MEMORANDUM

Date: March 8, 2017
To: Erik Neatherlin and Justin Allegro, Washington Department of Fish and Wildlife (WDFW)
From: John Ferguson, Anchor QEA, LLC; Neala Kendall and Robert Vadas, Jr., WDFW
Cc: Jim Kramer, Ruckelshaus Center; Robert Montgomery and Heather Page, Anchor QEA, LLC
Re: Literature Review of the Potential Changes in Aquatic and Terrestrial Systems Associated with a Seasonal Flood Retention Only Reservoir in the Upper Chehalis Basin

1. Summary

This memorandum summarizes literature related to potential impacts of a flood retention only (FRO) facility in the Chehalis Basin on aquatic habitat and biota. The combined FRO dam and reservoir is referred to as the facility, whereas the dam and reservoir components are referred to separately where appropriate. Relevant findings include the following:

- **Sediment:** A temporary increase in coarse sediment (cobble/gravel) storage would occur within the channel in the reservoir inundation area during operation of the reservoir. A more permanent storage of coarse sediment would occur within a smaller portion of the inundation floodplain (depending on reservoir elevation during the time of most bedload movement during flood storage). A temporary increase in fine-sediment accumulation would occur during the operation of the reservoir.
- **Vegetation:** Upland and riparian vegetation within the reservoir footprint would be lost or reduced, whether through deliberate removal or mortality due to inundation.
- **Channel structure:** The deposition of sediment and loss of riparian vegetation within the impoundment area would likely result in some channel widening in unconfined and moderately confined reaches (approximately half of the inundated channel length), which would result in decreased stream depth. Deposition associated with facility operation would not be as deep and widespread as the 2007 flood, and sediment-associated increases in width would be limited to smaller areas of the channel. Increases in width associated with loss of riparian vegetation would occur where vegetation is lost. Between reservoir impoundments, widened areas of the channel would slowly decrease in width as those areas are exposed to flow events.
- **Water quality:** Predictions of a water quality model indicated that a nearly 4 degrees Celsius (°C) increase in summer water temperatures could occur along the mainstem Chehalis River at the dam site (River Mile [RM] 108.3) compared to existing conditions. Warmer temperatures would favor the spread of non-native predators, such as walleye and smallmouth bass (*Theragra chalcogramma* and *Micropterus dolomieu*, respectively), in the upper Chehalis River. Downstream impacts to water temperature due to flood storage could result in minor changes

in temperature (increase or decrease) relative to current conditions, depending on whether the flood occurs during the peak wet season (December to February) or during the early or later stages of the wet season. Further investigation of this potential temperature increase is ongoing as of the date of this memorandum. The temperature increase presented here may change, depending on results of additional temperature modeling being conducted using updated hydraulic information.

- **Landslides:** Landsliding within the reservoir is not anticipated to result in major sediment inputs due to the slow drawdown rate prescribed in the Draft Operations Plan (Anchor QEA 2016a). With the loss of large trees, deep-seated landslides are likely to increase movement by creep (which would be imperceptible) and contribute minor amounts of sediment to the Chehalis River and tributaries above the dam.
- **Climate change:** Higher peak flows under future climate change scenarios would result in the facility impounding water more frequently and to higher reservoir elevations.
- **Salmonids:** Each of the physical changes described above would affect the quality of adult salmon (*Oncorhynchus* spp.) and steelhead (*O. mykiss*) spawning and rearing habitat between floods, but the effect would be variable in time and space. Based on analysis of conceptual design alternatives, the survival of juvenile salmonids migrating downstream through the dam is estimated to range from 85% to 95%, and survival of adults migrating upstream is estimated to range from 94% to 96% (see Table 4.2-5 in Anchor QEA 2016e). Key findings include the following:
  - The literature is consistent regarding the negative impacts of fine sediment deposition in spawning reaches. Egg-to-fry survival can be significantly limited by increased sedimentation. Sedimentation can result in direct mortality to eggs and fry. Low dissolved oxygen (DO) in redds associated with sediment can affect fry condition and shift fry emergence earlier or later, depending on the timing of the hypoxia event, and may result in a mismatch between hatching and optimal timing.
  - The timing of floods relative to the timing of spawning cannot be predicted. However, in general, flood storage would affect fall- and early-winter-spawning salmon species and cutthroat trout to a greater degree than steelhead and Pacific lamprey (*Entosphenus tridentatus*), which spawn during late winter and spring.
  - If flood storage occurs after spawning but prior to fry emergence, eggs or alevins in redds and interstitial pockets of the gravels would suffocate due to a lack of oxygen. The result would be a complete loss of eggs in any redd that is inundated. Low oxygen levels could occur from a lack of water flow through the gravels due to sedimentation, a lack of water flowing over the redds, or low DO levels in the bottom layer of water in the reservoir, which can become hypoxic if the reservoir is deep enough to stratify.
  - If a flood storage cycle (reservoir filling and drawdown) occurs within or shortly before adult salmon and steelhead spawning, any adult salmon or steelhead that pass through the outlet tunnels and enter the reservoir reach would find the reach modified by the deposition of

fine and coarse sediment. The extent and magnitude of the sedimentation would vary based on the location within the reach, the volume of water stored (i.e., the size of the flood), and the timing of spawning relative to the amount of flushing and mobilization of sediment that has occurred since the outlet gates were reopened and the river returned to natural channel flow conditions. Impacts to salmonids would occur from fine-sediment accumulation, although the magnitude of the effect would depend on these variables. Storing floodwater early in a spawning season would affect spawning and egg incubation that has yet to occur if the fines have not been mobilized after the flood and prior to spawning.

- If a flood occurs prior to the initiation of spawning by an adult salmon or steelhead, and an adult fish tries to enter the reservoir reach and spawn while the flood is being stored (the reservoir is full, being lowered, or large woody material [LWM] is being removed), spawning habitat in the reservoir footprint would be either largely or totally unavailable to the adult. Adult salmon and steelhead that approach the dam while floodwater is stored and enter the collection system and trap located at the base of the dam would be transported and released in the reservoir, above the reservoir, or in tributaries to spawn of their own volition. The trap-and-transport release strategies will be finalized in a future biennium.
- If no flood storage occurs in a given winter period, spawning and egg development would be affected by the degree to which the existing substrate has been mobilized by river flows after the last flood storage and prior to the spawning season. Changes in substrate composition between flood storages have not been modeled or estimated at this time. Additional sediment transport modeling is ongoing as of the date of this memorandum.
- Juvenile salmonid growth and survival may decrease if salmonids cannot move below the dam and then back upriver to access ideal temperature regimes, especially during periods when the outlet tunnels are closed except to maintain minimum flows downstream of the dam and flood flows are being impounded. Juvenile salmonid parr movement during winter has not been assessed; the available data on parr movement through the facility were collected during summer.
- Juvenile salmonids that utilize reservoir habitat during flood retention events may suffer increased mortality or decreased growth due to exposure to suboptimal conditions within the reservoir and their inability to move below the dam.
- Between flood storage events, salmonids using the reservoir footprint reach would see a reduction in food supply and composition due to a loss of riparian vegetation.

- **Lamprey:** Based on analysis of conceptual design alternatives, the survival of juvenile lamprey (macropthalmia) migrating downstream through the dam is estimated to be 95%, and survival of adults migrating upstream is estimated to be 96% (see Table 4.2-5 in Anchor QEA 2016e). Periodic inundation of lamprey redds and ammocoetes rearing in the reservoir footprint would likely result in mortality to eggs, due to suffocation, and could result in loss of ammocoetes, due to suffocation from low DO levels in the bottom layer of water in the reservoir, which can become hypoxic if the reservoir is deep enough to stratify. The reservoir footprint has an estimated 71.8 acres of area where slope is less than 5% (a level identified as having a high risk of stranding juvenile salmonids during reservoir drawdown operations; Anchor QEA 2017). These low-gradient areas could meet anadromous Pacific lamprey and resident river lamprey (*Lampetra ayresi*) and western brook lamprey (*Lampetra richardsonii*) rearing requirements. Under facility drawdown operations, juvenile lamprey that survived the inundation in these areas would be expected to incur a stranding rate of approximately 20%.

- **Other fauna:** The spawning and rearing of fishes other than salmon and steelhead would be affected in ways similar to what is described above for salmonids and lamprey, including being affected by a reduction in food supply between floods due to the loss of riparian habitat.

2. Background

2.1. Project Description

The proposed dam site is located south of State Route 6 in Lewis County, Washington, on the mainstem Chehalis River, approximately 1 mile south of Pe Ell at RM 108.3. The dam would provide approximately 65,000 acre feet of flood storage when filled to elevation 628 feet (mean sea level [MSL]; the spillway crest). The dam would have an estimated maximum structural height of 254 feet and a crest length of approximately 1,550 feet. The reservoir behind the dam would inundate up to 6 miles of river habitat during maximum flood storage.

2.2. Facility Operations During Flood Storage and Reservoir Drawdown

The dam will allow water to be impounded in a reservoir during a major flood. Major floods are classified as events that cause serious damage to downstream areas, the threshold of which is 38,800 cubic feet per second (cfs) recorded at the U. S. Geological Survey (USGS) gage in Ground Mound, Washington. The facility would not be operated during floods projected to be smaller than 38,800 cfs at Grand Mound and thus would be operated intermittently. Flow conditions that trigger water retention have a 15% probability of occurrence in any given year, which is approximately a 7-year flood (Anchor QEA 2016a). The amount of flow retention needed for each qualifying flood would vary based on inflow at the reservoir and the amount of flood storage needed to relieve flooding downstream.

Once a flood flow is predicted, and outlet tunnel gates would be closed to retain flood flows and the reservoir would be filled to a pool depth of 212 feet under peak flooding conditions such as those that occurred in 2007. Under these conditions, the surface elevation of the reservoir would be approximately 620 feet MSL and a minimum flow of 300 cfs would be released through the outlet tunnels. After flood flows dissipate, the reservoir would be emptied over a period of up to 32 days, depending on the volume of water stored.

To empty the reservoir, the outlet tunnel regulating gates would be opened and outflow increased from 300 cfs to about 6,500 cfs. This upper level of outflow would occur only during a very large flood. Reservoir drawdown rates during the release of stored water would be limited to 10 feet per day

(5 inches per hour), the rate of increase in outflow would be limited to about 1,000 cfs per hour, and the duration of the increase would be limited to about 5 hours. Following this initial drawdown period, outflow rates would decrease as the reservoir is drawn down as the reservoir elevation and head on the reservoir gates decrease. When the reservoir reaches an elevation between 500 and 528 feet MSL, the drawdown rate would be decreased to about 2 feet per day (1 inch per hour) to allow for debris management. Debris management operations would occur for approximately 2 weeks. Following debris management operations, and when the reservoir has reached an elevation of 500 feet MSL, drawdown rates would increase again to 10 feet per day (5 inches per hour) until the reservoir is emptied. The reservoir is empty at an elevation of 425 feet MSL, at which time the gates to the outlet structure located in the base of the dam would be opened and the Chehalis River would return to a free-flowing state (Anchor QEA 2016a).

This release of stored water from the reservoir is designed to ensure that additional flooding downstream of the dam does not occur, risk of landslides in the reservoir footprint is reduced, fish are not stranded, debris that accumulates in the reservoir can be removed, and geomorphic processes below the dam are preserved to the extent possible. The Draft Operations Plan (Anchor QEA 2016a) was developed to achieve the following objectives:

1. Provide flood reduction in downstream areas.
2. Preserve geomorphic processes downstream of the dam, including sediment transport, channel-forming flows, and, to some extent, LWM transport and channel migration.
3. Maintain slope stability in the reservoir to prevent landslides.
4. Keep the rate of change in flow rates downstream of the dam within accepted limits (ramping rates for river reaches below the proposed dam location were developed consistent with state agency interim criteria for drawdown below dams; WDFW and Ecology 2008).
5. Allow debris to be removed from the reservoir after floods.

2.3. Facility Operations During Non-flood Storage Periods

During periods between water storage operations, Chehalis River flow would pass through three outlet tunnels located at the base of the dam. The outlets would be rectangular tunnels that are either 10-feet-wide by 16-feet-high or 12-feet-wide by 20-feet-high. All three outlets are designed to mimic the hydraulic and sediment conveyance characteristics of the natural river channel at the dam location. During normal flow, the river is conveyed in an open-channel hydraulic condition through the tunnels and a bed of natural substrate would form on the tunnel floors. During these periods, water, sediment, and LWM up to 3 feet in diameter and 15 feet in length would flow through the outlet structures of the dam and be transported downstream.

2.4. Dam Fish Passage

During periods when flood storage is not occurring, fish passage would be provided through three outlet structures located at the base of the dam. The outlet tunnels are being designed to pass upstream and downstream migrating fish safely at flows below 2,000 cfs. A three-tunnel option was judged to more effectively meet the needs of the project than a two-tunnel option, while still providing flow velocities that mimic naturally occurring conditions upstream and downstream of the proposed dam structure (HDR 2016). Hydraulic analysis of the three-tunnel-option design and the upstream and downstream reaches of natural stream channel above and below the proposed dam showed that typical tailwater submergence of 6 feet over the invert elevation of the two 10-feet-wide by 16-feet-high tunnel outlets, and 9 feet of submergence over the invert elevation of the additional 12-feet-wide by 20-feet-high tunnel outlet. In this condition, the tunnel outlets are anticipated to replicate the stream discharge and velocity rating curves exhibited by the natural channel (through which fish would pass whether the dam is there or not) up through river discharges of 4,000 cfs, which is greater than the calculated peak fish passage design flow of 2,000 cfs. The peak fish passage design flow is the flow below which state and federal fish passage engineering criteria for velocities within the tunnels are met. Additional analysis of sediment transport associated with the three-tunnel option showed that the invert of the tunnels would likely be bedded with natural sediment most of the time. This material will naturally begin to sweep clear of the concrete bottom of the outlet tunnels at discharges above 2,000 cfs, or whenever the outlet tunnel sluice gate(s) are closing, by venturi action generated by higher velocity flow under the gates (HDR 2016). Based on analysis of conceptual design alternatives, the survival of juvenile salmonids migrating downstream through the outlet tunnels is estimated to range from 85% to 95%; survival of adults migrating upstream is estimated to range from 94 to 96%; and survival of adult and juvenile Pacific lamprey is estimated to be 96% and 95%, respectively (see Table 4.2-5 in Anchor QEA 2016e).

During water retention operations, passage of adult salmonids migrating upstream would be provided by trap-and-transportation facilities located downstream of the dam. The potential effects on the design and effectiveness of adult salmonid trap-and-transportation facilities from adding trap-and-transportation facilities for other species and life stages (e.g., juvenile salmonids, resident fishes, and adult Pacific lamprey) were discussed during the conceptual design of fish passage facilities for the dam. The upstream migration of juvenile salmonids, resident fishes, and adult Pacific lamprey may be accommodated by adding trap-and-transportation facilities designed specifically for these species and life stages. Addition of these facilities will be addressed during preliminary design of a fish collection and transportation system for the dam. When the dam is in operation and floodwater is being stored, fishes, such as juvenile salmonids that move downstream into the reservoir, would remain in the reservoir and not have direct access to reaches downstream of the dam unless they exit through the outlet tunnels located at the base of the dam, which would be partially open to pass minimum flows (300 cfs).

While flood storage in the reservoir is drawn down, adult and juvenile fishes could pass through one to three outlet tunnels that would be opened until the river returns to a free-flowing state, at which time all three outlet tunnels would be watered up (depending on river flow levels) and open for fish passage. The efficiency and survival of juvenile and adult fishes through the outlet tunnels during minimum flow releases and drawdown operations has not been assessed. The outlet tunnels are being designed to pass upstream and downstream migrating fish safely at flows below 2,000 cfs.

2.5. Geomorphology

The existing bed in the Chehalis River within the reservoir footprint is extremely mobile because of high velocities experienced due of its steep slope and confined channel. The river has the capability to transport a large volume of sediment, as indicated by the transport of the sediment deposited by the 2007 flood. Scour monitors installed near salmon-spawning sites between RM 88 and 116 recorded a range of scour from 0 to 0.4 foot following an approximately 1.5-year flood, and a minimum scour of 1 foot following a nearly 5-year flood (Watershed GeoDynamics and Anchor QEA 2016). However, scour and fill were locally much greater (Watershed GeoDynamics and Anchor QEA 2016).

When the facility retains water, it traps bedload sediment (cobble, gravel, and sand) and some portion of the finer silt and clay-sized particles being transported in the Chehalis River from upstream sources. This material would be deposited at the head of the reservoir, and the location of the deposition area would move upstream as the reservoir elevation is raised. When floodwater is no longer being impounded, some portion of the deposited materials would be re-entrained and transported downstream when inflow is large enough to mobilize the material. The deposited sediment would also include some fine-grained sediment, a portion of which would also be transported downstream as larger-sized gravel is re-entrained into the water column (Watershed GeoDynamics and Anchor QEA 2016).

2.6. Landslides

A total of 23 landslides were identified in the reservoir footprint. Three types of landslides were identified: deep-seated, shallow, rapid, and debris flows. Five of the landslides would either be removed during dam construction or would not be directly affected by the reservoir. Five of the remaining sites would be slightly sensitive to the highest reservoir levels, whereas the remaining 13 landslides identified would be subject to triggering or reactivation by fluctuating reservoir levels (Shannon & Wilson 2015).

2.7. Vegetation and Vegetation Management

Riparian vegetation differs among geomorphologic benches along lotic habitats due to differences in flood tolerances that outweigh nutrient differences (Naiman et al. 1989). Trees and shrubs are normally absent from the lower riparian zone (streambanks, bars, and small isles) where lotic inundation is frequent (Vadas and Sanger 1997; Osterkamp and Hupp 2010). Common non-flood-tolerant tree species include Douglas fir (*Pseudotsuga menziesii*), bigleaf maple (*Acer macrophyllum*), red alder (*Alnus rubra*), and bitter cherry (*Prunus emarginata*). While Whitlow and Harris (1979) consider red alder to be intolerant of flooding, other sources suggest the species can tolerate some flooding.

Pre-construction vegetation management actions proposed for the facility could include the removal of commercial timber from existing Washington Department of Natural Resources-defined riparian management zones (RMZs) along sections of the Chehalis River and tributaries in the reservoir footprint.

The actions would affect 405 acres within the elevation range of 424 to 567 feet MSL (Anchor QEA 2016b) and would primarily target all Douglas fir in the RMZs because this species would not be expected to survive in this inundation zone. Other non-flood-tolerant conifers and deciduous trees within this elevation range would also be removed and replaced by natural colonization or planted herbs and shrubs. For the remaining zones that range from elevation 567 to 627 feet MSL, inundation duration would range from 1 to 4 days and no harvesting of trees would occur (Anchor QEA 2016b). Depending on inundation timing and duration, some of the remnant non-flood-tolerant trees may eventually die and provide wildlife habitat as both snags and downed woody material. The uppermost inundation zone of the reservoir, from elevation 612 to 627 feet MSL, would be left as a predominantly coniferous forest (Anchor QEA 2016b).

3. Potential Physical Effects

3.1. Sediment Accumulation and Degradation

When the reservoir is impounding water during peak flow conditions, sand, coarser sediment, and woody debris would be deposited or trapped in the reservoir. Based on the hydrologic records from 1988 to 2015, water would have been impounded from 1 to 2 months during each of seven floods if the facility had been operating during that 27-year period. Incoming sediment would be deposited in the channel and floodplain at the (varying) elevation of the reservoir as the impoundment is filled. The deposition would occur between the dam and approximately RM 115, with the majority of the deposition occurring between RM 112 and 114 under most peak flow conditions.

Much of the coarse-grained sediments deposited within the channel would be transported downstream during freshets after the reservoir level drops. There would likely be some increase in fine-grained sediment within the active channel (defined as any part of the channel that has flowing water during flood retention as the reservoir level rises and then drops). However, this fine sediment would likely be entrained into the suspended sediment load and moved quickly downstream as the coarser sediment, which the fine sediment resides between, is mobilized during subsequent high flows. Fine-grained particles, such as silt and clay, deposited over the bottom of the entire inundation reservoir area would also likely be re-suspended and move downstream as suspended sediment load.

The operations of Mud Mountain Dam on the White River in Western Washington (an FRO facility) and impacts of dam removal (such as those on the Elwha River on the Olympic Peninsula of Washington) on sediment transport can inform flood storage actions in the Chehalis Basin. However, as discussed in greater detail in Section 5, the sediment regimes and operations at Mud Mountain Dam or during dam removals are very different than the Chehalis River scenarios. A better analogy for the effects of a Chehalis River dam operations on the in-channel and floodplain areas above the dam are the numerous logjams that formed and then broke apart during the 2007 Chehalis River flood. Sediment wedges were deposited behind the logjams, resulting in the temporary storage of coarse sediment within the channel and floodplain. When these logjams broke, much of the sediment within the channel was transported downstream and the portion of the sediment wedge that was in the floodplain remained in off-channel storage (see Figures 1 and 2). An effect seen in the 2007 logjam scenario was the accumulation of fine-grained sediment (e.g., silt and clay) throughout the impoundment, which would also occur during the approximately 32-day period that the reservoir remains full or partially full. In 2007, these fine-grained sediments were re-suspended as the reservoir behind the logjams was lowered, resulting in a small increase in suspended sediment and turbidity of released water as the reservoirs were drained.

Figure 1
Chehalis River near RM 118 Showing 2007 Flood Deposits

Figure 2
Chehalis River near RM 115 Showing 2007 Flood Deposits

3.2. Landslides

Based on geotechnical studies, landsliding within the reservoir is not anticipated to result in major sediment inputs due to the slow drawdown rate prescribed in the Draft Operations Plan (Anchor QEA 2016a), which was established to reduce the potential for landslides. During the first few cycles of reservoir filling and draining, shallow landslides around the reservoir perimeter are likely to occur, although the volume of these is not estimated to be significant. Using statistics from a watershed study (Weyerhaeuser 1994), a per annum estimate of 0.55 shallow landslides (3,200 cubic yards) would occur naturally (Shannon & Wilson 2014). However, the effect of a rising and falling reservoir has not been quantified, but could be developed in the future. Large tree removal may have a minor effect on the stability of slopes due to loss of evapotranspiration and root reinforcement. Specifically, soil loss by shallow instability on steep slopes owing to a loss of root reinforcement is likely, but would occur in small volumes such that it would be insignificant in comparison to the overall sediment load. A quantitative comparison has not been developed, but could be in the future. With the loss of large trees, deep-seated landslides are likely to increase movement by creep (which would be imperceptible) and contribute minor amounts of sediment to the river (Shannon & Wilson 2014). On landslides on slopes above the Chehalis River where deposited soil is not carried away by floodwaters, the soil deposit will remain on the slope, but could be entrained in the next inundating flood.

3.3. Channel Structure

The loss of riparian vegetation associated with dam construction and reservoir operation would likely result in some channel instability, leading to widening in unconfined and moderately confined reaches (increases in wetted width to depth [width:depth] ratios; Gordon et al. 1992). The deposition of sediment within the reservoir impoundment area would also contribute to some channel widening where such widening is possible. Approximately half of the upper Chehalis River inundation zone is comprised of moderately confined reaches where the valley width is between two and four times the active channel width and is susceptible to channel widening. The other half of the channel in the inundation zone is confined or controlled by bedrock and would have a limited capability to widen. Widening of the channel occurred during the 2007 flood, where the wetted channel increased from an average of 65 feet to 74 feet, and the active channel width (including non-vegetated bars) increased from an average width of 80 feet to 120 feet. Thus, the 2007 flood demonstrated that channels in the upper Chehalis River are sensitive to alteration in bottom topography (Watershed GeoDynamics and Anchor QEA 2016). However, deposition associated with facility operation would not be as deep and widespread as was the case with the 2007 flood, and sediment-associated increases in width would be limited to a shorter length of the channel (primarily in the upstream end of the reservoir fluctuation zone). Between flood storage operations, widened areas of the channel would slowly decrease in width. This is based on evidence from 2013 (6 years after the 2007 event) that indicates the wetted channel width had returned to a pre-2007 average width of 65 feet; whereas the active channel width had narrowed to an average of 112 feet from 120 feet, but had not returned to a pre-2007 average width of 80 feet (Watershed GeoDynamics and Anchor QEA 2016).

For Pacific salmonids and other fishes, the best average width:depth ratio in pool or run habitats is considered to be less than 7, and the worst conditions occur when ratios are greater than 25 (NMFS 1996; USFWS 1998). The average width:depth ratio for existing habitat in the reservoir reach has not been calculated.

To summarize, operating the facility is expected to affect the Chehalis River channel and nearby areas in the following ways:

- Result in some channel instability, leading to widening in unconfined and moderately confined reaches
- Alter the timing and rate of sediment transport, and potentially the rate and occurrence of channel migration, due to potential changes in channel conditions (e.g., an increase in channel bed elevation) and changes in flow

- Temporarily increase coarse sediment (cobble/gravel) storage within the channel in the inundation area
- Result in a more permanent storage of coarse sediment within a smaller portion of the inundation floodplain (depending on reservoir elevation during the time of most bedload movement during a flood)
- Temporarily increase fine-sediment accumulation during reservoir operation
- Result in a loss of riparian vegetation in the stream reaches subject to the longest inundation periods (e.g., the lowest elevation zones closest to the dam)

3.4. Potential Climate Change Effects

The effects of climate change on the hydrology of the Chehalis Basin were investigated by Mauger et al. (2016). They summarized previous research that suggested an increase in winter rainfall and intense storms, and a decrease in summer precipitation, could occur in the future and lead to higher peak (flood) flows and the potential for increased mass wasting/erosion and lower summer flows. Mauger et al. (2016) also ran two different hydrologic models for the Chehalis Basin using a range of potential climate change scenarios. The modeling produced a wide range of potential changes in streamflow, but also suggested that a general increase in winter streamflow and flood risk, and a decrease in summer low flows, is a likely scenario in the Chehalis Basin.

Higher peak flows under future climate change scenarios would result in the facility impounding water more frequently and to higher reservoir elevations. The increased volume of water stored would require additional days of drawdown, assuming the drawdown rules followed reflect the Draft Operations Plan (Anchor QEA 2016a). Based on the climate change scenario selected for further analysis (see Table 4.2 in Anchor QEA 2016a), the facility would impound water above elevation 450 feet MSL an additional six times (compared to predicted values based on historical events) over a 27-year period. Higher peak flows may also result in higher incoming sediment loads and additional sediment storage within the reservoir footprint and floodplains. More frequent impoundments of the reservoir would also result in less time between impoundment occurrences to flush fine sediment deposited in the channel. Therefore, it is likely that there would be more fine sediment in the gravel substrate under future climate conditions and more frequent retention of flood flows, which could decrease the quality of adult salmonid spawning habitat (see Section 4.2). In the future scenario under climate change but without the facility, peak flows, bank erosion, and bed scour downstream from the dam site would increase. Erosion is an important source of gravel needed for spawning habitat. A reduction, due to the facility, in increased peak flows downstream of the facility under future climate change scenarios could have both negative and positive effects on salmonids. The reduction would reduce erosion and gravel recruitment to spawning habitat (negative) and reduce scouring of redds (positive).

3.5. Large Woody Material

Current levels of LWM in the Chehalis River are low (Anchor QEA 2016c). Because of the confined nature of the channel, most LWM in the upper Chehalis River comes from infrequent inputs associated with mass wasting events, although some wood stored along the channel margins is entrained into the channel. There is little channel migration, and near-channel riparian stands are relatively small and contain short-lived species (such as alder), perhaps because of past harvesting practices or erosion from high-flow events. The 2007 flood provided a large input of LWM into the river channel from landslides. However, due to the intense nature of the flows associated with that event, most of the LWM was moved downstream through the channel or up onto the floodplain. In areas downstream of the facility, much of the LWM material was removed from the channel and floodplain and is not accessible to the current wetted channel.

Wood could be supplied to the facility from the Chehalis River upstream of the reservoir, tributaries, landslides in the reservoir area, or from trees in the reservoir area that are uprooted when inundated. During non-flood operations, wood up to 15 feet in length and 3 feet in diameter could be transported through the tunnel outlets located at the base of the dam. However, most wood is supplied during floods, and during flood operations, the dam would trap wood in the reservoir. Based on interpreting aerial photographs of past floods, the estimated volume of wood that would be trapped behind the facility during a 7-year flood is approximately 6,000 to 7,000 cubic yards (Watershed GeoDynamics and Anchor QEA 2016).

Trapping of large wood upstream of the dam during flood operations would reduce the potential wood load in the Chehalis River downstream of the dam. Large and small woody material that is moving through the system during floods would be trapped within the reservoir. The debris would be manually picked up and removed from the channel at a designated woody debris handling area as the reservoir is lowered during drawdown operations to between elevation 528 and 500 feet MSL. As a result, there would be little input of LWM to the channel between elevation 528 (approximately RM 109.9) and the dam site (approximately RM 108.2). Based on observations and analysis of historical aerial photographs, LWM begins to move at flows of approximately 9,000 cfs as measured at the USGS gage at Doty, Washington. The contribution of LWM to the river in the upper watershed is primarily from mass wasting, which occurs during large storm events that are above the 5-year recurrence interval level. It is anticipated that much of the LWM that is removed from the reservoir would be available for restoration projects or placement back into the river downstream from the dam. However, details of a LWM management plan are not available at this time, but could be developed in the future.

3.6. Water Quality

Any widened area of the channel in the reservoir inundation area that persists through the summer would be shallower than channel areas that did not change and vulnerable to increases in solar radiation, resulting in increased water temperatures, fish crowding, and the potential for anoxia events

(Hicks et al. 1991; Walthers and Nener 1997). Also, increased solar heating of the Chehalis River would occur due to a reduction in shading from the loss of riparian vegetation. Predictions from a water quality model indicated that a nearly 4°C increase in summer water temperatures over existing conditions could occur in the mainstem Chehalis River at the dam (RM 108.3; Anchor QEA 2016d). In the Crim Creek tributary upstream of the dam, an increase in water temperature of up to 5°C was predicted (Anchor QEA 2016e). Further investigation of this potential temperature increase is ongoing as of the date of this memorandum. Results of these studies will be used to refine the estimated increases in water temperature. Since warmer waters hold less DO and can stimulate biological activity that creates a greater demand for DO, lower DO concentrations are expected to occur in the Chehalis River within the reservoir footprint. With the increase in temperature of nearly 4°C along the mainstem Chehalis River at the dam site and a decrease in DO, there would be an impact on water quality. Model results suggest this temperature effect diminishes moving upstream from the dam (located at RM 108.3) along the mainstem Chehalis River. For example, at RM 114 the predicted increase is approximately 1°C.

Downstream from the dam, the greatest water quality impact is predicted to occur in the reach immediately below the dam, where water is predicted to be approximately 2 to 3°C warmer than existing conditions during summer (July 15). Water quality impacts are predicted to be negligible below the confluence of the Chehalis River with the South Fork Chehalis River (RM 88; Anchor QEA 2016e).

During the peak wet season (from December to February) or the early or later stages of the wet season, the model simulations indicated minor changes in temperature (either an increase or decrease) relative to current conditions downstream from the facility when it is storing water (Anchor QEA 2016e). These changes were not predicted to result in a violation of state water quality criteria for temperature for salmonids (Washington Administrative Code 173-201A-200), beyond what would occur under current conditions. Therefore, the release of water stored in the reservoir is expected to have a minor adverse impact on downstream temperatures from late fall through early spring (Anchor QEA 2016e).

4. Potential Biological Effects

4.1. Fish Stranding During Reservoir Drawdown Operations

The reservoir drawdown operations could result in the stranding of juvenile salmonids, larvae Pacific lamprey, and other small fishes (Anchor QEA 2017). Reservoir drawdown operations have been designed to reduce the stranding of salmonids by maintaining ramping rates that are less than the 7 to 16 inches per hour recommended by Bell et al. (2008), which is a range thought to reduce stranding or at least be independent of stranding. The reservoir drawdown rates (2 to 5 inches per hour) are also similar to rates used in laboratory studies conducted on juvenile Pacific lamprey, which indicated that stranding rates were 20% under test conditions of a 10% slope in substrate with a drawdown rate of 3 inches per hour (Liedtke et al. 2015). Thus, the drawdown rates that were developed based on salmonid stranding would likely reduce, or at least be independent of, stranding on juvenile salmonids.

The rates would reduce, but not eliminate, stranding of lamprey ammocoetes in the upper Chehalis River behind the proposed dam.

Based on a review of the literature and estimated slopes within the reservoir footprint, less than 5% of the reservoir footprint area poses a higher risk of stranding to rearing salmon and steelhead (i.e., areas where slope is less than 5% [71.8 acres or 9.5% of the total area]). Overall, the highest risk areas for stranding are in the canyon bottom where the Chehalis River currently flows (Anchor QEA 2017).

4.2. Salmonid Spawning Habitat – General

Female salmonids select, prepare, and guard redd sites. Redd sites are chosen based on the need for oxygenated water to flow, uninterrupted, over the embryos for several months. Site conditions vary with individual fish size and species; larger fish are able to excavate larger gravels and hold in faster flow. In general, suitable spawning habitat includes water that is approximately 1 to 2 feet deep and flowing at approximately 1 to 3.5 feet per second over coarse and small-to-medium gravel that is approximately 0.7 to 1.4 inches in diameter (Quinn 2005).

The survival of salmonid embryos to emergence from the streambed has been related to substrate and water flow conditions (Jensen et al. 2009). Egg incubation success is inhibited by reduced oxygen levels in the intragravel environment (known as oxygen sags). Reduced incubation success can result from: the effects of fine sediment on gravel permeability and the flow of oxygenated water through the redd environment, material infiltrating spawning and incubation gravels that consumes available oxygen, and fine particles (e.g., clay) that inhibit the exchange of oxygen across the egg membrane (Greig et al. 2005).

Female salmon and steelhead can alter the grain size and porosity of redd gravel during redd excavation, ensuring that ova begin incubation with an adequate flow of oxygenated water. Thus, the key to embryo survival is not the condition of spawning gravel before or immediately after spawning but during the several weeks or months of incubation. The incubation period coincides with seasonal high flows carrying sediment that can fill interstitial areas and restrict intragravel flow, negatively affecting egg and fry development and survival to emergence. The suitability of incubation habitat ultimately depends on how much, what size, and when sediment is transported (Lisle and Lewis 1992).

A meta-analysis of data on egg-to-fry survival of Chinook (*O. tshawytscha*), coho (*O. kisutch*), and chum (*O. keta*) salmon and steelhead (*O. mykiss*) showed that for each unit of sediment increase, coho salmon egg-to-fry survival tended to decline most rapidly and that of chum salmon declined least rapidly (Jensen et al. 2009). This study also reported that embryo survival dropped rapidly when the percentage of fine sediment (less than 0.033 inch in diameter) in redds was greater than 10% of the total, and a survival threshold for eyed-egg survival was observed when fines exceeded 25% to 30%. Jensen et al. (2009) defined threshold as a point in a non-linear relationship between sediment and survival (e.g., egg-to-fry or eyed-egg survival), above which survival is improbable.

In addition to causing mortality outright, oxygen sags during incubation may result in a shift in emergence timing. A substantial shift in the hatch timing of Atlantic salmon (*Salmo salar*) embryos was observed under reduced oxygen levels in laboratory experiments (Bloomer et al. 2016). The direction of this shift in timing (earlier versus later) was variable and determined by the timing of the sags. Extreme oxygen sags in the earlier stages of embryo development resulted in a developmental lag with alevin hatching later and at an underdeveloped state, while at the latest stages of development, oxygen sags caused premature hatching of severely underdeveloped alevin. Bloomer et al. (2016) also suggest that the post-hatch survival of Atlantic salmon embryos exposed to oxygen sags will be lower than those exposed to adequate oxygen levels due to subsequent predation and poor competitiveness.

Stream temperature controls the rate of embryo development and determines the period of incubation, and spawning occurs at a time that would result in eggs hatching at a presumably optimal time for fry survival (Heggberget 1988). Another factor related to the survival of salmonid embryos is scour, which can result in embryo mortality if scour depth intercepts egg burial depths. Mortality from scour depends on the timing and magnitude of floods relative to embryo incubation periods, the location of spawning within the stream network, and egg burial depths (Bjornn and Reiser 1991).

Lisle and Lewis (1992) simulated the effects of streamflow and sediment transport on the survival of salmonid embryos incubating in spawning gravels in a natural channel. They concluded the fraction of embryos that survive to emerge is expected to be extremely variable in streams where fish spawn during the high-flow season and the channel bed is at least moderately mobile, which is the case in the upper Chehalis River. They also concluded that in these situations, and where adult escapement is low, fish production may be limited in some years by the relationship between the sediment transport regime in the system and embryo mortality.

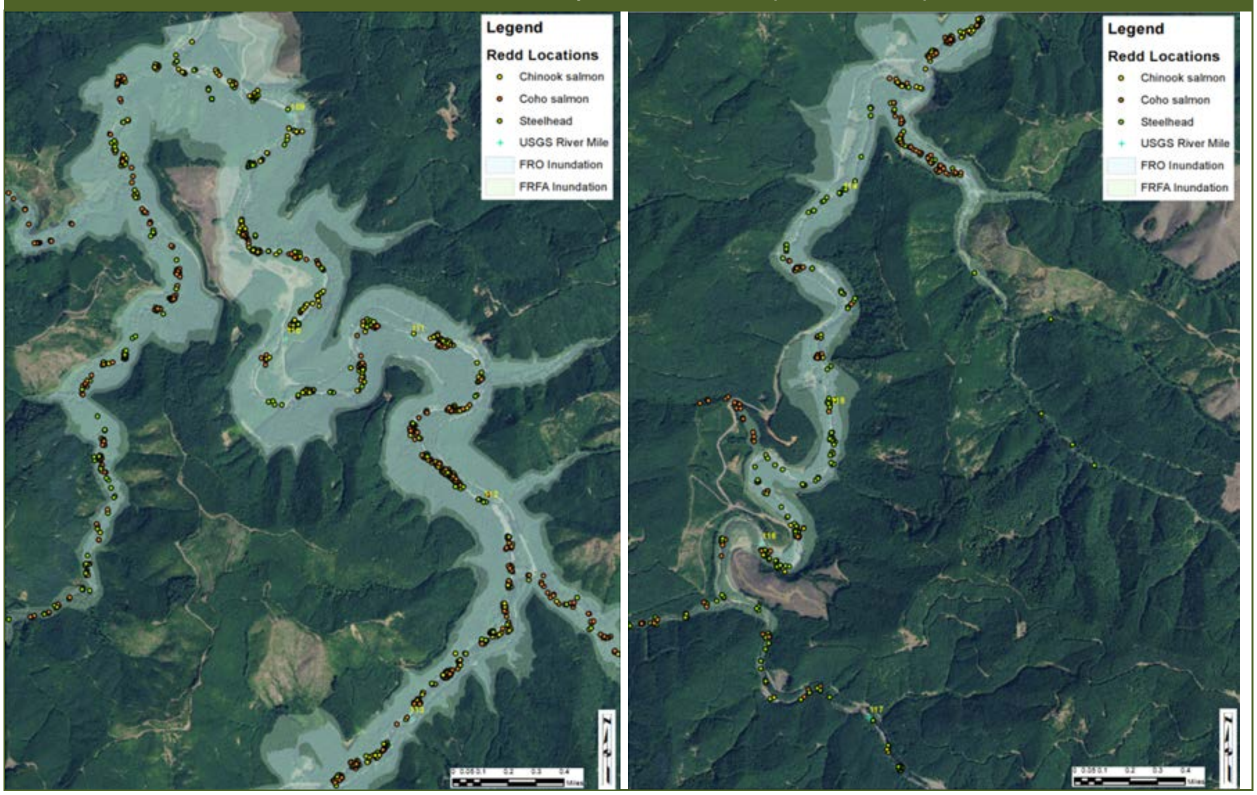
4.3. Salmonid Spawning Habitat – Upper Chehalis River

As discussed in the preceding section, stream temperature controls the rate of embryo development and determines the period of incubation. Sedimentation and scour events can result in embryo mortality but the level of mortality depends on the timing and magnitude of the sediments and floods, spawning location, and egg burial depths. Thus, the survival of embryos in the upper Chehalis River is expected to vary among years with environmental conditions.

To better address spawning location within and upstream of the reservoir reach, the Washington Department of Fish and Wildlife (WDFW) identified locations of Chinook and coho salmon and steelhead redds in the Chehalis River watershed upstream of RM 107 in 2013, 2014, 2015, and early 2016. Spawning for all species occurred in mainstem and tributary reaches located within the potential impoundment area starting at RM 108.3, with higher densities of redds being observed between RM 111 and 113.5 (see Figure 3). Analysis of 2014-2016 spawning ground survey data show that of all salmonids redds in the upper Chehalis River, 37% of steelhead, 41% of coho salmon, 83% of fall-run Chinook salmon, and 99% of spring-run Chinook salmon redds occur within the reservoir footprint area.

To assess the potential effects of bedload scour and fill on salmonid spawning habitat, in 2015 scour and fill levels under existing condition were measured at six locations near spawning sites between RM 88 and 116. Scour monitors were not installed within redds so as not to disturb the eggs, but adjacent to spawning sites in areas of similar water depth and velocity. Scour of up to 0.38 feet and fill of up to 1 foot was measured following a flow of 5,840 cfs, as measured at the USGS gage at Doty, which is approximately a 1.2-year flow event. At this flow level, substrate up to 2.6 inches in diameter had been mobilized. Following a flow of approximately 14,000 cfs (approximately a 4-year event), scour monitors were found at 2 of the 6 locations; presumably scour or fill had removed or covered the monitors at the other 4 sites. Scour of up to 1 foot was measured at one of the sites where the monitors were found (RM 110), with deeper scour and fill observed at the other sites where the monitors were not found. At this flow level, substrate up to 11.8 inches in diameter had been mobilized.

Figure 3
Locations of Anadromous Salmon and Steelhead Redds
Within the Reservoir Impoundment Area (2013 to 2016)



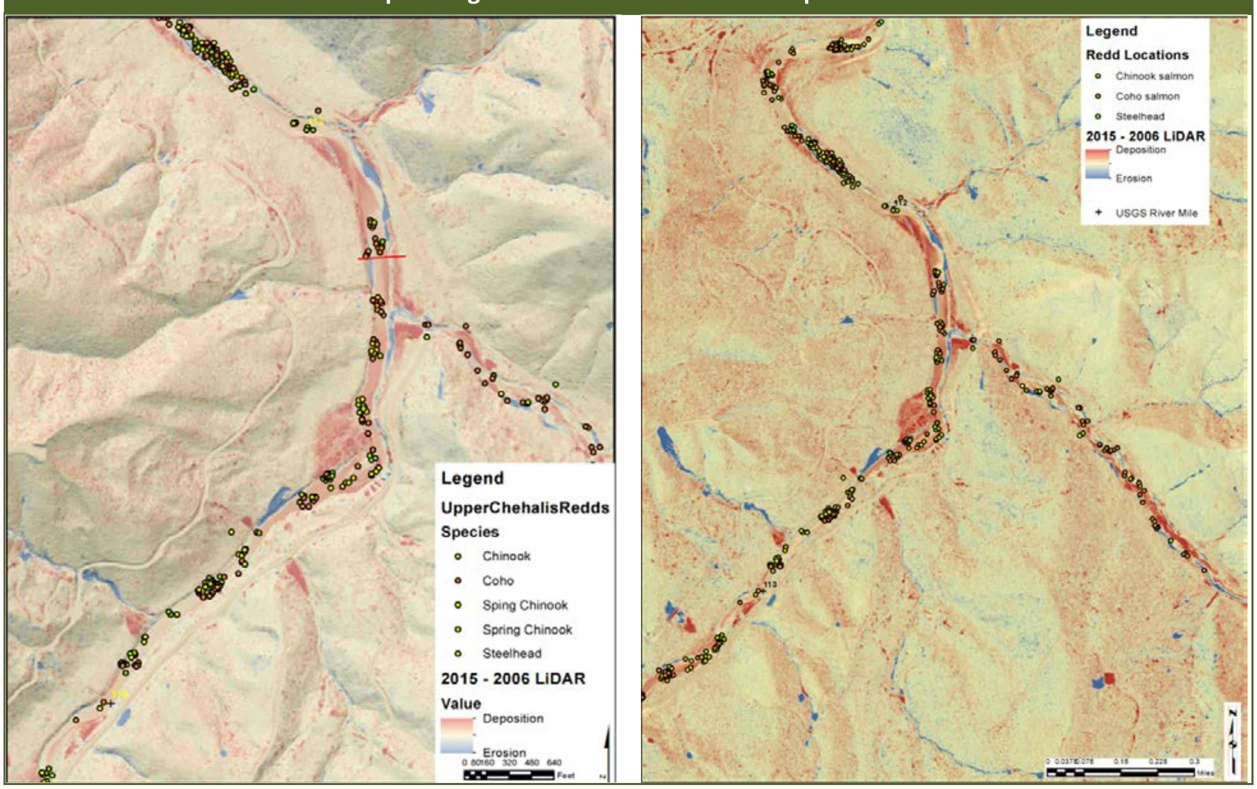
Note: The image on the right is a continuation of the image on the left.

These results indicate that the existing substrate in the Chehalis River is quite mobile, particularly in the areas where the 2007 flood deposits are still being processed and the channel is not yet in equilibrium, which are located primarily upstream of Elk Creek. After flood storage, transport of deposited sediments downstream through the previously impounded reservoir as the reservoir is drawn down would result in scour and fill as sediment is moved through the Chehalis River. During extremely large events such as the 2007 flood, there would be substantially more scour and fill, similar to what occurred in 2007 under the current (without dam) condition.

Although the magnitude of the 2007 flood was extreme and several million cubic yards of sediment moved through or were deposited in the Chehalis River channel and floodplain (an estimated 750 times the average annual sediment input), the local-scale effects of deposition behind temporary logjams in the potential impoundment area provide insights into how the river responds to sediment deposits within the channel and floodplain.

Due to its extreme nature, the 2007 flood caused widespread deposition within the channel and within the floodplain behind numerous logjams. Comparison of the 2015 and 2006 (pre-flood) LiDAR data shows deposition of up to 10 feet occurred in the floodplain where the channel was blocked by logjams (see Figure 4). As the logjams broke apart, the flows eroded a channel through the sediment wedge, leaving a portion of the deposit in the floodplain and along the channel margins. Based on the LiDAR comparison, deposits of up to 3 feet thick persist from the 2007 flood in some areas of the channel. These areas are being used for spawning Chinook salmon, coho salmon, and steelhead under current conditions (see Figure 4).

Figure 4
Spawning Locations and 2007 Flood Deposits



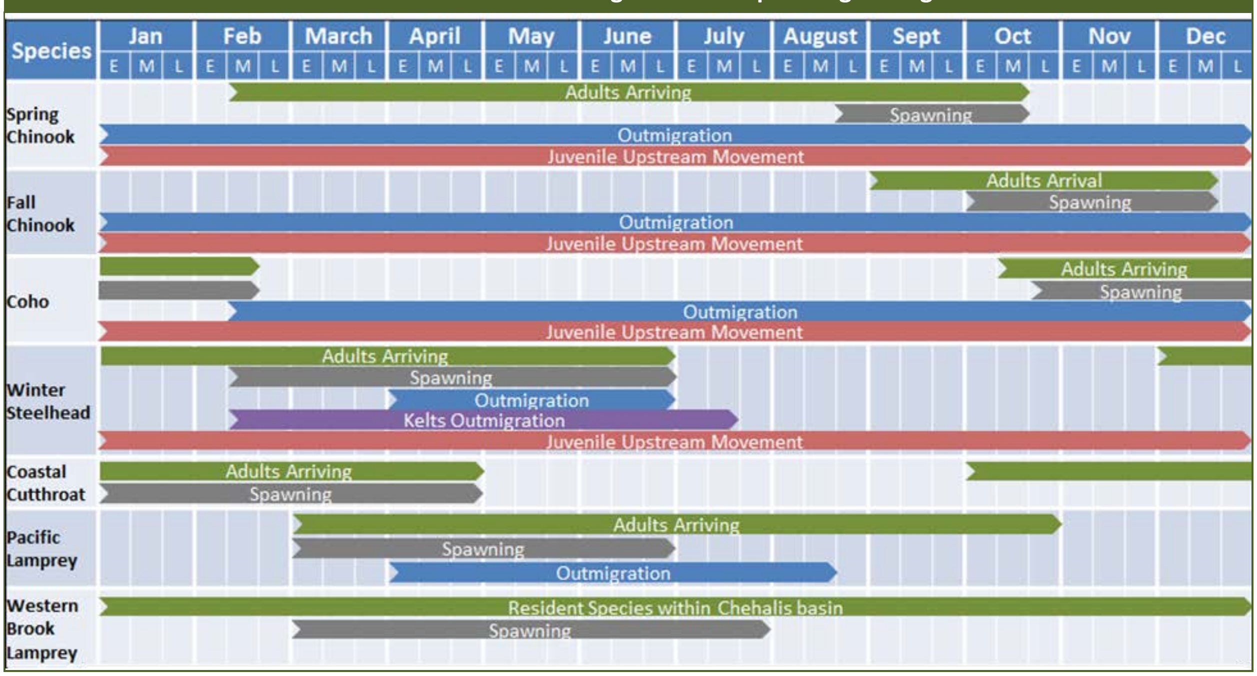
Note: The image on the right is a continuation of the image on the left.

This is analogous to how the river would deposit sediment when the reservoir is impounded and erode a channel through the deposits when the reservoir is drawn down, although deposition depths would likely be less and occur over a shorter channel distance during smaller floods. While some sediment would persist in the reservoir floodplain, much of the in-channel sediment would be re-entrained and moved through the river system during subsequent high flows.

The facility would likely impound water relatively infrequently (six times in 27 years based on 1988 to 2015 hydrology) and usually during the February to May timeframe. Initially, deposited sediment within the reservoir would contain a high level of fine sediment, but as flows transport the deposits when the reservoir is drawn down, the fine sediments would move into suspension and be transported downstream quickly. This is similar to the effects of the 2007 flood, where the substrate had an extremely high fine-sediment content initially, but subsequent high flows and redd construction by spawning fish removed fines from the surficial layer.

As part of developing fish passage alternatives for the facility, a team of biologists and engineers from various agencies and tribal organizations identified spawn timing for various anadromous fish species in the upper Chehalis River (see Figure 5).

Figure 5
Chehalis River Salmonid Migration and Spawning Timing



4.4. Summary of Effects on Salmonid Spawning Habitat Within Reservoir Footprint

Based on this information, water impoundment events due to the facility are likely to affect salmonid spawning habitat within the reservoir footprint as follows:

- Coarse sediment (cobble/gravel) storage within the channel in the inundation area would increase until it is mobilized by non-storage flow events and is transported downstream through the previously impounded channel as the reservoir drops. Scour and fill are expected to occur on the order of 1 to 2 feet (similar to a 4-year flood under current conditions). Thus, the process of sediments being mobilized and fines removed is likely to be similar to the existing (without-dam) condition, except for the period when materials deposited during the flood storage are mobilized.
- Each of these physical changes would affect the quality of spawning habitat between floods, but the effect is variable in time and space. The literature is consistent regarding the negative aspects of fine sediment being deposited on spawning reaches.
- A more permanent storage of coarse sediment within a small portion of the inundation floodplain outside of the wetted channel would occur, depending on reservoir elevation during the time of most bedload movement during a flood.
- Any coarse sediment deposited at the upper reach of the temporary reservoir would supply spawning gravels to these areas, or result in excessive deposits, until the materials are mobilized by subsequent flow events at various rates, depending on the size of the material.
- If no flood storage occurs, spawning and egg development would be affected by the degree to which the existing substrate has been mobilized by floods after the last flood storage event and prior to the spawning season. Changes in substrate composition between flood storages have not been modeled or estimated.
- If flood storage occurs prior to the initiation of spawning by an adult salmon or steelhead and an adult tries to enter the reservoir reach and spawn while the flood water is being stored (the reservoir is full, being lowered, or LWM is being removed), spawning habitat in the reservoir footprint would be either largely or totally unavailable to the adult. Adult salmon and steelhead that approach the dam while floodwater is stored and enter the collection system and trap located at the base of the dam would be transported and released in the reservoir, above the reservoir, or in tributaries to spawn of their own volition. Trap-and-transport release strategies will be finalized in the future.
- If flood storage occurred shortly before adult salmon and steelhead spawning, and the reservoir had been fully emptied and the river was returned to channel flow conditions, any adult salmon or steelhead that pass through the outlet tunnels and enter the reservoir reach would find the reach modified by the deposition of fine sediment and cobble. The extent and magnitude of the modifications would vary with location within the reach, the volume of water stored (i.e., the size of the flood), and the timing of spawning relative to the amount of flushing and mobilization

of sediment that has occurred since the outlets gates were reopened. Negative impacts would occur from fine-sediment accumulation, although the magnitude of the effect would depend on these variables. Storage early in a spawning season would affect spawning and egg incubation that is yet to occur if the fines are not mobilized after the flood.

- If flood storage occurs after spawning but prior to fry emergence, eggs or alevins in redds and interstitial pockets of the gravels would suffocate due to a lack of oxygen. The result would be a complete loss of eggs in any redd that is inundated. Low oxygen levels could occur from a lack of water flow through gravels due to sedimentation, a lack of water flowing over the redds, or low DO levels in the bottom layer of water in the reservoir, which can become hypoxic if the reservoir is deep enough to stratify.
- The timing of floods relative to spawn timing cannot be predicted. However, in general, flood storages would affect fall- and early-winter-spawning salmon species and cutthroat trout (*O. clarki clarki*) to a greater degree than steelhead and Pacific lamprey that spawn during late winter and spring.
- Increases in channel width associated with loss of riparian vegetation would occur where vegetation is lost, which would likely be in areas closest to the dam. Widening would also occur due to sediment deposition. Between impoundment events, widened areas of the channel would slowly decrease in width as the channel is reworked by flow. Channel widening in areas of salmon and steelhead spawning would result in reduced water depths and the suitability of the site for spawning.
- Increases in coarse sediment storage within the channel in the inundation area due to landslides or loss of root reinforcement due to vegetation removal is not anticipated to be large in magnitude.

4.5. Summary of Effects on Salmonid Spawning Habitat Downstream of Dam

A dam is likely to affect spawning habitats located downstream of the dam as follows:

- Flood storage could result in minor changes in temperature (increase or decrease) relative to current conditions downstream from the facility, depending on whether the flood occurs during the peak wet season (December to February) or during the early or later stages of the wet season, potentially affecting egg incubation there. Because the storage would be over a relatively short period, significant thermal stratification is not predicted to occur (Anchor QEA 2016d).
- Sediment retained in the reservoir footprint area during a flood would not be recruited to spawning habitats located downstream of the dam until the material is mobilized by higher-flow events that follow the flood storage. Since the timing of the subsequent mobilization is uncertain, the effects of delaying sediment recruitment to habitats downstream of the dam is also uncertain.
- Some portion of the incoming sediment would be retained permanently within the reservoir footprint outside of the active channel on the river floodplain. This material would not be

available to re-supply spawning gravels downstream of the dam until it is mobilized by higher-flow events and is transported downstream.

- Bed scour and its effects on redds located below the dam would decrease due to high-flow events being reduced and flood flows being impounded.
- LWM may not be available to areas below the dam in the same way that it is now due to the presence of the facility. LWM that is greater than 3 feet in diameter and 15 feet in length would not be able to pass through the outlet structures of the dam, even when water is not being retained. LWM would be trapped upstream of the dam during flood operations, reducing potential wood loading in the Chehalis River downstream of the dam.

4.6. Juvenile Salmonid Rearing Habitat – General

Many factors influence the growth and survival of juvenile salmonids in streams after hatching. Most juvenile salmonids spend at least some time in streams, though pink (*O. gorbuscha*) and chum salmon juveniles spend only a small amount of time there before outmigrating to the ocean. Temperature, flow, food availability, substrate, habitat composition (the proportion of pools, riffles, and glides), density and distribution of other fishes, and other characteristics of a river play a strong role in the distribution of performance of salmonids (Quinn 2005). While cold, well-oxygenated, sterile streams are ideal environments for embryo incubation, fry need food and warmer water for digestion.

How stream habitat composition would change as a result of flood storages has not been modeled or estimated. This is partly due to an inability to estimate how frequently flood storage events will occur, their timing during fish spawning and rearing periods, and the duration between flood storage events since the habitat features would partially or fully recover between events. Therefore, the potential effects of the facility on salmonid rearing habitat and rearing are organized into two periods, flood storage and non-flood storage, and are discussed in general terms.

4.7. Effects on Juvenile Rearing Habitat During Flood Storage

The habitat issues that affect salmonids in the Chehalis Basin vary considerably by sub-basin. The Chehalis Basin Salmon Habitat Restoration and Preservation Work Plan for WRIAs 22 and 23 provides a detailed synthesis of habitat conditions and identifies the most pressing habitat concerns (i.e., Tier 1 concerns) within each sub-basin (GHLE 2011). The most pressing habitat concerns identified include lack of LWM, passage barriers from culvert and road crossings, poor riparian conditions and riparian degradation, sedimentation, poor connection with the floodplain, high (summer) water temperatures, and poor estuarine habitat.

Storing floodwaters may further reduce habitat suitability for juvenile salmonid rearing. For example, while coho salmon benefit from an increased number of stream pools (Quinn 2005; Sharma and Hilborn 2001; Smoker 1955), a temporary reservoir with minimal or slow flow during flood storages may adversely affect salmon that are drift feeders and depend on flow to bring food to them (Quinn 2005).

Juvenile salmonids migrating downstream in the upper Chehalis River that enter the reservoir when the facility is in operation would have to exit the reservoir through the outlet tunnels during minimum flow releases (300 cfs), or remain in the reservoir for period of up to 32 days until the outlet tunnels at the base of the dam have been fully reopened to pass river flows up to 4,000 cfs. Changes in water levels and flow can also influence the territories that juvenile salmonids establish, which are important to their feeding, growth, and survival (Quinn 2005). For example, a higher density of fish in a given area or lower densities of food resulted in increased mortality for steelhead (Keeley 2001). During flood storage, juvenile salmonid habitat in the reservoir may be limited to areas near the banks (rather than across the entire channel), and thus salmonids may have a smaller area of suitable habitat available to them compared to the same reach when it is not impounded. However, if the total amount of bank area, which can be increased greatly during an impoundment, is suitable habitat for juvenile salmonids, overall suitable habitat may increase. Juvenile habitat area during flood storage has not been modeled and could be larger or smaller than the current river channel, depending on the depth and conditions assumed to be usable by juvenile salmonids in the reservoir.

Juvenile salmonids metabolize more efficiently at warmer temperatures, but need cooler temperatures when food resources are scarce to avoid starvation (Brett 1971; Armstrong et al. 2013). Recent research on juvenile coho salmon during summer months in Alaska discovered that the fish move daily between warmer and cooler waters to maximize their growth (Armstrong and Schindler 2013). Another study on juvenile coho salmon detected significant upstream and downstream movements during the transition from the summer dry season to the winter wet season, increasing growth and survival opportunities (Hance et al. 2016).

Recent studies on passive integrated transponder (PIT)-tagged juvenile Chinook salmon and steelhead in the upper Chehalis River found seasonal, daily, and within-a-given-day movements, including regular movements below and above the site of the proposed dam (Winkowski and Zimmerman, in press). Similar results have been found for PIT-tagged juvenile coho salmon in the upper Chehalis River (J. Winkowski, WDFW, unpublished data). These studies were conducted during summertime conditions; the behavior of parr during wintertime floods and how the operation of the dam could affect parr behavior during these events has not been evaluated.

When the dam is in operation and floodwater is being stored, juvenile salmonids that move downstream into the reservoir would not have direct access to reaches downstream of the dam unless they exit through the outlet tunnels. This access may be needed to meet their requirements (e.g., to escape increased turbidity, suboptimal temperatures, or predators). The design of facilities to collect juvenile salmonids (and resident fish and adult Pacific lamprey) below the dam when floodwaters are being impounded and transport them to release locations above the dam was considered during conceptual design of the dam fish passage facilities. This facility is discussed in greater detail in Section 4.9. The survival of juvenile salmonids migrating upstream through the outlet tunnels is estimated to range from 59% to 79% (see Table 4.2-5 in Anchor QEA 2016e).

While the reservoir is being drawn down after flood storage, adult and juvenile fishes would pass through 1 to 3 outlet tunnels that would be opened until the river returns to a free-flowing state. When in a free-flowing state, water would flow through the 3 outlet tunnels and the tunnels would be fully open for fish passage. The efficiency and survival of juvenile and adult fishes through the outlet tunnels during minimum flow releases and drawdown operations has not been assessed. The outlet tunnels are being designed to pass upstream and downstream migrating fish safely at flows below 2,000 cfs by meeting federal (NMFS 2011) and state (WDFW 2000) fish passage engineering design criteria.

To summarize, juvenile salmonids that utilize reservoir habitat during flood retention events may suffer increased mortality or decreased growth due to exposure to suboptimal conditions within the reservoir caused by the inability to move in and out of the reservoir footprint area. Research studies in the upper Chehalis River and in other basins have found that upstream and downstream seasonal, daily, and within-a-given-day upstream and downstream movements by juvenile salmonids occur during summer and fall, likely in order, to maximize growth and survival (Armstrong et al. 2013; Armstrong and Schindler 2013; Hance et al. 2016; Winkowski and Zimmerman, in press). It is not clear how storm events producing high flows during winter change these behaviors and, thus, how flood retention during these flows would impact juvenile salmonid growth and survival, due to a lack of information.

4.8. Effects on Juvenile Salmonid Rearing During Non-flood Storage Periods

While excessive quantities of fine sediments and increased turbidity are known to degrade salmonid spawning habitat and decrease egg-to-fry survival (see Section 4.2), their effects on rearing juveniles are less studied. There would be accumulations of fine-grained sediments in the deposition zone of the reservoir until they are mobilized and transported downstream as larger-sized gravel is re-entrained into the water column (as described in Section 3.3; Watershed GeoDynamics and Anchor QEA 2016). Increases in fine sediment and turbidity associated with the facility compared to current levels have not been estimated. Therefore, the potential effects of juvenile salmonids are described in general terms.

Chapman et al. (2014) found that an increase in suspended and deposited sediments had a negative effect on stream-dwelling salmonid feeding behavior, including feeding rate and reaction distance to a food item. Suttle et al. (2004) reported that increasing concentrations of fine sediments decreased juvenile steelhead growth and survival; with increasing fine sediment, invertebrate assemblages shifted from available prey organisms to burrowing organisms that were unavailable, so steelhead experienced lower food availability in channels with sediment than those less embedded. Higher levels of fine sediments were also shown to increase steelhead activity, so the fish spent less time sheltering behind or under cobbles and more time actively swimming, increasing their need to forage and decreasing their growth when food was not available (Suttle et al. 2004). Sigler et al. (1984) reported emigration of juvenile coho and steelhead from rearing channels with increased turbidity, which the authors interpreted as evidence that turbidity was stressful to the fish. Finally, acute lethal toxicities for exposure to suspended sediment have been reported for Chinook (Servizi and Gordon 1990), pink

(Servizi 1990), and coho salmon (Servizi and Martens 1992). Servizi and Martens (1992) also report that juvenile salmon can experience sublethal effects, indicative of increased stress, associated with these sediments. As discussed in Section 4.2, how stream habitat composition would change as a result of flood storages has not been modeled or estimated. This includes how fine sediments would be mobilized and whether there are any significant differences in sedimentation with the facility in place compared to current conditions. Therefore, it is difficult to estimate effects on juvenile salmonid survival.

4.9. Effects on Lamprey

Any effects on lamprey habitat from periodic flood storage would occur between approximately RM 108 and RM 114 of the mainstem Chehalis River. Lamprey ammocoetes (larvae) burrow into fine sediments of small streams and large rivers and filter feed on detritus and organic material until metamorphosing into the migratory juvenile life stage (Jolley et al. 2016). Larvae associate with low-water velocity, fine-particulate burrowing substratum, and pools at smaller scales, and with water depth and an open riparian canopy at larger spatial scales (Torgersen and Close 2004; Reid and Goodman 2015; Stone and Barndt 2005; as cited in Winkowski et al. 2016). Therefore, low-gradient areas with fine substrate within the reservoir footprint area and below the reservoir are potential areas of lamprey mortality during flood retention events and stranding during reservoir drawdowns.

Habitat classification for the majority (89%) of survey reaches above the dam site was categorized as riffle-pool; pool forming structures were primarily channel sinuosity (80%) and bedrock constrictions (11%), with large wood attributed to just 1% of the pool formation within the study area (Zimmerman and Winkowski, in press). While lamprey ammocoetes and redds have been observed in the reservoir reach (Winkowski et al. 2016), the amount of suitable spawning and rearing habitat within the reservoir footprint available to the species has not been quantified. Jolley et al. (2016) also observed larval Pacific lamprey nearby in the upper reaches of the Skookumchuck and Newaukum rivers, which when combined with the information from the upper Chehalis River indicates that Pacific lamprey may have a fairly broad distribution in the upper portion of the Chehalis Basin.

In 2015, WDFW surveyed lamprey in a total of 59 reaches near the proposed dam site during July, August, and September. There were 25 reaches sampled in the upper portion of the reservoir footprint, 24 in the lower portion and in several tributaries, and 10 reaches above the reservoir footprint or downstream of the dam. A summary report of the sampling effort notes that lamprey ammocoetes not identified to species occupied 49% of surveyed reaches, and that Pacific lamprey ammocoetes were identified in 41% of the reaches (Winkowski et al. 2016). Winkowski et al. (2016) also noted that the tributary portions of the inundation footprint are generally of a higher gradient with less depositional material and provide less available rearing habitat for ammocoetes than the mainstem Chehalis River, and that adult lamprey are known to spawn in Thrash Creek (WDFW unpublished data), which suggests larval drift is occurring to some degree. Western brook lamprey ammocoetes were only detected in supplemental surveyed reaches downstream of the proposed dam site; however, ammocoetes less than

70 millimeters (approximately 2.75 inches) were not identified to species. Small numbers of Pacific lamprey ammocoetes and lamprey redds were incidentally encountered by WDFW within the inundation footprint in instream amphibian surveys designed to detect amphibians (Hayes et al. 2016). Similarly, lamprey ammocoetes have been encountered in WDFW surveys of the middle and lower Chehalis River floodplain off-channel habitats and stream-associated "side-channel" habitat designed to detect other amphibians and stillwater-associated fishes (Hayes et al. 2015), though the lamprey encountered in these habitats have yet to be identified to the species level, which will be accomplished by genetic testing.

Similar to salmonids, the effect of periodic inundation on lamprey redds and ammocoetes rearing in the reservoir footprint would likely result in mortality to eggs and ammocoetes due to suffocation. The reservoir footprint has an estimated 71.8 acres of area where slope is less than 5% (a level identified as having a high risk of stranding juvenile salmonids during reservoir drawdown operations; Anchor QEA 2017). These low-gradient areas could meet Pacific lamprey rearing requirements.

The dam and reservoir would also alter channel substrate within the reservoir footprint, as discussed in Section 2.5. Once the flood threat has passed, the reservoir would be drawn down to channel grade. Larval lamprey that survived the flood storage are vulnerable to stranding because they have poor directional control over their mobility and reside in shallow littoral areas. Liedtke et al. (2015) conducted laboratory studies of dewatering to evaluate the effects of water management operations of hydroelectric dams on the Columbia River on lamprey ammocoetes. In this application, reservoirs fluctuate up and down within a relatively narrow (3- to 5-foot) range. Liedtke et al. (2015) found that a slow dewatering rate (3.0 inches per hour) stranded fewer fish (20%) than a fast rate (20.1 inches per hour; 53%). Under facility drawdown operations of 1 or 5 inches per hour (Anchor QEA 2016a), juvenile lamprey rearing in lower-gradient, fine substrates within the reservoir footprint area, or in mainstem Chehalis River reaches below the dam, would be exposed to dewatering. Based on a dewatering rate of 3 inches per hour in a laboratory study (Liedtke et al. 2015), juvenile lamprey in these areas would be expected to incur a stranding rate of approximately 20%.

Given that the outlet tunnels are being designed to match the current grade to pass upstream migrating adult salmonids and lamprey, downstream migrating juvenile salmonids and lamprey, and resident fish, passage effectiveness of adult lamprey migrating upstream through the tunnels is estimated to be 97%, survival is estimated at 99%, for a total estimated passage survival of 96% (see Table 4.2-5 in Anchor QEA 2016e). Adult lamprey spawn in spring and summer, which is later in the flood season. Therefore, the effects of floods on lamprey would be variable and depend on flood level (i.e., how much pool is inundated) and flood timing relative to spawn timing.

When flood storage does occur, lamprey passage would either be blocked for up to 32 days, or lamprey may pass through a low-volume lamprey entrance at a trap-and-haul system located downstream of the dam, if one is incorporated into the trap design. Once in the trap system, adult lamprey would be collected, transported, and released upstream of the dam. The low-volume entrance is being designed to the 30% preliminary design level in 2017; however, the results of the study will not be incorporated into the Final Environmental Impact Statement (EIS) but will be available for incorporation into a project-level EIS in the future. As part of the 30% preliminary design process, the Chehalis fish passage design team will assess the design trade-offs between designing entrances for salmonids only and adding the low-volume entrance for juvenile salmonids and other species. A recommendation or decision on whether to incorporate a low-volume entrance into the trap-and-haul facility for the dam has not been made.

If installed, the low-volume entrance for lamprey would be located next to a traditional high-velocity entrance for adult salmonids that meets federal (NMFS 2011) and state (WDFW 2000) design criteria. Bulk flow from the adult salmonid entrance would be used to attract lamprey to the low-volume entrance. In general, adult Pacific lamprey migrate following bulk flow and then look for ways to pass an obstruction by finding suitable routes or to attach to a wet wall and use a series of lunge and attach movements to climb the wall (e.g., Willamette Falls). The design of the entrances, ladder pools, and holding facilities for lamprey would incorporate the latest design information (e.g., Moser et al. 2011; Kirk et al. 2015). Walls of the lamprey entrance would be rounded, bollards (i.e., posts) would be placed along the floor to provide microhabitats for resting, and a lamprey bypass flume entrance would be located in the entrance pool to allow fish to exit the entrance pool and migrate up through the flume to a pool located at a higher elevation. Resting pools would be located in the flume based on Bonneville Dam designs, and surfaces would be selected that facilitate suction attachment by adult lamprey. Once in the upper pool, a wet wall would allow fish to climb the wall and, once over the top, drop into a hopper than can be loaded directly onto a truck for transportation upstream. During flood storage, passage success of adult Pacific lamprey through the low-volume entrance for the trap-and-transport system is estimated to range from 40% to 60%, which was based on discussions within the Chehalis fish passage design team and with NMFS lamprey researchers (Moser 2016).

Based on analysis of conceptual design alternatives, the survival of juvenile lamprey (macropthalmia) migrating downstream through the dam is estimated to be 95% (see Table 4.2-5 in Anchor QEA 2016e). The lamprey design efforts and impacts assessment to date have focused on the anadromous Pacific lamprey; future assessments could also focus on river lamprey and western brook lamprey.

4.10. Effects on Fauna

Flood storage and drawdown operations can be expected to reduce or eliminate terrestrial invertebrate and leaf detritus from entering streams as food (Allan 1995). Changes in vegetation in the reservoir footprint (described in Sections 2.7 and 4.11) have the potential to decrease the growth and survival of juvenile salmonids and other fishes in between flood storages. Food inputs derived from outside of the river can often be of great importance to juvenile salmonids (Dekar et al. 2012; Bilby and Bisson 1992). Fish in the upper Chehalis River that are dependent on the terrestrial invertebrates and detritus provided by riparian vegetation as food sources would see a reduction in food supply and composition due to the loss of riparian vegetation (Romero et al. 2005). Riparian invertebrates, detritus, and epiphytes are also important food sources for amphibians (Hicks et al. 2008), invertebrates, and insectivorous bats and birds (Jackson and Fisher 1986; Allan 1995; Milne 2015). Additionally, vegetation removal could result in a loss of cover for juvenile fishes to hide from predators and establish territories.

Also, as mentioned above, juvenile salmonid metabolism and growth are maximized at specific temperatures (Brett 1971), which is likely also the case for other fish species. Water temperature increases resulting from flood storage or a loss of shading (see Section 3.6) may negatively affect the growth and survival of fishes if current temperatures are already near the maximum range of their preference curves and the fishes do not have access to areas of cooler water. The effects of increasing water temperatures could be modeled and evaluated further in the future.

Any warming and channel widening that does occur could increase summer water temperatures enough to benefit predators such as walleye, smallmouth bass, and northern pikeminnow, which prefer warmer water and slower water velocities than salmonids (Colby et al. 1979; Monzyk et al. 2013). Thus, predation mortality on native fishes may increase in the upper Chehalis River. However, migrating smolts and native resident fishes are typically found in faster, midwater areas and migrate at night, which helps them avoid such fish predators (Patten 1971; Ruggles 1980; Zimmerman 1998).

4.11. Effects on Vegetation

As discussed in Sections 2.6 and 3.2, 13 of the 23 current landslides in the reservoir would be subject to triggering or reactivation by fluctuating reservoir levels (Shannon & Wilson 2015). The loss or removal of vegetation in the reservoir footprint would increase the potential for landslides and the release of sediment into the active channel. Soil loss by shallow instability on steep slopes owing to a loss of root reinforcement is likely, but would occur in small volumes that are insignificant in comparison to the overall sediment load (Shannon & Wilson 2014). Due to the loss of large trees, deep-seated landslides are likely to increase movement by imperceptible creep and contribute minor amounts of sediment to the river. If landslides occur on slopes above the river and the deposited soil is not carried away by floodwaters, the soil deposit would remain on the slope but could be entrained in the next flood that inundates the areas of the deposit.

Any vegetation not removed as part of vegetation management would be exposed to inundation during flood storage. Inundation can kill riparian vegetation due to physicochemical impacts (Naiman et al. 1989). Flooded trees—and in particular, upland-oriented, xeric conifers—would die within a few days after winter filling (Gill 1970; Whitlow and Harris 1979; Clatterbuck 2005). Although most tree species tolerate some flooding when they are dormant (McClean 1994) and oxygen is readily available, they typically die if the water is impounded for periods longer than the species tolerance limits, or if scour or fill damage the trunk or root system by rock or LWM accumulation (Gill 1970; Whitlow and Harris 1979; Naiman et al. 1989; Clatterbuck 2005). Inundation could have severe impacts for leafed-out seedlings and would reduce growth and biodiversity for annual-herbaceous plants because of decreased respiration, increased toxicity, and disease impacts (Whitlow and Harris 1979; Clatterbuck 2005). Sublethal impacts to trees from flooding include defoliation and reductions in both bud production and root-mycorrhizal (fungal) symbiosis during the next growing season (Whitlow and Harris 1979).

A Vegetation Management Plan will be prepared to address the management of vegetation during facility operations, and will focus on vegetation maintenance for safe and efficient operation of the facility and the restoration and enhancement of vegetation associated with fish and wildlife habitat within the reservoir footprint (Anchor QEA 2016b). The following types of actions will be addressed:

- Routine vegetation maintenance, including guidelines on what would trigger cutting, trimming, or removal of live vegetation after initial dam construction
- Post-construction re-vegetation efforts
- Post-construction vegetation monitoring
- Adaptive management approaches

The Vegetation Management Plan would consider planting species in the reservoir footprint area that are tolerant of floods during the growing season. For example, swamp-adapted deciduous and coniferous trees like Pacific Northwest cedars (*Thuja* spp.) can survive deep (4 to 12 inches), prolonged flooding for more than 1 year (Whitlow and Harris 1979), and moderately tolerant species can survive approximately 30 consecutive days of inundation.

A seasonal reservoir would have less riparian-floral impacts than a permanent reservoir in the upper Chehalis Basin, but riparian replanting should be considered to minimize thermal inputs (Whitlow and Harris 1979). Based on Whitlow and Harris (1979), the Vegetation Management Plan should consider leaving flood-tolerant woody species like deciduous shrubs and cedar trees in the reservoir footprint, as woody-riparian zones retain nutrients within stream reaches better than deforested ones for fish and wildlife benefits (Naiman et al. 1989; Allan 1995; Vadas 1997, 1998).

5. Information from Other Basins

Effects of other FRO-type dams in Western Washington can provide insights into how an FRO-style dam on the upper Chehalis River may affect channel geomorphology and substrate. One such example is Mud Mountain Dam, which is located in King County, Washington, a few miles southeast of Enumclaw. Of note, the operational and geomorphic regimes of Mud Mountain Dam and its watershed are very different from the Chehalis facility.

Mud Mountain Dam is located on the White River, which is a glacial system that carries an estimated 500,000 tons of fine-grained sediment each year. This level is approximately an order of magnitude greater than the Chehalis River, which is estimated to carry an average of 53,000 tons per year at the Doty gage. Mud Mountain Dam impounds water and sediment several times per year, while the

Chehalis dam is anticipated to impound water relatively infrequently (six times in 27 years based on 1988 to 2015 hydrology). Because of the extremely high fine sediment load and frequent impoundments, Mud Mountain Dam retains much more fine sediment within the impoundment area and river channel than is expected for the Chehalis facility.

Puyallup Tribal Fisheries staff have not observed spawning in the Mud Mountain Dam reservoir, which they attribute to fine sediment in the deposition zone that compromises habitat quality. While tribal staff believe that fish avoid spawning in the reservoir footprint, it is difficult to absolutely conclude that fish do not use this habitat for spawning as direct observations are challenging due to high turbidity levels in the river (Ladley 2016).

Systems where dams have been removed, such as the Elwha (Olympic Peninsula of Washington State) and White Salmon (a tributary to the lower Columbia River) rivers, may also be considered a source of information on the potential physical changes to instream habitat associated with flood storage events. However, information from these systems was not reviewed because evacuating the pools behind these dams during dam removal, and the mobilization of stored sediment by high flows after the removals, resulted in the release of sediment that had accumulated for up to 100 years. This is a much larger effect than would be expected from the release of several weeks of sediment accumulation behind the dam from one flood on the Chehalis River system.

6. References

Allan, J.D., 1995. *Stream ecology: structure and function of running waters.* New York: Chapman & Hall.

Anchor QEA (Anchor QEA, LLC), 2016a. *Draft Operations Plan for Flood Retention Facilities.* Prepared for the Chehalis Basin Work Group. November.

Anchor QEA, 2016b. *Technical Memorandum on Proposed Flood Retention Facility Pre-construction Vegetation Management Plan.* Appendix J to the Draft Chehalis Basin Strategy Programmatic Environmental Impact Statement. August 31.

Anchor QEA, 2016c. *Upper Chehalis Basin Large Wood Inventory.* Memorandum from J. Goldsmith (Anchor QEA) to B. Montgomery (Anchor QEA). September 8.

Anchor QEA, 2016d. *Draft Reservoir Water Quality Model.* Prepared for the Chehalis Basin Work Group. September.

Anchor QEA, 2016e. *Draft Chehalis Basin Strategy Programmatic EIS.* Prepared for the Washington State Department of Ecology. September 29.

Anchor QEA, 2017. *Literature review of fish stranding in reservoir environments.* Draft memorandum from J. Ferguson and S. Montgomery (Anchor QEA) to J. Allegro (Washington Department of Fish and Wildlife). January 3.

Armstrong, J.B., and D.E. Schindler, 2013. Going with the flow: spatial distributions of juvenile coho salmon track an annually shifting mosaic of water temperature. *Ecosystems*16:1429-1441.

Armstrong, J.B, D.E. Schindler, C.P. Ruff, G.T. Brooks, K.E. Bentley, and C. Torgersen, 2013. Diel horizontal migration in streams: juvenile fish exploit spatial heterogeneity in thermal and trophic resources. *Ecology* 94: 2066-2075.

Bell, E., S. Kramer, D. Zajanc, and J. Aspittle, 2008. Salmonid Fry Stranding Mortality Associated with Daily Water Level Fluctuations in Trail Bridge Reservoir, Oregon. *North American Journal of Fisheries Management* 28:1515-1528.

Bilby, R.E., and P.A. Bisson, 1992. Relative contribution of allochthonous and autochthonous organic matter to the trophic support of fish populations in clearcut and old growth forested headwater streams. *Canadian Journal of Fisheries and Aquatic Sciences* 49(3):540-551.

Bjornn, T., and D. Reiser, 1991. Habitat requirements of salmonids in streams. In *Influence of Forest and Rangeland Management on Salmonid Fishes and Their Habitats*, edited by W.R. Meehan. Bethesda, Maryland: American Fisheries Society Special Publication 19:83-138.

Bloomer, J., D. Sear, P. Dutey-Magni, and P. Kemp, 2016. The effects of oxygen depletion due to upwelling groundwater on the post-hatch fitness of Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences* 73(12):1830-1840.

Brett, J.R., 1971. Energetic responses of salmon to temperature. A study of some thermal relations in the physiology and freshwater ecology of sockeye salmon (*Oncorhynchus nerka*). *American Zoologist* 99-113.

Chapman, J.M., C.L. Proulx, M.A. Veilleux, C. Levert, S. Bliss, M.È. André, N.W. Lapointe, and S.J. Cooke, 2014. Clear as mud: a meta-analysis on the effects of sedimentation on freshwater fish and the effectiveness of sediment-control measures. *Water Research* 1(56):190-202.

Clatterbuck, W.K., 2005. *SP656 Shade and Flood Tolerance of Trees.* Knoxville: University of Tennessee, Agriculture Extension Service. Available from: http://trace.tennessee.edu/utk_agexfores/60.

Colby, P.J., R.E. McNicol, and R.A. Ryder, 1979. *Synopsis of biological data on the walleye Stizostedion v. vitreum (Mitchill 1818)*. Prepared for the Food and Agriculture Organization (FAO) of the United Nations. FAO Fisheries Synopsis No. 119. Available from: http://www.fao.org/docrep/017/ap924e/ap924e.pdf.

Dekar, M.P., R.S. King, J.A. Back, D.F. Whigham, and C.M. Walker, 2012. Allochthonous inputs from grass-dominated wetlands support juvenile salmonids in headwater streams: evidence from stable isotopes of carbon, hydrogen, and nitrogen. *Freshwater Science* 31:121-132.

Gill, C.J., 1970. The flooding tolerance of woody species - a review. *Forestry Abstracts* 31:671-688.

Gordon, N.D., T.A. McMahon, and B.L. Finlayson, 1992. *Stream hydrology: an introduction for ecologists.* New York: John Wiley & Sons.

GHLE (Grays Harbor County Lead Entity Habitat Work Group), 2011. *The Chehalis Basin Salmon Habitat Restoration and Preservation Strategy for WRIA 22 and 23.* Prepared with assistance by Grays Harbor County and Creative Community Solutions, Inc. June 30. Available from: http://www.chehalisleadentity.org/documents/.

Greig, S.M., D.A. Sear, and P.A. Carling, 2005. The impact of fine sediment accumulation on the survival of incubating salmon progeny: Implications for sediment management. *Science of the Total Environment* 344:241-258.

Hance, D.J., L.M. Ganio, K.M. Burnett, and J.L. Ebersole, 2016. Basin-scale variation in the spatial pattern of fall movement of juvenile Coho Salmon in the West Fork Smith River, Oregon. *Transactions of the American Fisheries Society* 145(5):1018-1034.

Hayes, M., J. Tyson, and K. Douville, 2015. *2015 Chehalis ASRP Off-Channel Extensive Surveys: 2nd Progress Report.* Draft report prepared for EIS development. Habitat Program Science Division, Aquatic Research Section, Washington Department of Fish and Wildlife. November 30.

Hayes, M., J. Tyson, and K. Douville, 2016. *2016 Chehalis ASRP Instream Amphibian Survey Report: 3rd Progress Report for Post-Feasibility Efforts.* Draft report prepared for EIS development. Habitat Program Science Division, Aquatic Research Section, Washington Department of Fish and Wildlife.

HDR (HDR, Inc.), 2016. Memorandum to J. Allegro, Washington Department of Fish and Wildlife regarding Fish Passage Conduits Through FRO Dam Alternative. August 15.

Heggberget, T.G., 1988. Timing of spawning in Norwegian Atlantic Salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences* 45:845-849.

Hicks, B.J., R.L. Beschta, and R.D. Harr, 1991. Long-term changes in streamflow following logging in western Oregon and associated fisheries implications. *Water Resources Bulletin* 27:217 226.

Hicks, T.L., D.E. Mangan, A.P. McIntyre, and M.P. Hayes, 2008. *Rhyacotriton kezeri* (Columbia Torrent Salamander) larval diet. *Herpetological Review* 39:456-457. Available from: http://wdfw.wa.gov/publications/pub.php?id=00137.

Jackson, J.K., and S.G. Fisher, 1986. Secondary production, emergence, and export of aquatic insects of a Sonoran desert stream. *Ecology* 67:629-638

Jensen, D.W., E.A. Steel, A.H. Fullerton, and G.R. Pess, 2009. Impact of fine sediment on egg-to-fry survival of Pacific salmon: A meta-analysis of published studies. *Reviews in Fisheries Science* 17(3):348-359.

Jolley, J.C., G.S. Silver, J.E. Harris, E.C. Butts, and C. Cook-Tabor, 2016. *Occupancy and Distribution of Larval Pacific Lamprey and Lampetra spp. in Wadeable Streams of the Pacific Northwest.* Vancouver: U.S. Fish and Wildlife Service, Columbia River Fish and Wildlife Conservation Office.

Keeley, E., 2001. Demographic responses to food and space competition by juvenile steelhead trout. *Ecology* 82(5):1247-1259.

Kirk, M., C. Caudill, E. Johnson, M. Keefer, and T. Clabough, 2015. Characterization of adult Pacific Lamprey swimming behavior in relation to environmental conditions within large-dam fishways. *Transactions of the American Fisheries Society* 144(5):998-1012.

Ladley, R. (Puyallup Tribe), 2016. Personal communication with S. Montgomery (Anchor QEA) regarding salmon and steelhead spawning upstream of Mud Mountain Dam. May 13.

Liedtke, T.L., L.K. Weiland, and M.G. Mesa, 2015. *Vulnerability of larval lamprey to Columbia River hydropower system operations—Effects of dewatering on larval lamprey movements and survival.* U.S. Geological Survey Open-File Report 2015-1157. Available from: http://dx.doi.org/10.3133/ofr20151157.

Lisle, T., and J. Lewis, 1992. Effects of sediment transport on survival of salmonid embryos in a natural stream: a simulation approach. *Canadian Journal of Fisheries and Aquatic Sciences* 49:2337-2344. Available from: https://www.southernregion.fs.fed.us/psw/publications/lisle/LisleCJFAS92.pdf.

Mauger, G.S., S.Y. Lee, C. Bandaragoda, Y. Serra, and J.S. Won, 2016. *Effect of Climate Change on the Hydrology of the Chehalis Basin.* Prepared for Anchor QEA. Seattle: Climate Impacts Group, University of Washington. Available from: https://cig.uw.edu/datasets/hydrology-in-the-chehalis-basin/.

McClean, J., 1994. Wetter is not always better: flood tolerance of woody species. *Watershed Protection Techniques* 1(4):208-210. Available from: http://www.cwp.org/?mdocs-file=4685&mdocs-url=falses

Milne, D.H., 2015. *Capitol Lake: the healthiest lake in Thurston County.* Prepared for the Capitol Lake Improvement & Protection Association. Available from: (http://www.savecapitollake.org/documents/healthiest-lake.html.

Monzyk, F.R., R. Emig, J.D. Romer, and T.A. Friesen, 2013. *Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs: 2012.* Corvallis: Oregon Department of Fish and Wildlife, Upper Willamette Research, Monitoring and Evaluation Program, Corvallis Research Lab.

Moser, M., M. Keefer, H. Pennington, D. Ogden, and J, Simonson, 2011. Development of Pacific lamprey fishways at a hydropower dam. *Fisheries Management and Ecology* 18:190-200.

Moser, M. (National Marine Fisheries Service Northwest Fisheries Science Center), 2016. Personal communication with J. Ferguson (Anchor QEA) and M. Garello (HDR) regarding design of fish passage structures in adult salmonid fish ladders to pass Pacific lamprey. August.

Naiman, R.J., H. Décamps, and F. Fournier, eds., 1989. Role of land/inland water ecotones in landscape management and restoration: proposals for collaborative research. UNESCO (United Nations Educational, Scientific, and Cultural Organization) MAB (Man and the Biosphere) Digest 4. Available from: (http://unesdoc.unesco.org/images/0008/000865/086505eo.pdf.

NMFS (National Marine Fisheries Service), 1996. *Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale.* Silver Spring, MD: National Marine Fisheries Service, Environmental and Technical Services Division, Habitat Conservation Branch. Available from: http://www.oregon.gov/ODOT/HWY/GEOENVIRONMENTAL/docs/Biology/NMFS_Matrix.pdf.

NMFS, 2011. Anadromous Salmonid Passage Facility Design. NMFS, Northwest Region, Portland, Oregon.

Osterkamp, W.R., and C.R. Hupp, 2010. Fluvial processes and vegetation — glimpses of the past, the present, and perhaps the future. *Geomorphology* 116:274–285.

Patten, B. G., 1971. Increased predation by the torrent sculpin, *Cottus rhotheus*, on coho salmon fry, *Oncorhynchus kisutch*, during moonlight nights. *Journal of the Fisheries Research Board of Canada* 28:1352-1354. Available from: (http://www.nrcresearchpress.com/doi/abs/10.1139/f71-210.

Quinn, T. P., 2005. *The behavior and ecology of pacific salmon and trout.* Seattle: University of Washington Press.

Reid, S., and D.H. Goodman, 2015. Detectability of Pacific Lamprey Occupancy in Western Drainages: Implications for Distribution Surveys. *Transactions of the American Fisheries Society* 144(2):315-322.

Romero, N., R.E. Gresswell, and J.L. Li, 2005. Changing patterns in coastal cutthroat trout (*Oncorhynchus clarki clarki*) diet and prey in a gradient of deciduous canopies. *Canadian Journal of Fisheries and Aquatic Sciences* 62:1797-1807. Available from: http://fresc.usgs.gov/products/papers/1398_Romero.pdf.

Ruggles, C.P., 1980. *A Review of the Downstream Migration of Atlantic Salmon.* Canadian Technical Report of Fisheries and Aquatic Sciences No. 952. Available from: (http://publications.gc.ca/site/eng/452084/publication.html.

Servizi, J.A., 1990. Sublethal effects of dredged sediments on juvenile salmon *In* Effects of dredging on anadromous Pacific coast fishes: workshop proceedings, edited by C. Simenstad. September 8 and 9, 1988. Washington Sea Grant Publication WSG-W090-1. Seattle: University of Washington.

Servizi, J.A., and R.W. Gordon, 1990. Acute lethal toxicity of ammonia and suspended sediment mixtures to chinook salmon (*Oncorhynchus tshawytsch*). *Bulletin of Environmental Contaminants and Toxicology* 4:650-656.

Servizi, J.A., and D.W. Martens, 1992. Sublethal responses of coho salmon (*Oncorhynchus kisutch*) to suspended sediments. *Canadian Journal of Fisheries and Aquatic Sciences* 49:1389-1395.

Shannon & Wilson (Shannon & Wilson, Inc.), 2014. *Preliminary Desktop Landslide Evaluation.* Prepared for the Chehalis Basin Work Group. July 23.

Shannon & Wilson, 2015. Landslide Reconnaissance Evaluation of the Chehalis Dam Reservoir. Prepared for the Chehalis Basin Work Group. September 22.

Sharma, R., and Hilborn, R., 2001. Empirical relationships between watershed characteristics and coho salmon (*Oncorhynchus kisutch*) smolt abundance in 14 western Washington streams. *Canadian Journal of Fisheries and Aquatic Sciences* 58(7):1453-1463.

Sigler, J. W., T.C. Bjornn, and F.H. Everest, 1984. Effects of chronic turbidity on density and growth of steelheads and coho salmon. *Transactions of the American Fisheries Society* 113(2):142-150.

Smoker, W. A., 1955. Effects of stream flow on silver salmon production in western Washington. Ph.D. dissertation. Seattle: University of Washington.

Stone, J., and S. Barndt, 2005. Spatial distribution and habitat use of Pacific lamprey (*Lampetra tridentata*) ammocoetes in a western Washington stream. *Journal of Freshwater Ecology* 20(1):171-185.

Suttle, K. B., M. E. Power, J. M. Levine, and C. McNeely, 2004. How fine sediment in riverbeds impairs growth and survival of juvenile salmonids. *Ecological applications* 14(4) 969-974.

Torgersen, C. E., and D.A. Close, 2004. Influence of habitat heterogeneity on the distribution of larval Pacific Lamprey (Lampetra tridentata) at two spatial scales. *Freshwater Biology* 49:613-630.

USFWS (U. S. Fish and Wildlife Service), 1998. *A Framework to Assist in Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Bull Trout Subpopulation Watershed Scale.* Washington, DC: U.S. Fish and Wildlife Service. Available from: http://www.fws.gov/montanafieldoffice/Endangered_Species/Bull_Trout_consultation/matrix.pdf.

Vadas, R.L. Jr., and J.E. Sanger, 1997. Lateral zonation of trees along a small Ohio stream. *Ohio Journal of Science* 97:107-112.

Vadas, R.L. Jr., 1997. *Assemblage structure of riparian and drifting invertebrates along environmental gradients in two streams of southern British Columbia.* Prepared for Environment Canada, Environmental Conservation Branch, Aquatic and Atmospheric Sciences Division. May. Available from: https://www.researchgate.net/publication/299553285_Assemblage_structure_of_riparian_and_drifting_invertebrates_along_environmental_gradients_in_two_streams_of_southern_British_Columbia.

Vadas, R.L. Jr., 1998. Human Impact on Aquatic and Riparian Ecosystems in Two Streams of the Thompson River Drainage, British Columbia. In *Forest-Fish Conference: Land Management Practices Affecting Aquatic Ecosystems*, edited by M.K. Brewin and D.M.A. Monita. Information Report NOR-X-356. Edmonton, AB: Natural Resources Canada, Forest Service, Northern Forestry Center, 13-30. Available from: http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/11639.pdf.

Vadas, R., 2015. *Literature Review for Chehalis River Flood-Control Issues: Salmon Reservoir Ecology*. Draft report prepared by Washington Department of Fish and Wildlife. December.

Walthers, L.C., and J.C. Nener, 1997. *Continuous Water Temperature Monitoring in the Nicola River, B.C., 1994: Implications of High Measured Temperatures for Anadromous Salmonids.* Canadian Technical Report of Fisheries and Aquatic Sciences 2158. Available from: http://www.dfo-mpo.gc.ca/Library/211230.pdf.

Watershed Geodynamics and Anchor QEA, 2016. *Geomorphology, Sediment Transport, and Large Woody Debris*. Draft report. October.

WDFW (Washington Department of Fish and Wildlife), 2000. Fishway Guidelines for Washington State. Draft Report dated April 25, 2000. Washington Department of Fish and Wildlife, Olympia, Washington.

WDFW and Ecology (Washington State Department of Ecology), 2008. Instream Flow Study Guidelines: Technical and Habitat Suitability Issues including fish preference curves. Updated April 5, 2004. Error correction update February 12, 2008. Available from: http://wdfw.wa.gov/publications/00574/wdfw00574.pdf.

Weyerhaeuser Company, 1994. *Chehalis headwaters watershed assessment, mass wasting analysis*.

Whitlow, T.H., and R.W. Harris, 1979. *Flood tolerance in plants: a state-of-the-art review.* Prepared for the U.S. Army, Chief of Engineers Office and Waterways Experiment Station, Environmental Water Quality and Operational Studies Technical Report E-79-2. Available from: http://www.dtic.mil/dtic/tr/fulltext/u2/a075938.pdf.

Winkowski, J.J., and M.S. Zimmerman, in press. Summer habitat and movements of juvenile salmonids in a coastal river of Washington State. *Ecology of Freshwater Fish*.

Winkowski, M., N. Kendall, and M. Zimmerman, 2016. *Upper Chehalis Instream Fish Study 2015.* Washington Department of Fish and Wildlife, Olympia, WA. FPT 16-11.

Zimmerman, M., 1998. An overview of Columbia River predation studies. In *Management Implications of Co-occurring Native and Introduced Fishes: Proceedings of the Workshop October 27-28, 1998, Portland, Oregon*, edited by Oregon Department of Fish & Wildlife and National Marine Fisheries Service, 89-92. Available from: http://docs.streamnetlibrary.org/Oregon/DFW/mngimpfinal.pdf.