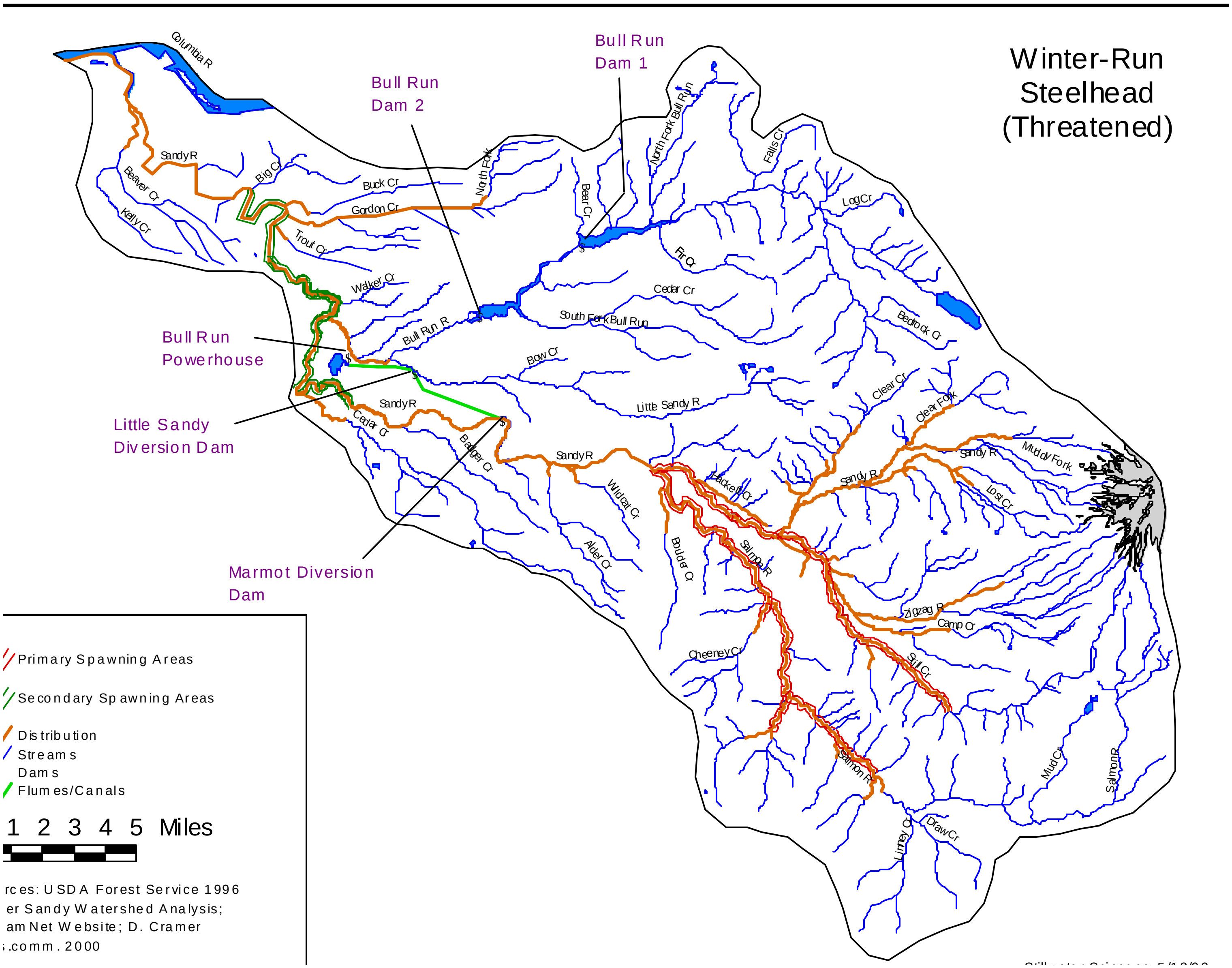



**Figure 6. Fish distribution map: coho salmon.**




rces: USDA Forest Service 1996
er Sandy Watershed Analysis;
am Net Website; D. Cramer
.comm. 2000

Figure 7. Fish distribution map: winter-run steelhead.

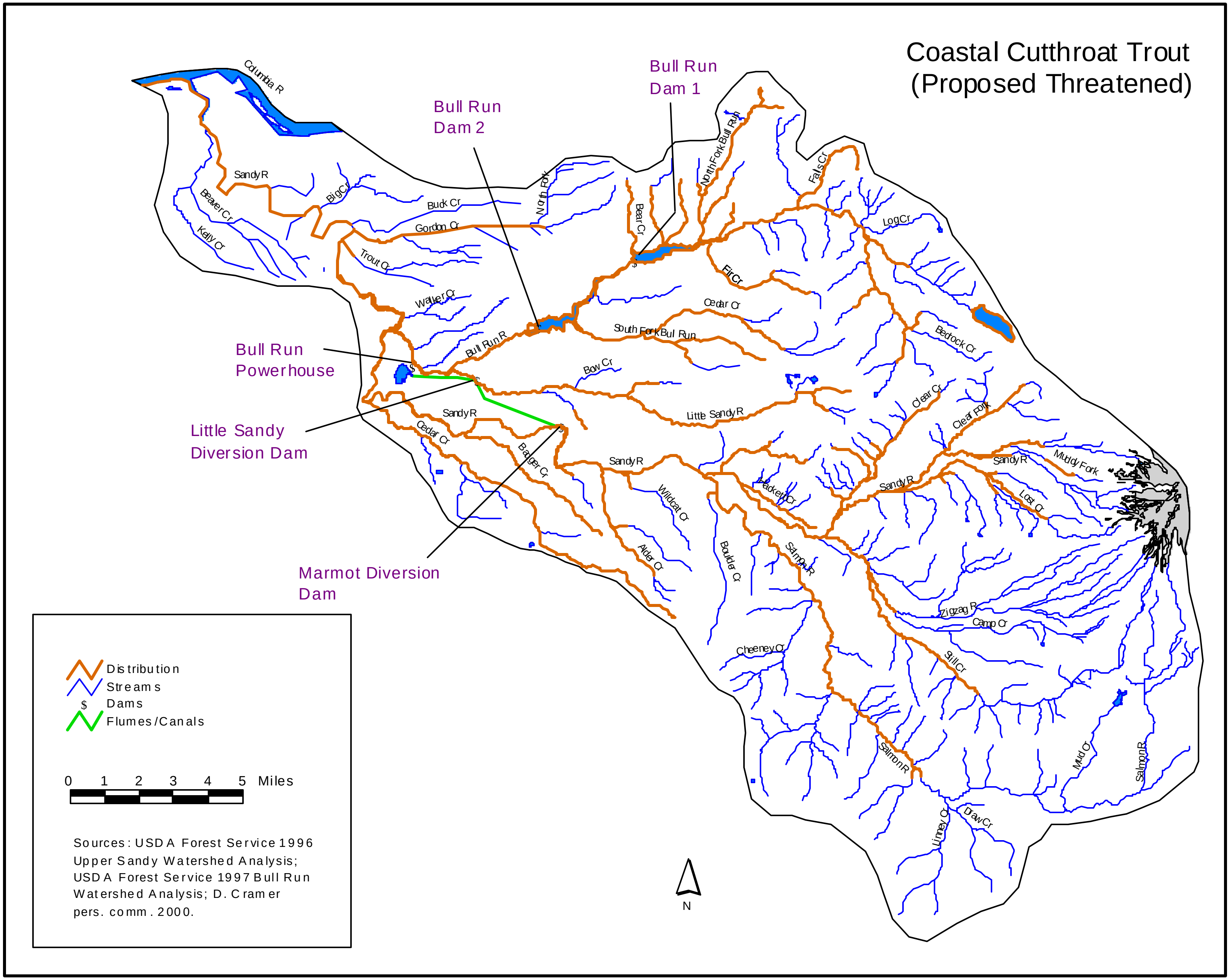
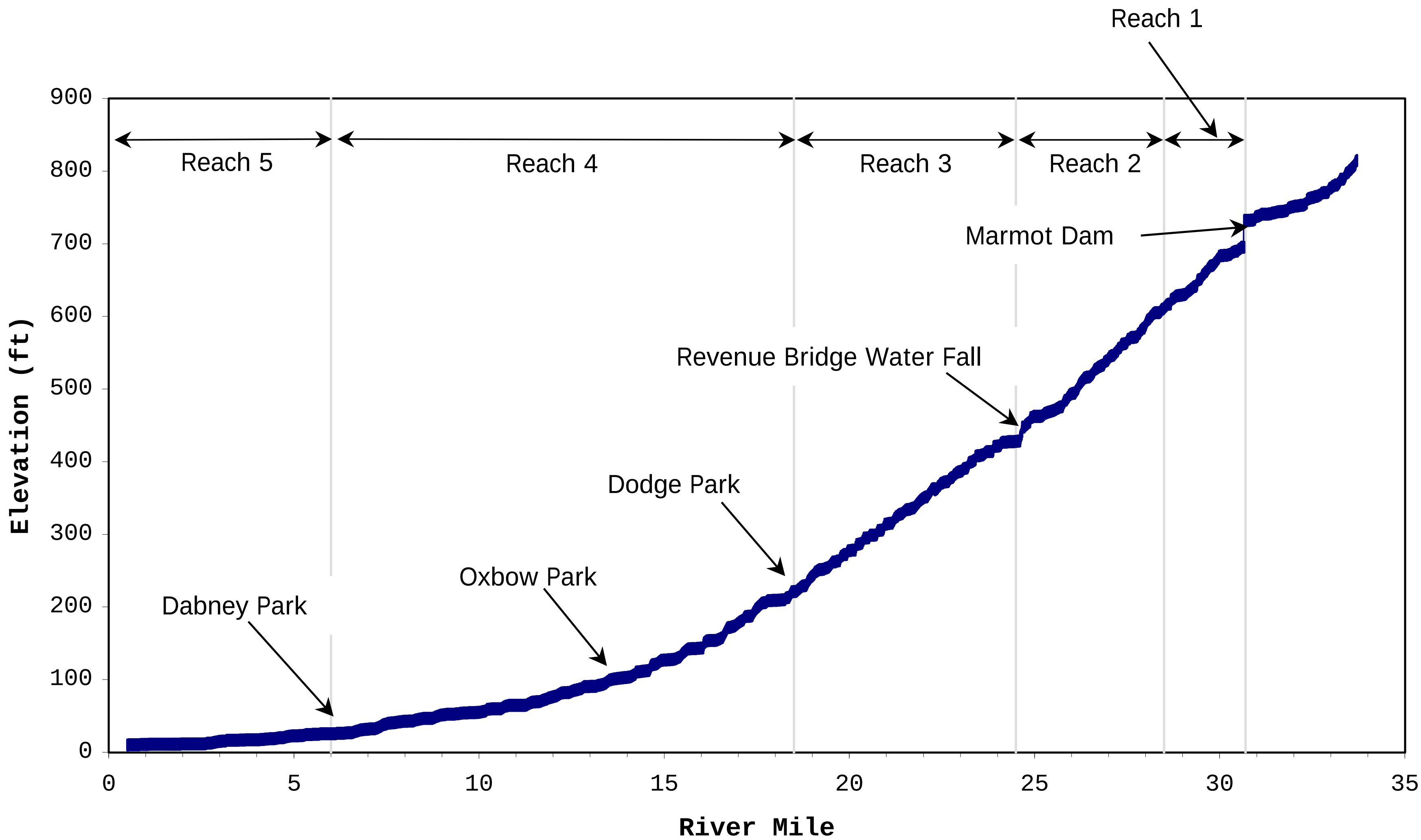



**Figure 8. Fish distribution map: coastal cutthroat trout.**

**Figure 9. Sandy River longitudinal profile, based on PGE photogrammety and geomorphic reaches delineated by Stillwater Sciences.**



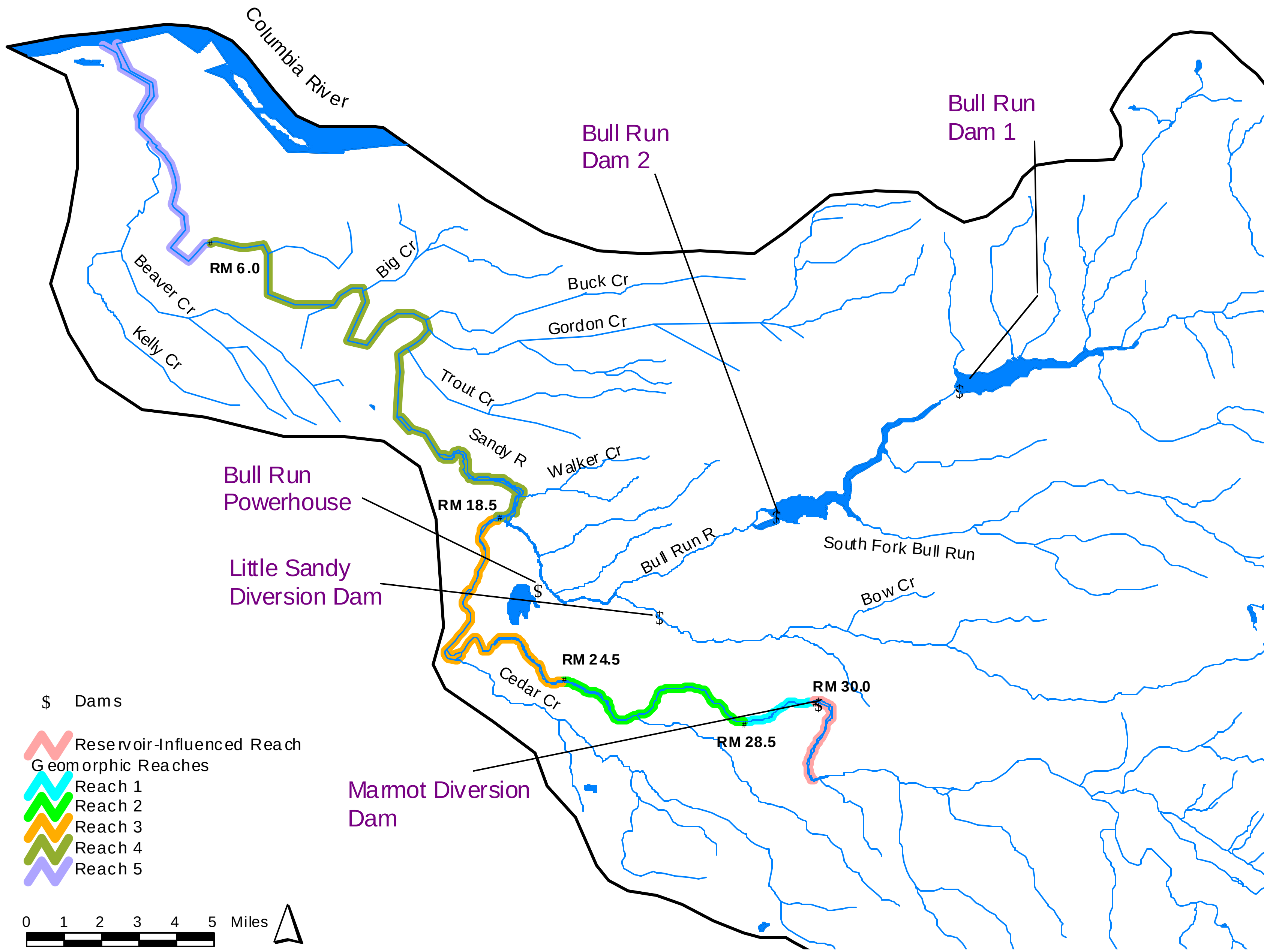
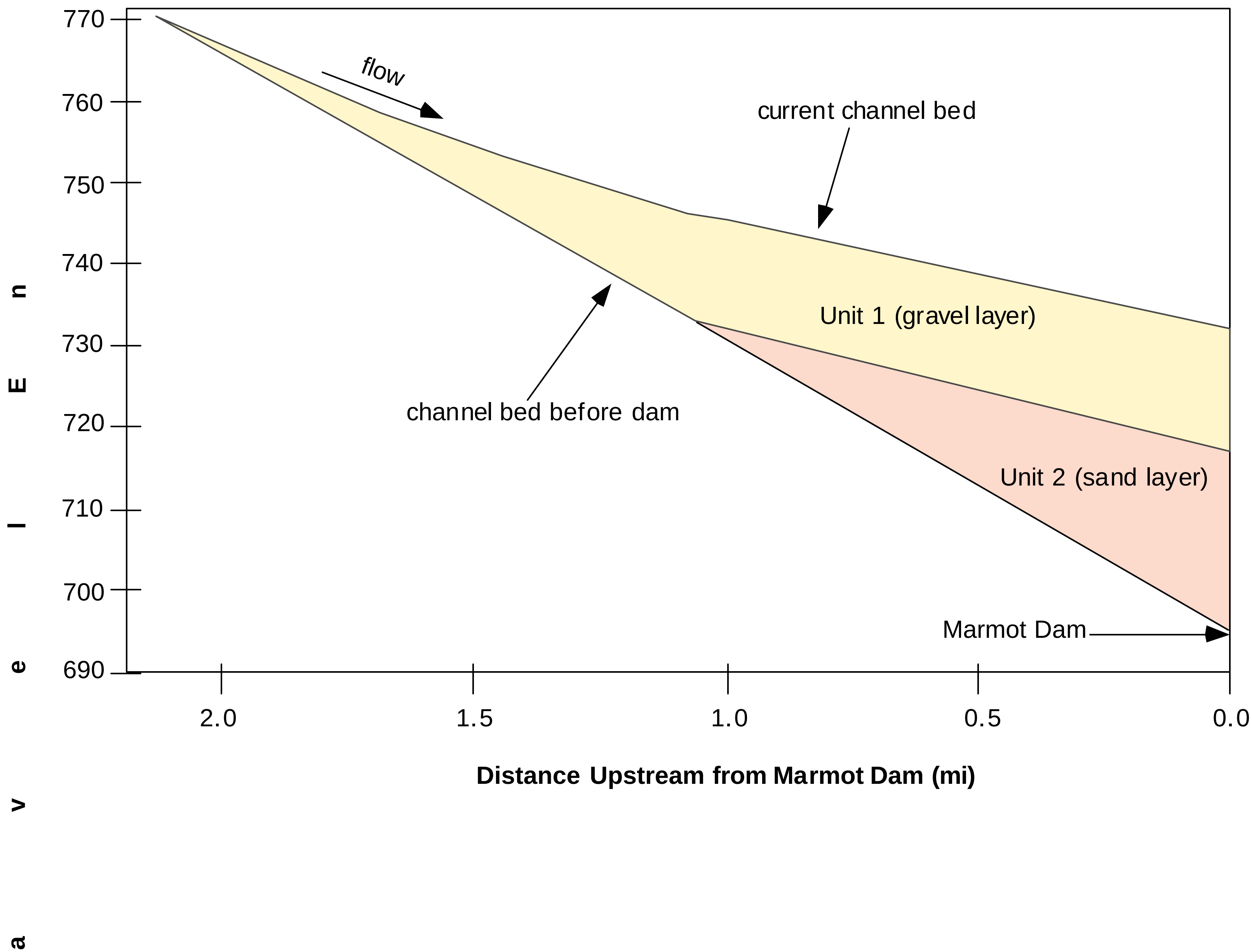



**Figure 10. Map of geomorphic reaches delineated by Stillwater Sciences on Sandy River.**

**Figure 11. Simplified representation of stratigraphy of Marmot Reservoir sediment deposit, based on Squier Associates coring study.**



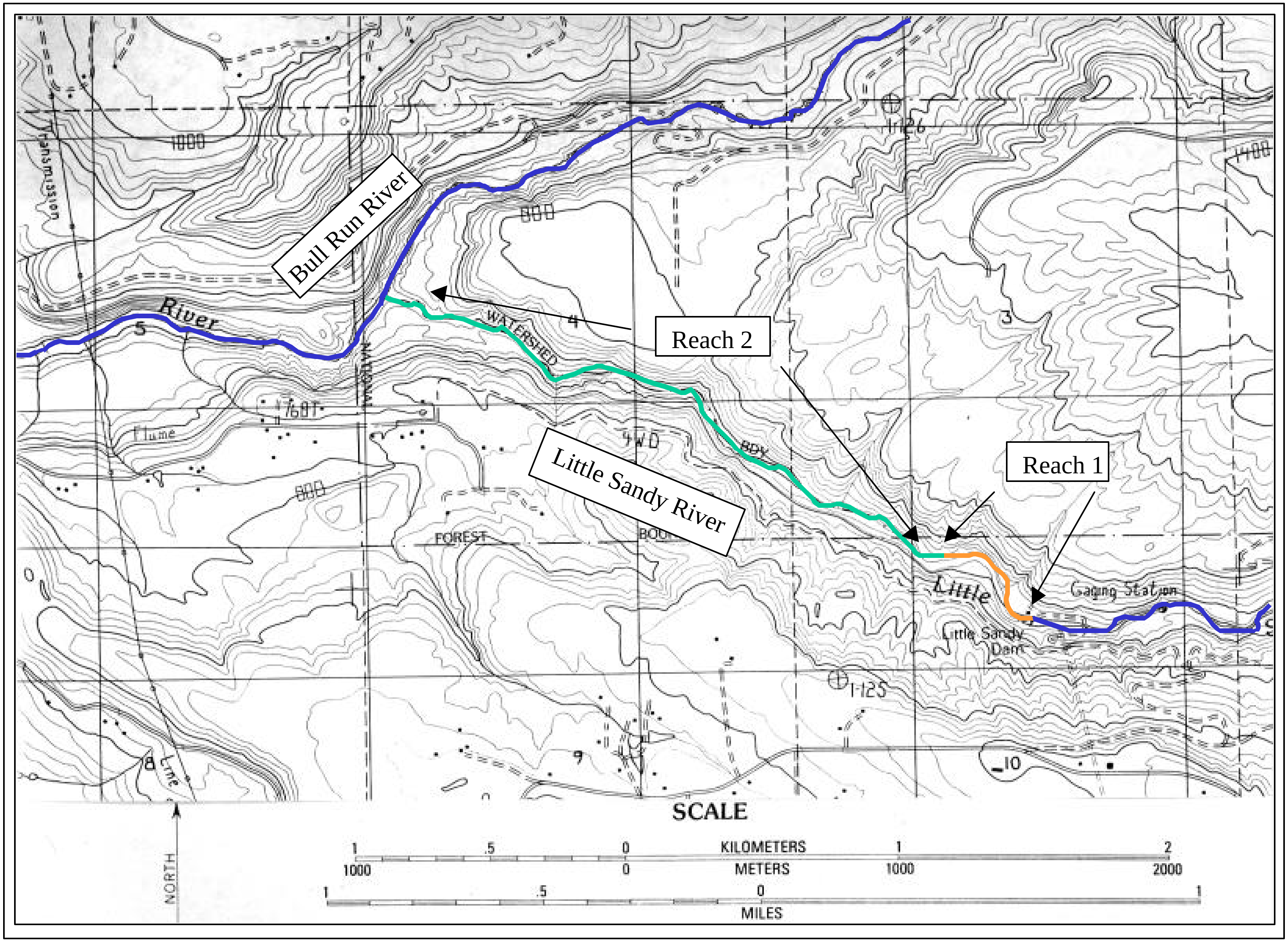



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**Figure 12. Map of Lower Little Sandy River.**

**Figure 13. Thickness of gravel deposition in Sandy River, reference run of numerical model (background sediment transport conditions, with no release of sediment from Marmot Dam; results can be considered analogous to Alternative A for removing Marmot Dam).**

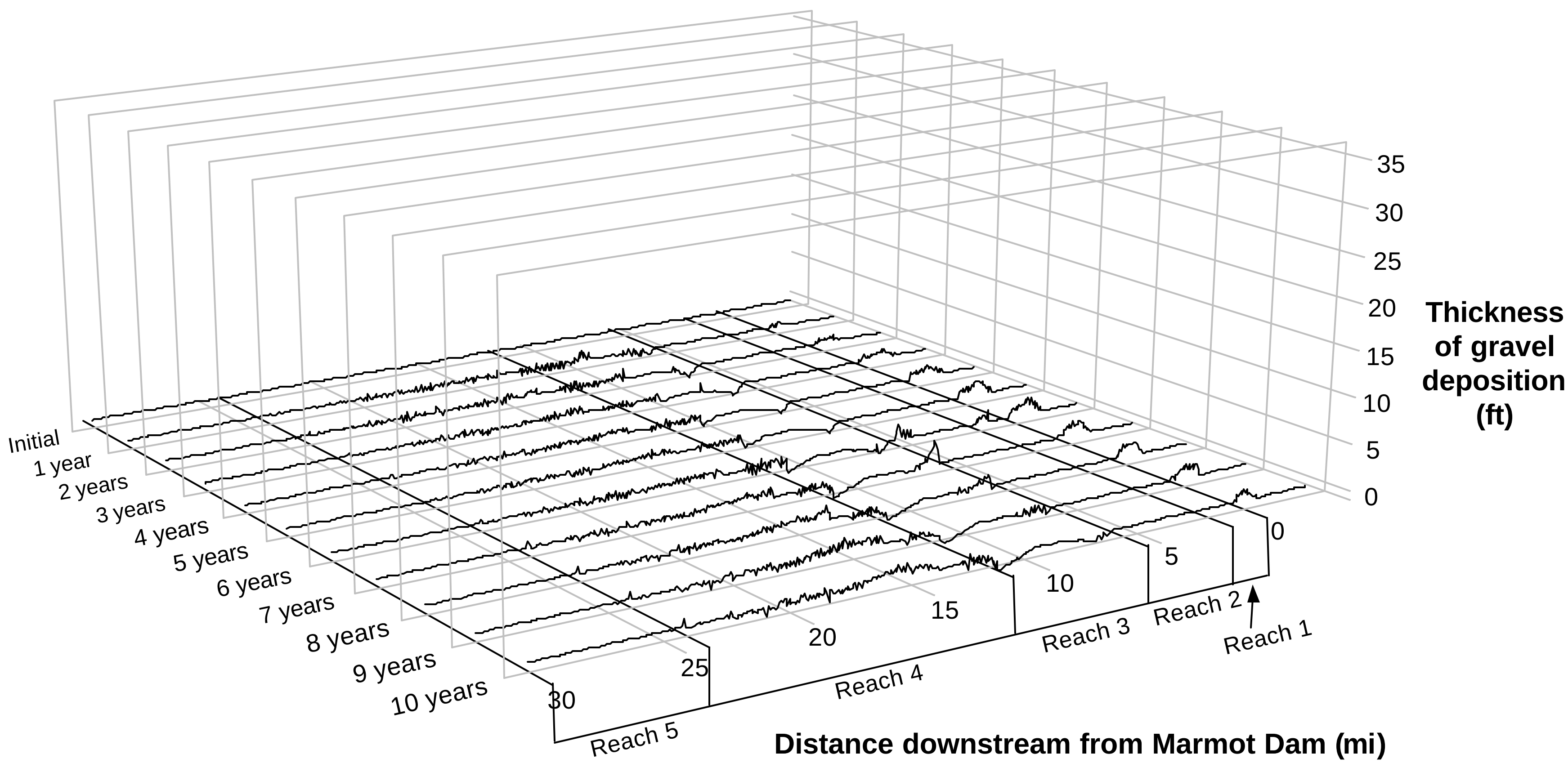

**Figure 14. Thickness of gravel deposition following removal of Marmot Dam (Alternative B).**

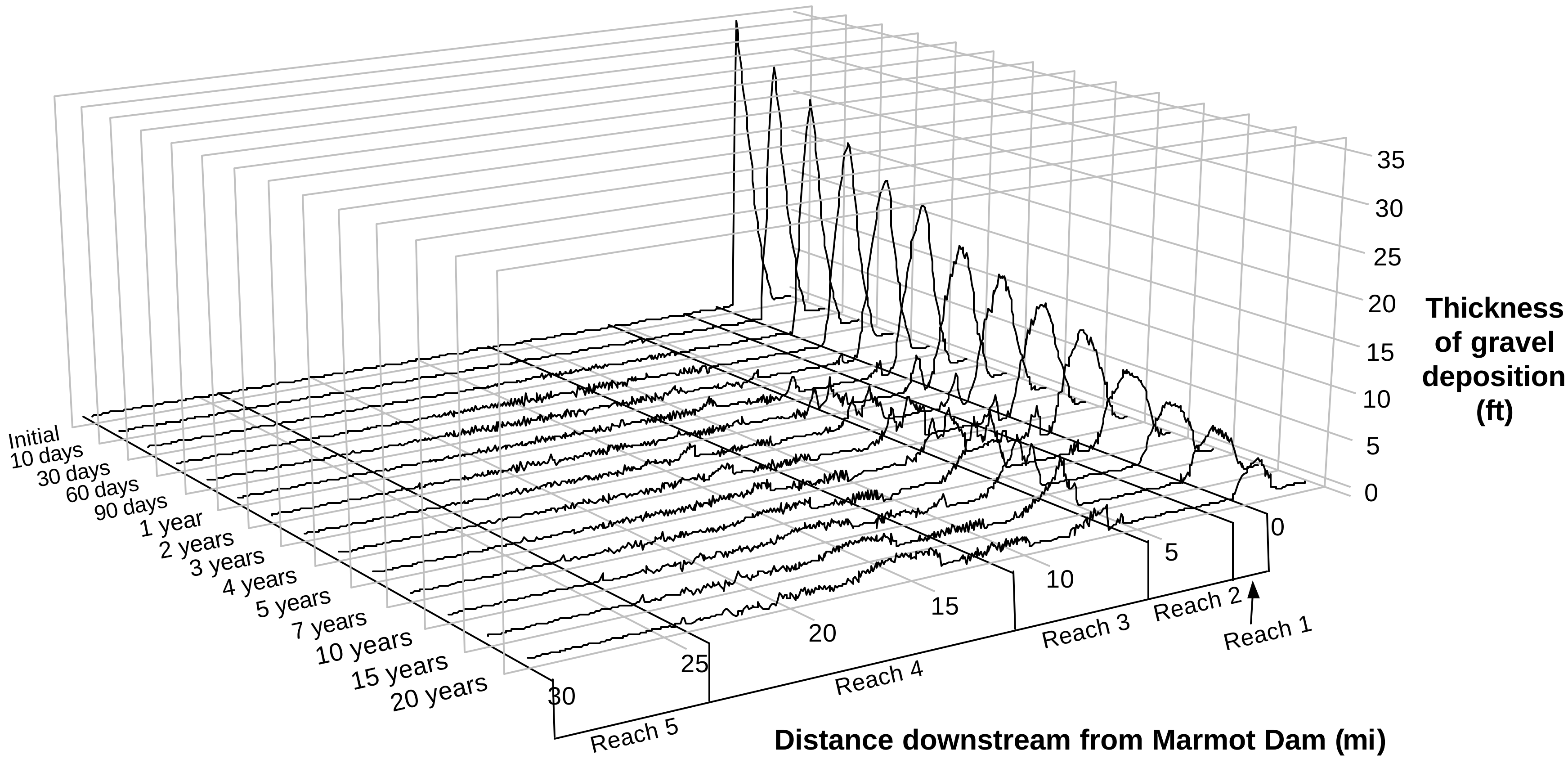

**Figure 15. Evolution of long profile in vicinity of reservoir following removal of Marmot Dam (Alternative B).**

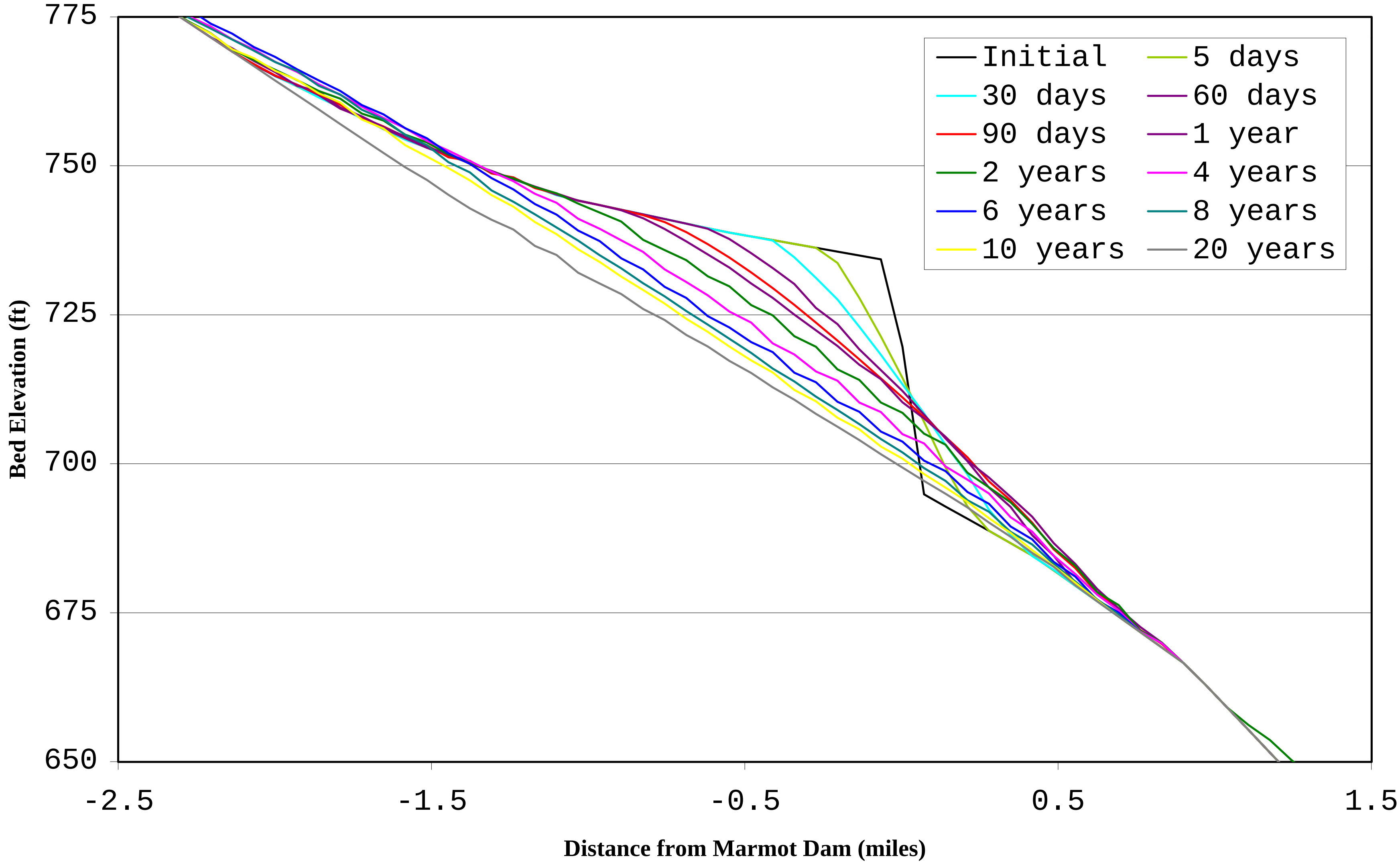


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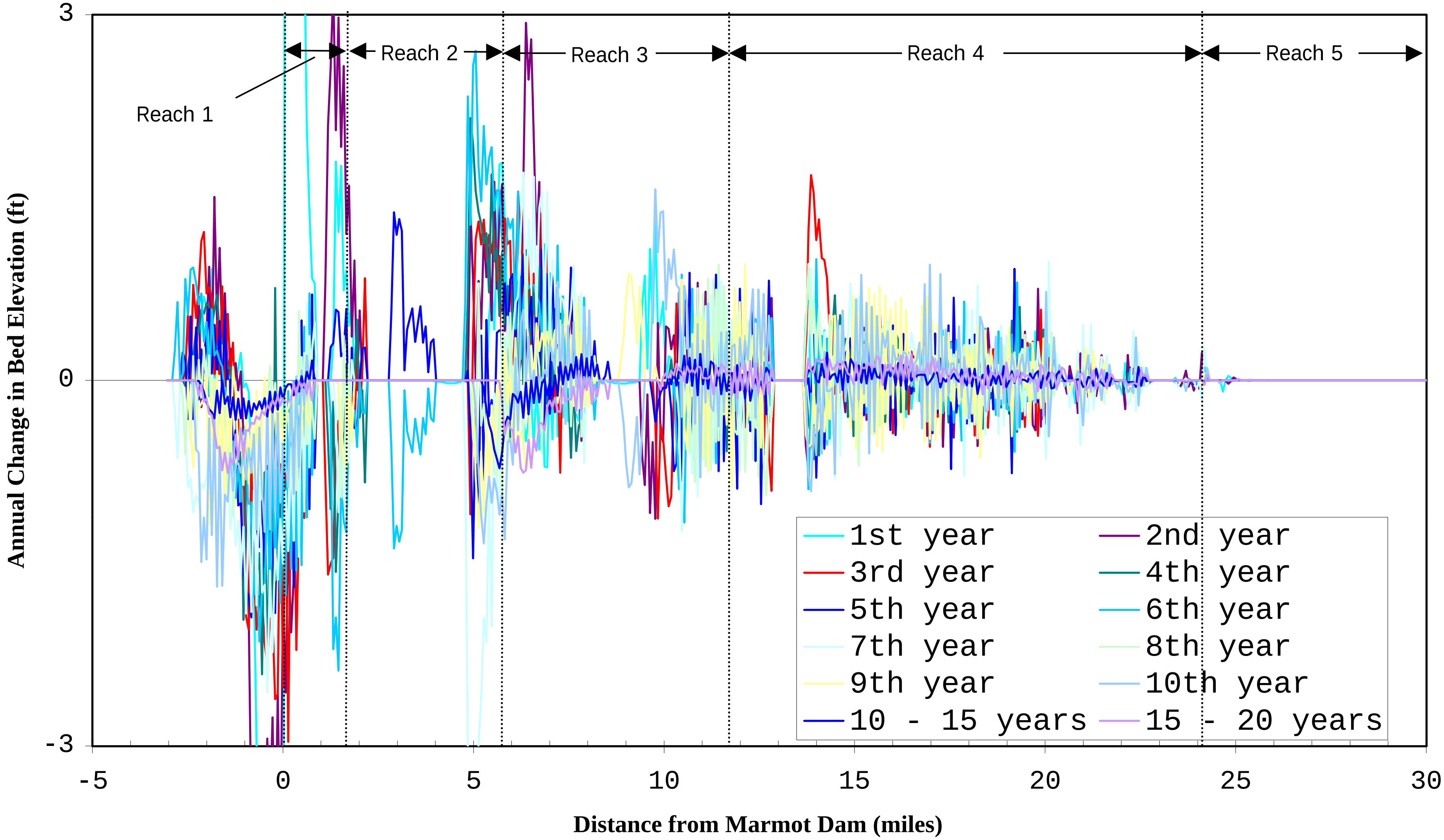
**Figure 16. Annual change in bed elevation following removal of Marmot Dam (Alternative B).**




Note: Individual years may be difficult to distinguish on this figure; however, the purpose of this graphic is to depict the typical range of annual changes in bed elevation indicated by numerical modeling rather than those occurring in a specific year.

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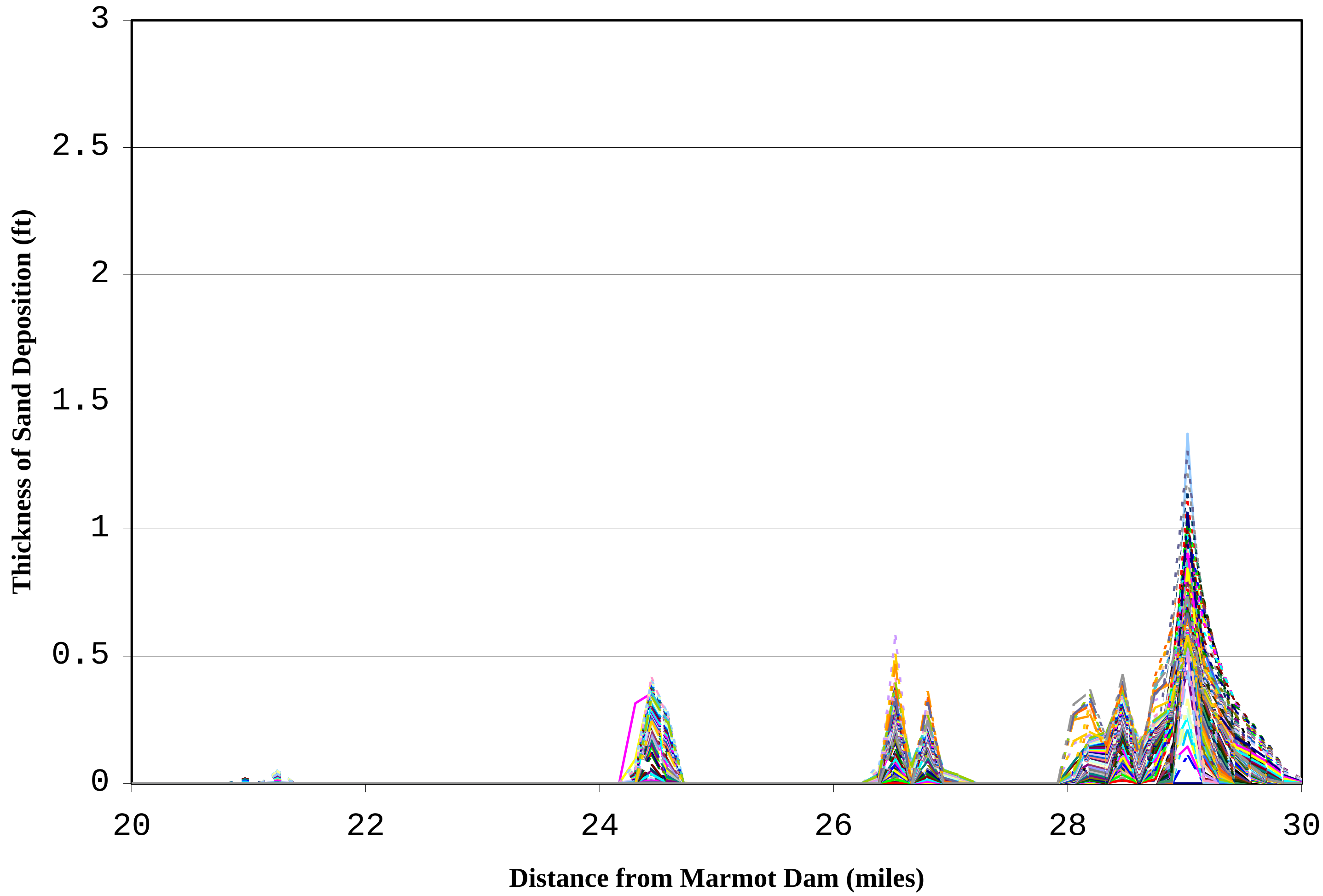
**Figure 17. Thickness of sand deposition in lower 10 miles of Sandy River following removal of Marmot Dam (Alternative B).**




Note: This figure depicts sand deposition thickness in first two years following dam removal. Deposition thicknesses fluctuate within and between years, as shown in Figure 18 for four locations (one in Reach 4, and three in Reach 5).

**Figure 18. Thickness of sand deposition at selected locations in the first two years following removal of Marmot Dam (Alternative B).**

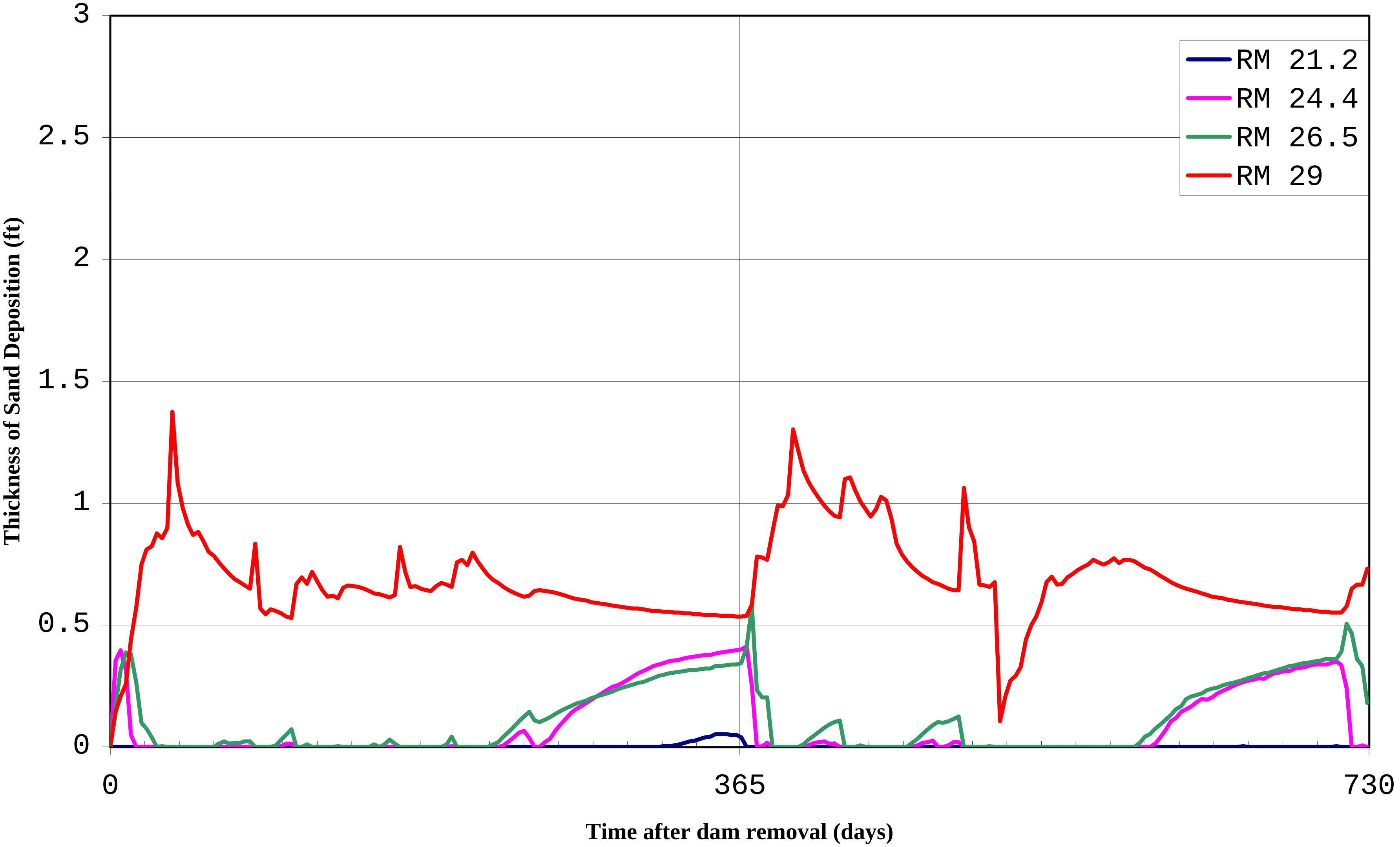



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**Figure 19. Daily sand release at Marmot Dam for 10 years following dam removal (Alternatives B and D).**

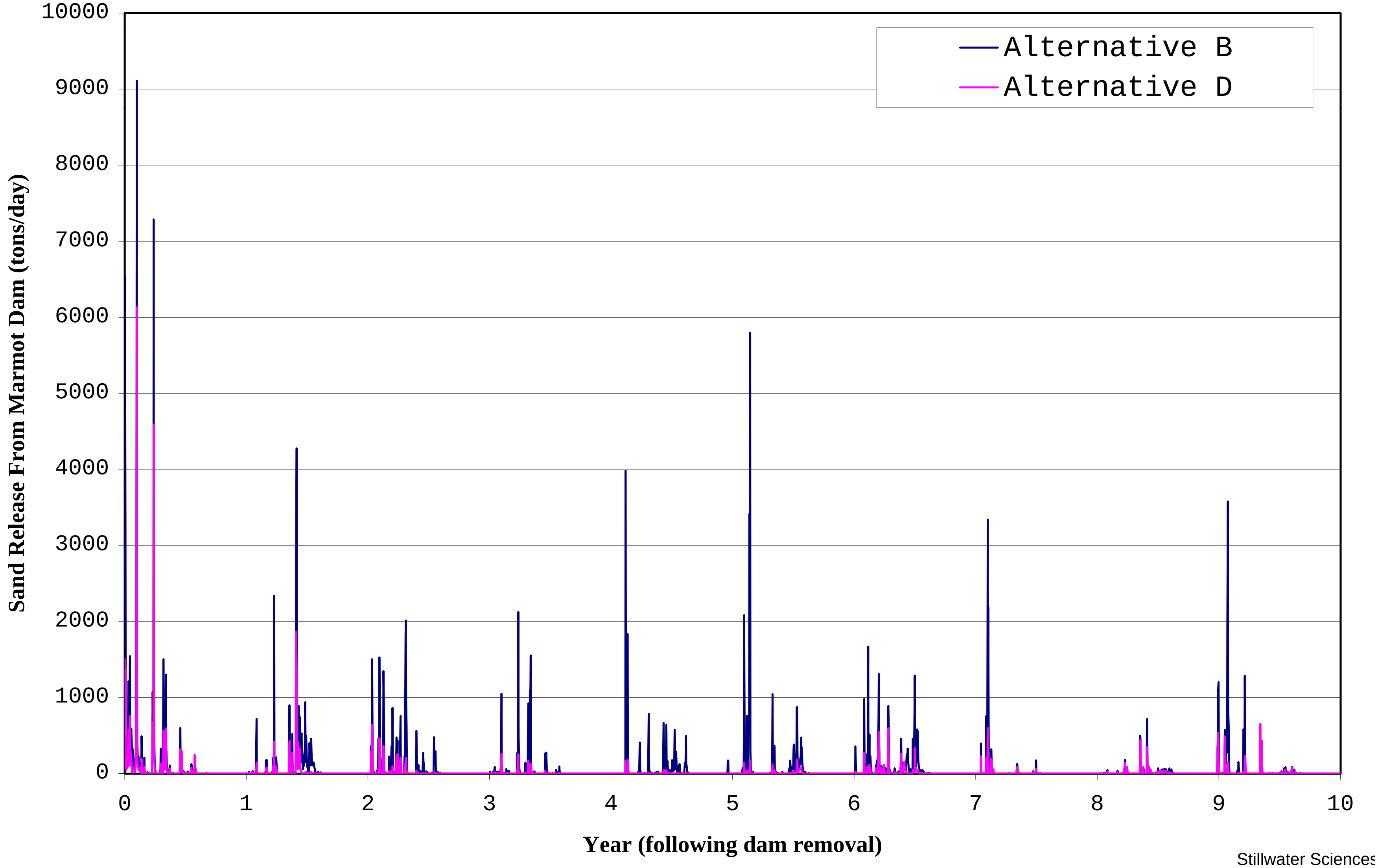

**Figure 20. Total suspended sediment (TSS) at selected locations in first two years following removal of Marmot Dam (Alternative B).**

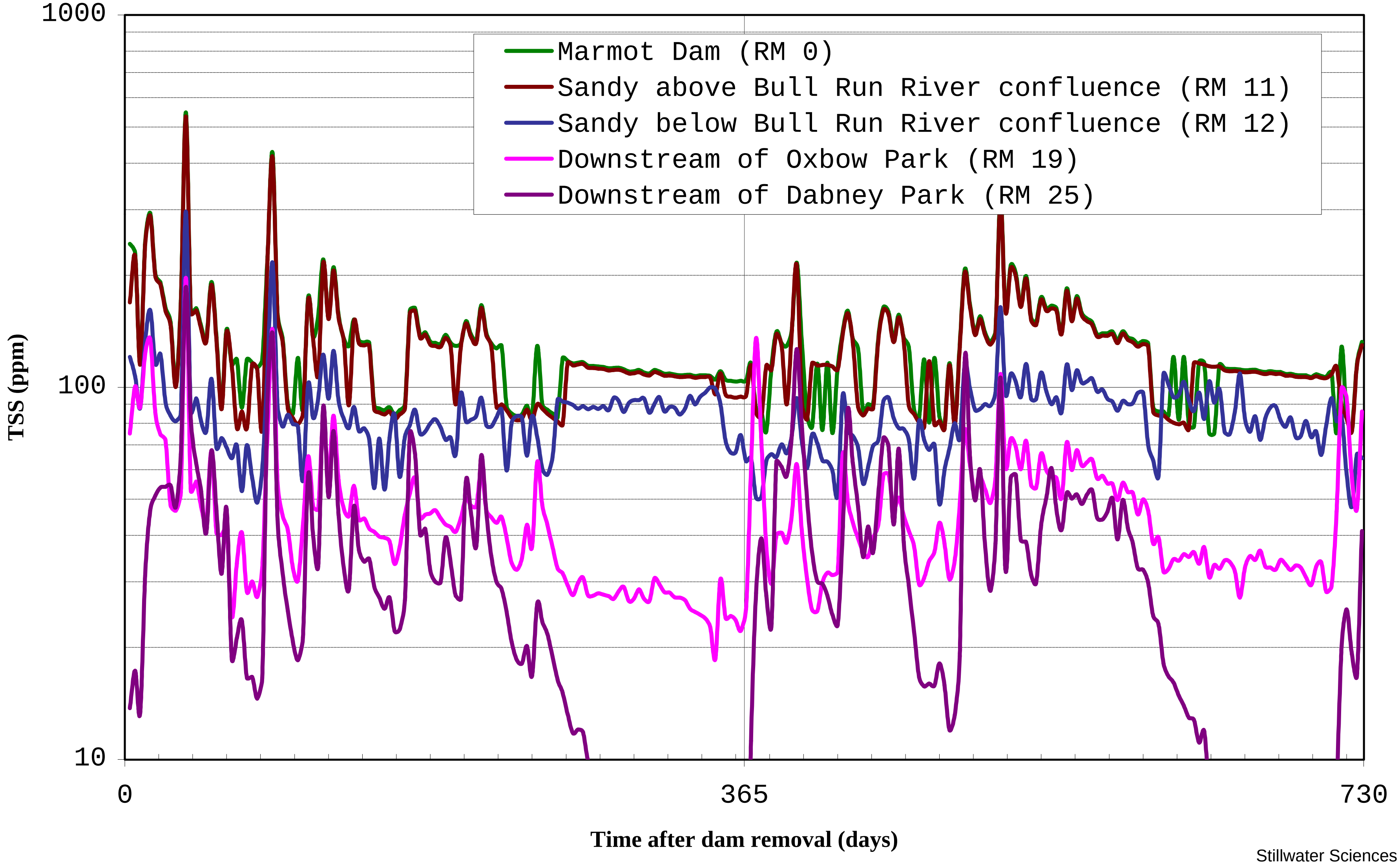

**Figure 21. Thickness of gravel deposition following lowering of Marmot Dam by 30 feet (Alternative C).**

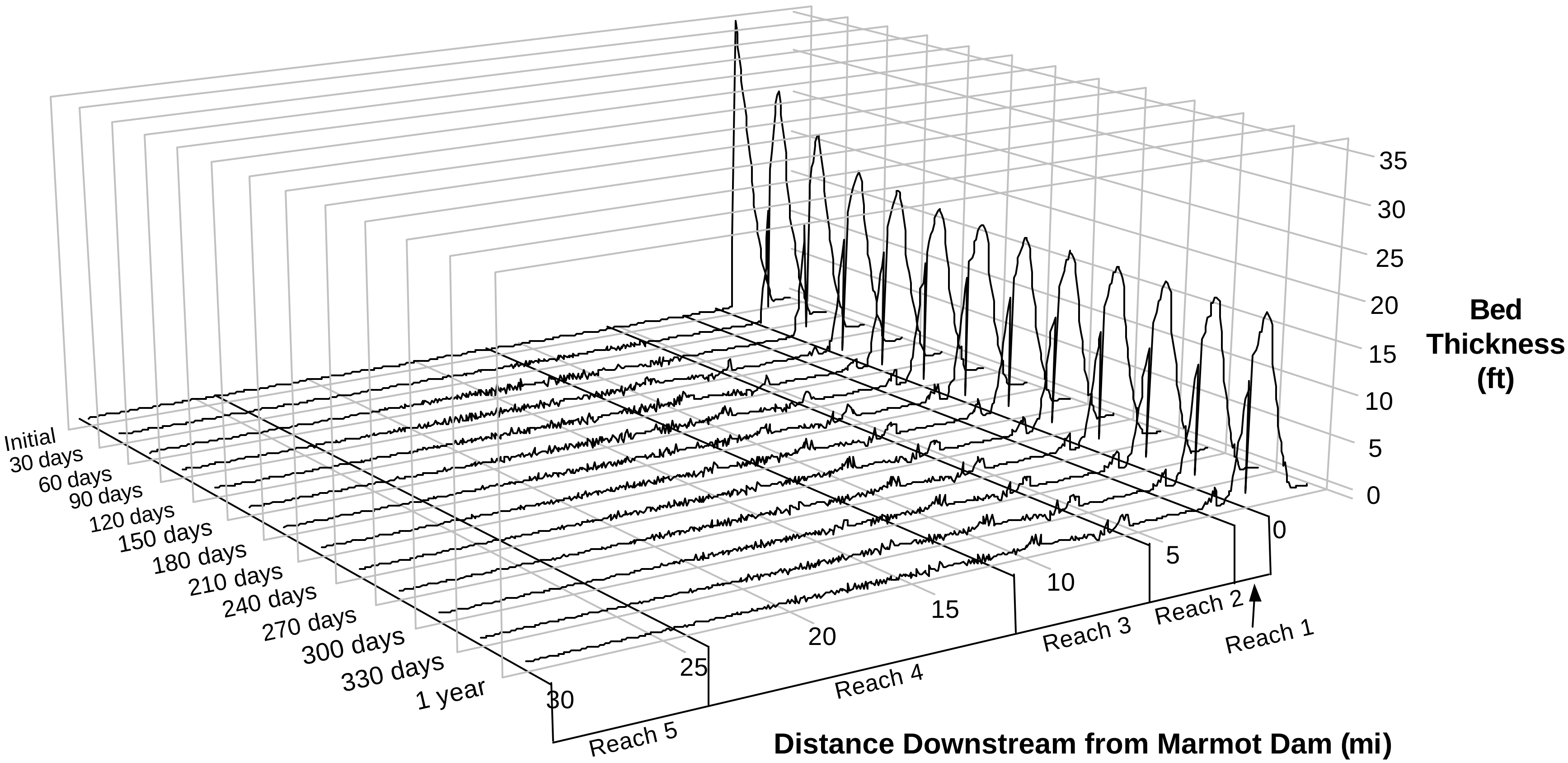

**Figure 22. Evolution of long profile in vicinity of reservoir following lowering of Marmot Dam by 30 ft (Alternative C).**

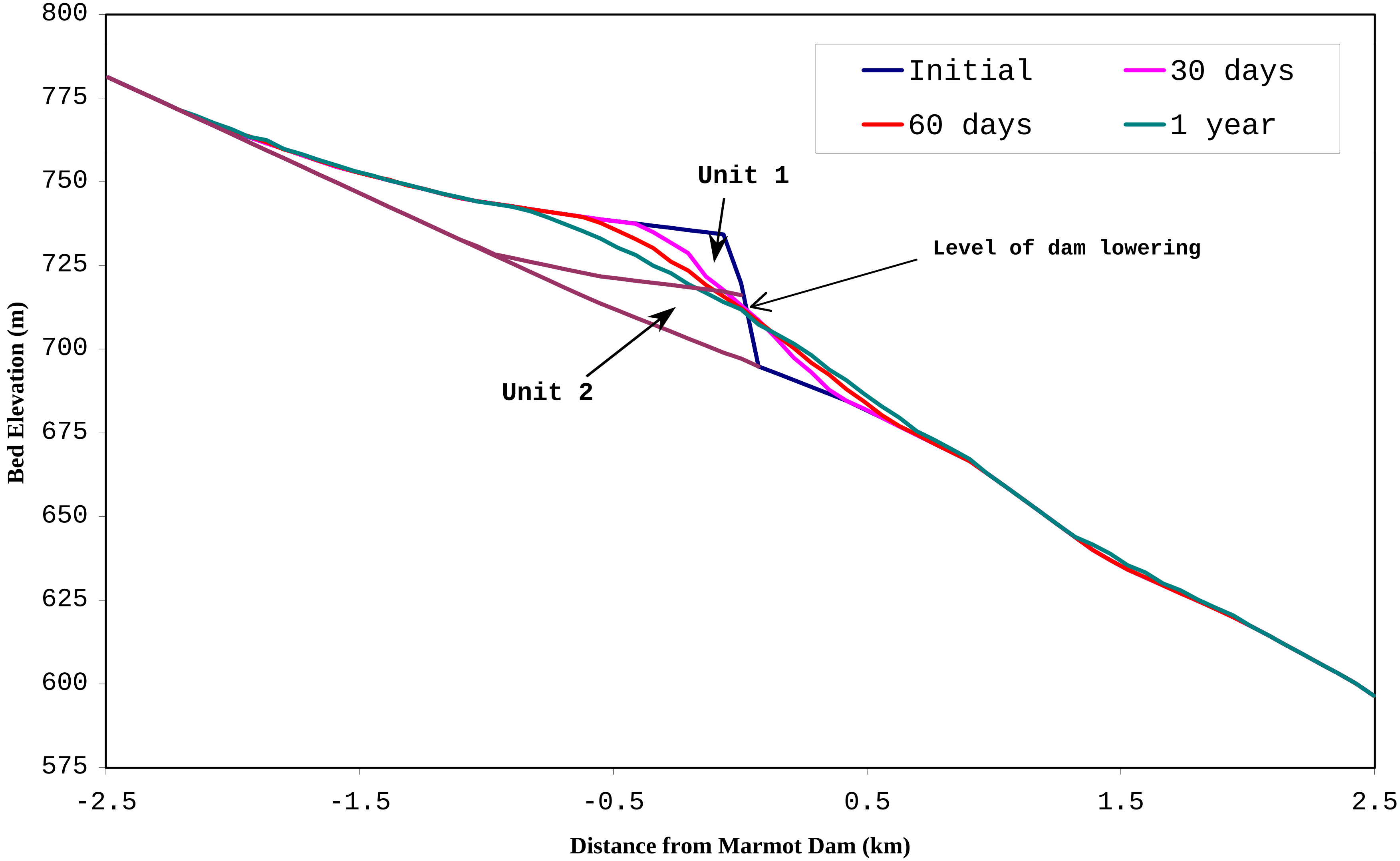


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**Figure 23. Evolution of long profile in vicinity of reservoir following removal of Marmot Dam and excavation of sediment to 2,700 feet upstream of the dam (Alternative D).**

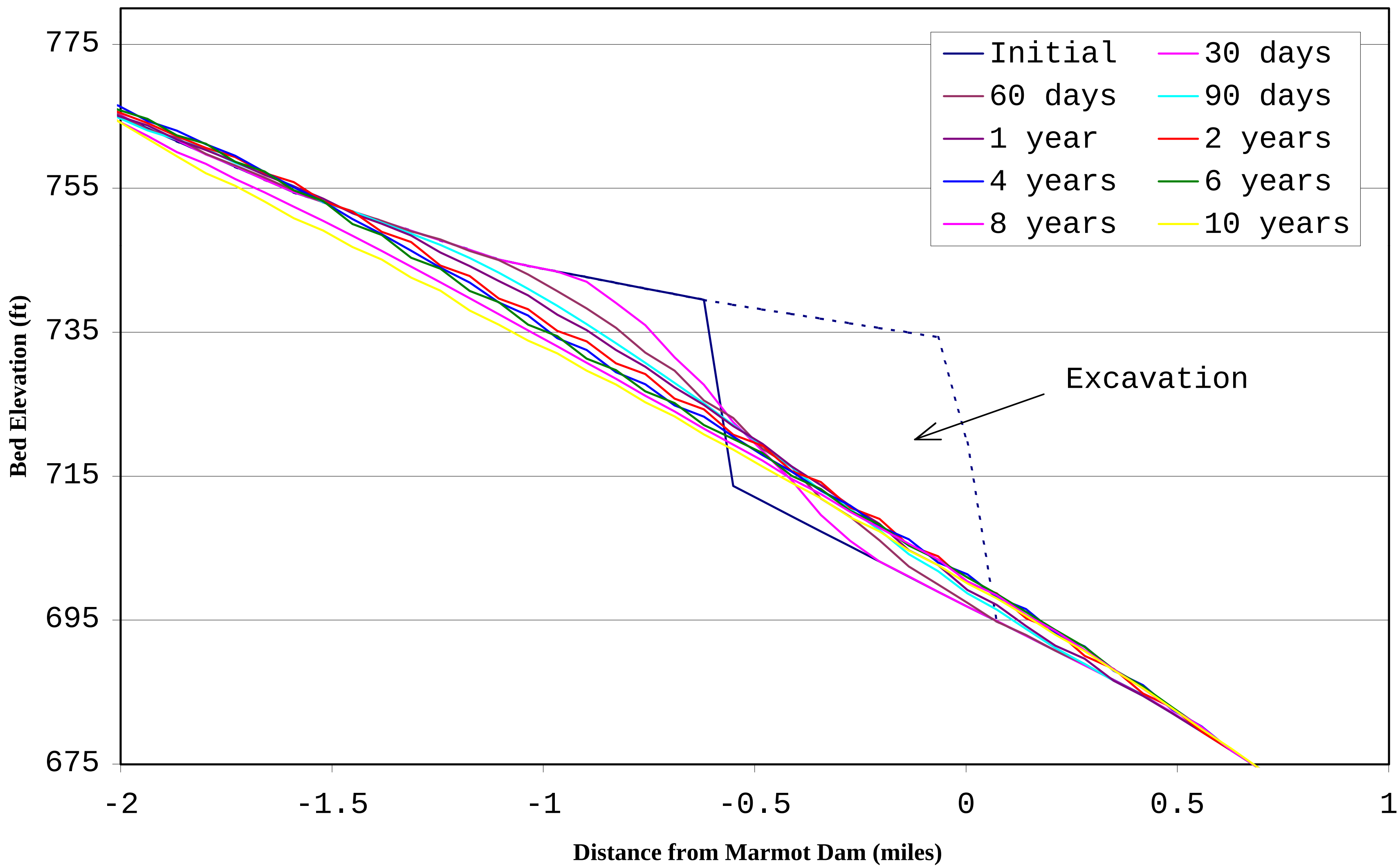


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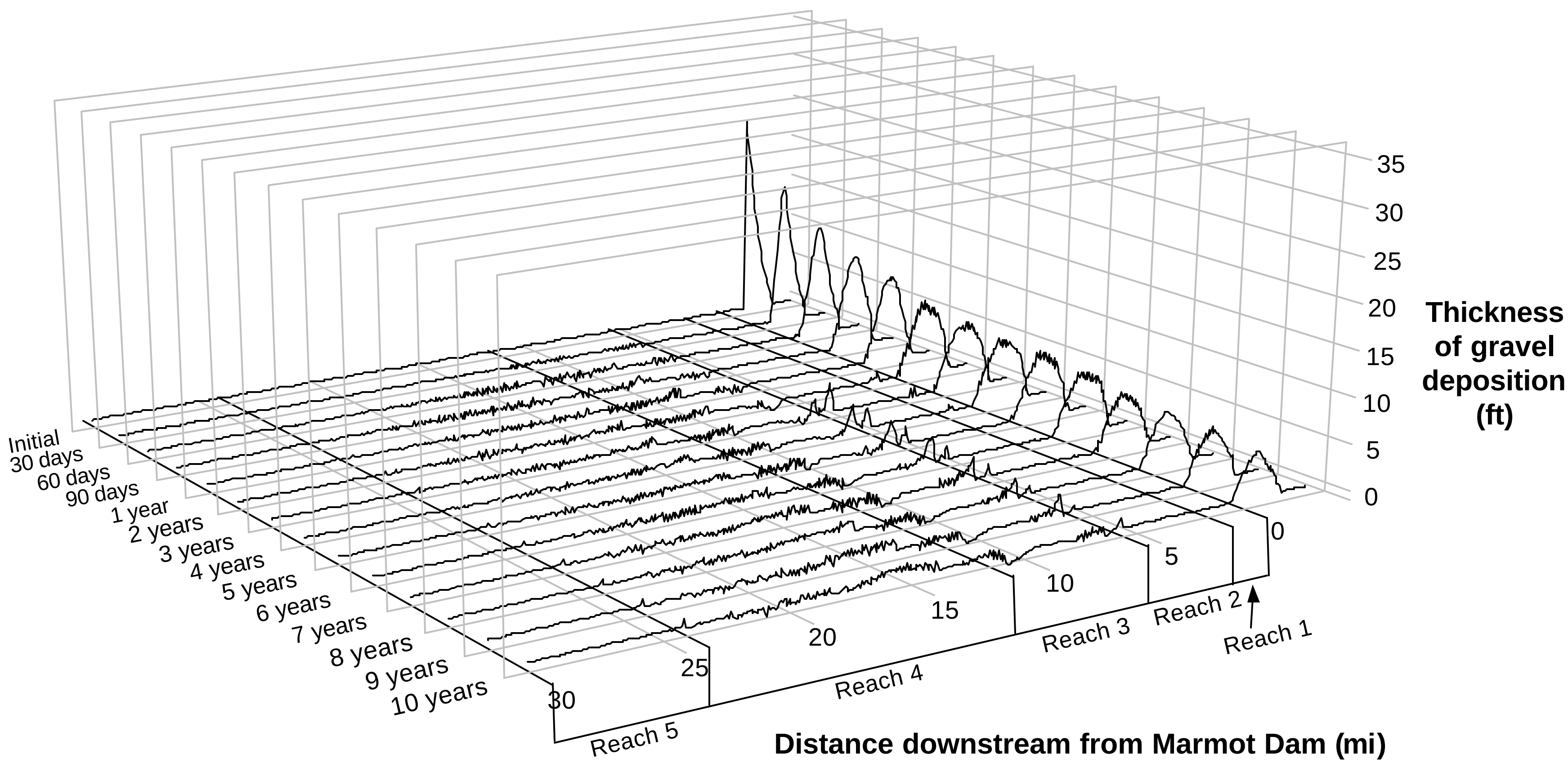
**Figure 24. Thickness of gravel deposition following removal of Marmot Dam and excavation of sediment to 2,700 feet upstream of the dam (Alternative D).**



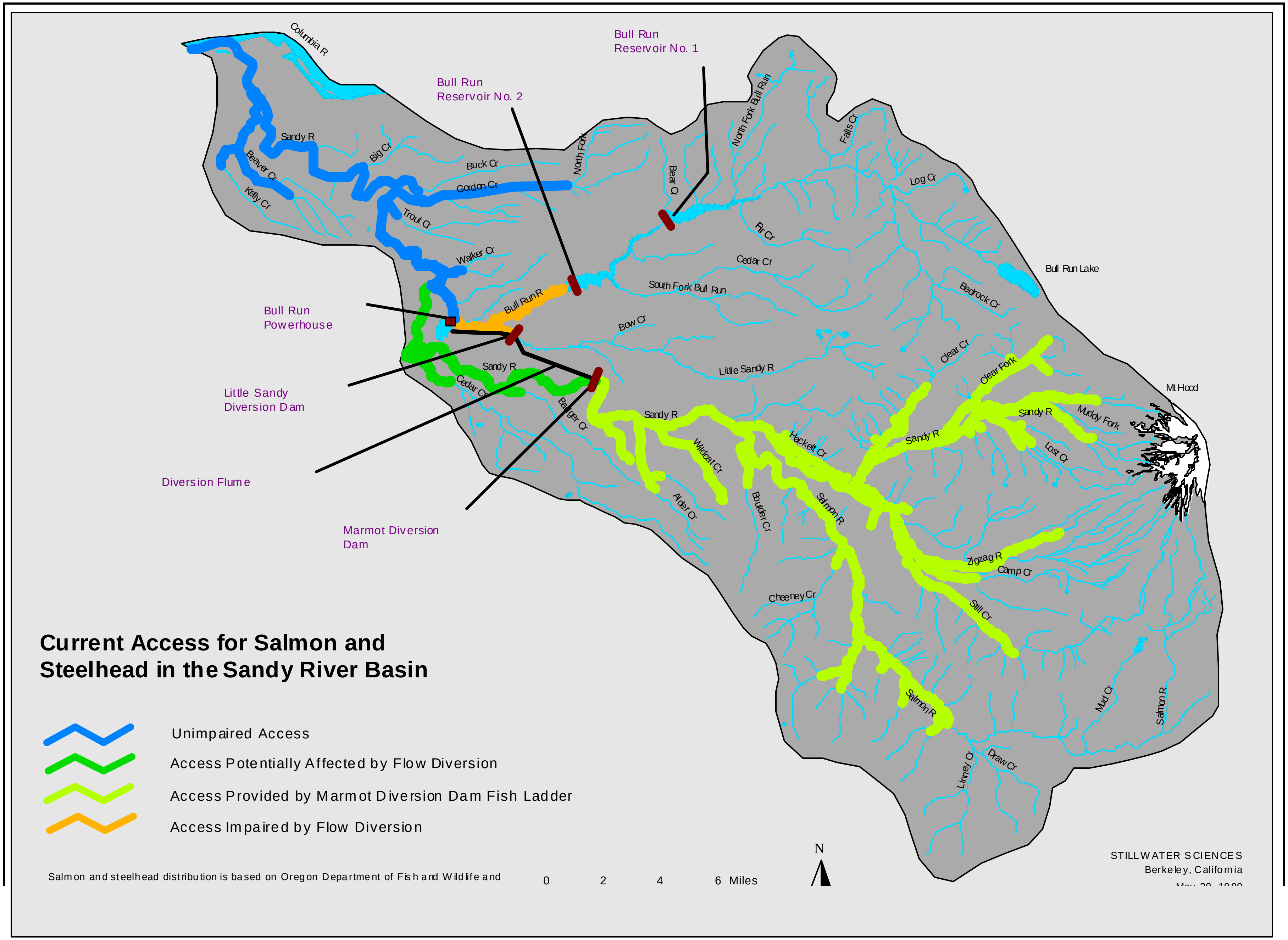



**Figure 25. Current access for salmon and steelhead in the Sandy River Basin, with Marmot and Little Sandy dams in place.**

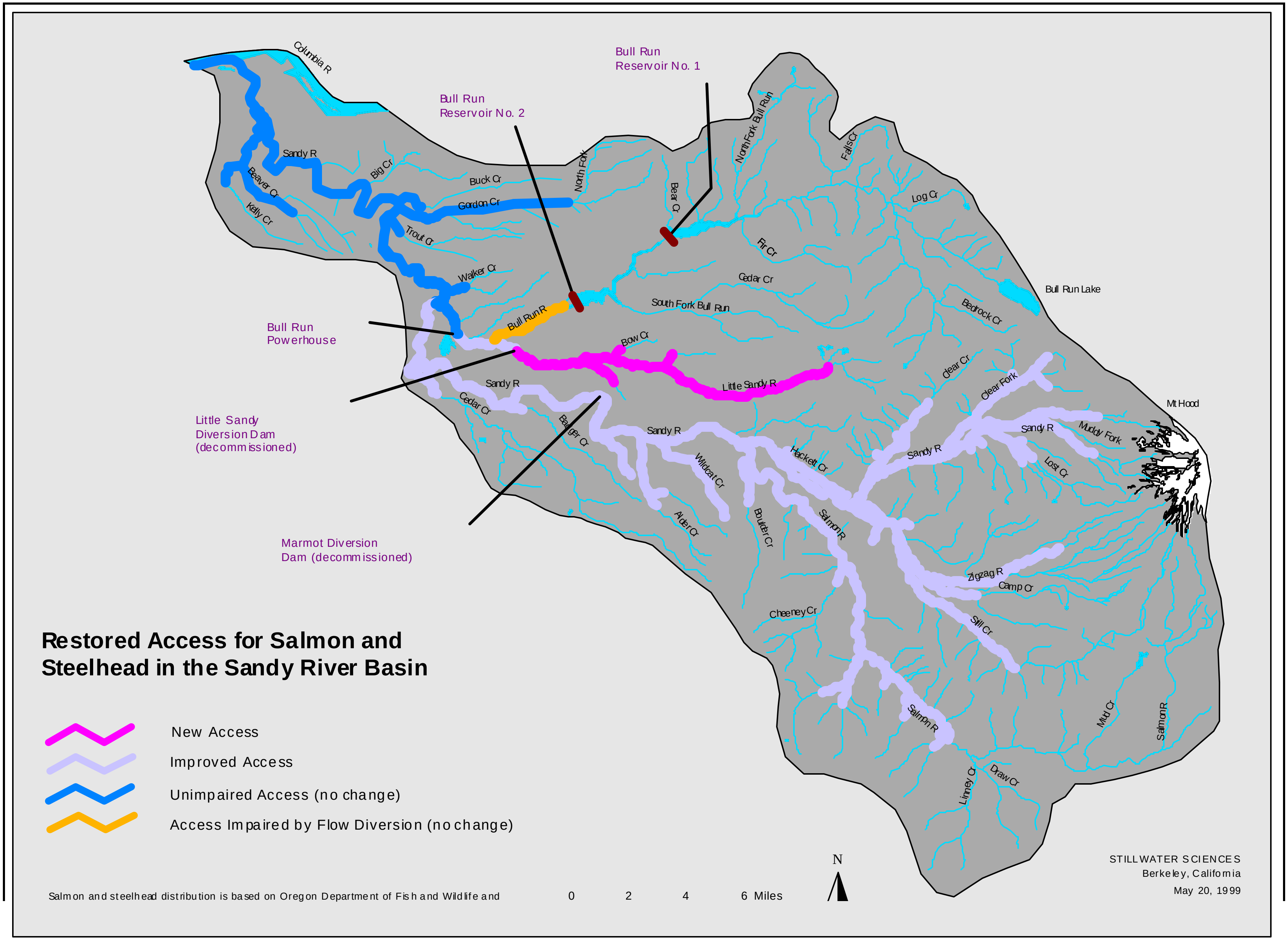



**Figure 26. Restored access for salmon and steelhead in the Sandy River basin, following removal of Marmot and Little Sandy dams.**