2.5 FISH PASSAGE

2.5 FISH PASSAGE

EXECUTIVE SUMMARY

There are no known natural impassable barriers in the mainstem Green River. The historic upstream extent of anadromous salmonid use is presumed to be to approximately RM 93 based on an analysis of gradient and a series of mapped cascades. The earliest documented anthropogenic barrier on the mainstem Green River was a wooden weir that was erected annually from 1904 to 1924 at the confluence of Soos Creek to allow capture of adult chinook in the mainstem.

Dams constructed in the Upper Green River sub-watershed have had the largest impact on the up and downstream passage of salmonids. The Tacoma Headworks, completed in 1913, was the first complete barrier to adult salmon and steelhead in the Green River, and it eliminated naturally reproducing anadromous fish production in the upper sub-watershed for 80 years. Howard Hanson Dam (HHD), constructed at RM 64.5 in 1962, also represents a complete barrier to the upstream passage of anadromous and resident fish.

Since 1982, between two and four million juvenile salmon and steelhead annually have been released upstream of HHD. In addition, in 1992, the Muckleshoot Indian Tribe (MIT), Tacoma, WDFW, and Trout Unlimited began cooperatively administering a temporary fish ladder and trap-and-haul program. Under the pilot program, between 7 and 133 adult steelhead annually have been captured in a temporary fish trap at the Headworks and either released upstream of HHD for natural spawning or used to produce fry for outplanting in the Upper Green River sub-watershed.

Downstream passage of juvenile salmonids also is interrupted by HHD. Current annual survival of juvenile salmon and steelhead migrating through HHD outlets is estimated to be between 5 and 25 percent based on a fish passage model and on-site monitoring data (Dilley and Wunderlich 1992, 1993). There are two main concerns regarding downstream fish passage associated with Howard Hanson Dam:passage through the dam, andpassage through the reservoir.

Studies conducted in the early 1990's indicated that the low survival rate of fish passing Howard Hanson Dam was primarily a function of two factors: 1) the spring refill operation strategy, which influences the ability of fish to locate the outlets; and 2) the low survival of juveniles passing through the bypass outlet pipe. Outmigrant studies indicate that there is little or no injury to juvenile fish using the radial gates, but injury rates through the bypass pipe ranges from 3 to almost 90 percent, depending on species and environmental conditions (Seiler and Neuhauser 1985; Dilley and Wunderlich 1992; 1993).

Passage through the reservoir also is believed to negatively impact juvenile salmonids migrating downstream from the Upper Green River sub-watershed. Aitkin et al. (1996) found that migration of juvenile coho salmon through Howard Hanson Reservoir took a significantly longer time at both mid- and high-pool elevations. Travel times for both coho and steelhead smolts were longest at mid-pool. Travel time was more closely related to refill rate than pool level, increasing as refill rate increased. Survival of fish passing through the reservoir has been identified as a concern, but cannot be assessed using existing data.

Most fish migrating downstream past Tacoma's existing Headworks pass over the dam spillway, where there is a potential for fish to be injured. Although there is no site-specific information on the hydraulic conditions or injury or mortality of fish at the Tacoma Headworks, information from studies at other projects suggest that the rate of mortality experienced by juvenile fish passing over a 17-foot spillway is probably low (R2 1998; Seiler et al. 1992). The second avenue of passage available at the Headworks is the pipeline intake. The existing Headworks intake screens do not meet NMFS or State screen criteria and juvenile salmonids can potentially be impinged on the intake and killed; very small juvenile salmonids could pass through the existing screens.

Passage of fish in the mainstem Green River also is influenced by instream flows. Low flows in the Green River are most likely to adversely affect adult chinook salmon moving upstream in August and September when flows are generally lowest. Recent high levels of coarse sediment inputs upstream of HHD and alterations in the flow regime downstream of HHD have transformed sections of the mainstem channel from what is believed to have been predominantly a single-thread pool riffle channel morphology to a braided morphology consisting of numerous shallow flow paths. Mainstem low flow concerns have been documented in the middle Green River between RM 31 and RM 45 and in the upper Green River near RM 83. In addition, because of the porous nature of alluvial fans that form at tributary junctions, water flowing across the fans is rapidly lost to seepage, and flows may disappear before reaching the foot of the fan (Levin 1981). Recent increases in sediment delivery linked to land management activities, in conjunction with low levels of LWD and reduced streamflows, have exacerbated low flow concerns and may impede passage of adult salmonid. Low flow concerns have been identified at the confluence of the mainstem Green River and Newaukum Creek and in a number of tributaries in the Upper sub-watershed.

Subsurface flows have also been observed in the alluvial valley portion of the North Fork Green River during late summer (Noble 1969; Hickey 2000b) and could prevent salmonids from entering the river or moving upstream. Operation of the North Fork well field by Tacoma could reduce flows in the North Fork, although there is currently no data on the extent of this potential impact.

High temperatures are also believed to affect upstream fish passage. Temperatures that exceed the optimum range identified by NMFS have been observed throughout the watershed from the upstream end of Howard Hanson Reservoir to the estuary. Temperatures exceeding potentially lethal limits have been measured in the Lower Green River and Green/Duwamish Estuary. As late as 1985, kills of adult chinook were reported in the Green/Duwamish Estuary (LeVander 1999).

Passage concerns also have been identified on some of the larger tributaries. In 1958, an earthen dam was constructed on the Black River approximately 1,000 feet upstream of the confluence with the Green River. This blocked passage of anadromous fish into Springbrook Creek. In 1972, the U.S. Soil Conservation Service (SCS) replaced the dam with the Black River Pumping Station (BRPS). Although it is equipped with upstream and downstream passage facilities, the

BRPS still poses a barrier to the upstream and downstream movement of salmonids at certain seasons. The upstream passage facility is normally operated from mid-September through 31 January annually. The operational window likely precludes the upstream migration of some anadromous and resident cutthroat trout and steelhead, which migrate upstream in the spring.

The BRPS also has a downstream passage facility that is operated from early April to mid-June each year, for approximately eight hours per day, Monday through Friday. Fish attempting to move downstream outside of that operational window are either prevented from exiting the Springbrook system or must pass through the unscreened large pumps (if operational). Juvenile chinook emerge and begin moving downstream in the Middle Green River system and Soos Creek as early as February (Jeanes and Hilgert 2000). Consequently, early downstream migrants would be prevented from exiting the Springbrook system. The existing screens and their placement at the BRPS do not meet current NMFS screening criteria. Adult salmonids cannot pass downstream via the downstream fish passage facility at the BRPS. Chinook salmon have been known to move upstream and become trapped in the Springbrook Creek system, where there is little if any suitable chinook spawning habitat.

Finally, interactions between humans and fish during the period when adult salmon are moving upstream may affect reproduction success. Streamside recreation or fish viewing activities have been observed to reduce the rate of upstream coho migration in the Middle and Lower Green River (Malcom 1996). In-water activities such a canoeing also have been observed to displace adult coho salmon downstream (Malcom 1996). In addition to direct disturbances, mammalian odors, such as those arising from dogs and people, have been observed to temporarily disrupt and slow the upstream migration rate of adult coho and chinook salmon. Salmon will expend energy as they are displaced downstream and then must again expend energy to move back upstream. In portions of the river with elevated temperatures, the energy loss and stress has the potential to increase pre-spawn mortality and reproductive success. Displacement of salmon from redds may result in incomplete redd construction, selection of less preferred redd sites, and incomplete spawning.

KEY FINDINGS

- There are no known natural impassable barriers in the mainstem Green River up to RM 93. The historic upstream extent of anadromous salmonid use is presumed to have been around RM 93 based on an analysis of river gradient and a series of mapped cascades.

- The earliest documented anthropogenic barrier on the mainstem Green River was a wooden weir erected annually from 1904 to 1924 on the mainstem Green River at the confluence of Soos Creek to allow capture of adult chinook in the mainstem.

- The Tacoma Headworks, which began construction in 1911 and was finished in 1913, was the first permanently constructed barrier to adult salmon and steelhead in the Green River. This dam has blocked anadromous salmonids from natural migration and reproduction in the Upper Green River sub-watershed for nearly 90 years.

- Salmonids that are not naturally produced (e.g., hatchery planted juveniles), juveniles from adult steelhead that were transported upstream of the dams, and resident trout may migrate downstream past Tacoma's existing Headworks. Most pass over the dam spillway, where there is a potential for fish to be injured. The second avenue of passage available at the Headworks is the pipeline intake. The existing Headworks intake screens do not meet NMFS or State screen criteria (1/4" mesh size from center strand to center strand, with 5/32" openings) and juvenile salmonids can potentially be impinged on the intake and killed; very small juvenile salmonids could pass through the existing screens.

- Howard Hanson Dam completed construction in 1962 at RM 64.5 and represents another complete barrier to the upstream passage of anadromous and resident fish. There are two main concerns regarding downstream fish passage associated with Howard Hanson Dam:

    1. **Passage through the dam**. The low survival rate of fish passing through Howard Hanson Dam is primarily a function of two factors: 1) the spring refill operation strategy, which influences the ability of fish to locate the outlets; and 2) the low survival of juveniles passing through the bypass outlet pipe. Current annual survival of juvenile salmon and steelhead migrating through HHD outlets is estimated to be between 5 and 25 percent based on a fish passage model and on-site monitoring data (Dilley and Wunderlich 1992, 1993). Out-migrant studies indicate that there is little or no injury to juvenile fish using the radial gates (Seiler and Neuhauser 1985; Dilley and Wunderlich 1992; 1993), but injury rates through the bypass pipe range from 3 to almost 90 percent, depending on species and environmental conditions.

    2. **Passage through the reservoir**. Aitkin et al. (1996) found that migration of juvenile coho salmon through Howard Hanson Reservoir took a significantly longer time at both mid- and high-pool elevations. Travel times for both coho and steelhead smolts were longest at mid-pool. Travel time was more closely related to refill rate than pool level, increasing as refill rate increased. Survival of fish passing through the reservoir has been identified as a concern but cannot be assessed using existing data.

- Recent high levels of coarse sediment inputs upstream of HHD and alterations in the flow regime downstream of HHD have transformed sections of floodplain channel types from essentially a single-thread pool riffle channel morphology to a braided morphology consisting of numerous shallow flow paths. These shallow paths are most likely to adversely affect juvenile coho and steelhead rearing in the mainstem and adult chinook salmon moving upstream in August and September when flows are generally lowest. Mainstem low flow concerns have been documented in the middle Green River between RM 31 and RM 45 and in the upper Green River near RM 83.

- Low flow concerns have been identified at the mouths of several of the Green River's tributaries, including Newaukum Creek and a number of streams in the Upper sub-watershed. This largely is due to the porous nature of alluvial fans. Water flowing across these fans is rapidly lost to seepage, and flows may disappear before reaching the foot of the fan (Levin 1981). An increase in channel sediment from logging in the Upper Green River sub-watershed, lower flows in the Middle Green River, and low levels of LWD in both reaches have exacerbated low flow concerns and may impede passage of adult salmonids.

- Subsurface flows have been observed in the North Fork Green River during late summer (Noble 1969; Hickey 2000b), and could prevent salmonids from entering the river or moving upstream. Operation of the North Fork well-field by Tacoma could reduce flows in the North Fork, although there currently are insufficient data on the extent of this potential impact.

- Water quality degradation can pose significant barriers to salmonid migration. Temperatures that exceed the optimum range identified by NMFS have been observed throughout the watershed from the upstream end of Howard Hanson Reservoir to the estuary. Temperatures exceeding potentially lethal limits have been measured in the lower Green River and Green/Duwamish estuary. As late as 1985, kills of adult chinook were reported in the Green/Duwamish estuary presumably from inadequate water quality parameter(s) that are not specified in this report

- In 1958, an earthen dam was constructed on the Black River, 1000 feet upstream from the Green River. Besides impeding salmonid migration into the Springbrook Creek system, this dam blocked flows from the Green River from backwatering into the remnant Black River, which could have provided some refuge habitat for salmonids during high flows. In 1972, the US Soil Conservation Service replaced the dam with the Black River Pumping Station (BRPS), which currently is operated by King County. Although it is equipped with upstream and downstream fish passage facilities, the BRPS can act as a barrier to migration of juvenile and adult salmonids due to inadequate screening, fishway design, and operation schedule.

- Adult salmonids cannot pass downstream via the downstream fish passage facility at the Black River Pumping Station. Chinook salmon have been known to move upstream and become trapped in the Springbrook Creek system, where there is little if any suitable chinook spawning habitat.

- Streamside recreation or fish viewing activities have been observed to reduce the rate of upstream coho migration in the Middle and Lower Green River (Malcom 1996). In-water activities such canoeing have also been observed to displace adult coho salmon downstream (Malcom 1996). In addition to direct disturbances, mammalian odors, such as those arising from dogs and people, have been observed to temporarily disrupt and slow the upstream migration rate of adult coho and chinook salmon. Salmon will expend energy as they are displaced downstream and then must again expend energy to move back upstream. In portions of the river with elevated temperatures, the energy loss and stress have the potential to increase pre-spawn mortality and reduce reproductive success. Displacement of salmon from redds may result in incomplete redd construction, selection of less preferred redd sites, and incomplete spawning.

DATA GAPS

There is limited information on the location of natural barriers or historical fish distribution, particularly for the Upper Green River sub-watershed:

- There is little information available to assess the historic impacts of operation of Tacoma's North Fork well field on fish passage in the North Fork Green River.

- The available information is inadequate to assess survival through Howard Hanson Reservoir.

- The rate of injury or mortality (if any) for fish passing the existing Tacoma Headworks is unknown.

- Data on fish passage barriers and other physical habitat in Newaukum and Soos Creeks is incomplete. This lack of physical habitat information is a WRIA-wide data gap for all tributary and mainstem reaches.

INTRODUCTION

Anadromous salmonids require passage between the ocean where the fish grow and mature to their natal streams where adult fish spawn, eggs incubate, and juvenile fish rear for a period of weeks to years. Resident fishes such as bull trout often reside in mainstem or large tributary channels, migrating upstream to spawn in small headwater streams or lakes. Upstream and downstream fish passage is influenced by physical impediments such as natural waterfalls, dams, or culverts; by hydrologic factors that influence variations in the flow regime; and by biological factors such as predation or behavioral responses to disturbances.

Natural physical barriers within the Green River Watershed include waterfalls, steep gradient cascades, or tributary channels that become too small or steep to support fish. The most common anthropogenic physical barriers in most watersheds are those associated with road crossings. Culverts installed to pass flow beneath roads my have perched outlets that exceed the leaping ability of some species. Other passage concerns frequently identified at culverts are high velocities, shallow flows, or steep gradients. Debris or sediment that collects at the culvert inlet may also interfere with or prevent up and downstream passage. Other anthropogenic physical barriers in the Green River Watershed include dams that have been constructed for flood control, water diversion, or other purposes.

Up and downstream migration of salmonids also is affected by hydrologic conditions. Naturally occurring low flows act to delay fish from moving into some tributary channels until flows are great enough to support successful spawning. Species that utilize shallow, low gradient tributaries that may be susceptible to low flows or adverse water quality conditions, such as chum and coho, have developed life histories such that upstream migration is timed to occur in seasons when flows are higher. Other species, such as steelhead and coastal cutthroat trout, which prefer steep, high gradient headwater channels, spawn in the spring when high flows that frequently scour the beds of such channels are less likely to occur. Water use and dams alter hydrologic conditions, interfering with upstream and downstream fish passage through reduced streamflows or lower flow velocities.

Finally, biological factors also can interfere with the upstream and downstream movement of fish. Adverse water quality conditions (e.g., high temperatures or low dissolved oxygen levels) may cause fish to avoid certain areas or delay their upstream migrations until conditions improve. Concentrations of predators caused by changes in habitat or riparian characteristics may prey on juvenile fish as they move downstream. Disturbances by recreational users or activities taking place on the stream banks may temporarily displace fish or increase stress levels and energy expenditure.

The following sections describe upstream and downsteam passage concerns in the mainstem Green River and larger tributaries (Soos, Newaukum and Springbrook creeks). Passage concerns on tributary streams are discussed further in Chapter 3.

UPPER GREEN RIVER (RM 64.5 TO RM 93)

PHYSICAL BARRIERS

NATURAL BARRIERS AND IMPEDIMENTS

There is only limited observational data of the most upstream extent of use by anadromous fish in the Upper Green River sub-watershed. Since the release of adult fish into the Upper Green River sub-watershed was initiated in 1980, winter steelhead have been observed spawning in the mainstem Green River as far upstream as RM 83 (Cropp 1999). The presumed historic upstream extent of use by chinook, steelhead, and coho was estimated by identifying the location at which the channel gradient steepened to over 12 percent, at approximately RM 91.8 (Cutler 2000). Numerous researchers have demonstrated a strong linkage between habitat features, gradient, and fish use (Montgomery et al. 1999; Benda et al. 1992; Kozel et al. 1987). The 12 percent gradient criterion is used by the Salmon and Steelhead Habitat Inventory and Assessment Project (SSHIAPP) to estimate the maximum potential extent of use by chinook, coho, sockeye, steelhead, and pink salmon; chum salmon are assumed to utilize only channels with a gradient of less than 8 percent. Although no known impassable barriers are mapped for the Upper Green River, the 12 percent gradient break generally coincides with the location of a series of cascades identified by Williams et al. (1975), supporting the presumption that this part of the channel probably represented the historic upstream-most extent of use by anadromous salmonids.

CULVERTS

There are no documented barrier culverts that would impede upstream migration in the mainstem Green River between Howard Hanson Reservoir and the confluence with Sunday Creek (Fox 1996; Fox and Watson 1997). However, a number of culverts that potentially prevent passage of juvenile salmonids into tributary streams have been identified (Figure Pass-1). Barriers to and in the tributary channels will be discussed in detail in Chapter 3.

HOWARD HANSON DAM

Howard Hanson Dam, located at RM 64.5, was constructed without upstream fish passage facilities. The Tacoma Headworks at RM 61.5 has blocked the upstream passage of anadromous salmonids in the mainstem Green River and to upriver tributaries since 1911. Upstream and downstream passage conditions at Tacoma's Headworks are described in the following section, (Middle Green River sub-watershed).

Construction of Howard Hanson Dam was completed in 1964. Flow is discharged from the reservoir through a 900-foot long, 19-foot wide concrete-lined horseshoe tunnel located near the south abutment of the dam. Two 10-foot by 12-foot high radial gates (invert elevation 1,035 feet) in the intake tower discharge flow through the tunnel in normal flow periods (Figure Pass-2). When water is stored behind the dam (spring and summer) flows are passed through a 48-inch bypass pipe that runs under the outlet tunnel and discharges into a stilling basin. The bypass entrance is an 8-foot square opening (elevation 1069 feet) with the 48-inch bypass pipe exiting through the floor of the bypass entrance. Flow through the bypass pipe (maximum discharge is 560 cfs) is controlled via a valve located on the downstream end (elevation 1,024 feet).

Plans are currently underway to improve fish passage at HHD. Downstream passage facilities will be provided as part of the USACE's proposed Additional Water Supply Project (AWSP). Tacoma will implement a fish trap and haul program as part of the Muckleshoot Indian Tribe/Tacoma Public Utilities Settlement Agreement. A fish collection facility will be constructed at the Tacoma Headworks, consisting of a fish ladder and holding facilities. Adult fish will be transported using a fish tank and truck. Any upstream passage of fish will be conducted under the direction of the NMFS and USFWS; upstream passage of fish currently listed as Threatened or Endangered under the ESA may be prohibited until it is demonstrated that the upstream passage program meets performance criteria (Hickey 2000a).

Upstream Migration

Howard Hanson Dam represents a complete barrier to the upstream passage of anadromous and resident fish. The Howard Hanson Dam Fish Passage Technical Committee (FPTC)[1] determined that a trap-and-haul facility in the vicinity of the Tacoma Headworks at RM 61 represented the most feasible method of passing fish over the 235- foot-high HHD. The FPTC does not consider construction of a fish ladder to pass anadromous salmonids over HHD a feasible alternative to restoring fish passage. If fish were passed into the 3.5-mile long reach upstream of the Tacoma Headworks, another barrier dam would have to be constructed between the Headworks and HHD to direct fish into the entrance of the HHD upstream passage facility. Howard Hanson Dam could not be used as a fish passage barrier because the outlet area is used to dissipate energy, thus fish would have a difficult time finding the entrance to a passage facility. The new barrier dam would have to be at least 12 feet high to ensure upstream migrants were successfully directed into the entrance of the passage facility, and would have to be located far enough downstream to avoid backwatering the HHD outlets.

Provision of upstream passage at HHD using a fish ladder with gradient of less than 12 percent would require a ladder at least 1,900 feet in length. Fish ladders of this length are uncommon because of habitat conditions within the ladder and water temperature concerns. Adult salmonids attempting to ascend a ladder of this length and height would be exposed to stress and potential

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[1] The Fish Passage Technical Committee is an advisory group convened by Tacoma and the USACE. The committee is a broad-based group of public and private individuals experienced in the design and evaluation of fish passage facilities; members include independent consultants and specialists from WDFW and NMFS. The initial purpose of the FPTC was to provide a planning document for use in the development of a permanent downstream fish passage facility at HHD under the AWSP. The FPTC will continue to supervise, provide guidance, and recommend modifications of the facility during the final design and construction phases of the project.

water quality deterioration. According to draft Washington State guidelines, fish transit times through fish ladders should be less than about 6 hours, effectively limiting the maximum height of a fish ladder to about 90 feet (Bates 2000).

Another limitation to installing a fish ladder at HHD is the large fluctuation in the reservoir level. Since the primary function of HHD (as authorized by Congress) is flood control, the water level behind the dam can vary by more than 150 feet during times when adult salmon and steelhead are migrating upstream. During times when the pool elevation is low, the fish that ascended the 235-foot high ladder would then need to be lowered as much as 150 feet to the level of the reservoir pool behind the dam. This would require that the adult fish either be returned in a high-velocity slide/chute to the pool level or via some type of mechanical elevator. In either case, the fish would experience additional stress associated with the passage facilities.

In addition, since the HHD reservoir pool must be drained prior to the flood control season, returning fish to the reservoir near the dam could greatly increase the rate of adult fallback if the fish remained in the reservoir and the pool was drawn down rapidly to prepare for flood storage. As an alternative to returning fish to the downstream end of the reservoir, the fish ladder could be extended to the upper end of the pool; however, this would entail extending the fish ladder by approximately 7.0 miles upstream of the dam. While an upstream ladder of this length is theoretically feasible, the risk of failure is much higher than a trap-and-haul facility.

Downstream Migration

Since 1982, between two and four million juvenile salmon and steelhead annually have been released upstream of HHD (USACE 1998). Current annual survival of juvenile salmon and steelhead migrating through HHD outlets is estimated to be between 5 and 25 percent based on a fish passage model and on-site monitoring data (Dilley and Wunderlich 1992, 1993). There are two main concerns regarding donwstream fish passage associated with Howard Hanson Dam:

- **Passage through the dam**. The low survival rate of fish passing Howard Hanson Dam is primarily a function of two factors: 1) the spring refill operation strategy, which influences the ability of fish to locate the outlets;

- **Passage through the reservoir.** The low survival of juveniles passing through the bypass outlet pipe. The original operational strategy for the HHD project, generally followed from 1962 to 1983, delayed the start of reservoir refill until June and thereby would have provided successful passage of downstream migrants (if present) through the radial gates. Once reservoir refill was initiated, nearly all inflow was stored and only water required to satisfy the existing instream flow target of 110 cfs at Palmer was released. Storing the water as quickly as possible minimized the duration, but exacerbated the magnitude of downstream impacts by dramatically cutting flows to the lower river once reservoir refill began. The historic refill strategy reduced flows from an average of 1,140 cfs at Auburn to a low flow of 234 cfs for an average 12-day period in early June (USACE 1995).

Between 1984 and 1991, HHD reservoir refill was delayed to allow for outmigration of juvenile salmonids, primarily through the radial gates. Between 1992 and 1998, HHD reservoir refill commenced much earlier, beginning in late March to mid-April, and the bypass pipe was used more frequently. Changes in the refill operations since 1991 gave priority to downstream resources, in particular steelhead spawning and incubation. Instead of delaying refill until late May, refill was typically begun in early to mid-April, before the peak of outmigration from the Upper sub-watershed. This change in operations resulted in decreased survival of smolts in following years. In particular, during low runoff years, early refill and low outflow appear to entrap a large portion of the outmigrating juveniles (Dilley and Wunderlich 1992, 1993). In 1992, at least 42 percent of all coho smolts outmigrated after their normal emigration season, and an unknown number may have residualized or died before emigrating during fall drawdown (Dilley and Wunderlich 1993).

The primary conclusion of dam passage outmigrant studies conducted in HHD reservoir was that spring refill, especially early spring refill, substantially delays and/or entraps migratory juvenile salmonids (Seiler and Neuhauser 1985; Dilley and Wunderlich 1992; 1993). Spring refill coincides with the main outmigration period of juvenile salmonids. As the pool fills, the outlets are submerged to depths of 35 to 112 feet. As inflow to the reservoir recedes, outflow from the dam is routed to the bypass pipe (flows less than 500 cfs).

During outmigration, juvenile fish may not find or be willing or able to use outlets that are deeply submerged. Juvenile fish require a near surface-outlet (typically 5 to 20 feet below the water surface) with a high discharge capacity outlet (exact volumes depend on site conditions). Therefore, at a time when fish need high flows and a shallow outlet, the project is reducing outflow (refill) and creating a deeper outlet (from 35 to 112 feet deep). Significant reductions in passage of coho yearlings during reservoir refill were observed in 1991. A large pulse of downstream yearling coho migrants was observed when discharge was switched to the radial gates in 1992, suggesting that fish are entrapped behind HHD when flows are passed through the bypass pipe during outmigration (Dilley and Wunderlich 1992; 1993). The USFWS researchers observed no significant relationships between passage of yearling chinook and outflow or operation of the bypass pipe. Chinook subyearlings were the only juvenile salmonids passing through the dam when the outlet pipe was submerged. However, the bulk of subyearling movement occurred during periods of high flows when the radial gates were in operation (Dilley and Wunderlich 1992; 1993). Of those smolts that do migrate downstream in the late summer and fall after being trapped in the reservoir, a large number are killed or injured because flows are generally passed through the bypass pipe at this time of year (USACE 1998).

Outmigrant studies indicate that there is little or no injury to juvenile fish using the radial gates (Seiler and Neuhauser 1985; Dilley and Wunderlich 1992; 1993). Juvenile fish passing HHD through the 10-foot diameter radial gates drop 26 feet under 45 feet of hydraulic head into a stilling basin with a concrete floor. In 1984, using test and control releases of fish into the radial and bypass gates, WDFW observed little injury or mortality of captured steelhead and coho smolts that had passed through the radial gates (Seiler and Neuhauser 1985).

In contrast, fish that pass through the 48-inch bypass pipe experience high mortality from impacts at sharp bends or turns within the pipe. Direct mortality in the bypass pipe can range from 1 percent to 100 percent depending on the amount of flow, water temperature, pool elevation, and time of year. During passage studies conducted in 1984, smolts introduced into the bypass pipe were injured or killed at the following rates: of 347 coho smolts examined, 9 were dead or severely injured (2.6%); and of 29 steelhead smolts examined, 10 were dead (35%)

(Seiler and Neuhauser 1985). Researchers from the USFWS also found higher injury and mortality rates for juveniles captured after passing through the bypass pipe than those that passed through the radial gates. In 1992, over 33 percent of all chinook subyearlings and 14 percent of chinook yearlings captured were dead following passage through the pipe (Dilley and Wunderlich 1993). The same USFWS researchers considered the observed mortality rate to be much lower than the actual rate, as numerous dead and injured fish were sighted in the tailrace but never captured and counted. In addition, up to 36 percent of chinook subyearlings, and 37 percent of chinook yearlings were injured or fully- to partially-descaled. Higher head (higher pool elevation) and warmer water temperatures may increase the injury rate; during one three-day period in September 1992, almost 90 percent of all captured juvenile chinook that passed through the bypass were found dead (Dilley and Wunderlich 1992; 1993). Coho yearling mortality was also high; between 14 May and 25 September, 25 percent of the yearling coho captured were dead (Dilley and Wunderlich 1992; 1993). The mortality of coho subyearlings was the lowest of all life stages (5 %), but those fish had the highest rate of descaling (32%).

HYDROLOGIC BARRIERS

LOW INSTREAM FLOWS

Low flows in the Green River are most likely to adversely affect adult chinook salmon that begin moving upstream in August and September when flows are generally lowest. Adult chinook require flow depths of at least one foot for unimpeded upstream passage (Bell 1986). Recent high levels of coarse sediment inputs have transformed many sections of the river upstream of HHD from essentially a single-thread pool riffle channel morphology to a braided morphology consisting of numerous shallow flow paths (Cupp and Metzler 1996; O'Connor 1997). Consequently, the upstream passage of adult chinook salmon is susceptible to delays and/or blockage during water years marked by low flows during the late fall and winter. For example, recent observations by USACE personnel during August and September indicated that a section of channel located near RM 84 went subsurface at low flows (Goetz 2000). The Green River left its former channel at this site, cutting across an airstrip at the former Lester Airport; the newly carved channel is straight, steep and shallow with a braided morphology. Observations made in the same area near the end of August 1998 noted a series of impediments to the upstream migration of chinook (MITFD 1998). These impediments took the form of extensive areas of shallow flow (<2 inches deep) and sharp breaks in stream gradient. At gradient breaks, the stream rose 1 to 2 feet over a distance of 2-4 feet and no pools that would facilitate jumping had formed at the downstream end. This combination of shallow flows and steep gradient breaks would impair the upstream migration of adult chinook salmon, particularly at the end of a long, energetically expensive journey to reach the Upper sub-watershed.

In addition to low flow concerns in the mainstem Green River, low flows may impede passage of adult fish into some of the larger tributaries. For example, eleven tributaries evaluated for the Lester Watershed Analysis have formed relatively steep (4-10 percent) alluvial fans where they leave the mountains and flow onto the Green River floodplain (Cupp and Metzler 1996). Because of the porous nature of the sediment deposits that create such landforms, water flowing across the fans is rapidly lost to seepage, and flows may disappear before reaching the foot of the fan (Levin 1981). Recent increases in sediment delivery from road and timber harvest-related landslides, in conjunction with low levels of LWD are have exacerbated low flow concerns at a number of tributary junctions, including Olsen Creek, Sweeney Creek, Humphrey Creek, and a number of unnamed tributaries (Malcom 1998) (Figure Pass-1). Low flow concerns and other impediments to fish passage in tributary channels are discussed in detail later in the chapter.

Subsurface flows have also been observed in the North Fork Green River during late summer (Noble 1969; Hickey 2000b) and could prevent salmonids from entering the river or moving upstream. Tacoma operates a well-field that taps the North Fork Green River aquifer, using the water to partially replace surface flows when the turbidity of the Green River reaches 3 NTUs and to completely replace surface flows at turbidity levels of 5 NTUs or greater.

The risk that Tacoma's use of the well field would adversely affect fish is greatest in the late summer and early fall. Turbidity data collected from the Green River over a five year period in the 1960's indicated that it is unlikely that there would be a need to operate the well field during July and August. However, there have been flows with a turbidity in excess of 5 NTU's in September that would necessitate use of the well field (see Table HYDRO-1 in the Hydrology section of this report). If pumping were to occur without a concurrent storm-related rise in streamflow, adult salmonids holding in the lower North Fork Green River channel could be exposed to channel dewatering or prevented from moving upstream into the North Fork Green River. There currently are no data regarding the effect of well-field use on the up or downstream passage of salmonids in the North Fork Green River. However, it is believed that use of the wells can affect flows in the North Fork Green River. Groundwater dynamics and the North Fork well-field operation are discussed in detail in Chapter 2.1 (Hydrology).

HOWARD HANSON RESERVOIR

In addition to exit-related delay, entrapment and injury, there is concern that juvenile salmon and steelhead require additional travel time to migrate through Howard Hanson Reservoir. The size of a low velocity impoundment can affect the outmigration of juvenile salmonids by causing residualization, extending the duration of travel and decreasing fish survival. The size of HHD reservoir ranges from 100 acres (1.5 miles long) to 871 acres (approximately 4.6 miles long) depending on the pool elevation (Table Pass-1). During the winter flood control season, the reservoir behind HHD is essentially held empty (pool elevation below 1,070 MSL), except when floodwaters are retained to provide downstream flood protection, which are then subsequently released. Between floods, conditions in the HHD reservoir are run-of river. At the maximum summer conservation pool elevation of 1,141 feet MSL, which is generally achieved by early June, the surface area of the impoundment is 871 acres with a volume of 30,400 acre feet. The reservoir is approximately 4.6 miles long at this pool level and has a perimeter of about 13 miles.

Juvenile salmonids moving downstream during their spring outmigration must pass through Howard Hanson Reservoir before reaching the dam. When the reservoir pool elevation is held below 1,070 feet MSL, outmigrants are assumed to pass quickly and safely through the pool in conditions approximately equivalent to run-of-river. As the reservoir level rises, downstream migrating fish must pass through an increasingly larger slack-water area. Juvenile salmonids migrating though the larger reservoir pool can be delayed, which affects smolt survival, timing of ocean transition, and thermal imprinting. As a general rule, juvenile outmigrant fish appear to cue into changes in water velocity, and, except when holding for resting or feeding, move towards areas of higher velocities within the low velocity reservoir.

Aitkin et al. (1996) found that migration of juvenile coho salmon through Howard Hanson Reservoir took a significantly longer time at both mid- and high-pool elevations (Figure Pass-3). Travel times for both coho and steelhead smolts were longest at mid-pool. Travel time was more closely related to refill rate than pool level, increasing as refill rate increased (Aitkin et al. 1996). Chinook juveniles were released only at high pool and at that reservoir level had a travel time comparable to coho. All fish utilized in this study were from hatchery releases. Chinook juveniles released for this study were held for extended rearing with the objective of growing them to the size of coho smolt prior to release, but due to budgetary constraints and slower than expected growth the size of chinook released ranged from 107 to 117 mm. These lengths were somewhat smaller than the 130 mm threshold used for coho but larger than would be expected for naturally spawned sub-yearling chinook (Warner 1996). Aitkin et. al. (1996) also found a weak relationship between fish size and migration rate, suggesting that delay may be of most concern for small, young chinook. Unfortunately it is difficult radio tag fish this size.

Out of 234 fish released, 150 tags were ultimately recovered at the HHD forebay. The fate of the remaining fish is unknown. Receivers missed or created false detections for 25 percent of the fish; other fish were never detected by the fixed receivers (Warner 1996). Overall, only 35 percent of the chinook released were detected in the reservoir forebay (Warner 1996). The detection rate was somewhat greater for coho and steelhead (average rate of 54 percent and 69 percent respectively). However, the detection rate varied with pool level, generally increasing as pool level increased (Table Pass-2). Radio-tagging studies performed to date are a reasonable means of assessing travel time and delay, but they cannot be used to assess survival of fish through the reservoir. At this time, it is unknown whether the reason fish were not detected in the reservoir forebay was a result of equipment or tag failure, predation, or residualism. Although unpublished data indicate that a number of fish were lost to predation (Warner 2000), additional studies are required to assess the reason for the relatively low tag-detection rate.

BIOLOGICAL BARRIERS

WATER TEMPERATURE

The optimum temperature range for upstream migration of chinook salmon is between 49 and 57.5^{o}F (Bell 1986). High temperatures increase the metabolic rate and result in the fish expending a greater amount of energy; adult fish have been known to cease migrating or die unspawned when subjected to extreme temperatures (Bell 1986). Lethal levels for adult salmonids vary according to such factors as acclimation temperature and the duration of the increase, but they are generally in the range of 73 to 84 ^{o}F (Bjornn and Reiser 1991; Caldwell 1994). Although the Upper Green River is not listed on the 1998 Washington State 303(d) list for temperature violations, water temperatures of inflow to HHD generally exceed the Class AA standard of 60.8^{o}F at some point in most years (USACE 1998). This is greater than the preferred temperature range for rearing and spawning salmonids, and thus could delay upstream migration of adult fish. Furthermore, exposure to these temperatures occurs after the fish have undergone a stressful, energetically expensive journey through the warm waters of the Lower and Middle Green River and have ascended through the turbulent water and steep cascades of the Green River gorge. The effect of temperature-induced stress on the fitness and reproductive ability of salmonids in the mainstem Green River is currently unknown.

PREDATOR CONCENTRATIONS

There is currently no data on the rate of predation on downstream migrating juvenile salmonids in the HHD reservoir. Past experience at other Pacific Northwest reservoirs has revealed that downstream migrating juvenile salmonids may encounter increased predation when they enter a low velocity impoundment. Populations of predators (e.g., northern pike minnow [Ptychocheilus oregonensis]) have been listed as a cause of lower survival of juvenile salmonids in many Pacific Northwest systems (Cada et al. 1994; Ledgerwood et al. 1994). Rieman et al. (1991) estimated that 14 percent of all juvenile salmonids that enter the John Day Reservoir on the Columbia River are consumed by a combination of northern pikeminnow, walleye (Stizostedion vitreum), and/or smallmouth bass (Micropterus dolomieui). Surveys of the HHD Reservoir to date have not identified warmwater gamefish or northern pikeminnow; however, large resident trout or residualized salmon represent a predation risk to downstream migrating salmonids (Tacoma 1999).

MIDDLE GREEN RIVER SUB-WATERSHED (RM 32 TO RM 64.5)

PHYSICAL BARRIERS

NATURAL BARRIERS AND IMPEDIMENTS

There are no natural physical barriers or impediments to upstream migration on the mainstem Green River in the Middle Green River sub-watershed.

SOOS CREEK WEIR

From 1904 to 1924, a wooden weir was erected annually near the on the mainstem Green River at the confluence of Soos Creek to allow capture of adult chinook in the mainstem (Becker 1967). The weir often washed out during high flows in October, however, presumably allowing numerous fish to escape and continue upstream.

TACOMA HEADWORKS

In 1913, construction of Tacoma's Headworks Diversion Dam at RM 61.0 was completed 3.5 river miles downstream of the eventual site of HHD (Figure Pass-4). The existing concrete gravity diversion dam is 17 feet high with a crest length of 150 feet. The dam is founded on bedrock and both abutments are keyed into rock. The diversion supplies water to a pipeline that carries water from the diversion dam south and west to Tacoma. The pipeline has a capacity of 113 cfs. The existing intake is 20 feet wide and located in the right abutment immediately upstream of the existing diversion dam.

The existing Headworks dam currently lacks permanent upstream and downstream fish passage facilities and represents a complete barrier to upstream migrating adult salmonids. Plans are currently underway to modify the Headworks as part of the Second Supply Project and include provisions for both upstream and downstream passage facilities.

Upstream Passage

The Tacoma Headworks diversion dam was the first complete barrier to adult salmon and steelhead in the Green River. It eliminated naturally reproducing anadromous fish production in the Upper sub-watershed for 80 years. Since 1992, the Muckleshoot Indian Tribe (MIT), Tacoma, WDFW, and Trout Unlimited have cooperatively administered a temporary fish ladder and trap-and-haul program. Under the pilot program, between 7 and 133 adult steelhead have been captured at the Headworks fish trap and either released upstream of HHD for natural spawning or used to produce fry for outplanting in the Upper Green River sub-watershed.

Downstream Passage

The existing Headworks has minimal fish screening facilities. Two routes are currently available to juvenile fish migrating downstream below Tacoma's existing Headworks. The first is direct passage over the dam spillway. Water flows over the dam and onto a flat concrete apron (Figure Pass-5)

In general, mortality of juvenile fish passing over dams is a function of the height of the structure, the maximum velocity of water (which is primarily dependent on dam height), and the configuration of the channel immediately downstream of the dam. For small fish (<100 mm), mortality is near zero even for falls of as much as over 100 feet, provided they land in water (Figure Pass-6). Larger fish (>300 mm) begin to experience mortality at falls greater than 50 feet (Figure Pass-6). Fish mortality is also influenced by the maximum velocity of the flow passing over a dam (Figure Pass-7). Where flows passing over a dam empty into a deep pool or stilling basin, mortality is essentially zero at velocities less than 40 feet per second (fps). However, shallow flow or obstructions such as exposed rocks below the spillway appear to increase the rate of mortality (Figure Pass-7) and injury. Approximately seven to eight percent of the juvenile salmonids passing a 190-foot high sediment retention structure on the North Fork Toutle River were injured by passage down a 480-foot long section of an exit ramp with a rough surface that discharged into a pool containing large rocks at a velocity of 50 fps (Seiler et al. 1992).

Although there is no site-specific information on the hydraulic conditions or injury or mortality of fish at the Tacoma Headworks diversion dam, information from studies at other projects suggest that the rate of mortality experienced by juvenile fish passing over a 17-foot spillway is probably low (R2 1998; Seiler et al. 1992). Fish passing through the radial gates at HHD drop 26 feet onto a concrete slab with no apparent injury (Seiler and Neuhauser 1985). However, because the channel configuration downstream of the Headworks diversion dam consists of a shallow concrete apron (Figure Pass-8), it must be assumed that juvenile and adult salmonids passing downstream over the Tacoma Headworks under its current configuration could be injured at some flows.

The second avenue of passage available at the Headworks is the pipeline intake. The existing intake screens are galvanized steel measuring 1/4" from center strand to center strand, with 5/32" openings. The existing Headworks intake screens do not meet NMFS or State screen criteria and juvenile salmonids can potentially be impinged on the intake and killed (Tacoma 1999). In addition, very small juvenile salmonids could pass through the existing screens.

Under its First Diversion Water Right Claim (FDWRC), Tacoma has withdrawn up to 113 cfs of water at the Headworks diversion facility since 1913. Before about 1950, withdrawals were generally less than 113 cfs. However, since about 1950, the pipeline has been operated at capacity. During periods of high turbidity, the North Fork well field is used as an alternate source of clear water or mixed with surface water from the Green River to reduce turbidity levels to less than 5 NTU's. Since periodic high turbidity events are relatively common during the spring, the actual average daily withdrawal during the period juvenile salmon are migrating downstream (February through June) is currently somewhat lower than 113 cfs. For 1997 through 1999, average daily withdrawal from the Green River was 89.3 cfs for March, 88.3 cfs for April, 93.3 cfs for May, and 106.7 cfs for June (Hickey 2000c). These withdrawals represent approximately four to nine percent of the average daily flows (Table Pass-3).

In addition, fish congregating in front of the screens were often drawn into the intake when the screens were being cleaned (Hickey 2000a). Juvenile salmon believed to have been released upstream of HHD have been identified in McMillin Reservoir (Finney 2000). Fish entrained into the flow line no longer contribute to the Green River salmonid population.

In 1997, backup screens were installed behind the regular screens in order to maintain a screened intake when the front screens were being cleaned (Figure Pass-8). Since that time, no juvenile salmonids have been observed in McMillin reservoir (Hickey 2000b). The physical and flow characteristics of the backup screens are similar to the primary screens. Consequently, the potential for injury and mortality when the backup screens are in use is the same as that for the primary screens.

CULVERTS

There are no stream crossings (culverts or bridges) that represent barriers to upstream or downstream passage in the mainstem through the Middle Green River sub-watershed. A number of culverts and levees that prevent access to tributary channels and off channel have been identified (Figure Pass-4). These barriers may prevent access to protected lateral habitats for juvenile salmonids rearing in the mainstem Green River. Passage barriers on individual tributaries will be discussed in further detail later in this chapter.

HYDROLOGIC BARRIERS

LOW INSTREAM FLOWS

Between RM 32 and RM 45, the Green River is unconstrained by levees in many areas and is therefore substantially wider than the channelized Lower Green River (RM 0 to RM 25) or the Green River gorge (RM 45 to RM 58). The current morphology of the Middle Green River was largely determined by major floods in the late 1950s, before construction of HHD (Perkins 1993). Thus, under the existing flow regime, the Green River channel from RM 32 to RM 45 is wider and shallower than would be expected in a similar river with a similar natural flow regime. At a flow of 1,000 cfs at Auburn, the average wetted width of the middle Green River was 148 feet as compared to 119 feet in the lower Green River (Caldwell and Hirschey 1989). Historically, the wetted width has been substantially narrower than 148 feet when chinook began spawning in early September through October because flows at that time rarely exceeded 600 cfs and were often less than 400 cfs (Malcom 2000).

Under the existing flow regime there are a number of areas where the upstream passage of chinook is susceptible to blockage or impairment during low flow conditions (Figure Pass-4). Analysis of transect and stage:discharge data collected at shallow riffles in the Middle Green indicated that flows of 225 cfs had a depth of at least one foot (Caldwell and Hirschey 1989), which should provide sufficient upstream passage for adult chinook salmon. However, surveys conducted by the Muckleshoot Indian Tribe between 30 August and 1 September 1999, found an average depth of 0.74 feet over riffles. In many instances, the average depth over individual riffles was shallower and no deeper water routes around the riffle were observed (Malcom 2000). Flows at Auburn during those surveys ranged from 291 to 301 cfs (USGS 2000). Historically, late summer low flows lower than 225 cfs were common and have been known to impede the upstream migration of adult chinook salmon. For example, during severe drought conditions in 1987 when annual seven-day low flow at the Auburn gage was 157 cfs, the MIT and WDFW hand-excavated channels through riffles in the vicinity of Neely Bridge (RM 41) to provide adult salmon passage through shallow areas (Hickey 1999).

The extent to which the recently observed low flow barriers exceed those that would have occurred under natural conditions is unclear. The extent of braided and multiple thread channels was greater in the early part of the 20th century, which may have resulted in flows low enough to restrict passage to upstream reaches even under natural conditions. Such barriers may serve to prevent fish from entering areas where they would otherwise be susceptible to high water temperatures or predation. However, changes in the flow regime, sediment transport regime, and physical habitat have likely exacerbated natural low flow conditions and are believed to have negatively impacted anadromous salmonids in the Green River (Grette and Salo 1986).

BIOLOGICAL BARRIERS

WATER TEMPERATURE

Several sections of the Middle Green River are currently on the 1998 303(d) list because of water temperature concerns (Figure Pass-4). The 303(d) list identifies stream segments where "beneficial uses", including fish habitat, are impaired. NMFS indicates that water temperatures between 50 and 57 °F are considered to be functioning properly for salmonid migration and rearing; temperatures greater than 57°F are functioning "at risk," and temperatures greater than 64 °F are considered to be "not properly functioning" (NMFS 1999).

Upstream of Flaming Geyser Park (RM 42.9), the Green River is classified as a Class "AA" water and must meet the State water temperature criteria of 60°F. In the early summer, water temperatures of the HHD outflow are generally lower than the inflow temperatures, as water is drawn from the lower reservoir levels. By late summer the supply of cool water is exhausted and water temperatures increase somewhat (USACE 1998). In 1992, maximum equilibrium[2] temperatures of the HHD outflow generally ranged from 60 to 64 °F in August before showing a cooling trend in September from 63°F early in the month to 52 °F late in the month (Caldwell 1994). Temperatures below HHD in August and early September are therefore functioning "at risk" for migration and rearing according to the NMFS criteria (Table Pass-4).

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[2] Maximum equilibrium temperatures was defined as the maximum water temperature present on at least 5 to 10 occasions within the month (Caldwell 1994).

Water temperatures at the Tacoma Headworks are generally independent of the HHD outflow temperature, suggesting the influence of cooler outflows from HHD extend only a limited distance downstream of the dam (Caldwell 1994). Maximum equilibrium temperatures throughout July and August at the Tacoma Headworks exceeded 64 ^{o}F (Caldwell 1994). While these water temperatures exceed the range considered optimal for upstream migration and could result in avoidance, delays, stress, disease and increased pre-spawn mortality, they are below lethal limits (Table Pass-4).

No water temperature data are available within the Green River gorge but water temperatures there are hypothesized to be cooler. Direct solar radiation occurs over a limited time period because the gorge is shaded by high and steep sideslopes. In addition, groundwater inflows associated with springs mapped on USGS topographic maps are believed to contribute cooler water. For these reasons, the gorge might be expected to provide holding habitat for adult salmonids during the late summer when temperatures elsewhere in the river are high.

Between RM 42.3 and RM 31, the Green River is classified as a Class "A" water and must meet a water temperature standard of less than 64 ^{o}F (WDOE 1998). Multiple excursions beyond the standard were recorded at RM 41.5 and RM 35 in 1992. Maximum equilibrium temperatures in August ranged from 72.5 to 75.2 ^{o}F (Caldwell 1994), which was within the range of potentially lethal temperatures (Bjornn and Reiser 1991). Moreover, water temperatures exceeded 64^{o}F for 30 to 40 percent of the total hours measured in August (Table Pass-5).

Water temperature in rivers in the Pacific Northwest often is a function of elevation and shading (Sullivan et al. 1989). While the Green River is too wide for even mature riparian vegetation to completely shade the entire channel in many reaches, particularly braided sections, surface water temperature differences were measured between reaches of similar elevation and different riparian character (Caldwell 1994). Actual high water temperatures were similar, but the extent and duration of high temperatures was lower in reaches with intact riparian zones or trees on top of hydromodified banks (Caldwell 1994).

Pools may serve as thermal refuge areas for rearing juveniles and upstream migrating adult fish during the summer months in areas where they are fed by seeps of groundwater inflow or intragravel flow (Bilby 1984; Nielsen et al. 1994). Pool temperatures in August 1992 were investigated to determine whether such refuge areas were present in the Middle Green River (Caldwell 1994). In all 27 pools surveyed over a 7.5 mile reach between RM 34 and 41.5, water temperatures were the same as water temperatures in non-pool habitat (62 to 64 ^{o}F), suggesting a complete mixing of the water column and that thermal refugia are generally not available to upstream migrating adult salmonids in the Middle Green River (Caldwell 1994). Surveys of pools between RM 33 and RM 42 conducted by the MIT in August 1998 also found no difference between surface water temperatures and pool bottom temperatures (Malcom 2000).

BEHAVIORAL BARRIERS

During the months of July, August, and parts of September, the Green River between Flaming Geyser Park and Soos Creek is used extensively for recreational boating. Streamside recreation or fish viewing activities have been observed to reduce the rate of upstream coho migration (Malcom 1996). In-water activities such as canoeing also have been observed to displace adult coho salmon downstream (Malcom 1996). Because of the smaller channel and higher level of boating activity during the period when adult chinook salmon migrate upstream, a similar displacement would be expected to occur with adult chinook. The potential for instream recreation to impair the upstream migration of adult chinook salmon is emphasized by the response of chinook on redds to recreational boating. In 1993, the Sawtooth National Forest (SNF) reported that displacement of salmon from redds had been observed in association with floatboating activities (SNF 1994a,b,c,d). Displacement of salmon from redds disrupts spawning activities. Since salmon travel long distances to reach spawning areas, they have limited energy reserves for spawning. Displacement of salmon from redds may result in incomplete redd construction, selection of less preferred redd sites, and incomplete spawning. These occurrences could reduce the number of fry emerging from the gravel the following spring (SNF 1994a,b,c,d). Incomplete spawning includes eggs not released from the female, egg scattering, inadequate coverage of the eggs, and eggs released at redd depths insufficient to foster proper incubation (SNF 1994a,b,c,d).

In addition to direct disturbances, mammalian odors, such as those arising from dogs and people, have been observed to temporarily disrupt and slow the upstream migration rate of adult coho and chinook salmon, although the rate of upstream migration recovered within thirty minutes (Brett and MacKinnon 1954). Observations in the Sammamish River, where mammalian odors were accompanied by instream activities such as boating or swimming dogs, suggest that instream activity can displace hundreds of salmon downstream and that the recovery time can exceed two hours (Malcom 1996). Salmon will expend energy as they are displaced downstream and then must again expend energy to move back upstream. In portions of the river with elevated temperatures, the energy loss and stress has the potential to increase pre-spawn mortality and decrease reproductive success. This problem is particularly important in the Middle Green River due to the exposure of upstream migrating adult chinook to elevated water temperatures

LOWER GREEN RIVER SUB-WATERSHED (RM 11 TO RM 32)

PHYSICAL BARRIERS

NATURAL BARRIERS AND IMPEDIMENTS

There are no natural impediments to upstream or downstream migration of anadromous salmonids in the lower mainstem Green River.

BLACK RIVER PUMPING STATION

In 1958, an earthen dam was constructed on the Black River approximately 1,000 feet upstream of the confluence with the Green River. The purpose of this structure was to control outflows from the Black River and to prevent flows on the Green River from backing up into the Black River/Springbrook Creek floodplain during floods. Six 48-inch diameter culverts extended through the dam and were fitted with flapgates. In 1972, the U.S. Soil Conservation Service (SCS) replaced the dam with the Black River Pumping Station (BRPS) to provide a means of releasing flood flows from the Black River/Springbrook Creek system when the Green River is at high stage. The BRPS is currently operated and maintained by King County Department of Natural Resources. Except where indicated by specific citations, the following description of the

BRPS and associated fish passage facility comes from a comprehensive fisheries assessment of the Mill, Garrison and Springbrook Creek system conducted for the Cities of Kent and Tukwila (Harza 1995).

During flood periods on the Green River, the pumping station acts as a dam, preventing floods from backwatering into the Black River and the wide valley floor of the lower Springbrook Creek system. Water levels downstream of the pumping station range from –4.0 to +21.5 feet MSL, depending on tidal conditions and the water level of the Green River. Water surface elevations upstream of the pumping station are normally held in the range of 0.0 to 2.0 feet, but can reach as high as 13.0 feet. The pumping station consists of a series of eight pumps, and can pass flows of up to 2,945 cfs. Two large pumps with a capacity of approximately 1,028 cfs are also present, but have not yet been brought on line.

The BRPS represents a barrier to the upstream passage of salmonids. In addition, the ability to control the water surface elevations upstream of the BRPS often results in a situation where the downstream water surface is higher than the upstream water surface. In order to pass upstream and downstream migrating salmonids around the structure, a unique fish passage system has been constructed and is in operation. A combination of a fish ladder and fishway chute are used for upstream passage. Fish migrating downstream are diverted around the pumps using an air lift pump to raise the fish to the downstream water levels. The general layout of the BRPS and fish passage facilities are illustrated by Figure Pass-9

Upstream Passage

Upstream fish passage facilities are located on the south side (left bank) of the pumping station. They consist of a combination fish ladder and fishway chute (Figure Pass-10). The main components of the upstream fish passage facility are a supply pump, denil fish ladder, a false attraction weir, and a fishway chute. Fish enter the denil fishladder, swim up and over the false weir, and are then returned to the river upstream of the project via the fishway chute.

The denil ladder extends from the downstream pool on the south side of the BRPS approximately 60 feet horizontally and 14 feet vertically to a resting pool below the false weir. From the resting pool, fish enter the second portion of the ladder that extends 25 feet horizontally and seven feet vertically to the top resting pool. The velocity of the five cfs flow directed through the ladder is approximately 2.5 to 3.0 feet per second. This velocity is well within the normal range for this type of ladder and is suitable for adult salmon (Bell 1986). These velocities are at the upper limit of sustained swimming speeds for juvenile fish (Bell 1986) and thus likely prevent upstream migration of juvenile fish.

From the top resting pool, fish pass over the false weir and down the fishway chute. The fishway chute drops from approximate elevation 16.0 feet to 2.0 feet, creating a potential vertical drop of 2.0 feet at the end of the chute when the upstream water surface is held at 0.0. The 60 foot long chute is an open channel for the first 10 feet, a closed pipe for 25 feet and ends in an open channel for the final 25 feet. The inside of the chute is coated with vinyl to protect fish from abrasion.

The upstream passage facility is normally operated from mid-September through 31 January of each year. Before 1993, the upstream passage facility was usually operated 24 hours per day, Monday through Friday. Since 1993, the upstream passage facility has been operated about 24 hours per day, seven days per week, during the seasonal window. The operational seasonal window likely precludes the upstream migration of some anadromous and resident cutthroat trout and steelhead.

The species composition of fish migrating upstream was assessed in 1994 by trapping adult fish in a net pen installed in the forebay of the BRPS, immediately below the outflow of the fishway chute (Harza 1995). A total of 229 coho salmon and 14 chinook were trapped between 17 September and 9 December (Harza 1995). Fair coho spawning habitat was noted in some reaches, although the streambed appeared to be unstable and flow levels may have been insufficient for successful spawning (Harza 1995). Stream temperature and dissolved oxygen levels often reached lethal levels during the time when adult chinook were present (Harza 1995). Springbrook Creek is on the 1998 303(d) list for exceeding temperature and DO criteria at RM 0.1 and 1.5 (WDOE 1998). Adult salmonids, including chinook, that move upstream past the BRPS cannot exit the Springbrook system as there are no provisions in the downstream passage facility to allow them to do so. Once adult salmonids are allowed upstream they are believed to experience high levels of stress or be killed outright prior to successful spawning (Harza 1995).

Downstream Passage

The downstream passage facilities provide a means of transporting juvenile salmonids migrating towards the ocean around the BRPS. The downstream fish passage facility consists of entrance fish ports and associated piping, an air lift system, deaeration tank and transport pipe (Figure Pass-13). Fish travelling through the system enter through the fish ports on the upstream side of the dam. The fish are then transported to the air lift system and into the deaeration tank. Fish exit the deaeration tank via a bypass pipe that delivers them to the pool downstream of the dam.

The entrance ports to the system are located at elevation +2.0 and –2.0 and are adjacent to the fish screens for the pumps on the south half of the structure on the south side of the BRPS (Figure Pass-13). The airlift pumps draw flow into the transport pipes, attracting fish to the entrance ports. Fish travelling downstream move across the screens and into the ports. Except for the two large pumps, fish are prevented from entering the pumps by 1/4 inch mesh screens. To date the large, unscreened pumps have not been used during the late winter or spring (April to June). The existing screens and their placement do not meet current NMFS screening criteria.

After entering the fish ports, the fish descend a vertical fiberglass pipe to elevation –17.0 feet, and are then directed towards the airlift through a horizontal collection pipe. As the horizontal pipe passes into the airlift chamber, it turns vertically 90 degrees and descends to elevation –39.0 feet. At this point, the fish go through two more 90 degree elbow turns and then enter the airlift pump. Air added at –39.0 feet displaces water at the base of the vertical column, lifting the fish to +13.0 feet and into the deaeration tank.

The dimensions of the five-foot deep deaeration tank are 9.5 feet by 9.5 feet. The entrance to the 18-inch diameter fiberglass downstream transport pipe is located at the west end of the tank. This pipe transports fish approximately 108 feet horizontally to the fishway exit. The exit invert pipe is at 10.0 feet elevation, which can vary in height above the receiving water; normally, the drop is approximately 6 feet from the pipe to the receiving pool.

The downstream passage facility is operated from early-April to mid-June each year, for approximately eight hours per day, Monday through Friday. Fish attempting to move downstream outside of that operational window are either prevented from exiting the Springbrook system or must pass through the unscreened large pumps (if operational). Juvenile chinook emerge and begin moving downstream in the Middle Green River system and Soos Creek as early as February (Jeanes and Hilgert 2000). Consequently, early downstream migrants may be prevented from exiting the Springbrook system. Adult salmonids cannot pass downstream via the downstream fish passage facility.

Flapgates

Flapgates have been installed on many of the tributaries to the Lower Green River to control backwatering that may occur during floods. The flapgates allow discharge from the tributaries to the Green River during low flow periods, but are forced shut by water pressure when the flow level of the Green River exceeds the elevation of the outlet, thereby preventing water from the Green River from flowing into the tributaries. The design of these flapgates also prevents juvenile salmonids overwintering in the lower river from accessing lower velocity off-channel habitats during flood flows. Individual flapgates on smaller tributary streams are discussed in more detail in Chapter 3.

HYDROLOGIC BARRIERS

LOW INSTREAM FLOWS

No areas of low instream flows that could act as a barrier to upstream migration of adult salmonids have been identified in the lower Green River. The river is typically confined between levees throughout this reach, and thus has a lower width to depth ratio than might be expected under natural conditions.

BIOLOGICAL BARRIERS

WATER TEMPERATURE

Between RM 11 and RM 31, the Green River is a Class A waterbody. Numerous violations of the Class A temperature criteria (64 ^{o}F) have been recorded at RMs 12.5, 14.0, 18.3, 20.0, and 27.0 (Table Pass-4). In 1984, Fisheries Sciences reported maximum water temperatures of 73 to 74 ^{o}F near RM 11 (Fisheries Sciences 1984 as cited in Caldwell 1994). Since 1984, the METRO (King County) Renton Water Treatment Plant outflow has been routed out of the Green River and into Puget Sound, changing conditions near RM 11. However, Caldwell (1994) also measured maximum equilibrium temperatures ranging from 72 to 74 ^{o}F in this reach and found that temperatures exceeded 64 ^{o}F up to 71 percent of the time during August. These temperatures exceed the range required for properly functioning habitat according to NMFS (1999) and sometimes reach potentially lethal levels (Table Pass-4).

A number of investigators have indicated that high water temperatures may delay adult upstream migration in the Lower Green River sub-watershed (Figure Pass-12). Grette and Salo (1986) stated that elevated river water temperatures in this section of the river delayed the upstream migration of chinook. However, no specific information regarding the frequency, duration, or effect of temperature-related delays on the upstream migration of salmonids was located.

BEHAVIORAL BARRIERS

Behavioral barriers in the Lower Green River are generally similar to those described earlier for the Middle Green River, although disturbance is believed to be less. This is because this section of the river is not used as extensively for in-stream recreation, although there is an expanding trail system on top of the levees.

GREEN/DUWAMISH ESTUARY (RM 0 TO RM 11)

PHYSICAL BARRIERS

The mainstem Duwamish River and Estuary is largely a deepwater channel with no physical barriers to upstream or downstream migrations by adult or juvenile salmonids (Figure Pass-12).

A number of small tributaries to the Duwamish Estuary that may have supported rearing by juvenile chinook salmon in the past have been isolated from the estuary by diking and filling with placement of culverts, often with tide gates, through the fill. The mouth of Hamm Creek has been partially restored in recent years to the point where juvenile chinook salmon can access habitat in the lower reaches of the creek that has been inaccessible for decades and adult coho are accessing the stream for spawning. In the channel behind Kellogg Island, the Port of Seattle excavated a channel into a small, 0.4-acre, off-channel wetland (the Puget Estuary) at Terminal 107. The site has been planted with wetland plants and the surrounding slopes with upland buffer plants. The Port of Seattle is evaluating the potential for daylighting Puget Creek into this estuary to further improve habitat for anadromous fish. Until that happens, Puget Creek remains inaccessible to salmonids.

HYDROLOGIC BARRIERS

The mainstem Duwamish River and Estuary is largely a deepwater channel with no hydrologic barriers to upstream or downstream migrations by adult or juvenile salmonids.

BIOLOGICAL BARRIERS

Historically, late summer water quality conditions (low dissolved oxygen and high temperature) in the estuary likely constituted a temporary barrier to upstream migration by adult chinook salmon [Salo 1969; see Chapter 1.2, (Water Quality)]. As late as 1985, kills of adult chinook were reported (LeVander 1999). However, since the diversion to Puget Sound of the outfall from the Renton sewage treatment plant in 1986, these conditions have not been recently reported.

Although chemical and thermal barriers do not appear to be present currently in the Duwamish Estuary, a gradual upward trend of maximum summer temperatures in the estuary has been shown, with temperatures reaching 23^{o}C (73.4^{o}F) in surface waters between RM 3 and 7 in 1995. These temperatures, if present throughout the water column (which is unlikely), could have delayed upstream movements of adult salmon (e.g., Bell 1986). This trend, if continued, could result in a return to conditions of the 1970s and 1980s when water quality barriers occurred with regularity.

MAJOR TRIBUTARIES

PHYSICAL BARRIERS

SOOS CREEK (RM 0 – RM 13)

Natural Barriers and Impediments

The headwaters of Soos Creek arise on a rolling glacial outwash plain. In such landforms, streams often originate in wetlands and exhibit low gradient palustrine type channels (Chapter 2.3) until flows become sufficient to regularly transport coarse sediment. The gradient of mainstem Soos Creek is 1 to 2 percent throughout its course (Cutler 2000) and no natural barrier falls or cascades have been identified (Williams et al.1975). The upstream extent of spawning by anadromous fish, including chinook salmon, is not known, but is presumed to be limited by flow, substrate, or in-stream vegetation and not gradient. Juvenile fish are expected to use the entire length of available channel and associated wetlands for rearing.

Soos Creek Hatchery and Weir

The Soos Creek salmon hatchery, located at RM 0.7, was constructed in 1901 and has been in continuous operation since that time. Between 1902 and 1924, portable double racks were installed in the mainstem Green River at the mouth of Soos Creek to provide eggs for the hatchery, since chinook salmon did not enter Soos Creek at that time (Becker 1967). Annual installation of the portable weirs on the mainstem was discontinued in 1924, as large numbers of chinook had begun to return to Soos Creek by that time (Becker 1967).

The existing hatchery rack consists of two removable weirs located approximately 100 feet apart that are used to create a holding pond (Figure Pass-14). The weirs are generally installed around August 15, when the first chinook begin to arrive and removed around the third week of November when coho egg take requirements have been met (Chamblin 2000). A sheet-pile dam, used to divert water into the hatchery, is located just upstream. The diversion dam is equipped with a fish ladder (Figure Pass-15).

The hatchery rack acts as a barrier when it is in place. However, large storm events or other unforeseen occurrences may wash out the weirs or allow fish to pass the structure. For example, during a storm in September 1997, over 8,000 chinook were able to leave the hatchery and move upstream into Soos Creek when the weir failed (Finney 2000). Beavers have also been responsible for causing holes that allow adult salmonids to migrate upstream (Kerwin 2000). When the hatchery weirs are not in place, anadromous salmonids can move freely upstream. The hatchery does not interfere with the downstream movement of juvenile fish.

Culverts

Although a number of barriers associated with road crossings have been identified on tributary streams (Figure Pass-4), no existing barriers to upstream migration in mainstem Soos Creek have been identified. However, there are numerous barriers on tributary streams, which are discussed in Chapter 3. No systematic survey of barriers has been completed in the Soos Creek drainage but it is expected that additional barriers, including possible barriers on the mainstem, may be located in the future.

NEWAUKUM CREEK (RM 0-RM 12)

Natural Barriers and Impediments

There is no observational data of the upstream-most extent of use by anadromous fish in Newaukum Creek. However, chinook have been observed as far upstream as RM 12.0 (Spawning Ground Survey Database, WDFW). The presumed upstream extent of use by chinook, steelhead, and coho, estimated by identifying the location at which the channel gradient steepened to over 12 percent, occurs at approximately RM 13.5 (Cutler 2000). The 12 percent gradient break identified on Newaukum Creek occurs about ½ mile downstream of an impassable cascade near RM 9 identified by Williams et al. (1975).

Culverts

No barriers associated with road crossings have been identified on mainstem Newaukum Creek. However, since no systematic survey of barriers has been completed in the Newaukum Creek drainage, it is expected that barriers could be located in the future.

HYDROLOGIC BARRIERS

SOOS CREEK

Low Instream Flows

Low flows reportedly reduce the ability of chinook to reach the Soos Creek hatchery (WDFW and WWTT 1994). This influences natural spawning downstream of the hatchery as well as the number of chinook that may be released upstream of the hatchery rack. The specific location of low flow concerns was not identified and could include low flow concerns in the mainstem (WDFW and WWTT 1994). However, a declining trend in the average 7-day low flows just upstream of the hatchery has been identified (Culhane 1995) and is discussed in more detail in Chapter 2.1 (Hydrology). Declining flows support the hypothesized low flow concerns in Soos Creek.

NEWAUKUM CREEK

Low Instream Flows

Deposition of gravel at the mouth of Newuakum Creek where it enters the Green River floodplain has created a small alluvial fan. Because alluvial fans are formed of deep, porous deposits of generally coarse sediment that readily transmits water, streams flowing across such sites are naturally highly vulnerable to low or subsurface flows (Levin 1981). Shallow or subsurface flows currently impede the upstream migration of adult chinook salmon into Newuakum Creek, especially the early run component (Malcom 1999; Boehm 1999). Passage impediments are further exacerbated by the lack of deep holding pools on the fan and throughout the lower mile of channel in Newuakum Creek (Malcom 1999).

No information describing the specific location of low flow concerns was located for the remainder of Newaukum Creek. However, as with Soos Creek, a declining trend in the average 7-day low flow has been identified (Culhane 1995). The average 7-day low flow generally occurs during the period when chinook salmon are migrating upstream, suggesting that additional areas of low flow concerns may be present in Newaukum Creek.

BIOLOGICAL BARRIERS

SOOS CREEK

Water Temperature

There are no segments of mainstem Soos Creek listed on the 1998 Washington State 303(d) list for temperature concerns (WDOE 1998). Consequently, temperature is currently assumed not to limit the upstream migration of adult salmonids in Soos Creek. However, temperature concerns that represent potential passage barriers have been identified on a number of tributaries (Figure Pass-4). In addition, dissolved oxygen levels less than 8 mg/l have been recorded near RM 10. Low DO levels could cause salmonids to avoid entering this section of the stream, thereby delaying upstream migration.

NEWAUKUM CREEK

Water Temperature

There are currently no segments of mainstem Newuakum Creek listed on the 1998 Washington State 303(d) list due to temperature or DO concerns (WDOE 1998). However, temperatures greater than the NMFS criteria for properly functioning habitat (57^{o}F) have been recorded at the USGS gage near RM 1.0 (Malcom 1999).

Table Pass-1. Howard Hanson Reservoir Pool Physical characteristics at various pool elevations (USACE 1998).

Pool Elevation (feet MSL)	Surface Area (acres)	Volume (acre-feet)	Length (miles)	Perimeter (miles)	Description
1,035	0	0	0	0	Run of River
1,070	100	1,200	1.5	3.1	Turbidity Pool
1,100	255	6,300	2.8	6.8	
1,130	560	17,265	3.9	11.2	
1,141	763	25,400	4.3	12.2	Conservation Pool
1,147	871	30,400	4.6	13.5	Drought Pool

Table Pass-2. Tag detection success rate at the forebay for salmoninds released into Howard Hanson Reservoir in 1995.

Species	Pool Level	Number Released	Number To Forebay	Detection Rate
Coho	low	36	17	47%
Steelhead	low	36	17	47%
Coho	mid	36	14	38%
Steelhead	mid	36	26	72%
Chinook	high	17	6	35%
Coho	high	38	28	73%
Steelhead	high	34	30	88%

Table Pass-3. Average withdrawal at TPU Headworks as a percentage of mean daily flow during the period when juvenile salmonids are migrating downstream (Source: TPU 2000).

Month	Average Daily Flow (Cfs)	Average Withdrawal (Cfs)	Percent Of Daily Flow Withdrawn
March	1,819	89.3	5%
April	1,922	88.3	5%
May	1,806	93.3	5%
June	1,208	106.7	9%

Table Pass-4. Recorded temperature conditions relative to water quality standards, NMFS habitat criteria for migration and rearing and potential lethal limits at various locations within the mainstem Green River.

Location	Max. Recorded Temperature	Nmfs Properly Functioning[1]	Exceeded ?	State Wq Standard	Exceeded?	Potential Lethal	Exceeded?
RM 69	>60 °F[3]	50-57 °F	Yes	60.8 °F	unknown	73 - 84 °F	unknown
RM 64.5	62-64 °F[4]	50-57 °F	Yes	60.8 °F	Yes	73 - 84 °F	No
RM 60.8	65 °F[4]	50-57 °F	Yes	60.8 °F	Yes	73 - 84 °F	No
RM 41.5	73.4 °F[4]	50-57 °F	Yes	64 °F	Yes	73 - 84 °F	Yes
RM 35	74.3 °F[4]	50-57 °F	Yes	64 °F	Yes	73 - 84 °F	Yes
RM 32	64-72.5 °F[5]	50-57 °F	Yes	64 °F	Yes	73 - 84 °F	No
RM 27	72.5 °F[4]	50-57 °F	Yes	64 °F	Yes	73 - 84 °F	No
RM 20	73.4 °F[4]	50-57 °F	Yes	64 °F	Yes	73 - 84 °F	Yes
RM 18.3	>64 °F[6]	50-57 °F	Yes	64 °F	Yes	73 - 84 °F	unknown
RM 14	>64 °F[6]	50-57 °F	Yes	64 °F	Yes	73 - 84 °F	unknown
RM 12.5	73.4-75.2 °F[4]	50-57 °F	Yes	64 °F	Yes	73 - 84 °F	Yes

[1] NMFS 1999.
[2] Bjornn and Reiser 1991; Caldwell 1994; MacDonald et al. 1991.
[3] USACE 1998.
[4] Caldwell 1994.
[5] Unpublished data from USGS cited in Caldwell 1994.
[6] WDOE 1998.

Table Pass-5. Results of temperature monitoring conducted on the mainstem Green River in 1992 (from Caldwell 1994).

Location	Maximum Equilibrium Temperature in July And August	Hours Over 64°f	Percent of Total Time Over 64 °f in August	Maximum Equilibrium Temperature in September
RM 41.5	73.4 °F	383	30%	66.2 °F
RM 35	74.3 °F	663	45%	68 °F
RM 27	72.5 °F	621	46%	ND
RM 20	73.4 °F	839	57%	68 °F
RM 13	73.4-75.2 °F	1140	71%	68 °F

ND=No data.

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Figure Pass-13. Black River pumping station downstream fish passage facility. (Source: Harza 1995).

Figure Pass-14. Hatchery rack at Soos Creek hatchery, RM 0.7, March 2, 2000 looking downstream and looking upstream. (Source: R2 Resource Consultants).

Figure Pass-15. Diversion weir and fish ladder at Soos Creek hatchery, RM 0.7, March 2 2000 (Source: R2 Resource Consultants).