Summary Report to Assist Development of Ecosystem Flow Recommendations for the Coast Fork and Middle Fork of the Willamette River, Oregon

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25 June 2007

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Introduction

The Willamette River Flow Project

The Nature Conservancy (TNC) and the U. S. Army Corps of Engineers (USACE) are collaborating on a project to determine environmental flow requirements for the Willamette River and its tributaries and to design and test alternative flow releases from the dams that can meet these requirements. The project is part of the Sustainable Rivers Project (SRP), a national effort by TNC and USACE to investigate opportunities to change Corps Dam operations ("reoperate") to achieve more ecologically sustainable flows, while maintaining or enhancing project benefits. Through the SRP, TNC and USACE have developed and tested a process for identifying and refining environmental flow objectives (Richter et. al. 2006). The process utilizes a series of steps to define environmental flow requirements, implement changes in operation of dams to meet those flow objectives, monitor and model the effects of those changes on both the river ecosystem and the operation of the dams, and refine over time.

The Willamette River Flow Project is being conducted in conjunction with the USACE Willamette Floodplain Restoration Feasibility Study. This feasibility study is designed to identify opportunities to restore natural floodplain function in the Willamette River basin to provide ecosystem restoration, natural flood storage, and other benefits. The initial study phase has focused on the Coast and Middle Forks of the Willamette River. These subbasins contain 6 of the 13 dams in the Willamette system; their operation has implications for the operation of the other dams in the system. To date, the Floodplain Restoration Study has focused on two important aspects of the aquatic ecosystem: 1) identifying habitat, flow and water quality requirements for a variety of aquatic and floodplain species; and 2) describing and evaluating the current channel and floodplain morphological characteristics, and their changes from historic condition. Partners in the feasibility study include the Willamette Partnership, the Willamette Middle and Coast Fork Watershed councils, the Oregon Department of Fish and Wildlife, and The Nature Conservancy. There is also an inter-disciplinary expert and stakeholder group of approximately 20 federal, state and local entities plus private landowners that informs the process.

The Willamette River Flow Project will build upon the Floodplain Restoration study by developing environmental flow requirements for the reaches downstream of the Corps dams and linking those flows to opportunities for stream channel and floodplain restoration, and to improvement in operation of the dams. Given the existing floodplain restoration study, the initial SRP efforts will use the Coast and Middle Forks and the mainstem Willamette immediately downstream of these tributaries as a pilot study that can be replicated in the rest of the Willamette system. River flows from both subbasins have been greatly affected by operation of the dams: 56% of the drainage area of the Coast Fork and 87% of the Middle Fork drain into USACE reservoirs. General effects of the reservoirs include reduced peak flows, lower spring flows, increased summer low flows, and infrequent bankfull and out-of-bank flows. The Willamette Flow Project partners anticipate the study will be expanded in the future to encompass the other major tributaries controlled by USACE dams.

Summary Report Purpose

This Summary Report is a key step in the process of establishing ecological flow requirements for the Middle and Coast Forks of the Willamette River. The report synthesizes background information on the flow needs for key ecosystems, communities and exemplar species of the Middle Fork, Coast Fork, and upper mainstem Willamette River.

The Summary Report provides the information basis for a Flow Recommendation Workshop which will develop ecosystem-based flows in the lower Middle and Coast Forks as well as the mainstem Willamette River immediately downstream of their confluence. The ultimate goals of this workshop will be to provide the USACE with recommendations for new flow paradigms incorporating changes to timing, magnitude, and duration of dam discharges. TNC and USACE have categorized four major environmental flow components to be addressed in the Summary Report and during the Workshop:

1) low flows (seasonal, annual and extreme low flows);
2) high flow pulses (up to bankfull discharge);
3) small floods (overbank flows, approximately 2- to 10-year return period);
4) large floods (floodplain maintenance flows, > approximately 10-year return period).

The information presented below aims to prioritize available information based on its relevance for characterizing the relationship between these four environmental flow components, fluvial geomorphic processes and biotic responses or ecological processes. The Summary Report includes both key findings of linkages among specific environmental flow components, geomorphic processes, biotic responses, and ecological processes as well as qualitative ecological models illustrating the connection between natural hydrographs and life cycles of exemplar species and ecological processes and functions.

Dam construction and concomitant changes in river discharges are not the only factors affecting the Willamette River ecosystem. Land use conversion from native floodplain forests and prairies to agricultural and urban/suburban development, increases in contaminants, changes in sediment delivery amounts and rates, wetland draining, gravel extraction, timber and fish harvest, introduction of invasive species, hatchery operations and numerous other factors all contribute to the present-day highly modified ecosystem. In this review, we attempt to include such factors as a context for changed flows, but recognize we cannot cover all of them in depth. In addition, a considerable amount of ink has been spilled on the effects of dams and dam operations on specific species and species assemblages in the Willamette River Basin (e.g., USACE 2000: available from USACE Portland Office; NWPCC 2004: available at: http://www.nwcouncil.org/fw/subbasinplanning/willamette/plan/). We will use these reports as a starting point for much of the information presented here, and will not attempt to include all the results covered in these two reviews.

The impacts of dams on rivers, floodplains, and riparian areas have been well documented (e.g.,Ward and Stanford 1995, Ligon et al. 1995, Nilsson and Berggren 2000, Galat et al.. 1998, Poff et al.. 1997 for general references, USACE 2000, NWPCC 2004 for the Willamette River). Attempts to modify or to reverse some of these impacts have begun on a number of large rivers in North America (e.g., Toth et al. 1998, Molles et al. 1998, Rood et al. 2003) and in Europe (e.g., Hughes and Rood 2003). Targeted impacts have ranged from the species-specific (e.g., Rood and Mahoney 2000) to attempts to restore self-sustaining ecosystem processes (e.g., Molles et al. 1998). An increasing array of new technical tools (e.g., Harman and Stewardson 2005) and conceptual frameworks (e.g. Whiting 2002, Kondolf et al. 2006, Richter et al. 2006) is providing a generalized context for undertaking large scale restoration projects. The process and product presented here owe much to previous endeavors sponsored by the USACE/TNC Sustainable Rivers Project, including those from the Bill Williams River (Shafroth and Beauchamp 2005), the Savannah River (Meyer et al. 2003) and Big Cypress Creek/Caddo Lake (Winemiller et al. 2005).

In contrast to the plethora of studies pertaining to the effects of dams, there are comparatively few data with direct measures of flow requirements for the biota of the Willamette River basin and relatively few studies of the effects of dams on the aquatic ecosystems of the Willamette River and its tributaries. Most of the available information pertains to relationships between the timing of species-specific life history stages and discharge regime and does not explicitly identify flow needs. Additional data on the relationships between discharge parameters such as water quality and geomorphology have been included to encompass flow and habitat requirements for some species found in the basin. The information presented below is organized as follows:

1. An overview of the Coast and Middle Forks study area, including a description of the base condition hydrology and the changes to this hydrologic regime due to dam operations;
2. A summary of the data pertaining to physical processes and conditions, including water quality (e.g., temperature) and geomorphic processes (e.g., floodplain function) and their flow requirements.
3. A summary of the data pertaining to biological and ecological process, including more detailed information for exemplar riparian and aquatic species, both native and introduced and their flow requirements.

At the beginning of each section, we will highlight the primary findings (termed “key elements”) of the literature review. Where appropriate, the impacts of the four major environmental flow regimes (see above for definitions) will be presented at the end of each topic section. These impacts are presented in their entirety in Table 26.

Background

Study Area Description

Key Elements

- 13 USACE dams regulate discharge in the Willamette basin.
- The Willamette basin has a distinct winter wet/summer dry climate, with 95% of the precipitation occurring from October through June.
- Geology creates major hydrologic differences between and within drainages.

The 4,645 hectare (11,478 acre) Willamette River basin is home to more than 70% of the population of the state of Oregon. As such, it has also become one of the most intensively flow-managed subbasins within the state. The USACE operates 13 dams within the greater Willamette basin (Figure 1). Six of these flow regulation structures lie within the Coast and Middle Forks, the most southerly and most-upstream of the main hydrologic basins (Figure 2). Operation of the these six structures have significant effects on the main stem Willamette all the way to its confluence with the Columbia River in Portland, some 200 miles downstream.

The Coast Fork basin covers an area of approximately 1725 km^2 (665 mi^2), with the headwaters in the Calapooya Mountains of the Coast Range and the foothills of the Cascades Range. The Middle Fork basin is almost twice the area (3533 km^2 or 1363 mi^2), and its headwaters extend to the Cascade crest and encompass Waldo Lake. The two forks come together 187 river miles (308 km) above the Columbia to form the mainstem of the Willamette River. The relative size and location of the two basins is also reflected in their topography, with the Coast Fork showing somewhat lower topographic relief compared to the steep Cascade peaks of the Middle Fork (Figures 3a and 3b). The two basins also differ greatly in their underlying geology (Figure 4). The Middle Fork basin is composed predominantly of volcanic rock, including the water-rich High Cascades basalts (Tague and Grant 2004). In contrast, the western half of the Coast Fork is predominantly siltstones typical of Coast Range geology, while the eastern portion of the basin shares a similar volcanic lithology with the lower portions of the Middle Fork. Both basins contain relatively shallow alluvial deposits in the downstream areas; this alluvium has a proportionately greater extent in the Coast Fork, particularly below the USACE dams.

The amount, form and timing of precipitation inputs and the resulting hydrologic response for the two basins are driven by a combination of geographic position, topography, and geology. Both basins receive the majority of their precipitation between October and April (Figures 5a and 5b), with a pronounced period of drought from July through September. However, the Middle Fork basin, with its headwaters in the high Cascade Mountains, receives a much greater amount of snowfall than the lower elevation Coast Fork (Figure 6). Snowfall in the High Cascades, in concert with younger volcanic basalts, produces a different hydrograph than that seen with lower elevation streams. High Cascades basins, such as those found in the upper reaches of the Middle Fork, typically exhibit higher summer base flows, slower recession rates, and faster responses to winter storm events (Tague and Grant 2004). Winter snowfall at all elevations not only contributes to later season stream flows, but can also be a major source of flood waters when warm, wet storm fronts bring copious amounts of rainfall.

These infrequent “rain-on-snow” events are usually the trigger for high stream and river discharges associated with lowland flooding.

Hydrologic Network and Discharge Regime

Key Elements

- Two flood control dams (Dorena and Cottage Grove) are in the Coast Fork sub-basin.
- Three flood control dams (Hills Creek, Lookout Point, Fall Creek) and one reregulating dam (Dexter) are in the Middle Fork sub-basin.
- USACE dams significantly reduce the height and volume of flow during peak flood events, but extend the duration of high volume flows (at or below bankfull) as stored flood waters are released.
- USACE dams approximately double low flow discharges during summer on the Middle Fork.
- Flow management has increased the duration of flows close to bankfull discharge for major floods, but the frequency of bankfull events has been decreased by reservoir operations.
- The number of days of small floods has increased for the Middle Fork.
- Effects of flow management are more pronounced during dry years or critically dry years.

The most fundamental process altered by dam construction and operation is stream discharge (which we also refer to as flow). Dam operations modify all aspects of the natural hydrologic regime, including timing of discharge, flow magnitude, periodicity, and duration (Lytle and Poff 2004). Dams may be operated to provide navigable waterways, generate electrical power, dampen flood flows, provide recreational opportunities, improve downstream water quality, supply water for agriculture or municipal uses, or some combination (USACE 2000). An additional important function of the Willamette dams is to augment flows during dry periods for water quality improvement and protection of aquatic habitat. The modification of the natural hydrologic regime has impacts on an array of processes and organisms, both upstream and downstream of the structure itself.

Within the Coast Fork and Middle Fork sub-basins of the Willamette River, the USACE operates a total of six dams, two on the Coast Fork, and the remainder on the Middle Fork (Figure 7, Table 1). Five of the six dams function as flood control reservoirs (Dexter dam on the Middle Fork is a re-regulating structure) and also serve to mitigate downstream water quality issues (USACE 2000). In addition, power is generated from the dam complex on the Middle Fork (Hills Creek, Lookout Point and Dexter) when sufficient water and power needs coincide. There is some slight use of these reservoirs for irrigation (Table 2). This demand is low compared to requirements for in-stream beneficial uses including mitigation for water quality concerns, which are determined at points along the main-stem Willamette River (Tables 3a and 3b). At present, flows from both systems are fully allocated (PNWERC 2002).

Typical dam operations during floods attempt to maintain flows at downstream control points below bankfull (Figure 8) by holding back some portion of upstream waters.

These operations generally affect duration and timing as well as heights of the flood flows (Table 4), and generally occur during the wet months of November through March.

For purposes of this review, we will use flow data from a subset of the gages (Figure 7, Table 5) managed by the US Geological Survey (USGS). The gages at Goshen and Jasper provide an integrated perspective of all USACE operations on the Coast and Middle Forks, respectively. The gage at Springfield is unfortunately no longer in operation, but it does give us some information on the behavior of the conjoined Coast and Middle Forks only; the Harrisburg gage is still in operation, but it is below the confluence of the McKenzie, which contributes a significant amount of water to the Willamette River. We have also included the gage at Albany, downstream of several other major tributaries as well (the Long Tom, Santiam, Mary's, and Luckiamute Rivers) because it has the longest period of record of any gage within the greater Willamette Basin. Chris Nygaard of the USACE prepared summary hydrology graphs for Jasper (Middle Fork), Goshen (Coast Fork), Albany (mid-mainstem) and reconstructed flows for the confluence of the Middle Fork and Coast Fork at Springfield based on the flows from Jasper and Goshen combined (Figures 9-57). Additional hydrological analyses based on TNC's Indicators of Hydrologic Alteration (IHA) software package were performed by Jeff Opperman of TNC for the Jasper, Goshen, and Harrisburg gages; these analyses are provided in full in Appendices 1 -3, and provide supplementary assessments.

In the discussion below, we will present the impacts of the dams on the flow regime of these four reaches. Data will be presented to illustrate inter-annual variation, seasonal changes, daily fluctuations due to the combined effects of power generation and water withdrawals (none designed in operation schedule). We will categorize these pre- and post-impoundment impacts on the four discharge regimes:

1. Low summer flows (may include drought impacts)
2. High flow pulses (up to bankfull heights)
3. Small, overbank floods: recurrence intervals of 2-10 years
4. Large floodplain-encompassing floods: recurrence intervals of >10 years.

Hydrology of the Middle Fork of the Willamette River

Data from 1935-2005 clearly illustrate the influence of flow management on the hydrologic regimes of the Middle Fork (Table 5b, Figures 9 and 10). The Middle Fork of the Willamette River has a distinct wet and dry hydrologic regime, which is typical of the Pacific Northwest coastal basins. Prior to dam construction, major floods occurred frequently from November through March and flow reached its minimum during summer (Figures 11 and 12). Largest floods typical occurred from December through February. Smaller floods were common in early fall and late spring. After construction and operation of the dams, the magnitude of floods decreased markedly and most flows were maintained within bankfull channel (Figures 13, 14). Early fall floods were largely eliminated by dam operations (Figure 10). Summer flow was augmented and increased to more than 2-3 times the unregulated summer flows. The full impact of flow management on floods is evident after 1965 (Figure 15). Flow management limits peak flood flows to near bankfull in peak flows with less than an 80% exceedence. The system's ability to limit the peak flows decreases for floods with less than 10% exceedences (Table 5b, Figures 16 and 17). The Jasper flow duration curve illustrates the duration and magnitude of low flow and high flow augmentation of daily mean flows.

An increase in flow magnitude is seen in regulated low flows greater than 50% exceedance. The 90% exceedance flow has increased from approximately 900 cfs unregulated to 1400 cfs regulated. Regulated high flows are lower than unregulated at exceedances less than 10% with a plateau near bankfull flows for durations less than 0.2% exceedance. No significant duration of flow exceeding near bankfull conditions exist in the regulated daily mean flow data (Figure 17). Days of near bankfull discharge (90 to 100% of bankfull) are extended after dam construction but occur less frequently than for unregulated flows (Figure 18). Comparisons of regulated and unregulated flow are provided for wet and dry years, as well as average years (Figures 19 and 20). Alteration of the unregulated hydrograph is more pronounced in dry years than in wet years (Figure 19). Overall, dam operations have reduced flows in late winter and spring and increased base flows from early summer through late fall (Figures 14 and 17).

Hydrology of the Coast Fork of the Willamette River

Data from 1935-2005 for the Coast Fork also illustrate the influence of flow management on the hydrologic regimes (Figures 21 and 22) but the effect is less than that observed for the Middle Fork. Prior to dam construction, major floods occurred frequently from November through March (though lower in magnitude than the Middle Fork) and flow reached its minimum during summer (Figures 23 and 24). Smaller floods were not uncommon in early fall and late spring. After construction and operation of the dams, the magnitude of floods decreased markedly and most flows were maintained within bankfull channel (Figures 25 and 26). The 1996 flood was notably higher in the Coast Fork (as compared to historical floods) (Figure 21) than the same flood in the Middle Fork (Figure 9). Summer flow was augmented and increased to more than 2-3 times the unregulated summer flows. The full impact of flow management on floods is evident after 1956 (Figure 27). Peak flood flows are reduced to roughly half of unregulated flood flows for the 50% to 0.2% flood frequency flows (Table 5b and Figure 28). The Goshen flow duration curve illustrates the duration and magnitude of low flow and high flow augmentation of daily mean flows. An increase in flow magnitude is seen in regulated low flows greater than 50% exceedance. The 90% exceedance flow has increased from approx 60 cfs unregulated to 190 cfs regulated. Regulated high mean daily flows are lower than unregulated at exceedances less than 2%. The percent of time exceeding bankfull flow (12,000 cfs) has decreased with regulation from 1% to 0.2%. Regulated mean daily flow still exceeds flood stage (15,000 cfs) 0.1% of the time. (Figure 29). Days of near bankfull discharge (90 to 100% of bankfull) are extended after dam construction but occur less frequently than for unregulated flows (Figure 30). Comparisons of regulated and unregulated flow are provided for wet and dry years, as well as average years (Figures 31 and 32). Alteration of the unregulated hydrograph is more pronounced in dry years than in wet years (Figure 31). Overall, dam operations have reduced flows in late winter and spring and increased base flows from early summer through late fall (Figures 26 and 29) but the effects of flow management are not as pronounced for the Coast Fork in comparison with the Middle Fork.

Hydrology below the Confluence of Middle Fork and Coast Forks, mainstem Willamette River

As expected, flow at the confluence of the Middle Fork and Coast Fork at Springfield illustrates hydrologic patterns intermediate to those of the two forks. Data for all comparable hydrological properties are presented as a context for the implication of flow operations for the mainstem Willamette River (Figures 33-44). As observed for both the

Middle and Coast Forks, dam operations have reduced flows in late winter and spring and increased base flows from early summer through late fall (Figures 38 and 41) but the effects of flow management are not as pronounced as in the Coast Fork.

Hydrology of the upper mainstem Willamette River

An additional context for the hydrological influences of dam operations on the mainstem Willamette River is illustrated in the data from the Albany gaging station of USGS (Table 5b, Figures 45-56). This is the longest hydrological record in the state. Flows upstream of Albany are regulated not only by USACE projects on the Coast and Middle Forks, but also by those on the Long Tom (one dam) and McKenzie (two dams) subbasins. The long record prior to dam construction (1893-1949) exhibits several major floods that far exceed the floods of recent decades (e.g., 1964, 1996). Flow management clearly has eliminated early fall floods, substantially dampened winter and spring floods, and augmented summer and fall base flows. Management of flow from its tributaries has substantially altered the natural flow regime of the mainstem Willamette River.

Physical Processes and Conditions: Flow Requirements

Water Quality

Key Elements

- As flow, or water volume, increases, rate of thermal warming decreases…
- Water temperature and cold water refuges are determined by the relative proportions of surface water and groundwater inputs.
- Flow regime alteration potentially affects hyporheic processes, which can have significant impacts on water temperature.
- Existing USACE dam operations have direct influences on water temperature downstream of dams.
- Early summer temperatures are colder and late summer/fall temperatures are warmer than natural river temperatures due to reservoir operations.
- Mercury concentrations from natural geologic sources and mining are elevated in the Coast Fork.
- Impacts of land use have offset changes in dam-induced suspended sediment and turbidity levels.

The presence and operation of dams can have profound consequences for water quality as well as water quantity (e.g., Pinay et al. 2002, Rounds and Wood 2001). Within the Willamette basin, the primary water quality parameter affected by the USACE dams is water temperature, with secondary impacts on dissolved gases, such as oxygen, and contaminants, such as pesticides, heavy metals, and excess nutrients. Water quality parameters are influenced directly by the modified hydrologic regime and indirectly by the changes in geomorphic processes both above and below the dams (see below).

Temperature

Water temperature is a critical determinant of physiology and survival in almost all non-mammalian aquatic organisms (e.g., ODEQ 2006, NWPCC 2004, McCullough et al. 2001). Both aquatic plants and animals have upper and lower thermal tolerance limits as well as optimal or critical temperatures for different phases of their life cycles. Tolerances for suboptimal temperatures, both warmer and colder, can vary widely within a given species. Discharge strongly influences water temperature in streams and rivers. In general, the rate of warming decreases as water volume increases because of both 1) the relationship between thermal input and the mass of water and 2) the influence of bed friction on the velocity of the water mass and residence time of water in a reach. Water temperature and coldwater refuges also are determined by the relative proportions of surface water and groundwater inputs. Reservoir releases can alter those proportions and change downstream thermal regimes. Alteration of discharge by dam operations has altered thermal regimes in major tributaries of the Willamette River (ODEQ 2006, Rounds et al. 1999).

Releases from reservoirs also contribute volumes of water with thermal loads that reflect the portion of the reservoir from which the releases are drawn. The temperature of water released from the dam is a function of reservoir surface area and depth. During the warm summer months large impoundments, such as those present on the Coast and Middle Forks, develop thermal stratification. As a result, reservoir releases in summer may either increase or decrease the temperature in the river downstream. Cooler water from the hypolimnion of the thermally stratified reservoirs is released in early summer. All USACE dams in the Coast and Middle Forks draw their outflows from the hypolimnion, deep within the reservoir pool. The outflow location, combined with summer flow augmentation mandates, generates cooler downstream early summer temperatures than were present historically. In late summer, the thermocline breaks down, and the reservoirs are rapidly emptied in preparation for fall and winter flood storage capacity. This process ensures that downstream water temperatures are warmer than historical norms, and this pattern can persist into November, depending on annual weather patterns (ODEQ 2006, USACE 2000). In addition, reservoir waters released in late spring and early summer are typically colder than likely historic temperatures (ODEQ 2006) due to the storage of colder winter waters behind the dams.

Under the standards of the federal Clean Water Act, the Oregon Department of Environmental Quality (ODEQ) surveyed and reported portions of streams and rivers that did not meet temperature (or other water quality) standards. Standards have been established for rearing, salmon and steelhead spawning, and cold water refuges. Timing of use determines when standards are applied to specific reaches (see Figure 57 for illustration of timing of spawning use for Willamette basin). The entire mainstem of the Willamette River, and several reaches in the Middle and Coast Forks were found to be impaired by excessively warm water temperature (Table 6).

Within the Coast Fork, water temperatures are monitored at a series of sites above and below both reservoirs (Figure 58). The Row River downstream of Dorena Dam and the Coast Fork Willamette downstream of Cottage Grove Dam exceed temperature criteria for the entire year (Figure 59). In the Coast Fork, 106 miles of streams and rivers have been designated as impaired based on the state's temperature standards under the Clean Water Act. Water temperatures are monitored at a variety of locations within the Middle Fork subbasin (Figure 60), but most of the sites are in streams above the dams. In the Middle Fork, 136 miles are temperature impaired for rearing, and 76 miles are listed as thermally impaired for salmon and steelhead spawning. The Middle Fork Willamette below Dexter Dam and Fall Creek below the Fall Creek dam both exceed state temperature standards. Other 303(d) stream segments listed for water temperature in the Middle Fork are not affected by dam operation (Figure 61). The water temperature data collected by ODEQ and other agencies and groups during 2001 and 2002 revealed high water temperatures (exceedence values, Table 7) in the below-dam river reaches, particularly when compared to temperatures from tributaries emptying into the reservoirs (Table 8).

Temperatures in the Middle Fork and Coast Fork exceeded the salmon and steelhead spawning criterion of 13℃ in early spring (May 15) . The numeric criterion for salmon and trout rearing was met from mid-May until mid-June when temperatures began to exceed 18℃. From mid-June into mid-September (2001 and 2 002), river temperatures exceeded the salmon and trout rearing criterion (18ºC). Stream temperatures again met the numeric 18℃ criterion by mid-September, but br iefly exceeded the spawning criterion of 13℃ again in the middle of October (F igure 62). The period of exceedence strongly corresponds to the period of fall drawdown in which the Middle and Coast fork reservoirs are being drawn down to reach the winter flood control pool. Regulated flows during this period are generally higher than natural unregulated flows would be. However, none of the dams on the Middle and Coast forks have the ability to selectively withdraw water from different elevations in the reservoir; all of them draw water through regulating outlets and penstocks near the bottom of the reservoir. Consequently, the colder waters of the hypolimnion are drawn off first, leaving only the warmer surface waters in the reservoir by late season.

For each of the sub-basins within the greater Willamette Basin, ODEQ (2006) has performed total maximum daily load (TMDL) analyses, and has recommended water quality management plans to meet the TMDL targets. The water quality management plan calls for the reservoir to use no portion of the human allowance for thermal load in the Willamette basin. This required temperature target is established for each reservoir (Tables 9 and 10), and is substantially lower than current temperatures recorded below these dams in September and October. Temperature targets for these reservoirs are being refined through monitoring and modeling. It is expected the TMDL load allocations cannot be met without significant structural modifications to the dams to allow selective withdrawal. However, modifications of reservoir operations may be help to moderate downstream temperatures and perhaps reduce the frequency and durations of exceedence. Changes in temperature in the Middle Fork, Coast Fork, and Row River (Figure 63) illustrate effect of current impacts that lower early summer temperatures and increase late summer and fall temperatures. The targeted thermal regimes will result in maximum temperature in July through early September, followed by the natural cooling during fall. In developing the TMDL, ODEQ also modeled a series of minimum flow targets recommended by National Marine Fisheries Service (NMFS) in their draft 2004 Biological Opinion. These patterns are also illustrated in the modeling of the NMFS Biological Opinion, though the shift toward the natural thermal regime is not as strong (Figure 64).

Flow also determines the rates and locations of exchange of surface and subsurface water through the gravel bed of the river, the hyporheic zone (see below). Cold water refuges are defined in OAR 340-041-0002(10) as “those portions of water body where, or times during the diel temperature cycle when, the water temperature is at least 2℃ colder than the daily maximum temperature of the adjacent well mixed flow of the water body”. Refuges include habitats where temperature sensitive cold water species may find refuge when ambient stream temperatures are stressful. Spatial distribution (both longitudinal and lateral) of coldwater habitats in the upper Willamette River between Albany and Eugene, was mapped in summers of 2005 and 2006. Five major types of lateral habitat were investigated in addition to mainstem longitudinal temperature pattern: 1) alcoves on gravel bars, 2) alcoves on floodplains, 3) side channels, 4) gravel bars without alcoves, and 5) embayments. Side channel temperature did not differ substantially from mainstem temperatures, and embayments tended to be warmer than mainstem temperatures. However, floodplain alcoves exhibited a greater abundance of habitats colder than the mainstem, in some cases maintaining temperature more than 8˚C colder than the mainstem (Figure 65, Gregory et. al. unpublished data). Coldwater habitats also were found on gravel bars along the mainstem, but the temperature differences were less than observed in floodplain alcoves. The distribution of cold water refuges is illustrated in the reach near Norwood Island in the mainstem Willamette (Figure 66). Restoration of flows that maintain complex channel morphology is likely to create a mosaic of floodplain and bar alcoves, which provide habitats more than 2˚C colder than the mainstem. In addition, decreases toward natural summer low flows would also increase the relative influence of subsurface inputs and create more extensive cold water habitats.

Nutrients and Toxic Pollutants

In addition to temperature, ODEQ and other agencies also regularly monitor a suite of additional water quality parameters at key locations within the Coast and Middle Fork basins. Aside from temperature, overall water quality is generally considered to be good in these two subbasins (Table 11). However, mercury contamination from old mining operations and natural lithology continues to be a concern in portions of the Coast Fork, both above and below the reservoirs (Figure 67). Samples from water, sediment and biota have shown elevated levels of mercury (e.g., Morgans 2003, Ambers and Hygelund 2001), with a significant portion of it from abandoned mines on the Coast Fork (above Cottage Grove dam); natural lithology and erosional processes appear to be the primary contributor to elevated mercury concentrations above Dorena Dam on the Row River (ODEQ 2006). Because mercury binds to small particles in the water column (ODEQ 2006), it is not unreasonable to suppose that reservoir operations which increase suspended sediment loads could affect mercury concentrations downstream of the dams. The current TMDL for mercury in these systems is not yet at a stage where recommended changes to dam operation have been considered.

Algal blooms have been noted at some point in all of the reservoirs on the Coast and Middle Forks (e.g., Youngberg et al. 1971, Scheidt and Nichols 1976, USACE 2005). Considered "nuisance" blooms by most management agencies, particularly when they are comprised of toxic blue-green species such as *Anabaena flos-aquae*, these planktonic algae usually are concentrated in comparatively small portions of the particular reservoir. Although they could conceivably pass through the reservoir outflows, there is little evidence they have any impact on downstream biota.

Sediment and Turbidity

Water velocities slow dramatically as rivers enter reservoir impoundments. This velocity reduction causes settling of sediment particles of all sizes, particularly the smaller silt and clay size fractions; the dam essentially functions as a very effective sediment storage facility. Sediment can originate from upstream sources (which may be affected by storm magnitude and land use impacts such as forest harvest; c.f. Ambers 2001), or from erosion of shoreline by wave action or the process of filling and draining the reservoir (Youngberg et al. 1971). Dams typically decrease the amount of fine suspended sediments downstream, resulting in lower turbidity levels, although some of the reservoirs in the study area, particularly Hills Creek, have a long history of turbidity issues both within the reservoir and downstream of the dams (Youngberg et. al 1971). These increased turbidities downstream are particularly notable during reservoir drawdown or flood releases when fine particles are entrained (USACE 2000). Dam-induced changes to the hydrologic regime are therefore expected to change the size and distribution of suspended sediments (Wentz et al. 1998). There are relatively few data on the effects of the Upper Willamette system dams on downstream suspended sediment and turbidity; most studies are limited to impacts on water quality above the dam (e.g., Ambers 2001, Youngberg et al. 1971). Some early work on the mainstem Willamette and major tributaries suggested there had been no change in the relationship between sediment load and streamflow when pre- and post-dam data were compared (Laenen 1995; Figure 68). However, this work was limited in its duration (3 years) and spatial extent (Salem gage), but did indicate local channel erosion and changes in land use activities were also important to turbidity and suspended sediment loads. In addition, there has been a decrease in the size of suspended particles transported since dam construction was completed (Laenen 1995).

Parameter	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
Water Quality				
Temperature	Higher in summer	No impact	No impact	No impact
Nutrients	Rates of primary production and microbial activity increase	Concentrations may increase, especially in early rain events Biological effects less than summer because of lower light and temperature Mobilization from sediment increases	Concentrations may increase and transport from floodplain increases Biological effects less than summer because of lower light and temperature Mobilization from sediment increases	Concentrations may decrease because of dilution Transport from floodplain increases Biological effects less than summer because of lower light, turbidity, and temperature Mobilization from sediment and floodplain increases
Turbidity	Low in summer May increase after drought with first rain events	Increases Timing and magnitude depend on land use and geomorphology	Increases Timing and magnitude depend on land use and geomorphology	Increases Timing and magnitude depend on land use and geomorphology
Toxics/pollutants	Concentrations may increase due to lack of dilution and effect of temperature Biological effects may be greater Mobilization from sediment low	Mobilization from sediment increases	Mobilization from sediment and adjacent floodplain increases	Mobilization from sediment and adjacent floodplain increases

Summary of impacts of the four environmental flow regimes on water quality parameters (subset from Table 26).

Geomorphology and floodplain inundation

Key Elements

- Large floods move sediment and gravel and contribute to development of channel complexity.
- Bankfull and overbank flows provide connection among the primary channel and secondary or side channels.
- Prior to dam construction, the combination of frequent flood flows and an abundant source of bedload material resulted in the formation of mid-channel gravel bars and islands in both the mainstem Willamette and Cascade tributaries, such as the Middle Fork.
- High flows allowed river channels to migrate within the floodplain, creating new channels and abandoning older ones, thereby creating features such as oxbow lakes, sloughs, and alcoves. These processes generate a complex mosaic of different patches of sediments, with vegetation of varying heights and ages.
- USACE dams and bank hardening projects have simplified channel morphology and decreased off-channel habitats, gravel bars and island areas of the Middle Fork, Coast Fork, and mainstem Willamette River.
- Bed composition has shifted to larger average sediment sizes immediately downstream of dams.
- Sources of coarse sediment from upstream transport and downstream channel avulsion have been reduced by dams.
- Hyporheic exchange has been reduced by channel and floodplain simplification and flow augmentation during summer low flow.
- Changes in flood duration and extended periods of bankfull discharges may increase bank failure rates and provide a local source of coarse and fine sediments.
- Lack of large overbank floods has decreased both the formation of complex floodplain surfaces and recruitment of new sources of coarse sediments.

The geomorphic impacts of reservoirs and dam operations are inextricably intertwined with hydrologic regimes. As a result, this section will overlap extensively with material presented previously for hydrologic processes but will emphasize geomorphic consequences of those relationships. Fundamentally, dams alter the energy for channel change by modifying discharge and blocking upstream contributions of sediment, ranging from coarse cobbles to fine silts and clays (see Kondolf and Whitlock 1996, Whiting 2002 for reviews). Reduction or removal of sediment supply sources combined with changes in flow magnitude and duration generate a series of cascading impacts on downstream parameters ranging from water quality to floodplain morphology. These impacts in turn have strong influences on all stream biota, from microscopic algae to black cottonwoods, and from mayflies to bald eagles. Compounding these dam-influenced changes to river geomorphology are additional anthropogenic modifications, including bank-hardening revetments, gravel mining operations, and land cover conversions from natural vegetation to agricultural or urban areas. We will attempt to address these complex issues separately, but we recognize they are all strongly inter-related.

The rivers and floodplains the first Euro-American settlers encountered in the Willamette Basin reflected the dynamic nature of these ecosystems. In an unaltered state, these systems are in a continuous cycle of formation and destruction mediated by flood disturbances (Gregory et al. 1991). The General Land Office (GLO) surveys of the 1850's provide some clues to pre-settlement channel configuration and natural vegetation. Maps generated based on this information base (PWNERC 2002) show some differences between the Coast and Middle Fork. According to this survey, the Row River and Coast Fork below the present-day dam locations were primarily single channels, with relatively few side channels, sloughs, and islands (PNWERC 2002). The width of the wetted channel below the confluence of the Coast Fork and Row River averaged approximately 100 meters, and surveyors noted only five small island complexes. In contrast, the lower Middle Fork drainage was a braided channel with numerous side channels, islands, sloughs, and off-channel ponds (PNWERC 2002). Today, many of these island and side channel complexes are submerged beneath Lookout Point and Dexter dams. The same pattern is also evident in the mainstem Willamette River above Albany (PNWERC 2002).

At approximately the same time the dams were being constructed, additional flood protection in the form of revetments was also installed on river banks below the dams (Table 12). In each subbasin, a total of approximately 5 miles of bank protection has been installed. Most of these revetments have been installed in areas of potentially active channel change and movement (Figures 69a and 69b). One effect of this bank armoring, combined with changes in patterns and duration of overbank flows, has been a reduction in the ability of the river to maintain connections between the primary channel and secondary or side channels (PNWERC 2002). The more recent impacts of these two processes are outlined in time-series illustrations (Dykaar 2005) for short, 5-6 mile reaches in each subbasin. The Coast Fork (Figure 70) example is located on the mainstem of the river, below both Cottage Grove and Dorena dams. The section of the Middle Fork analyzed (Figure 71) extends from just below Dexter Dam to the Fall Creek confluence. Both river basins show a loss of island area and concomitant decrease in channel complexity after completion of the dams and installation of the revetments, but data are lacking to determine whether there has been channel incision below the dams, and whether the channels have widened (due to bank failure) or narrowed (due to declines in peak flows).

The pattern of channel simplification due to dam construction and bank hardening is a common pattern on large river systems (e.g., Schmetterling et al. 2001) Within the greater Willamette River basin, both geology and revetments determine the susceptibility of stream banks to erosion (Wallick et al. 2006). The alluvium deposits below the Coast and Middle Fork dams and in the upper Willamette River are a combination of comparatively erodible Holocene alluvium mixed in with more resistant Pleistocene gravels. Bank revetments are even more resistant to erosion (Wallick 2006; Figure 72), and are commonly placed against the Holocene alluvium. The combination of revetment protection of erodible geologies and diminished stream hydraulic power has diminished the ability of the river to migrate laterally and has resulted in a predominantly single simplified channel. Perhaps somewhat paradoxically, there has been an increase in erosion rates along unarmored portions of some river banks. The present reservoir-management regime maintains bankfull discharges for extended periods during winter months, allowing soils to become well-saturated, and then drops flows sharply (Figures 17, 30, 42 and 54). This has resulted in numerous instances of bank slumping and failure (USACE 2000). Such processes occurred in pre-dam years, but were probably less likely because of floodplain vegetation, large wood, and shorter periods at bankfull discharge. Larger overbank flows were important for sculpting floodplain features, creating channel complexity, and maintaining ecological processes associated with the floodplain.

In addition to altering the hydraulic ability of streams to move sediments (Whiting 2002), dams also block the upstream sources of sediments and, in forested areas, large wood. In the Willamette basin, most of the sediment supply originates in the large tributaries (Klingeman 1973). The different parent geologies of Coast and Middle Forks contribute different amounts and sizes of sediment. Streams originating in Coast Range geologies, such as the mainstem Coast Fork, contribute twice the amount of suspended sediment compared to Cascade Range streams, such as the Middle Fork (Laenen 1995). The sediment contributions from Cascade streams tend to be coarser and similar to substrates found in the mainstem Willamette. In contrast, Coast Range systems typically contribute more finely grained sediments, including silts and sands (Klingeman 1973, USACE 2000). In terms of downstream effects on the mainstem Willamette, the USACE dam projects have effectively blocked a large proportion of the source of coarser sediments preferred by some of the native biota. This effect is also likely seen on the Middle and Coast Forks below the dams, although data are lacking on channel bed composition in these areas.

Prior to dam construction, the combination of frequent flood flows and an abundant source of bedload material resulted in the formation of mid-channel gravel bars and islands in both the mainstem Willamette and Cascade tributaries, such as the Middle Fork and the McKenzie (Ligon et al. 1995). These bar forms may coalesce into more complex floodplain features that could be generated without large overbank flows (Dykaar 2005). The increased boundary shear stress immediately downstream of the dams has resulted localized increases in bed coarseness (Ligon et al. 1995). Without high peak flows, these channels have stabilized, and there has been a loss of ability of the river to cut into the banks and recruit new sources of coarse sediments (Ligon et al. 1995). Unless tributaries can replace these upstream and lateral losses, smaller secondary channels fill with fine sediments, riparian vegetation encroaches, and the once complex braided channel becomes a simplified single thread (USACE 2000, Lignon et al. 1995, Gutowsky 2000, Dykaar and Wigington 2000).

The change in discharge regime has likely also affected the size and functionality of the hyporheic portion of rivers below dams (Whiting 2002). The hyporheic zone may be most easily thought of as the area of subsurface water flow beneath the surface waters of rivers and streams (Figures 73 and 74). Hyporheic flow is not ground water, but rather a dynamic movement of surface waters into the river bed where they can interact with groundwater. Hyporheic zones can be thought of as a mid-way point between surface and ground waters, and can be affected by both (see Stanford and Ward 1993, Malard et al. 2002 for reviews). Movement of water through this zone can affect a number of water quality parameters, including temperature and nutrient concentrations (Malard et al. 2002, Fernald et al. 2001, Fernald et al. 2006, Lancaster et al. 2006, Wentz et al. 1998). Recent work in the upper Willamette River has demonstrated that as much as 70% of the summer surface discharge flows through the hyporheic zone at some point (Fernald et al. 2001), with greatest storage volumes present at high flood flows (Laenen and Bencala, 2001). In the Willamette River, hyporheic areas can lower surface water temperatures (Fernald et al. 2001, Lancaster et al. 2006) and can influence patterns of nitrogen and phosphorus uptake (Hinkle et al. 2001, Fernald et al. 2006). These hyporheic flowpaths are commonly associated with river landscape features subject to continual flood-induced changes, primarily porous gravel reaches and channel features such as alcoves and side-channels (Fernald et al. 2001, 2006). The combination of the loss of complex channels and the decline in inputs of gravels from upstream sources has led to potential losses of hyporheic exchange and connectivity; some estimates suggest the decline has been as much as five-fold (PNWERC 2002). Changes in dam operation that restore hyporheic flow may also impact water quality parameters including stream temperature and nutrient concentrations.

The waters and river channels of the Coast and Middle Forks and the greater Willamette River do not exist in isolation from the rest of the surrounding landscape. Prior to anthropogenic changes of land cover and river flows, there was a tight connection between the river and its floodplain. Historically, unregulated high flows allowed river channels to migrate within the floodplain, creating both new channels (avulsion) and abandoning older ones, thereby creating features such as oxbow lakes, sloughs, and alcoves (PNWERC 2002). In addition, the high overbank flows created new floodplain deposits and added to existing islands and terraces. The floodplain generated consisted of a complex mosaic of different patches of sediments, with vegetation of varying heights and ages. Large, rare floods were particularly important in creating this type of complex floodplain; the present-day hydrologic regime consists instead of small magnitude but high frequency events which have lesser, although still important, impacts (Tockner et al. 2000).

Evidence from historical floods provides some information on the pre-dam extent of the floodplain in the Coast and Middle Forks (PNWERC 2002, Figure 75). At the height of the flood of record, in 1861, areas up to 2 km in width were inundated on the Middle Fork below the Fall Creek confluence and on the Coast Fork below Row River. Similar areas were inundated in the last large floods before the dams were constructed, in 1943 and 1945. The impact of flood control operations on floodplain inundation can be seen in the extent of the 1996 flood. The floodplain/floodways determined by FEMA (Figure 76) generally reflect these historical flood extents. However, there are some portions of the lower Coast and Middle Forks that were once part of the floodplain, and are now considered to be outside of the zone of flooding. As the rivers become increasingly disconnected from the surrounding floodplain, increasingly large flows are required to make these connections again.

Floodplain vegetation, both dead and living, plays an important part in mediating stream flows and generating floodplain surfaces (see Figure 77; Latterell et al. 2006, Steiger et al. 2005). Large wood, like sediment, is transported and rearranged by floods. The loss of large wood from these areas has numerous causes: historically it was removed from channels to increase navigability, and today upstream sources are blocked by USACE dams. When present, however, wood plays an important geomorphic role in creating bar and island features (Gurnell and Petts 2002, Gurnell et al. 2002). There are still accumulations of large wood in the rivers of the Willamette (Gregory et al, unpublished), but it likely originates in stream-side as opposed to upstream forests. As agricultural and urban areas encroach on floodplain forests, this source of large wood is also diminishing.

Parameter	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
Sediment	Little or no movement or delivery	Input from bank erosion, mostly fine particles Some mobilization of bed materials.	Turnover of some sediment, some gravel bars cleared Increased mobilization of bed materials.	Extensive lateral erosion and deposition Vertical accretion deposition Scour, formation of gravel bars
Channel Geomorphology	No major changes Fine sediment deposition in channel	Accretion/reshaping of riffles and bars Possible channel downcutting, formation of sediment deposits across side channels	Erosion of oversteepened banks Some lateral channel movement Significant reshaping, possible movement, of bars and riffles.	Change in channel geometry Possible new channels formed Major reshaping and movement of bars
Delivery of large wood	No changes	Possible streamside forest inputs	Adjacent forest inputs Transport from upstream. Some mobilization of in-channel large wood.	Adjacent forest inputs Channel avulsion inputs Transport from upstream Major mobilization of in-channel large wood.
Floodplain Structure	No change	Floodplain margins modified by bank failure, especially if flows remain at bankfull for extended periods. Some bank erosion by flow.	Floodplain margins modified by bank failure, especially for steep banks if flows drop rapidly Sediment deposits in secondary channels removed by high flows. More significant bank erosion by flow.	Floodplain margins modified by bank failure, bank erosion (lateral migration) and channel avulsion New channels may form Sediment deposits in secondary channels removed by high flows Relative size of secondary channels may change
Hyporheic	Subsurface exchange may increase because of lower proportion of surface flow Influence of subsurface flow on surface water	Water recharge in bars and floodplains increases Surface water may have greater influence on hyporheic zone as	Water recharge in bars and floodplains increases Surface water may have greater influence on hyporheic zone as	Water recharge in bars and floodplains increases Surface water may have greater influence on hyporheic zone as surface water head increases

Parameter	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
	may be more evident	surface water head increases Silt and sediment flushed from interstitial spaces, increasing potential hyporheic exchange	surface water head increases Silt and sediment flushed from interstitial spaces, increasing potential hyporheic exchange	Silt and sediment flushed from interstitial spaces, increasing potential hyporheic exchange New channels and bars provide areas of greater permeability and increased hyporheic exchange

Summary of impacts of the four environmental flow regimes on geomorphic parameters (subset from Table 26).

Biological/Ecological Conditions: Flow Requirements

Key Elements

- The Natural Flow Regime concept has served as a major guiding principle for river management throughout the world.
- The concept of Environmental Flow Recommendations focuses on identifying specific elements of the flow regime, e.g. low flows, high flow pulses, small floods and large floods that provide ecological benefits, and determining target flow regimes to meet those objectives.

Organisms inhabiting flowing waters and adjacent riparian areas and floodplains are adapted to natural patterns of both floods and droughts (Bunn and Athington 2002, Lytle and Poff 2004). This "natural flow regime" (sensu Poff et al. 1997) encompasses several parameters in terms of the temporal variability of river flows, including flow magnitude, duration, frequency, and predictability. There is also a spatial component to this flow regime: depending on the magnitude and duration (and possibly the frequency), different portions of river channels and floodplain features may experience flooding (or conversely, drought). The plants and animals inhabiting these dynamic ecosystems exhibit a number of adaptations to flow, including behavioral, morphological, and life history (Lytle and Poff 2004). Organisms with life history adaptations appear to be particularly vulnerable to changes in flow regime, because the different stages of the life cycle are synchronized to discharge. Species with behavioral and/or morphological adaptations may be better able to cope with modified flow regimes. Many plants and animals use a combination of these adaptations to cope with life in this environment; for example, seed dispersal in willows is frequently timed to occur during peak flows (life history), but plants can also germinate from vegetative fragments carried by floodwaters (morphology) (Karrenberg et al. 2002).

The impacts of dam operation on stream, riparian, and floodplain biota have been extensively documented (e.g., Poff et al. 1997, Nilsson and Berggren 2000, Nilsson and Svedmark 2002). In the Pacific Northwest, the impacts from the system of USACE-operated dams in the Willamette basin have received considerable recent attention and review (e.g., USACE 2000, NWPCC 2004). Plant and animal species listed or proposed for listing under state and federal endangered species statutes have garnered particular attention. We will use the information presented in these and other documents as a starting point for the text below. We will provide life history and habitat information for "exemplar species", both terrestrial and aquatic, native and introduced, and will attempt to relate these parameters to dam operations. Although the discussion will concentrate on these exemplar species, we will try to maintain an overall focus on the ecosystem processes affected.

Terrestrial Vegetation

Key Elements

- Two major aspects of flow that strongly influence vegetation—magnitude and timing—have been altered by dam operation in the Coast Fork, Middle Fork, and downstream mainstem Willamette River.

- Magnitude of winter floods has been reduced, which affects floodplain inundation, sedimentation, and patch creation.
- Magnitude of summer low flow has been increased, which influences regeneration and seedling survival.
- Timing of the transition between winter high and summer low flows has been shifted, which alters the survival of black cottonwood and early seral species.
- Alteration of flow magnitude and timing increases the potential for invasion of non-native species.
- Magnitude of winter high flows is important for floodplain inundation, creation of vegetation patches, creating bare soil for seed germination.
- Rate of streamflow recession is critical to survival of black cottonwood and willow.
- Dam operation may affect spread of invasive species such as giant knotweed and reed canarygrass.

For temperate floodplain forests, two different types of flood discharges typically ensure healthy plant communities. “Maintenance flows” correspond more or less to minimum annual flows, and contrast with “regeneration flows”, larger floods occurring only episodically (Hughes and Rood 2003). Maintenance flows may be easily provided by dam operations, but regeneration flows are typically more difficult to attain. Maintenance flows typically have been modeled using systems such as IFIM and PHABSIM, although these methodologies are less used now due to a realization they focus too much on target species, require expensive and extensive data inputs, don’t work well in large systems, and don’t work particularly well for floodplain systems (Hughes and Rood 2003). Regeneration flows usually are of large enough magnitude to rework channel morphology, create new, bare surfaces and generate new channel-floodplain connections, and typically are over-bank heights. In this type of flow, also termed flushing flows (sensu Kondolf 1998), timing, stage, and hydrograph shape are all critical. Although flushing flows are an important hydraulic tool (Kondolf and Wilcock 1996), they cannot provide any of the sediment stored behind dams. Unlike maintenance flows, regeneration flows do not occur annually: in the Pacific Northwest they are most frequently tied to episodic climatic events, particularly rain-on-snow weather patterns. Because many floodplain plant species are comparatively long-lived, regeneration discharges that occur on a decadal or longer basis may be required to provide the level of channel and floodplain change to ensure perpetuation of native plant communities.

Although floodplain plants are strongly affected by fluvial processes, it must be emphasized this is a two way interaction. Vegetation can affect geomorphic surfaces by protecting river banks from erosional discharges and by slowing flows and thereby allowing sediment (and propagule) deposition (Hupp and Osterkamp 1996). The hydraulic impacts of vegetation on sediment dynamics may be particularly important to floodplain plant species diversity. In addition to sediment, depositional areas frequently contain propagules as well as bits of roots or branches which, depending on species, may be able to sprout (Steiger et al. 2005); this seedbank can be very different from the adjoining vegetation. Depending on configuration and amounts, mineral sediments can either kill seedlings by burial, or may contain appropriate levels of moisture and nutrients for seed success. The decline of sediment inputs due to dams can therefore have both direct and indirect affects on floodplain vegetation communities.

Prior to Euro-American settlement, plant communities of the Willamette River floodplain and its major tributaries, including the Coast and Middle Forks, were a mosaic of forests, wetlands, prairies, and oak-dominated savannas (PNWERC 2002). In contrast to the cottonwood-dominated gallery forests of more arid climates (ranging from the east slope of the Cascades to the Mississippi River), the Willamette floodplain forests did not have a single dominant tree species. Most was a complex mix of Oregon ash, black cottonwood, Oregon white oak, big-leaf maple, red or white alder (depending on elevation), with conifers (Douglas fir, red cedar, Willamette ponderosa pine) present as well. Stands dominated purely by black cottonwood were limited to the large islands of the Columbia River, and a few small patches on the lower Santiam River (PNWERC 2002). Understory species in this community included willow, hazel, ninebark, vine maple, hawthorn, “coarse grass”, and “briars” (quotation marks refer to GLO surveyors’ notations).

Conversion of the floodplain forest and prairies to farmland and towns began in the mid-1850’s. Changes in river channel morphology began with snag removal and dredging in the 19th century, progressed to cut-off of lateral channels and bank armoring, and culminated with the construction of the USACE flood-control dams in the mid-20th century. The combined effects of these changes have resulted in an 80% decrease in native floodplain vegetation in the mainstem Willamette (PNWERC 2002). A similar pattern is seen on the Coast and Middle Forks below the downstream-most dams (Figure 78). Lack of channel movement and reworking of channel and floodplain sediments has resulted in a decrease in floodplain surface complexity. In areas not subjected to land cover conversions, there has been a general trend of decreasing patch diversity and a concomitant increase towards more homogenous forested communities, with little opportunity for early seral stage communities to develop (Gutowsky 2000; Dykaar and Wigington 2000, Fierke and Kauffman 2005, 2006).

The floodplain plant communities of the Willamette River and its large tributaries are home to a diverse flora with varying life histories and discharge sensitivities and requirements. We have chosen several “exemplar species” for additional discussion; for some habitat and flow requirements are well-studied. However, for many species, including some of the most common, little is known of their flow requirements. Below we will provide information on two early seral stage species, black cottonwood and willow; three common floodplain trees, Oregon ash, bigleaf maple, and white alder; and three understory species, reed canarygrass and giant and Japanese knotweed. The latter three species are considered invasive, although data on reed canarygrass suggests it may be native to the Willamette region (see below).

Cottonwood and Willow

Cottonwood is perhaps the single most studied floodplain tree species in North America. There is a wealth of information on life history, habitat and flow requirements, and the impacts of dams on riparian cottonwoods ranging from the plains of Canada and the United States westward into the Great Basin, Inland Northwest and Willamette Valley (see Lytle and Merritt 2004 for recent review). In the Willamette basin, the species present is black cottonwood, variously known as *Populus trichocarpa* and *P. balsamifera* ssp. *trichocarpa*. Cottonwoods are members of the willow family, Salicaeae, and many of the life history parameters and habitat requirements for cottonwood are shared by other willows, including the familiar Pacific willow of the Willamette, *Salix lasiandra* (also known as *S. lucida* or *S. lucida* ssp. *lasiandra*). In addition to the Pacific willow, as many as five other species of *Salix* are found in different portions of the Willamette basin; their individual flow requirements are unknown. Both species are widely distributed in Oregon (Figures 79 and 80), and are common in the Willamette. Due to a lack of information on flow requirements for Pacific willow, we have assumed they would be similar to black cottonwood, at least for initial establishment (Figure 81).

Black cottonwood and riparian willows are considered pioneer species: all require bare, moist mineral soils for germination; (Dixon 2003, Karrenberg et al. 2002). These surfaces can range from bare gravel bars generated by annual flood events (Rood et al. 2003) or large overbank flows which deposit bare soils on the floodplain (Scott et al. 1996). These species are wind-pollinated, with copious amounts of seeds produced each year from May through June in the Willamette (Dykaar and Wigington 2000; Figure 81). The seeds are viable for only one to two weeks under optimum conditions; if flows are high, and seeds stay wet for long periods of time, viability declines to as little as two or three days (Steinberg 2001). Once the seed finds appropriate sediment, germination typically takes place within 8 – 24 hours. The seedlings are highly resistant to inundation and sediment deposition, but are shade intolerant (and hence will not germinate under existing stands). Once germinated, the rate of stream flow recession is critical (Amlin and Rood 2003). The roots lengthen and follow the decline of the water-table; too swift a recession rate, and the seedlings will not survive. Survival of seedlings was greatest at recession rates of 0 – 2 cm/day and root length development was greatest at 1 cm/day (Mahoney and Rood 1991). Willow seedlings are somewhat more tolerant of anaerobic conditions than cottonwood, enabling them to colonize slightly different portions of the channel and floodplain (Amlin and Rood 2003, Steinberg 2001). The production of long roots comes at the cost of slower shoot elongation and leaf production in both species (Kranjcec et al. 1998). Both cottonwood and willow can also reproduce from broken branches and root fragments; large floods can therefore transport not only seed propagules, but vegetative ones as well (Kranjcec et al. 1998).

Other studies of Populus species have observed similar responses to flooding and drwadon rates. A study of plains cottonwood (*P deltoides molinifera*) in Minnesota for that 75% of the trees on the floodplain became establish after floods >10-yr recurrence interval Bradley and Smith (1986). Flood reduction by reservoirs caused a decline in the cottonwood downstream. Dams on the St. Mary River and neighboring rivers in Alberta, Canada caused 50-70% decreases in cottonwood abundance downstream of the dams (Rood et al. 1995).

Recruitment dynamics of cottonwood tend to be episodic throughout its range (Lytle and Merritt 2004), including the Willamette basin (Dykaar and Wigington 2000, Fierke and Kauffman 2006), reflecting the timing and magnitude of flow events. Plants produce enormous quantities of seed each year, so recruitment is driven by the availability of suitable germination habitat. In areas with dam regulation of the hydrograph and sediment inputs, such habitat has become progressively less available (Dykaar and Wigington 2000, Fierke and Kauffman 2006, Rood et al. 2003). Once established, cottonwoods can live 100 – 200 years (Steinberg 2001), with channel migration and bank cutting among the major sources of natural mortality. Regulation of flows has had significant consequences for the population structure of cottonwood (Lytle and Merritt 2004, Fierke and Kauffman 2006, Dykaar and Wigington 2000), although the development of the “recruitment box model” (Mahoney and Rood 1998) has proven to be an important tool for modifying dam flows to restore cottonwood recruitment. A summary of the interactions among flow, geomorphic landform, and population structure is shown in Table 13.

Ash, Maple, Alder

Other tree species in Willamette floodplain forests, Oregon ash (*Fraxinus latifolia*), Figures 82 and 83), bigleaf maple (*Acer macrophyllum*, Figures 82 and 84), and white alder (*Alnus rhombifolia*, Figures 81 and 85), are much less well-studied, particularly in the lowland, non-commercial forest portions of their ranges. During the GLO surveys in the mid-nineteenth century, Oregon ash was frequently listed as a dominant species of the forests along the Willamette River and its major tributaries (PNWERC 2002). In the remaining forest patches, it is still one of the most common tree species (Mindy Simmons, pers. comm.), and is considered a late-successional dominant (Fierke and Kauffman 2005 and 2006). Flowers are pollinated by wind during the summer months, and seeds drop from the trees in late summer and are dispersed throughout the autumn and winter months. Like willow and cottonwood, Oregon ash seeds are dispersed by both wind and water. Unlike *Populus* and *Salix*, however, the large ash seeds have a comparatively long life of up to one year, and can germinate even after prolonged immersion in water. Seeds germinate rapidly during the spring, on a wide range of soil types, but prefer moist soils with high organic matter content. Ash seedlings can tolerate poorly drained soils and cycles of inundation and drying, and are also quite shade tolerant. They cannot tolerate continual immersion, however, and consequently are not found in permanent wetlands. Oregon ash is typically found on higher floodplain terraces and poorly drained swales; due to this position on the landscape, seeds are as likely to disperse laterally as they are downstream. Oregon ash can attain ages in excess of 200 years.

Like Oregon ash, bigleaf maple is a late successional species in Willamette floodplain plant communities (Fierke and Kauffman 2005 and 2006), and can reach ages of 150 – 250 years (Franklin and Dryness 1973). It is widely distributed on both a macroscale (Figure 84) and microscale, able to tolerate both steep hillslopes and river bottoms; it is even more shade tolerant than Oregon ash (Uchytil 1989, Dave Hibbs pers comm.). Seeds are produced in the fall (Figure 82), and germinate with the onset of autumn rains. Seedlings can persist for up to 15 years in the understory, and grow rapidly as soon as light becomes available (Uchytil 1989). Like Oregon ash, it is moderately tolerant of flooding, and can probably survive up to two weeks inundation (Dave Hibbs, pers comm.).

White alder, *Alnus rhombifolia* (Figures 81 and 85) is an early seral stage species (Uchytil 1989). Like its closely related congener, red alder (*A. rubra*), white alder is found along perennial streams and rivers, but is limited to lowland valleys as opposed to montane regions: historically, there was little overlap between the two species. Seeds drop from the trees in late summer or early fall, and are dispersed by both wind and water. White alder requires bare mineral soils for germination, and can colonize many of the same habitats as cottonwood. Seedlings require continuously moist sites, and will suffer high mortalities under dry conditions (Uchytil 1989). Like cottonwood, it is quite shade intolerant, and can regenerate from sprouts as well as seeds (Uchytil 1989). Unlike maple, it survives some sediment deposition, and can reproduce by layering under these conditions.

Invasives

In addition to the impacts of changing fluvial geomorphic regimes and land use conversion, riparian and floodplain plant communities also are subject to impacts of introduced and invasive species (Tabacchi et al. 1996, 2005). Invasive species can outcompete indigenous plant species, thereby affecting numerous other organisms dependent on the native communities. Recent studies both in North America and in Europe have documented an increasing number and extent of invasive plants within floodplain and riparian communities (Tabacchi et al. 1996). Within the Willamette lowlands, one of the more abundant species affecting plant communities is reed canarygrass, *Phalaris arundinacea*. (Figure 81). Reed canarygrass has been implicated as part of the reason for the decline of native tree species throughout the United States (Lyons 1998) and in the Willamette lowlands (Fierke and Kauffman 2005, 2006). The state of Oregon classifies it as a noxious weed (IUCN website), and great efforts are made to control its distribution (e.g., Lyons 1998). However, *Phalaris arundinacea* appears to be native to the Pacific Northwest. Early botanical collections from the inland Northwest suggest it was present prior to the first Euro-American settlement (Merigliano and Lesica 1998) in large lowland river systems, wetlands, and some isolated montane areas. Collections in the Oregon State University Herbarium date from the mid-1870's near the confluence of the Willamette River with the Columbia (Figure 86). The first European cultivars were not introduced to the Willamette Valley until after World War I. Some have hypothesized the present populations are hybrids between native and introduced cultivars (Merigliano and Lesica 1998, Lyons 1998), but there are presently no known morphological means of discriminating between the cultivars of this highly variable species (Lyons 1998). Samples from the OSU Herbarium collection document an increase in the number of locations of occurrence for *Phalaris* (Figure 86); some of this spread appears to coincide with the operation of the USACE dams in the Willamette basin, an effect that has been documented in areas where reed canarygrass is not native (Lyons 1998, Kercher and Zedler 2004a). *Phalaris* flowers in early spring, and requires cold temperatures to trigger flowering. Although it produces enormous numbers of seeds, it spreads even more readily by water-borne root fragments (Kercher and Zedler 2004a). It is highly resistant to all forms of hydrologic management: in contrast to other invasives, such as tamarisk in the Southwest (Molles et al. 1998, Levine and Stromberg 2001), restoration of pre-dam flow regimes do nothing to reduce the abundance of reed canarygrass (Kercher and Zedler 2004a andb). *Phalaris* prefers finely textured, poorly drained soils and does particularly well in areas of high nutrient inputs. Only deep shade, and possibly low nutrients, limit its distribution on floodplains (Lyons 1998), where it can form impenetrable rhizome mounds within two years of establishment. Presence of these mats makes establishment of other native species difficult if not impossible.

Two more recently introduced invasive plants, Japanese and giant knotweed, have been found within the Willamette basin, including recent collections on the Middle Fork (Figure 87). Japanese knotweed (*Polygonum cuspidatum*, also classified as *Fallopia japonica* and *Reynoutria japonica*) has been introduced to both Europe and North America, and has been well studied in both places; comparatively little is known of the closely related giant knotweed, *P. sachalinense*. Both species outcompete native plants by virtue of extremely early emergence in spring (Figure 82) and rapid growth (up to 3 meters during the growing season). Seed production in the introduced cultivars appears to be somewhat rare (Seiger 1991). However, both knotweeds can regenerate from extremely small fragments of rhizome: less than 5 grams of root material is needed. The rhizomes break up easily during flood flows, and are readily transported downstream and deposited on banks (Seiger 1991). These rhizome fragments can survive at sediment depths of up to 1 meter (and have been observed growing through two inches of asphalt). Both *Polygonum* species tolerate a wide range of conditions, including high temperatures, drought, flooding, high salinity, and a range of light conditions from full sunlight to deep shade (Seiger 1991).

Species	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
Black Cottonwood	Extreme drought decreases seedling survival Young tree survival may decrease Rate of flow decrease critical to seedling survival	New gravel bars create instream colonization sites for next season	Seedlings and young trees on floodplain may be eroded Sediment deposits may benefit young trees New bars and floodplain surfaces create colonization sites for next season	Seedlings and young trees on floodplain may be eroded Vegetative reproduction increases from tree fall and fragmentation Sediment deposits may benefit young trees New bars and floodplain surfaces create colonization sites for next season
Willow	Extreme drought decreases seedling survival Young tree survival may decrease	New gravel bars create instream colonization sites for next season	Seedlings and young trees on floodplain may be eroded Vegetative reproduction increases from tree fall and fragmentation Sediment deposits may benefit young trees New bars and floodplain surfaces create colonization sites for next season	Seedlings and young trees on floodplain may be eroded Vegetative reproduction increases from tree fall and fragmentation Sediment deposits may benefit young trees New bars and floodplain surfaces create colonization sites for next season
Oregon ash	Extreme drought decreases seedling survival Young tree survival may decrease	Inundation and increased soil saturation are favorable to establishment and competition with other species New gravel bars create instream	Inundation and increased soil saturation are favorable to establishment and competition with other species Seedlings and young trees on floodplain may	Inundation and increased soil saturation are favorable to establishment and competition with other species Seedlings and young trees on floodplain may be eroded Sediment deposits may

Species	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
		colonization sites for next season	be eroded Sediment deposits may benefit young trees New bars and floodplain surfaces create colonization sites for next season	benefit young trees New floodplain surfaces create colonization sites for next season
Big-leaf maple	Extreme drought decreases seedling survival Young tree survival may decrease	Little effect	Seedlings and young trees on floodplain may be eroded Sediment deposits may benefit young trees	Seedlings and young trees on floodplain may be eroded Vegetative reproduction increases from tree fall Sediment deposits may benefit young trees
Reed Canarygrass	Drought may allow canarygrass to outcompete other riparian species	Sediment deposits may benefit Erosion and redeposition of grass clumps may increase dispersal	Sediment deposits may benefit Erosion may clear some areas Erosion and redeposition of grass clumps may increase dispersal	Sediment deposits may benefit Erosion may clear some areas Erosion and redeposition of grass clumps may increase dispersal
Knotweeds	Drought may allow knotweeds to outcompete other riparian species	Sediment deposits may benefit. Erosion and redeposition of root clumps may increase dispersal	Sediment deposits may benefit Erosion may clear some areas Erosion and redeposition of root clumps may increase dispersal	Erosion may clear some areas Sediment deposits may benefit Erosion and redeposition of root clumps may increase dispersal

Summary of impacts of the four environmental flow regimes on exemplar terrestrial plant species (subset from Table 26)

Terrestrial Vertebrates: Birds and Mammals

Key Elements

- Alteration of flow regimes affects the food resources and habitats of terrestrial wildlife.
- Large and small floods create different patch types which provide important habitats for terrestrial species.
- Bankfull and overbank flows are important for development of floodplains which provide winter feeding grounds for species such as bald eagles.

Birds

A total of 154 bird and 69 mammal species spend all or part of their life cycle within the greater Willamette Basin (Table 14); many of these species are closely associated with riverine habitats, including floodplains and wetlands. Vegetation community type and diversity are important correlates of bird and mammalian abundance and distribution (e.g. Knutson et al. 2005). Consequently, anthropogenic activities which affect plant community distribution and structure can have important consequences for wildlife species. For example, loss of floodplain forest habitat has been linked to local extinction of the yellow-billed cuckoo (*Coccyzus americanus*) and the black-crowned night heron (*Nycticorax nycticorax*) in the Willamette valley (PNWERC 2002).

Considerable data exist for two bird species near the top of the floodplain food web, bald eagles (*Haliaetus leucocephalus)* and ospreys *(Pandion haliaetus)*. Numbers of both species have increased dramatically over the past 10 -20 years, presumably as a result of declines in egg-shell thinning pesticide use and improvement in habitat (Frank Isaacs, pers. comm.). Bald eagles are a federally- and state-listed threatened species, and have been the focus of conservation efforts for the past three decades. They are year-round residents of the Willamette River area, including locales above and below the Coast and Middle Fork dams. In lowland areas, eagles nest in large floodplain trees, preferably Douglas fir, but as populations have increased they have increasingly constructed their large nests in black cottonwood (Isaacs and Anthony 2003). Most nests (98%) are in living trees with the open structure and large, strong branches needed for nest support. In the Willamette Valley, nest construction begins in the winter months; with egg-laying peaking in mid-March. The young hatch by late May, and are fledged during the summer months. Although nests may be located along rivers, lakes or reservoirs, eagles forage widely: during nesting season, their home range averages 8 square miles, but may be considerably larger (Isaacs and Anthony 2003). The birds in the Willamette forage primarily on fish (either dead or stolen from other birds) and waterfowl; the older birds are more efficient hunters than younger individuals, with the latter frequently feeding on carrion or robbing other species (Frank Isaacs, pers comm.). Bald eagles are highly migratory during the late summer and autumn months, primarily following food sources such as salmon runs. One particularly important source of winter feeding in western Oregon is floodplains: flooded areas both attract waterbirds and also drown small mammals, both of which are important prey items to bald eagles (Frank Isaacs, pers. comm.). Changes to dam operations which increase floodplain inundation could be beneficial to bald eagle populations during the winter months.

Unlike bald eagles, ospreys are highly migratory. They return from their wintering grounds in Central and South America in March, often to the same nest as the previous years, and begin breeding behavior shortly thereafter. Ospreys are much more closely tied to open water than bald eagles, with their nests located within 2 miles of water (Henny 2003). In the Willamette Valley, the young typically fledge in early August, and the birds leave the area in September. During this nesting season, adult and then young birds collect food by diving up to depths of 45 cm (Henny in Marshall et al. 2003). Their diet consists almost entirely of live fish, preferably in the 11 – 30 cm size class. In the Willamette, the vast majority of the prey are largescale suckers (83% by biomass), followed by northern pikeminnow (7%), common carp (6%) and bass and bullheads (1 - 2% each) (Henny 2003). Because of their foraging strategy, ospreys require comparatively clear water, and will preferentially hunt in shallower portions of most water bodies. During periods of increased turbidity, such as high flood flows, foraging efficiency drops (Frank Isaacs, pers. comm.). Although susceptible to egg-shell thining from pesticides, osprey populations also declined due to loss of floodplain lakes and large dead trees required for their nests. They have successfully pioneered use of reservoirs to replace the lakes, and utility poles to replace the trees (Henny 2003). Hydrologic regimes which include long periods of high turbidity between March and September could negatively affect osprey foraging behavior.

Mammals

Three of the mammals most closely tied to floodplains and water are herbivorous aquatic rodents: the American beaver (*Castor canadensis*), the native muskrat (*Ondatra zibethicus*), and the introduced nutria (*Myocastor coypus*). In the Willamette lowlands, all three live in burrows in river banks along permanent waterways, and as such, are all susceptible to negative effects from prolonged bankfull discharges. The dam-building activities of beaver are confined to smaller tributaries and occasionally to side channels and alcoves. Beaver populations have declined greatly from historical levels, and their present numbers are comparatively low; they produce only one litter per year, and are still trapped by fur collectors (Csuti et al. 1997) or removed as a "pest species" in urban, agricultural or industrial forest lands. In contrast to beaver, both the native muskrat and introduced nutria are capable of producing two or three litters per year, with the result that densities of 3 to 10 individuals per hectare of either species are not uncommon (Csuti et al. 1997). The nutria was introduced to Oregon in 1937 and has since spread throughout the Coast Range, Willamette Valley, and Cascade foothills. Within the Willamette Valley, the native muskrat has become almost extinct, its niche apparently filled by the invasive nutria (Bob Anthony, pers. comm.).

Species	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
Terrestrial Vertebrates				
Birds	Relatively little effect near river. Shore birds may be affected if area of shoreline habitat diminishes. Summer low flow augmentation reduces availability of emergent gravel bars, shoreline complexity, and vegetation perches.	Relatively little effect near river.	Patchy changes in habitat by flood alteration of riparian vegetation, gravel bars, and floodplain margin. Scavengers may benefit.	Habitats may be destroyed or created by floodplain change. Scavengers may benefit.
Mammals	Relatively little effect near river.	Relatively little effect near river.	Floods may decrease survival, particularly for less mobile species. Patchy changes in habitat by flood alteration of riparian vegetation, gravel bars, and floodplain margin. Scavengers may benefit	Floods may decrease survival, particularly for less mobile species. Habitats may be destroyed or created by floodplain change. Scavengers may benefit.

Summary of impacts of the four environmental flow regimes on birds and mammals (subset from Table 26)

Aquatic Invertebrates

Key Elements

- Little is known about composition or flow requirements of the aquatic macroinvertebrate communities of the mainstem Willamette River and its larger tributaries.
- The discharge regime plays a particularly critical role in dispersal of macroinvertebrates: most species have evolved life histories which take advantage of temporal and spatial variation in flows to colonize downstream and/or lateral habitats
- Longer lived and more sedentary invertebrates are likely to be more vulnerable to flow modification.
- Alteration of thermal regimes may influence invasion of non-native mollusks.

Macroinvertebrates, which include taxa ranging from oligchaetes to arthropods to mollusks, are among the organisms most strongly and immediately affected by changes to hydrologic regimes (e.g., Gore et al. 2001, Malmqvist 2002, Bunn and Athrington 2002 for reviews, see also Figure 88). With some notable exceptions (see below), most lentic invertebrate species are comparatively short-lived, relying on a combination of morphological adaptations, specialized behaviors and/or life history characteristics to survive in dynamic riverine environments (Lytle and Poff 2004). Invertebrates are important components of aquatic ecosystems, and play significant roles in processes such as nutrient cycling, turnover of organic materials, and as a source of food for other species including fish, amphibians and waterfowl. They frequently have specific requirements in terms of sediment size and stability, water chemistry (particularly temperature and dissolved oxygen), and hydraulic parameters (Malmqvist 2002). Many are strongly adapted to the predictability of high and low flow periods; disruptions of this cycle can have profound consequences for invertebrate biodiversity (Malmquist 2002, Resier et al. 2005). In cases where flow variability is high and predictability is low (flow “peaking”), such as below hydroelectric dams, the macroinvertebrate community may be dominated by a few disturbance-tolerant taxa (Bunn and Athington 2002). The discharge regime plays a particularly critical role in dispersal: most species have evolved life histories which take advantage of temporal and spatial variation in flows to colonize downstream and/or lateral habitats (Bunn and Athington 2002; Lytle and Poff 2004). Consequently, changes in the timing and magnitude of discharge can have profound impacts on persistence as well as distribution of a number of taxa (Malmqvist 2002).

Within the greater Willamette River basin, there is a wealth of information on invertebrate communities, life histories, distribution, and abundance (see Altman et al. 1997 for summary). However, the vast majority of these data originate in relatively small drainages (“wadeable streams”) as opposed to the mainstem Willamette River or any of its major tributaries, including the Middle and Coast Forks. There is a long history of attempts to use benthic invertebrates as bio-indicators of water quality throughout the basin, beginning in the 1950’s (Deschamps 1952, cited in Altman et al. 1997) and continuing into the mid-1990’s (Tetra Tech reports 1994, 1995). Recently, the USEPA, with the ReMAP program, has begun some limited sampling of benthic macroinvertebrates in the mainstem Willamette and some large tributaries (Alan Herlihy, pers. comm.). Most of the sampling in these larger systems has been limited to collection during summer base flows, and in a limited number of easily (and safely) accessible habitats, such as riffles, river margins and revetments (Hjort et al. 1984).

Comparison of these few sampling efforts is made more difficult by differing methodologies and varying degrees of taxonomic resolution. At present, there is no systematic long-term monitoring of benthic macroinvertebrates in the larger rivers of the Willamette basin, so basic information on species distribution, abundance and persistence is fragmentary at best, and largely unknown.

Short-lived Species

Among the species most sensitive to water quality impairment are the "EPT" taxa, Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddis flies). Depending on taxon, these organisms may be herbivores, detritivores, predators, or may switch food resource with life history stage. All have complex life histories (see Figure 89 for Willamette River examples) involving multiple larval molts (or instars) and short-lived (and in some orders, non-feeding) adults. Some of these species, such as the Trico mayfly (*Tricorythodes* sp.), are capable of producing several generations per year, enabling them to respond rapidly to flood disturbance events (Figure 89). Other species in the same order, such as the March Brown mayfly (*Rhithrogena morrisoni*), have only one generation per year; they metamorphose and emerge as adults in a large locally-synchronized pulse in March and April. Caddisflies, such as the large and locally-abundant October caddis (*Dicosmoecus gilvipes*) also have synchronized adult emergence, but in the early autumn; this caddis also has a more complex life cycle, involving a series of five juvenile instars, pre-pupation, pupation, and finally metamorphosis and adult emergence. The impacts of changing flow regimes likely would be least for organisms such as the Trico mayfly, moderate for the March Browns, and most severe for the October caddis. Of particular importance to all of these organisms is the rate of flow change and its impacts on both velocity and water temperature (see review by Reiser et al. 2005).Numerous instream flow models have developed for particular fish species; however, in order to maintain the benthic invertebrate communities many of these fish depend on, the flow models generally require some modification (e.g., Gore et al. 2001, Figure 90).

Long-lived Species

In addition to a diverse aquatic insect fauna, the Willamette River is home to several freshwater mussel species, including the Western Pearlshell mussel, *Margaritifera falcata* (figure 38). Freshwater mussels differ markedly from other aquatic invertebrates in a number of life history characteristics (Table 15). Pearlshell mussels are one of the longest-lived animals on earth, with average life spans of 60-70 years and ages greater than 100 years not uncommon (Nedeau et al. 2006). Mussel beds provide habitat for other macroinvertebrates (e.g., Vaughn and Spooner 2006), and may play an important role in suspended particulate and nutrient dynamics at low flows (Howard and Cuffney 2006a). The most common species in the Pacific Northwest, *Margaritifera* need cold, clean water with relatively stable substrates (Nedeau et al. 2006). Given the appropriate substrate and flow refugia, adult mussels are capable of surviving high flood flows (Howard and Cuffney 2003, Vannote and Minshall 1982). Adult mussels are sessile, and the species disperses by means of a parasitic larva. Spawning is triggered in early spring by a combination of flow and temperature; females brood the fertilized eggs, and release the glochidia larvae in late spring, again dependent on flow and temperature (Nedeau et al. 2006; Figure 91). The larvae attach to the gills of freshwater fish, particularly salmon and cutthroat trout, and disperse by means of their host fish species. The mechanism that triggers larvae to leave the fish host are unknown; however, once they drop off the fish, larvae spend several years in the sediments before they are able to reproduce (Strayer et al. 2004). Dam construction and operation are frequently cited as the greatest threat to the dispersal and survival of freshwater mussels (Hardison and Layzer 2001, Strayer et al. 2004, Nedeau et al. 2006). Although mussel beds may be persistent under natural flow conditions, changes in flow regime, substrate size and distribution, water temperature, and abundance and movement of migratory fishes can all have negative impacts. Seasonal changes in dam discharge from natural patterns influence both adult survival and recruitment of juveniles by changing flow hydraulics (Hardison and Layzer 2001, Howard and Cuffney 2003, 2006b) and sediment size and distribution (Morales et al. 2006, Nedeau et al. 2006). In the Willamette Basin, freshwater mussels also face an introduced species, the Asian clam *Corbicula fluminea*. *Corbicula* can attain remarkably high densities in a wide range of habitats, thereby outcompeting native mussels, and also is known to consume their glochidia larvae (Nedeau et al. 2006). Unlike the native species, *Corbicula* does not tolerate water temperatures below 3°C. The effects of non-native fish introductions on mussel populations are unknown, but may be significant (Nedeau et al. 2006). In addition to the Pearlshell mussel, several other species of freshwater mussels are found in the Willamette basin, including at least two species of the floater, *Anodonta,* as well as the Western ridged mussel, *Gonidea angulata*. The latter species can tolerate fine sediments, and has begun to replace the *Margaritifera* in rivers with increased loads of suspended sediments (Vannote and Minshall 1982).

Species	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
Aquatic Invertebrates				
Mussels, long-lived, adults not mobile	Release of larvae is temperature sensitive. Increased larval survival in low flow years.	Limited effects of sediment scour or deposition if short pulses. Long periods at bankfull provide greatest risk	May destroy beds in areas of high scour or deposition or clean them of accumulated sediments.	May destroy beds in areas of high scour or deposition or clean them of accumulated sediments
Mayflies, short-lived, adults and larvae mobile	Little effect unless riffle habitats decline or area of aquatic habitat is greatly reduced.	Likely to scour new habitat Recolonized by survivors in river bed, downstream larval drift, or aerial dispersal of egg-laying adults.	Likely to scour new habitat Recolonized by survivors in river bed, downstream larval drift, or aerial dispersal of egg-laying adults.	Likely to scour new habitat Recolonized by survivors in river bed, downstream larval drift, or aerial dispersal of egg-laying adults.
Caddisflies, short-lived adults and larvae limited mobility	Little effect unless riffle habitats decline or area of aquatic habitat is greatly reduced. Survival may decrease if temperatures increase greatly	Likely to scour habitat and cause mortality. Recolonized by survivors in river bed or aerial dispersal of egg-laying adults. Dispersal by drift less important.	Likely to scour habitat and cause mortality. Recolonized by survivors in river bed or aerial dispersal of egg-laying adults. Dispersal by drift less important.	Likely to scour habitat and cause mortality. Recolonized by survivors in river bed or aerial dispersal of egg-laying adults. Dispersal by drift less important.

Summary of impacts of the four environmental flow regimes on exemplar aquatic invertebrate species (subset from Table 26)

Aquatic Vertebrates

Amphibians and Reptiles

Key Elements

- High flood flows likely serve to maintain and to create nesting areas for western pond turtles
- Large floods that can restore complex backwater habitats will likely benefit western pond turtles
- Overbank flows are important for creating breeding sites for red-legged frogs
- Amphibians and reptiles are strongly affected by loss of floodplain wetland habitat and alteration of thermal regimes.
- Several reptiles and amphibians in the Coast Fork and Middle Fork are listed as threatened or sensitive.
- Invasion of non-native bullfrogs has been linked to declines in native frogs.

Within the entire Willamette Basin, there are 19 amphibian and 15 reptile species (including two turtles, see Table 16). All are native to the area with the notable exception of one introduced frog (see below). The combined impacts of land use change leading to habitat loss, dam construction and operation, stream channelization, increase in chemical pollutants, and direct and indirect effects of introduced species has caused significant population declines in many of these organisms. Two frog species, the spotted frog (*Rana pretiosa*) and the foothill yellow-legged frog (*Rana boylii*), likely are locally extinct within Upper Willamette (USACE 2000, Nussbaum et al. 1983, C. Pearl, pers. comm.).. Two other species, the red-legged frog (*Rana aurora*) and the Western pond turtle (*Actinemys marmorata*) are of special concern to state and federal agencies.

Western Pond Turtle

Despite their name, Western pond turtles are not limited solely to ponds, but also are found in backwaters, sloughs, marshes, and low-velocity regions of large rivers (Hays et al. 1999, NWPCC 2004). Once widely distributed and abundant in the Willamette valley, pond turtle numbers have declined since the beginning of the 20th century (Csuti et al. 1997), although exact numbers and distribution are not known (D. Veseley, pers. comm..). Some of the largest remaining populations are found in shallow areas of the Row River and Fern Ridge and Lookout Point reservoirs (NWPCC 2004, USACE 2000). Smaller populations are located within and below other reservoirs of the Coast and Middle Forks, as well as backwaters of the upper Willamette River (USACE 2000. K.. Beal, pers. comm.). Wooded riparian patches near open areas appear to be a predictor for adult turtles: most hibernate in forested floodplains and uplands (Hays et al. 1999), and the downed wood provides important basking sites (NWPCC 2004). In addition to requirements for comparatively low velocity habitats, sunny, open areas with little vegetation for nesting habitat are critical (ODFW 2000, Hays et al. 1999, D. Veseley pers.comm.). Nests are constructed during early summer; the young hatch about 3 months later, and remain in the nest until the following spring (Hays et al. 1999, USACE 2000). Once emerged, young turtles are vulnerable to a number of predators, including introduced bullfrogs (ODFW 2000), and do not attain sexual maturity until approximately 10 years of age; pond turtles may live as long as 40 years (Nussbaum et al. 1983, Csuti et al. 1997). High summer flows on the Middle Fork make the river less hospitable to western pond turtles by increasing velocity and decreasing temperature. In contrast, turtles are routinely observed along some sections of the Coast Fork, where summer flows are much closer to historic levels (K. Beal, pers. comm.). Changes in flood regime have been identified as one of the causes of population decline (ODFW 2000), because floods likely distributed turtles along the river and promoted population mixing. High flood flows probably also served to maintain and to create nesting areas (K. Beal, pers. comm.). Modification of the present flow regime and channel simplification to restore complex backwater habitats and their connections may improve western pond turtle populations.

Red-legged Frog

Red-legged frog (*Rana aurora*) breeding sites are usually found in relatively heavily vegetated locations with significant areas flooded in winter and spring. Breeding sites in the Willamette Valley can be associated with upland ponds as well as floodplain forest wetlands (Adams et al. 1999, Pearl et al. 2005). These breeding sites expand with the onset of winter rains and overbank flood flows, and may be dry by mid-summer. *Rana aurora* breeds and lays its eggs in these shallow ponds during January and February (Figure 92), and the eggs hatch within one to two months (Nussbaum et al. 1983, C. Pearl, pers. comm.).. Tadpoles spend approximately 3 months in the pools before metamorphosing to adults, who show increased survival in areas with or near trees (Pearl et al. 2005, NWPCC 2004). Red-legged frogs occasionally breed in side channels and sloughs associated with large rivers (Pearl et al. 2005). They generally oviposit in areas of little or no current, but specific velocity requirements for egg and tadpole survival have not been identified. Population declines of *R. aurora* in the Willamette Valley were noted over 20 years ago (Nussbaum et al. 1983), but quantitative data are sparse (C. Pearl, pers. comm.). As with other amphibian species, red-legged frogs may be indicators of a number of environmental insults due in part to their use of different habitats over their life history. Egg masses may be stranded by fluctuating water levels. Both larvae and adults may be vulnerable to increases in UV radiation (Blaustein and Kiesecker 2002), changes in thermal regime, common chemical pollutants such as fertilizers (e.g. Nebeker and Schuytema 2000), loss of habitat due to land use conversion, invasive plants (which fill in breeding habitat) and animals (which may consume eggs, tadpoles and adults, see below) (Kiesecker and Blaustein 1997, 1998, Pearl et al. 2004, NWPCC 2004). Loss and alteration of wetlands associated with agriculture and urban areas is likely one of the most critical challenges for red-legged frogs in the Willamette Valley (C. Pearl, pers. comm.).

Bullfrog

The bullfrog, *Rana catesbeiana*, was introduced to the Willamette Valley in the late 1920's or early 1930's (Nussbaum et al. 1983). Considered one of the "100 World's Worst Invasive Species" (Crayon 2005), it is implicated in the declines of some native fish and amphibians. In the Willamette Valley, the life history of *R. catesbeiana* differs from the native *R. aurora* (Figure 92). Bullfrogs breed and lay eggs during the summer months. Once hatched, tadpoles require a minimum of 12 months under ideal conditions (warm temperatures and abundant food) to metamorphose to adults; tadpole lifespans of up to 2 years are not uncommon (Nussbaum et al. 1983, Csuti et al. 1997), although recent work in the Willamette basin suggests bullfrogs may be evolving shorter time periods in the tadpole stage (Selina Heppell, pers. comm..). Bullfrog tadpoles therefore require deeper, more permanent waters than the native species, and have lower survival rates in the temporary wetlands often used by red-legged frogs. Adult bullfrogs may overwinter in burrows created by nutria, another introduced vertebrate (NWPCC 2004). Both juvenile and adult bullfrogs can prey on red-legged frogs (Kiesecker and Blaustein 1997, Pearl et al. 2004). However, non-native fish including small- and large-mouth bass, are also important predators of native frogs (NWPCC 2004). The presence of bullfrogs may force behavioral changes that render *R. aurora* more vulnerable to predation by introduced fish (Kiesecker and Blaustein 1997, Figure 93). In a further twist, native dragonfly nymphs can prey on bullfrog tadpoles, but the abundance of the nymphs decreases in the presence of non-native sunfish (Adams et al. 2003). Modification of flow regimes could be an important tool to both limit introduced bullfrogs and improve populations of native red-legged frogs. Discharges that go up on to floodplains and then recede may help provide the temporary pond habitats for *Rana aurora* breeding but not used by *R. catesbeiana*.

Species	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
Amphibians				
Red-legged frog	May decline if habitat dries up	Likely to scour habitat and cause mortality.	Likely to scour habitat and cause mortality. Survival increased if temporary wetlands created. Adult dispersal and egg production may increase if wetland habitats increase.	Likely to scour habitat and cause mortality. Survival increased if temporary wetlands created, but may allow bullfrogs to invade. Adult dispersal and egg production may increase if wetland habitats increase.
Bullfrog	May decline if habitat dries up	Likely to scour habitat, cause mortality.	Likely to scour habitat, cause mortality. If flood connects river to deep ponds, could increase. Possible increased mortality in tadpoles. Adult dispersal, egg production may increase if wetland habitats increase.	Likely to scour habitat , cause mortality. If flood connects river to deep ponds, could increase. Possible increased mortality in tadpoles. Adult dispersal and egg production may increase if wetland habitats increase.
Reptiles				
Western pond turtle	May decline if habitat dries up. Augmented summer flows decrease available habitat.	Little effect	If flood connects river to deep ponds, could increase abundance. Possible increased mortality in young. Adult dispersal, reproduction may increase if wetland habitats increase. Increased scour may provide nest sites.	If flood creates floodplain ponds or connects river to deep ponds, could increase abundance. Possible increased mortality in young. Adult dispersal and reproduction may increase if wetland habitats increase Increased scour may provide nest sites

Summary of impacts of the four environmental flow regimes on exemplar aquatic amphibians and reptiles (subset from Table 26

Fish

Key Elements

- Fall flood pulses are important for passage of adult salmon.
- Magnitude, timing and duration of spring flows are important cues for upstream migration of adult salmon and downstream migration of salmon smolts.
- Bankfull and overbank flows are important for Oregon chub, which inhabit backwaters and isolated floodplain habitats.
- For salmon and steelhead, adequate “incubation flows” must be maintained over redds created during spawning.
- Influences of flow modifications and thermal regime due to dam operation differ between spring- and fall-spawning native fish species.
- Spring-spawning species include coastal cutthroat trout, lamprey and all native cyprinids (minnows), suckers, and sculpins.
- Fall-spawning species include Spring Chinook salmon and bull trout
- Non-native species (e.g., bass, catfish, mosquitofish, carp) are typically spring and early summer spawners.
- Flow modification in any season potentially affects the growth and survival of juvenile fish.
- Flow modifications in spring influence both adults and fry of spring spawning species.
- Flow modifications in autumn influence both adults and fry of fall spawning species.
- In the mainstem Willamette and major tributaries, native fish species may be migrating during any month of the year.
- Dam operations have been linked directly and indirectly to declines in Spring Chinook salmon.
- Channel and floodplain simplification have been identified as major factors leading to the declines in Oregon chub, Pacific lamprey, and possibly coastal cutthroat trout.
- Creation of warmer, more lacustrine habitats in the Willamette River favor the invasion by bass, carp, catfish, and other non-native species.

The impacts of dam construction and operation on fish and fisheries have been well documented globally (e.g. Nixon 2004) and locally (USACE 2000, NWPCC 2004 for reviews). Dam operations affect fish distribution and abundance both directly and indirectly. Direct impacts are due to modification of components of the flow regime (see above), including timing, magnitude, and duration at both annual and inter-annual intervals. Dams indirectly affect many fish species by changes in water quality, including but not limited to temperature, turbidity, and environmental contaminants. Other indirect impacts include modification of habitat by changes to size and distribution benthic sediments, (e.g., spawning gravels), loss of preferred habitats, (e.g., off-channel rearing locations), reduction in habitat complexity (e.g., loss of large wood accumulations), increasing prevalence of diseases or parasites, and increasing habitat suitability for invasive species, which may impact natives through either competition or predation.

Within the Willamette River basin there are a total of approximately 60 fish species, of which only 31 are native (PNWERC 2002, Table 17). There is a trend towards increasing numbers of warm water, non-native species along a downstream longitudinal gradient (Figure 94). A subset of these species is present in the study area (Table 17); the Middle Fork has somewhat greater species richness than the Coast Fork due in part to greater basin area and the presence of both lowland and Cascade province fauna. The Middle Fork apparently also has additional introduced species. Despite the array of species, most management attention has been focused on a handful of native endangered species, mostly salmonids (USACE 2000, NWPCC 2004, Table 18). The impacts of dam operation and other anthropogenic effects on these half dozen species have been documented recently in great detail (USACE 2000, NWPCC 2004). For this planning review, we will again focus on a handful of “exemplar species”. For those exemplars which overlap with species documented in previous reviews, we will provide a very brief summary supplemented with more recent study results.

We have selected eight species as exemplars with varying life histories, as follows:

Anadromous salmonid	Spring Chinook	*Oncorhynchus tshawytscha*
Anadromous non-salmonid	Pacific lamprey	*Lampetra tridentata*
Resident salmonid	Cutthroat trout	*Oncorhynchus clarki clarki*
Resident non-salmonid	Brook lamprey	*Lampetra richardsonii*
	Oregon chub	*Oregonichthys crameri*
	Large scale sucker	*Catostomus macrocheilus*
Invasives	Smallmouth bass	*Micropterus dolomieui*
	Largemouth bass	*Micropterus salmoides*

Spring Chinook

The Upper Willamette Spring Chinook (*Oncorhynchus tshawytscha*) has been a species of concern for decades. Most recently, two reviews have compiled the extensive information available related to the biology of this species, and the impacts of dam operations (USACE 2000) and other anthropogenic factors on its decline (NWPCC 2004). In addition, National Marine Fisheries Service Technical Recovery Team has recently provided an in-depth analysis of historical population structures and distributions (Myers et al. 2006). Populations began to diminish in the early 20th century as a result of land use and water quality changes and accelerated with the construction of the USACE dams on the major tributaries in the eastern portion of the basin (NWPCC 2004, USACE 2000). Historically, the Middle Fork population was probably the largest of all the Willamette subpopulations. However, with the construction of the USACE dams, over 80% of the spawning habitat was blocked, and the population appears no longer to be self-sustaining (NWPCC 2004). Like other west-side basin tributaries, the Coast Fork apparently never supported a particularly large run of Chinook (USACE 2000).

Spring Chinook enter the Columbia River and lower Willamette River in February through April. They move over Willamette Falls (now by fish ladder after modification of Willamette Falls) in April through June after river temperatures exceed 10°C (Howell et al. 1985, Nicholas 1995). Spawning in the Upper Willamette occurs from September through October (Mattson 1948, Nicholas 1995, Willis et al. 1995, K. Reis, pers. comm..). Some juvenile salmon migrate downstream as fry or fingerlings, though the fate of early-migrating individuals is unknown. They may move into lower river habitats or they may not survive, but they are not physiologically capable of tolerating the higher salinities of the estuary until late summer of their first year. Juveniles can become smolts and migrate to the estuary or ocean at the end of their first summer or as yearlings (Nicholas 1995, Willis et al. 1995). Most Spring Chinook from the upper Willamette River now enter the ocean as yearlings. Adults return as 4 to 6 year-old fish. Historically, most Willamette Spring Chinook returned at 5 years, but now the run has shifted to the majority returning at 4 years.

Flow modifications have several potential effects on upper Willamette River Spring Chinook. Discharge and temperature are major cues for salmonid life histories, and alteration of the timing of flow or river temperatures can alter the growth and survival of all riverine life history stages. River flows and their influence on stream temperature potentially affect the survival of early migrating juveniles. Flow reductions can cause cooler water in spring, which potentially reduces the growth of fish rearing in the river. Flow increases in the autumn can cause warmer temperatures, which may affect spawning adults or cause earlier emergence of fry (Kostow 1995).

Timing of adult returns and subsequent spawning has changed from historical conditions under the influence of various management practices, including but not limited to hatchery impacts and dam operations. The present timing of egg hatching and emergence from the gravel nests, juvenile rearing locales, and timing of smoltification and outmigration (Figure 95) undoubtedly also have changed from historical patterns (NWPCC 2004, USACE 2000). Like most salmonids, Chinook salmon are particularly sensitive to the intertwined parameters of discharge and water temperature. The demands of this important species influence current operations of the USACE dams in the Willamette basin (Tables 19 – 24). Present day considerations for dam discharge include needs for general “aquatic life” as well as upstream passage requirements, and spawning, incubation, and rearing flows for returning anadromous salmonids (USACE 2000).

Despite these prescriptions for dam discharge, the impact of dams on downstream thermal regimes continues to be an issue of concern for Chinook, although a great deal is known about its temperature needs (Table 25). Chinook spawning and rearing in the Coast Fork and Row Rivers is limited by warm water temperatures and low flows (note that current low flows are higher than unregulated flows from July through September; see Fig. 11)(USACE 2000). On the Middle Fork, the thermal and discharge picture is more complex. It has been suggested (ODEQ 2006), that the cold summer releases from the Middle Fork reservoir complexes are too cold for summer rearing. However, during late summer/early autumn draw down, water temperatures are too warm to stimulate Chinook spawning and egg-laying, with the result that these behaviors are delayed until late in the year (USACE 2000). The warm temperatures may also result in accelerated development of fry, which emerge from the gravels earlier and are thereby exposed to higher winter flows (ODEQ 2006).

Water temperature and velocity as well as the magnitude, timing and duration of spring flows were undoubtedly important cues for downstream migration of smolts (USACE 2000). Current dam operations produce lower spring discharges (see above, also Figure 95) and different temperature regimes, leading to potentially longer and slower smolt migration rates (USACE 2000). Rearing habitat for young and out-migrating Chinook has also become a source of concern (NWPCC 2004). An increasing body of evidence from other large river systems suggests floodplain habitats may have been important flow refuges and nursery areas for young Chinook (e.g, Sommer et al. 2001, Feyrer et al. 2004); loss of these areas combined with bank simplification through revetments has had deleterious consequences for other salmonid populations (Schmetterling et al. 2001). Recent work in the Upper Willamette mainstem has found winter use of floodplains, alcoves, and ephemeral streams by numerous native species, including Chinook (PNWERC 2002, Colvin 2005). During winter flows, these areas apparently provide refuge both from high flows and introduced predators, as well as food from terrestrial and aquatic sources (Fernald et al. 2006, Colvin 2005).

Dam and reservoir operations have been implicated in fungal (NWPCC 2004) and parasitic (Stocking and Bartholomew, in press) infections. The increased discharges are correlated with lower temperatures, both of which are implicated in lower rates of infection. Smolts which experience high discharges during outmigration tend to have lower overall rates of infection. Higher flows may decrease abundance of intermediate hosts for infections such as whirling disease (*Myxobolus cerebralis*; Hallett and Bartholomew 2006). Similar results have been observed for *Ceratomyxa shasta*; prevalence of intermediate hosts was greatest in areas of comparatively low flow (Stocking and Bartholomew, in press).

Lamprey

In contrast to the plethora of data available for Spring Chinook, comparatively little is know about the life cycle and flow needs of another native anadromous species, the Pacific lamprey (*Lampetra tridentata*). Pacific lamprey are large, parasitic only in the marine adult stage, and historically were probably quite abundant in the Willamette River (NWPCC 2004). The same changes to discharge, temperature, and sediment parameters that affect salmon likely also have led to the observed declines in Pacific lamprey (Kostow 2002). Adults return in late spring and spend the summer and autumn in the river before spawning as early as February (at Willamette Falls) or as late as July (Figure 96); some individual adults may be repeat spawners (like steelhead; NWPCC 2004). Pacific lamprey require small gravels for their nests, but fine silts and clays for larval rearing, which can last up to seven years (Kostow 2002). Young *L. tridentata* (which are filter-feeders, and not parasitic) are particularly susceptible to rapid flow fluctuations, and can be stranded if discharges drop rapidly. Water temperatures greater than 22^{o}C cause mortalities of eggs and larvae; however, additional temperature and flow requirements are largely unknown (Kostow 2002). Larval outmigration appears to be triggered by a combination of discharge and temperature, and usually occurs in the spring (Kostow 2002). The much smaller Western Brook lamprey (*Lampetra richardsonii)* presents a markedly different life cycle from *L. tridentata* (Figure 96), but has similar flow, temperature, and sediment requirements. Unlike the Pacific lamprey, brook lamprey are neither anadromous nor parasitic. Brook lamprey spawn in late spring as water temperatures rise to 10^{o}C; the eggs drift at night into silty backwater areas, where they hatch and metamorphose up to six months later (Kostow 2002). The filter-feeding ammocoete larvae spend the next five years in these areas before metamorphosing to adults, spawning, and dying (Kostow 2002). Both species require complex low velocity areas for rearing, and loss of these low gradient floodplain habitats has been cited as a major cause for the observed declines in abundance of both species, particularly Pacific lamprey (Kostow 2002)

Coastal Cutthroat Trout

Coastal cutthroat trout, *Oncorhynchus clarki clarki,* are the most widely distributed fish species in the Willamette basin. Cutthroat are found in the mainstem river above and below Willamette Falls and range into small headwater streams in both Cascade and Coast Range basins. Cutthroat trout found below Willamette Falls are frequently anadromous, and are considered to be a separate stock, part of the Lower Columbia River ESU (USACE 2000, NWPCC 2004). The populations above Willamette Falls exhibit considerable life history variability in terms of movement. Resident stocks appear to be more common in small montane basins, and spend their lives within a relatively restricted portion of the stream. Lowland populations are more likely to exhibit an adfluvial life history (Figure 97), moving into small tributary streams to spawn and then migrating at various times into large rivers to grow (NWPCC 2004). Both life history types spawn in small streams, but the adfluvial form typically attains larger sizes and potentially longer life spans (NWPCC 2004). Timing of spawning (and movement to tributaries for adfluvial individuals) ranges from January in the lowlands to July in the High Cascades, and appears to be triggered by temperature and discharge patterns (NWPCC 2004, USACE 2000). Likewise, downstream migration of adfluvial juveniles is triggered by falling temperatures and possibly changes in discharge (USACE 2000). Young cutthroat trout prefer low velocity stream margins and backwaters for rearing (Moore and Gregory 1988). During winter flood flows, they actively use ephemeral floodplain habitats on both the mainstem (PNWERC 2002) and tributaries (Colvin 2005). Although temperature requirements for this species have been documented (Table 25), flow needs have not. Recent modeling efforts have suggested a combination of land use conversion, loss of low velocity habitat and flow regime changes are responsible for population declines in lowland areas (PNWERC 2002). Mainstem populations between Corvallis and Willamette Falls are susceptible to infections by the parasite *Ceratomyxa shasta* (NWPCC 2004) and have diminished as a result of high levels of this parasite.

Oregon Chub

The Oregon chub, *Oregonichthys crameri*, is endemic to the lowlands of the Willamette River basin. Once widely distributed, *O. crameri* currently is found only in a few isolated locations along the Willamette River and its larger tributaries, including the Middle and Coast Forks (NWPCC 2004). Population declines were noted in the 1980's, and the species was listed as a federally protected species in 1993 (NWPCC 2004). Oregon chub inhabit backwaters and isolated floodplain habitats (Scheerer et al. 2002), and were probably once more common inhabitants of these slackwater areas. The loss of floodplain habitats and connectivity to larger river systems is one of the main contributing factors to the decline of the Oregon chub, and correlates with the construction of revetments and dams (see above). However, these isolated habitat fragments now provide the chub with some of the few remaining refuges from introduced predators and competitors, such as bullfrogs, largemouth bass, and bluegill (Scheerer et al. 2002, NWPCC 2004). In ponds and backwaters connected to reservoirs or rivers containing exotic fish species, Oregon chub are likely to be rare or absent; the presence of bullheads (*Ameiurus* spp) and centrachids have strong negative impacts on *Oregonichthys* (Scheerer et al. 2002). Although these invasive species inhabit the same low velocity habitats as Oregon chub, the chub has a greater tolerance for low water temperatures, and can spawn and grow when competitors and predators such as bass are inactive (Paul Scheerer pers. comm.). Exact flow and temperature requirements for the chub are largely unknown (see Figure 95 for life history), although chub in the Middle Fork Willamette apparently require a water temperature of at least 15^{o}C to spawn (Scheerer et al. 2006). Chub are frequently found in the same locales as red-legged frogs (Paul Scheerer pers. comm.) suggesting these two species may respond to similar temperature and discharge regimes.

Large Scale Sucker

Despite their widespread distribution and apparently high abundance, comparatively little is know of the local autecology, including flow requirements, for the large scale sucker, *Catostomus macrocheilus*. Suckers live in larger rivers and streams, and are rarely found in small headwater basins; numerous studies have documented their presence in the mainstem Willamette as well as it major tributaries on both sides of the basin (Altman et al. 1997 for review). Like cutthroat trout, largescale suckers exhibit an adfluvial life history (Figure 97): when spring water temperatures begin to warm, breeding age adults move into smaller tributaries to spawn. The pelagic young hatch within two weeks, and begin moving downstream after they metamorphose to the benthic form (Scott and Crossman 1973). Because of their preference for benthic habitats and food, they have frequently been analyzed for the presence of a range of environmental toxics, including heavy metals, pesticides, PCB’s and pulp mill effluents (Altman et al. 1997). In the Willamette, *C. macrocheilus* is an important prey resource for a large number of other species, particularly birds such as osprey (see above), herons, mergansers, as well as otters and other fish, particularly northern pikeminnow. Like other resident fishes, largescale suckers are frequently found in off-channel sloughs and floodplain ponds; these habitats appear to be particularly important for smaller size classes (PNWERC 2002).

Large- and Small-mouth Bass

Among the fish introduced to the Willamette basin, largemouth and smallmouth bass (*Micropterus salmoides* and *M. dolomieui* respectively) have had some of the greatest impacts on native aquatic fauna. Between 1890 and 1895, both species were introduced to Oregon and Washington by the U.S. Bureau of Fisheries to provide sport fisheries. In the 1970’s, ODFW, using the same rationale, performed additional introductions of smallmouth above Willamette Falls in the 1970’s. Both species prefer clear quiet water and comparatively warm water temperatures (Figure 97), although smallmouth can tolerate somewhat lower water temperatures (IUCN 2006). Feeding and reproduction stop when temperatures drop below 10^{o}C; juvenile survival below these temperatures is poor, although adults can tolerate much lower winter water temperatures (IUCN 2006). Both species are found in same low velocity habitats, including river edges, sloughs, backwaters, and floodplain ponds connected to large rivers and streams; these are the same habitats preferred by presently at-risk native species including red-legged frogs, Oregon chub, and spring Chinook smolts. Both species of bass compete with native fish as juveniles, and prey upon them as adults (NWPCC 2004). Regional concerns have been raised about negative impacts of bass predation on salmonids, but substantial effects have not been documented. An additional refuge is provided by rip-rap, where high densities of both bass species have been documented (see Schmetterling et al. 2001 for review, also Hjort et al. 1984). Both *Micropterus* species are tolerant of a wide range of environmental conditions except for high flows (IUCN 2006). Reconnection of presently isolated floodplain habitats may inadvertently cause the demise of native species by allowing invasives such as bass to occupy them (Feyer et al. 2004, Scheerer et al. 2002). However, comparatively shallow off-channel areas with low temperatures, high flows, and possibly high turbidity tend to have fewer invasive species and more natives (Sommer et al. 2001, Paul Scheerer pers. comm.).

Species	Drought/Low Flow	High Flow Pulse (Up to bankfull)	Small Flood (Overbank, 2-10 yr interval)	Large Flood (Floodplain maintenance, >10 yr interval)
Fish				
Spring Chinook	May decrease summer populations of juveniles in upstream tributaries because of habitat reduction. Spring drought may decrease smolt outmigration or adult upstream migration.	Small floods will have minor impacts. Flushing sediment from sediment may increase spawning success and decrease storage of pathogens in sediments.	Intermediate floods will have minor impacts in early fall or late winter. Spawning success and egg survival in redds may decrease if bed is mobilized. Juvenile survival may be reduced in simplified river reaches. Flushing sediment from sediment may increase spawning success and decrease storage of pathogens in sediments.	Large floods will have moderate impacts in early fall or late winter. Spawning success and egg survival in redds may decrease if bed is mobilized. Juvenile survival may be reduced in simplified river reaches. Flushing sediment from sediment may increase spawning success and decrease storage of pathogens in sediments.
Pacific Lamprey	Less affected than other fish because they rear in intergravel environment. As stream habitat shrinks, survival of juveniles may decrease.	Small floods will have minor impacts. Flushing sediment from sediment may increase survival, food supply, and spawning success.	Intermediate floods may decrease survival if gravel deposits are scoured and eliminated. Flushing sediment from sediment may increase survival, food supply, and spawning success.	Large floods may decrease survival if gravel deposits are scoured and eliminated. Flushing sediment from sediment may increase survival, food supply, and spawning success.
Western Brook Lamprey	Less affected than other fish because they rear in intergravel environment. As stream habitat shrinks, survival of juveniles may decrease.	Will have minor impacts. Flushing sediment from sediment may increase survival, food supply, and	May decrease survival if gravel deposits are scoured and eliminated. Flushing sediment from sediment may increase	May decrease survival if gravel deposits are scoured and eliminated. Flushing sediment from sediment may increase survival, food supply, and

Species	Drought/Low Flow	High Flow Pulse (Up to bankfull)	Small Flood (Overbank, 2-10 yr interval)	Large Flood (Floodplain maintenance, >10 yr interval)
		spawning success.	survival, food supply, and spawning success.	spawning success.
Cutthroat Trout	Minor impacts in the mainstem river. Adult trout use of tributaries may be reduced by spring drought. If tributary stream habitat diminishes or warms during drought, juvenile survival may decrease. If temperature increases substantially, survival and distribution may decrease because of thermal tolerance and disease.	Small floods will have minor impacts. Flushing sediment from sediment may increase spawning success and decrease storage of pathogens in sediments.	Intermediate floods may decrease survival slightly, but also may increase survival by increasing transport of food resources from the floodplain. Fish may be able to use tributary junction environments more extensively. Reduction of warm water non-native species may benefit native species.	Large floods may decrease survival, but also may increase survival by increasing transport of food resources from the floodplain. New riffles and pools may expand available habitat. If channel changes reduce available habitat, effects may be negative. Reduction of warm water alien species may benefit native species.
Oregon Chub	May decrease summer populations of juveniles in floodplain tributaries because of habitat reduction as streams and ponds dry up.	Small floods may increase floodplain habitat and increase dispersal.	Intermediate floods will have minor impacts. Reconnected floodplain habitats may benefit dispersal. Negative effects of floods on predators may increase survival of chub.	Large floods may cause mortality and displacement. Reconnected floodplain habitats may benefit dispersal. Negative effects of large floods on predators may increase survival. If floods increase predators, survival may decrease.

Species	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
Large scale sucker	Minor impacts in the mainstem river. As nearshore habitat shifts and shrinks, larval survival may decrease.	Small floods will have minor impacts. Flushing sediment from gravel may increase spawning success.	Intermediate floods may decrease survival slightly, but also may increase survival by increasing transport of food resources from the floodplain. Fish may be able to use tributary junction environments more extensively.	Large floods may decrease survival, but also may increase survival by increasing transport of food resources from the floodplain. New riffles and pools may expand available habitat. If channel changes reduce available habitat, effects may be negative.
Largemouth Bass	Favored by warm water and more lacustrine habitat. Survival may increase during drought.	Small floods will have minor impacts.	Intermediate floods decrease survival for non-native species.	Large floods decrease survival for non-native species.
Smallmouth Bass	Favored by warm water and more lacustrine habitat. Survival may increase during drought.	Small floods will have minor impacts.	Intermediate floods decrease survival for non-native species.	Large floods decrease survival for non-native species.

Summary of impacts of the four environmental flow regimes on exemplar fish (subset from Table 26).

Summary

The technical review is designed to present a framework for discussion among participants at the Environmental Flows Workshop. The workshop is intended provide the USACE with recommendations for flow modification to benefit the biota inhabiting the river and floodplain ecosystems downstream of the dams in the Coast Fork and Middle Fork Willamette River. A summary of the concepts and information in this technical review is presented in Table 26 and Figure 98. We recognize these two summaries do not present all available information or linkages. We recommend them as starting points for developing a framework to establish environmental flow requirements in the Middle Fork and Coast Fork of the Willamette River.

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Tables

Basin	**Dam Name**	**Date Completed**	**Upstream Drainage Area (mi2)**	**Length (miles)**	**Surface Area (mi2)**	**Volume (acre-feet)**	**Spillway Height (feet)**	**Average Power Generated (MW)**	**Draw-down Priority**
Coast Fork, Main	Cottage Grove	1942	104	3.0	1.6	33,500	97	--	5th
Coast Fork, Row R.	Dorena	1948	265	5.0	2.7	77,600	115	--	5th
Middle Fork Fall Cr.	Fall Creek	1965	184	10.3	2.7	125,000	133	--	5th
Middle Fork, Main	Hills Creek	1961	389	7.6	4.1	356,000		222.3	4th
Middle Fork, Main	Lookout Point	1953	991	14.2	1.3	453,000		445.8	1st
Middle Fork, Main	Dexter	1954	991 (rereg)	2.8	6.1	27,500	24	102.7	NA

Table 1. Dams of the Coast and Middle Forks. Data from USACE 2000, NWPCC 2004 and PNWERC 2002.

Reach	Reservoir Providing Water	Number of Contractors	Total Acre-Feet Contracted	Total Acres Served
Willamette River				
Downstream of Santiam River	All	38	9,743	6,596
Santiam River–Long Tom River	All except Santiam River basin reservoirs	20	4,718	2,318
Long Tom River–McKenzie River	All except Santiam River basin reservoirs and Fern Ridge	9	1,192	570
McKenzie River–Coast Fork	Fall Creek, Dexter/Lookout Point, Hills Creek, Cottage Grove, Dorena	1	10	4
Middle Fork Willamette River				
Downstream of Fall Creek	Fall Creek, Dexter/Lookout Point, Hills Creek	1	136	54
Fall Creek–Dexter	Dexter/Lookout Point/Hills Creek	3	88	36
Fall Creek	Fall Creek	3	29	12
Coast Fork Willamette River				
Middle Fork – Row River	Dorena, Cottage Grove	12	1,375	568
Row River – Cottage Grove	Cottage Grove	1	56	45
Row River	Dorena	1	51	21

Table 2. Water withdrawals presently under contract for irrigation (USACE 2000). Data for McKenzie and Santiam systems omitted. From USACE 2000.

Month	Normal Year at Albany	Drought Year at Albany	Normal Year at Salem	Drought Year at Salem
June	---	4,000	---	5,500
July	4,500	4,000	6,000	5,500
August 1-15	5,000	4,500	6,000	6,000
August 16-31	5,000	4,500	6,500	6,000
September	5,000	5,000	7,000	6,500
October	5,000	---	7,000	---

Table 3a, minimum flow requirements (in cfs) at Albany and Salem (USACE 2000).

Water Year and Month	Volume from Storage for Albany	Volume from Storage for Salem (includes Albany)
Low Water Year (1973)		
June	0	0
July	83,812	124,368
August	143,325	221,605
Totals	227,136	345,973
Low Water Year (1977)		
June	0	0
July	84,316	135,993
August	134,897	209,625
Totals	219,213	345,619
Average Water Year (1986)		
June	0	0
July	33,383	68,448
August	124,137	169,292
Totals	157,520	237,740

Table 3b: Volume of water required (in acre-feet) to meet minimum flow requirements at Albany and Salem (USACE 2000).

Project	**Coast Fork Willamette at Goshen**	**Middle Fork Willamette at Jasper**	**McKenzie at Vida**	**Willamette at Harrisburg**	**Long Tom at Monroe**	**Willamette at Albany**	**North Santiam at Mehama**	**South Santiam at Waterloo**	**Santiam at Jefferson**	**Willamette at Salem**
Cottage Grove	3,000			3,000		3,000				3,000
Dorena	5,000			5,000		5,000				5,000
Hills Creek		8,000		8,000		8,000				
Lookout Point		15,000		15,000		15,000				15,000
Fall Creek		4,500		4,500		4,500				4,500
Cougar			6,500	6,500		6,500				6,500
Blue River			3,700	3,700		3,700				3,700
Fern Ridge					3,000	3,000				3,000
Green Peter								11,000	11,000	
Foster								18,000	18,000	18,000
Detroit							17,000		17,000	17,000
Total Evacuation [1]	8,000	19,500	10,200	37,700	3,000	40,700	17,000	18,000	35,000	75,700
Bankfull Flow [2]	**12,000**	**20,000**	14,500	**42,000**	6,000	70,000	17,000	18,000	35,000	90,000
Regulation Goal	12,000	20,000	14,500	42,000	4,650	70,000	17,000	18,000	35,000	90,000

[1] Above control point.

[2] At control point.

Source: Portland District, USACE

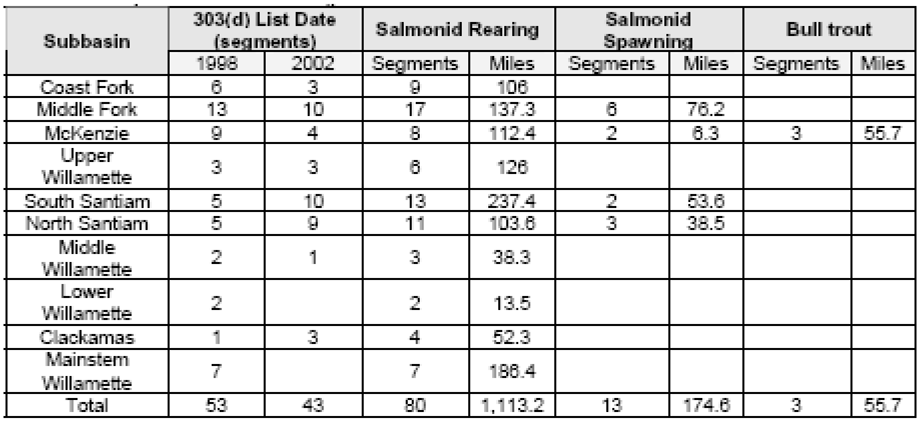
Table 4. Maximum flood flow releases (cfs) for normal flood control for all dams in the Willamette system. Measurement points include both sites on the main-stem and the major tributaries (USACE 2000).

Basin	Gage Name	Gage Number	Area Upstream (mi2)	Date of Operation
Coast Fork	Goshen	14157500	642	1950 - present
Middle Fork	Jasper	14152000	1,340	1952 - present
Mainstem	Springfield	14158000	2,030	1920 - 1957
Mainstem	Harrisburg	14166000	3,420	1944 - present
Mainstem	Albany	14174000	4,840	1892 - present

Table 5a. USGS gages on the Coast and Middle Forks and mainstem Willamette River used in this review.

BASIN	INTERVAL (YEARS)	UNREGULATED DISCHARGE (CFS)	REGULATED DISCHARGE (CFS)
Middle Fork (Jasper)	2	39,900	20,000
	10	82,100	20,000
	50	123,000	25,300
	100	141,000	35,500
Coast Fork (Goshen)	2	26,700	15,800
	10	49,800	25,500
	50	71,100	40,500
	100	80,400	48,000
Willamette (Albany)	2	113,000	70,000
	10	198,000	117,000
	50	280,000	171,000
	100	316,000	199,000

Table 5b. Draft flood frequency and magnitude under unregulated and regulated conditions for three gages: Middle Fork at Jasper, Coast Fork at Goshen, and Willamette River at Albany. Flood frequency data are preliminary and have not received final approval. Subsequent review may result in significant revisions to the data. Data prepared by Chris Nygaard, USACE.



Subbasin	303(d) List Date (segments)		Salmonid Rearing		Salmonid Spawning		Bull trout	
	1998	2002	Segments	Miles	Segments	Miles	Segments	Miles
Coast Fork	6	3	9	106				
Middle Fork	13	10	17	137.3	6	76.2		
McKenzie	9	4	8	112.4	2	6.3	3	55.7
Upper Willamette	3	3	6	126				
South Santiam	5	10	13	237.4	2	53.6		
North Santiam	5	9	11	103.6	3	38.5		
Middle Willamette	2	1	3	38.3				
Lower Willamette	2		2	13.5				
Clackamas	1	3	4	52.3				
Mainstem Willamette	7		7	186.4				
Total	53	43	80	1,113.2	13	174.6	3	55.7

Table 6. Number of reaches listed as temperature impaired (ODEQ 2006).

Site Name	**River Mile**	**Period of Exceedence of 7-day moving mean of the daily maximum**	**Number of Exceedences during season**	**Highest Value of 7-day moving mean of daily maximum (^{o}C)**
Middle Fork at mouth	0.1	6/16/2001 – 9/20/2001 7/7/2002 – 9/17/2002	92 49	21.7 19.6
Coast Fork at Goshen	5.4	Pre 8/19/2001 – 10/04/2001 5/28/2002 – 9/23/2002	48+ 119	23.7++ 25.9
Willamette above McKenzie cfl	177	Pre 6/26/2001 – 9/919/2001 6/24/2002 – 9/16/2002	89+ 77	22.0* 19.6
Willamette at Harrisburg	161	6/17/2001 – 9/18/2001 6/23/2002 – 9/14/2002	90 77	22.5 20.5
Willamette at Albany	119.3	Pre 8/14/2001 – 9/21/2001 6/12/2002 – 9/16/2002	39+ 98	22.5++ 22.1 “

Table 7. Summer temperature exceedence data summary for 303(d) listed segments in the Coast and Middle Fork Willamette (ODEQ 2006), and portions of the mainstem Willamette considered in this review. A “++” indicates warmer maxima may have occurred prior to the sampling period; “*” indicates maxima were likely included during the period of record; “+” indicates maxima probably occurred prior to the sampling period.

Subbasin:	Coast Fork Willamette				Middle Fork Willamette					
Reservoirs:	Cottage Grove		Dorena		Hills Creek		Dexter/ Lookout Pt.		Fall Creek	
	downstream	upstream	downstream	upstream	downstream	upstream	downstream	upstream	downstream	upstream
Apr	9.5		8.8	10.8		7.9	8.7		7.5	
May	10.4	11.4	10.2	16.5		11.0	9.5	13.2	11.3	
Jun	11.9	15.5	11.1	22.3	7.9	14.2	11.7	17.4	14.0	15.9
Jul	13.7	19.9	13.3	20.4	8.6	13.6	14.0	16.5	17.2	15.8
Aug	17.1	18.3	13.2	18.2	11.0	12.5	16.9	13.9	16.6	13.5
Sep	19.5	16.4	14.1		16.0		18.3	10.2	9.8	
Oct	15.5		16.2				15.9		12.9	
Nov	10.6		10.3				12.3		10.8	

Table 8 Observed median seven-day rolling average temperatures downstream of USACE Coast and Middle Fork dams and monthly median seven-day rolling average of flow-weighted upstream tributary temperatures. All values in ^{o}C (ODEQ 2006).

Subbasin:	Coast Fork Willamette	Coast Fork Willamette	Middle Fork Willamette	Middle Fork Willamette	Middle Fork Willamette	McKenzie	McKenzie	South Santiam	North Santiam	Upper Willamette
Reservoirs:	**Cottage Grove**	**Dorena**	**Hills Creek**	**Dexter/ Lookout Pt.**	**Fall Creek**	**Cougar**	**Blue**	**Foster/ Green Peter**	**Big Cliff/ Detroit**	**Fern Ridge**
Jan	No Allocation Necessary									
Feb										
Mar										
Apr	9.4	8.8	5.8	6.5	6.5	5.5	5.5	6.1	5.4	9.0
May	11.4	10.8	7.8	8.6	8.6	7.7	7.6	8.2	7.3	10.8
Jun	15.5.0	16.5	11.0	13.2	12.2	10.0	9.9	12.4	9.7	14.6
Jul	19.9	22.3	14.2	17.4	15.9	11.7	11.2	18.4	12.8	16.7
Aug	18.3	20.4	13.6	16.5	15.8	10.9	10.6	18.0	12.8	16.0
Sep	16.4	18.2	12.5	13.9	13.5	9.5	9.5	15.5	10.9	14.0
Oct	13.5	15.3	9.6	10.2	10.6	7.2	7.2	12.6	7.7	8.0
Nov			9.6	10.2	10.6	7.2	7.2	12.6	7.7	
Dec	No Allocation Necessary									

Table 9. Target temperatures (in ^{o}C) by month for all USACE reservoirs in the Willamette basin (ODEQ 2006).

Subbasin	Stream Name	River Mile	Season	Criteria	Temp (^{o}C)
Coast Fork	Coast Fork	0 – 31.3	Summer	Rearing	17.8
	Row R.	0 – 7.4	Summer	Rearing	17.8
Middle Fork	Fall Cr.	0 - 7	Summer	Rearing	17.8
	Middle Fork	0 – 15.6	Summer	Rearing	17.8

Table 10. Temperature criteria for 303(d) listed segments of river below USACE dams in the Coast and Middle Fork Willamette (modified from ODEQ 2006).

Site	STORET Number	River Mile	Summer Average	FWS Average	Minimum Seasonal Average
Coast Fk. Willamette R. u/s Cottage Grove	402051	23.9	81	86	81
Row R. @ County Rd. Br.	402053	2.8	90	93	90
Coast Fk. Willamette R. @ Creswell	402048	12.8	82	90	82
Coast Fk. Willamette R. @ Mt. Pisgah Pk.	402955	3.0	86	86	86
Middle Fk. Willamette R. @ Jasper Br.	402054	8.0	93	92	92
Willamette R. @ HWY 126 (Springfield)	402027	185.3	91	90	90
McKenzie R. @ Coburg Rd.	402044	7.1	90	92	90
Willamette R. @ HWY 99E (Harrisburg)	402023	161.2	89	89	89
Long Tom R. @ Stow Pit Rd. (Monroe)	402820	4.7	78	76	76
Mary's R. @ HWY 99W (Corvallis)	402041	0.2	82	77	77
Willamette R. @ Corvallis	402020	131.4	87	86	86
Calapooia R. @ Queens Rd. (Albany)	402860	3.0	67	67	67
Willamette R. @ Albany	402018	119.3	85	81	81

Table 11. Seasonal Average OWQI Results for the Upper Willamette Basin (WY 1986 -1995).
http://www.deq.state.or.us/lab/wqm/wqi/upwill/upwill3.htm

RIVER	NAME	RIVER MILE	BANK	LENGTH	STRUCTURE TYPE	YEAR BUILT	CONSTRUCTION AUTHORITY	SPONSOR	MAINTENANCE AGREEMENT	MAINTENANCE CATEGORY	MAINTENANCE DEFICIENT	COMMENTS
CF	EVANS	1.3	R	1225	STONE	1949	FCA (U)	1	N	4D,1C	N/A	NONE
CF	MCBEE (DORENA RES.)	2.3	L	52	PLUG	1952	FCA (U)	57	N	N/A	N/A	INACTIVE
CF	SEAVEY PROPERTY	2.4	R	1107	STONE	1957	FCA (S)	16	Y	3D	Y	SPONSOR ON DEFICIENT LISTING
CF	ESTEP (DORENA RES.)	2.5	L	85	PLUG	1952	FCA (U)	57	N	N/A	N/A	INACTIVE
CF	SEAVEY BRIDGE	3.0	R	1300	STONE	1950	FCA (U)	1	N	1D	N/A	NONE
CF	SEAVEY LOOP	3.1	L	765	STONE	1956	FCA (S)	16	Y	1D	Y	SPONSOR ON DEFICIENT LISTING
CF	MIKESELL(DORENA RES)	3.2	L	143	PLUG	1952	FCA (U)	57	N	N/A	N/A	INACTIVE
CF	MCCULLY	3.6	B	3655	STONE	1950	FCA (U)	1	N	3C	N/A	NONE
CF	GOSHEN	4.2	L	1030	STONE & GRAVEL APRON	1944	EMERGENCY	3	N	3D	N/A	MAINTENANCE NOT AUTHORIZED
CF	LWR MELTON (DORENA)	9.0	L	1046	STONE	1952	FCA (U)	57	N	3C	N/A	NONE
CF	MELTON (DORENA RES)	9.2	R	2350	STONE	1951	FCA (U)	57	N	4D	N/A	NONE
CF	JENKINS (DORENA RES)	9.6	L	2692	STONE	1951	FCA (U)	57	N	4D,3C	N/A	NONE
CF	HASKINS (DORENA RES)	10.1	R	2020	STONE	1951	FCA (U)	57	N	4C	N/A	2 SITES, 1380 LF & 640 LF
CF	SLY (DORENA RES)	10.7	L	890	STONE	1952	FCA (U)	57	N	3C	N/A	2 SITES, 247 LF & 643 LF
CF	HAROLD	11.1	L	1660	STONE	1952	FCA (U)	1	N	4C	N/A	NONE
CF	LOWER BENTER	11.4	R	1254	STONE	1952	FCA (U)	1	N	3C	N/A	NONE
CF	BENTER (DORENA RES.)	11.6	L	2000	STONE	1951	FCA (U)	57	N	3C	N/A	NONE
CF	RINEHART(DORENA RES)	12.1	R	2400	STONE	1951	FCA (U)	57	N	4C	N/A	NONE
RR	VEATCH (DORENA RES)	0.2	R	986	STONE	1952	FCA (U)	57	N	3D	N/A	NONE
RR	HEMENWAY(DORENA RES	0.5	L	1275	STONE	1952	FCA (U)	57	N	1C	N/A	NONE
MF	DORRIS-LEONARD	187.0	R	2250	STONE	1951	FCA (U)	1	N	3D,1B	N/A	NONE
MF	BOOTH-KELLY	190.8	R	2570	STONE	1950	FCA (U)	1	N	4D	N/A	NONE
MF	A. C. CLEARWATER	191.4	R	1980	STONE	1949	FCA (U)	1	N	4D	N/A	NONE
MF	WILSON	192.0	R	3503	STONE	1954	FCA (S)	23	Y	3C	N	SPONSOR HAS DISBANDED
MF	LAIRD	192.7	L	3689	STONE	1954	FCA (S)	23	Y	3B	N	SPONSOR HAS DISBANDED
MF	NATRON	193.5	R	950	STONE & WOOD. BARR.	1948	FCA (U)	1	N	3D	N/A	NONE
MF	FISHER	195.5	B	7900	STONE & LEVEES	1958	FCA (S)	54	Y	3C,4B,4D	N	LEVEE ON BOTH BANKS
MF	SALMON CREEK	229.4	B	6300	STONE & LEVEES	1959	FCA (S)	55	Y	N/A	N	NONE

River
MF - Middle Fork Willamette River
CF - Coast Fork Willamette River
RR - Row River

Construction Authority
FCA (S) - Flood Control Acts (Sponsored Projects)
FCA (U) - Flood Control Acts (Unsponsored Projects)
R&H - River and Harbors Acts
Emergency - Emergency Bank Protection Projects

Maintenance Category
1 - High Value - High Risk (structures 0' to 75' from river bank)
2 - High Value - Low Risk (structures > 75' from river bank)
3 - Low Value - Low Risk (revetment under attack)
4 - Low value - No Risk

A - Cleared revetment or grass cover only
B - Combined grass, shrub and brush cover
C - Shrub and tree cover
D - Predominently tree cover

Maintenance Deficient
Y - Yes
N - No
N/A - Not applicable

Maintenance Agreement
Y - Yes
N - No

Sponsors

1. Corps of Engineers
2. Rivers and Harbors Acts
3. Emergency Projects
16. Linn County District Improvement Company No. 3, Shedd, OR
23. Willamette-Natron Water District, Eugene, OR
54. Willamette-Alder Creek Improvement District
55. City of Oakridge
57. Dorena Reservoir

Table 12. Revetments on Coast and Middle Fork Willamette subbasins (PNWERC 2002, USACE 2000).

Fluvial process	Flow	Landform	Community patterns
Narrowing	one to several years of flow less than that necessary to mobilize channel bed	channel bed	variable spatial patterns; usually not even-aged stands
Meandering	frequent moderate flows	point bars	moderate number of even-aged stands, arranged in narrow, arcuate bands; strong left-bank, right-bank asymmetry in ages based on meander pattern; flood training or stems common
Flood deposition	infrequent high flows	flood deposits	small number of linear, even-aged stands; flood training of stems rare

Table 13. Effects of flow and geomorphology on cottonwood stand patterns (from Scott et al 1997).

.

Common Name	***Scientific Name***	**Origin**
Mammals		
Pacific Shrew	*Sorex pacificus*	Native
Water Shrew	*Sorex palustris*	Native
Pacific Water Shrew	*Sorex bendirii*	Native
Trowbridge's Shrew	*Sorex trowbridgii*	Native
Baird's Shrew	*Sorex bairdi*	Native
Fog Shrew	*Sorex sonomae*	Native
Shrew-Mole	*Neurotrichus gibbsii*	Native
Townsend's Mole	*Scapanus townsendii*	Native
Coast Mole	*Scapanus orarius*	Native
Little Brown Myotis	*Myotis lucifugus*	Native
Yuma Myotis	*Myotis yumanensis*	Native
Long-Eared Myotis	*Myotis evotis*	Native
Fringed Myotis	*Myotis thysanodes*	Native
Long-Legged Myotis	*Myotis volans*	Native
California Myotis	*Myotis californicus*	Native
Silver-Haired Bat	*Lasionycteris noctivagans*	Native
Big Brown Bat	*Eptesicus fuscus*	Native
Hoary Bat	*Lasiurus cinereus*	Native
Townsend's Big-Eared Bat	*Corynorhinus townsendii*	Native
Pallid Bat	*Antrozous pallidus*	Native
Brazilian Free-Tailed Bat	*Tadarida brasiliensis*	Native
Pika	*Ochotona princeps*	Native
Brush Rabbit	*Sylvilagus bachmani*	Native
Eastern Cottontail	*Sylvilagus floridanus*	Introduced
Snowshoe Hare	*Lepus americanus*	Native
Black-Tailed Jackrabbit	*Lepus californicus*	Native
Mountain Beaver	*Aplodontia rufa*	Native
Townsend's Chipmunk	*Tamias townsendii*	Native
California Ground Squirrel	*Spermophilus beecheyi*	Native
Golden-Mantled Ground Squirrel	*Spermophilus lateralis*	Native
Eastern Gray Squirrel	*Sciurus carolinensis*	Introduced
Western Gray Squirrel	*Sciurus griseus*	Native
Eastern Fox Squirrel	*Sciurus niger*	Introduced
Douglas' Squirrel	*Tamiasciurus douglasii*	Native
Northern Flying Squirrel	*Glaucomys sabrinus*	Native
Western Pocket Gopher	*Thomomys mazama*	Native
Camas Pocket Gopher	*Thomomys bulbivorus*	Native
American Beaver	*Castor canadensis*	Native
Deer Mouse	*Peromyscus maniculatus*	Native
Dusky-Footed Woodrat	*Neotoma fuscipes*	Native
Bushy-Tailed Woodrat	*Neotoma cinerea*	Native
Western Red-Backed Vole	*Clethrionomys californicus*	Native
White-Footed Vole	*Phenacomys albipes*	Native
Red Tree Vole	*Phenacomys longicaudus*	Native
California Vole	*Microtus californicus*	Native
Townsend's Vole	*Microtus townsendii*	Native
Long-Tailed Vole	*Microtus longicaudus*	Native
Creeping Vole	*Microtus oregoni*	Native
Gray-Tailed Vole	*Microtus canicaudus*	Native

Common Name	***Scientific Name***	**Origin**
Water Vole	*Microtus richardsoni*	Native
Muskrat	*Ondatra zibethicus*	Native
Black Rat	*Rattus rattus*	Introduced
Norway Rat	*Rattus norvegicus*	Introduced
House Mouse	*Mus musculus*	Introduced
Pacific Jumping Mouse	*Zapus trinotatus*	Native
Common Porcupine	*Erethizon dorsatum*	Native
Nutria	*Myocastor coypus*	Introduced
Coyote	*Canis latrans*	Native
Gray Wolf	*Canis lupus*	Extinct
Red Fox	*Vulpes vulpes*	Introduced
Gray Fox	*Urocyon cinereoargenteus*	Native
Black Bear	*Ursus americanus*	Native
Grizzly Bear	*Ursus arctos*	Extinct
Raccoon	*Procyon lotor*	Native
American Marten	*Martes americana*	Native
Fisher	*Martes pennanti*	Native
Ermine	*Mustela erminea*	Native
Long-Tailed Weasel	*Mustela frenata*	Native
Mink	*Mustela vison*	Native
Wolverine	*Gulo gulo*	Native
Western Spotted Skunk	*Spilogale gracilis*	Native
Striped Skunk	*Mephitis mephitis*	Native
Northern River Otter	*Lutra canadensis*	Native
Mountain Lion	*Felis concolor*	Native
Feral House Cat	*Felis catus*	Introduced
Lynx	*Lynx canadensis*	Native
Bobcat	*Lynx rufus*	Native
Elk	*Cervus elaphus*	Native
Black-Tailed Deer	*Odocoileus hemionus*	Native
Birds		
Pied-Billed Grebe	*Podilymbus podiceps*	Native
Western Grebe	*Aechmophorus occidentalis*	Native
American Bittern	*Botaurus lentiginosus*	Native
Great Blue Heron	*Ardea herodias*	Native
Green Heron	*Butorides virescens*	Native
Black-Crowned Night-Heron	*Nycticorax nycticorax*	Extinct
Canada Goose	*Branta canadensis*	Native
Wood Duck	*Aix sponsa*	Native
Green-Winged Teal	*Anas crecca*	Native
Mallard	*Anas platyrhynchos*	Native
Northern Pintail	*Anas acuta*	Native
Blue-Winged Teal	*Anas discors*	Native
Cinnamon Teal	*Anas cyanoptera*	Native
Northern Shoveler	*Anas clypeata*	Native
Ring-Necked Duck	*Aythya collaris*	Native
Harlequin Duck	*Histrionicus histrionicus*	Native
Barrow's Goldeneye	*Bucephala islandica*	Native
Bufflehead	*Bucephala albeola*	Native
Hooded Merganser	*Lophodytes cucullatus*	Native

Common Name	***Scientific Name***	**Origin**
Common Merganser	*Mergus merganser*	Native
Ruddy Duck	*Oxyura jamaicensis*	Native
Turkey Vulture	*Cathartes aura*	Native
California Condor	*Gymnogyps californianus*	Extinct
Osprey	*Pandion haliaetus*	Native
White-Tailed Kite	*Elanus caeruleus*	Native
Bald Eagle	*Haliaeetus leucocephalus*	Native
Northern Harrier	*Circus cyaneus*	Native
Sharp-Shinned Hawk	*Accipiter striatus*	Native
Cooper's Hawk	*Accipiter cooperii*	Native
Northern Goshawk	*Accipiter gentilis*	Native
Red-Shouldered Hawk	*Buteo lineatus*	Native
Red-Tailed Hawk	*Buteo jamaicensis*	Native
Golden Eagle	*Aquila chrysaetos*	Native
American Kestrel	*Falco sparverius*	Native
Peregrine Falcon	*Falco peregrinus anatum*	Native
Ring-Necked Pheasant	*Phasianus colchicus*	Introduced
Blue Grouse	*Dendragapus obscurus*	Native
Ruffed Grouse	*Bonasa umbellus*	Native
Wild Turkey	*Meleagris gallopavo*	Introduced
California Quail	*Callipepla californica*	Introduced
Mountain Quail	*Oreortyx pictus*	Native
Virginia Rail	*Rallus limicola*	Native
Sora	*Porzana carolina*	Native
American Coot	*Fulica americana*	Native
Killdeer	*Charadrius vociferus*	Native
Spotted Sandpiper	*Actitis macularia*	Native
Common Snipe	*Gallinago gallinago*	Native
Wilson's Phalarope	*Phalaropus tricolor*	Native
Black Tern	*Chlidonias niger*	Native
Marbled Murrelet	*Brachyramphus marmoratus*	Native
Rock Dove	*Columba livia*	Introduced
Band-Tailed Pigeon	*Columba fasciata*	Native
Mourning Dove	*Zenaida macroura*	Native
Yellow-Billed Cuckoo	*Coccyzus americanus*	Extinct
Barn Owl	*Tyto alba*	Native
Western Screech-Owl	*Otus kennicottii*	Native
Great Horned Owl	*Bubo virginianus*	Native
Northern Pygmy-Owl	*Glaucidium gnoma*	Native
Spotted Owl	*Strix occidentalis caurina*	Native
Barred Owl	*Strix varia*	Native
Great Gray Owl	*Strix nebulosa*	Native
Long-Eared Owl	*Asio otus*	Native
Short-Eared Owl	*Asio flammeus*	Native
Northern Saw-Whet Owl	*Aegolius acadicus*	Native
Common Nighthawk	*Chordeiles minor*	Native
Black Swift	*Cypseloides niger*	Native
Vaux's Swift	*Chaetura vauxi*	Native
Anna's Hummingbird	*Calypte anna*	Native
Rufous Hummingbird	*Selasphorus rufus*	Native

Common Name	***Scientific Name***	**Origin**
Belted Kingfisher	*Ceryle alcyon*	Native
Lewis' Woodpecker	*Melanerpes lewis*	Extinct
Acorn Woodpecker	*Melanerpes formicivorus*	Native
Red-Breasted Sapsucker	*Sphyrapicus ruber*	Native
Downy Woodpecker	*Picoides pubescens*	Native
Hairy Woodpecker	*Picoides villosus*	Native
Black-Backed Woodpecker	*Picoides arcticus*	Native
Northern Flicker	*Colaptes auratus*	Native
Pileated Woodpecker	*Dryocopus pileatus*	Native
Olive-Sided Flycatcher	*Contopus cooperi*	Native
Western Wood-Pewee	*Contopus sordidulus*	Native
Willow Flycatcher	*Empidonax traillii*	Native
Hammond's Flycatcher	*Empidonax hammondii*	Native
Dusky Flycatcher	*Empidonax oberholseri*	Native
Pacific-Slope Flycatcher	*Empidonax difficilis*	Native
Western Kingbird	*Tyrannus verticalis*	Native
Horned Lark	*Eremophila alpestris*	Native
Purple Martin	*Progne subis*	Native
Tree Swallow	*Tachycineta bicolor*	Native
Violet-Green Swallow	*Tachycineta thalassina*	Native
Northern Rough-Winged Swallow	*Stelgidopteryx serripennis*	Native
Cliff Swallow	*Petrochelidon pyrrhonota*	Native
Barn Swallow	*Hirundo rustica*	Native
Gray Jay	*Perisoreus canadensis*	Native
Steller's Jay	*Cyanocitta stelleri*	Native
Western Scrub-Jay	*Aphelocoma californica*	Native
Clark's Nutcracker	*Nucifraga columbiana*	Native
American Crow	*Corvus brachyrhynchos*	Native
Common Raven	*Corvus corax*	Native
Black-Capped Chickadee	*Poecile atricapillus*	Native
Mountain Chickadee	*Poecile gambeli*	Native
Chestnut-Backed Chickadee	*Poecile rufescens*	Native
Bushtit	*Psaltriparus minimus*	Native
Red-Breasted Nuthatch	*Sitta canadensis*	Native
White-Breasted Nuthatch	*Sitta carolinensis*	Native
Brown Creeper	*Certhia americana*	Native
Rock Wren	*Salpinctes obsoletus*	Native
Bewick's Wren	*Thryomanes bewickii*	Native
House Wren	*Troglodytes aedon*	Native
Winter Wren	*Troglodytes troglodytes*	Native
Marsh Wren	*Cistothorus palustris*	Native
American Dipper	*Cinclus mexicanus*	Native
Golden-Crowned Kinglet	*Regulus satrapa*	Native
Western Bluebird	*Sialia mexicana*	Native
Townsend's Solitaire	*Myadestes townsendi*	Native
Swainson's Thrush	*Catharus ustulatus*	Native
Hermit Thrush	*Catharus guttatus*	Native
American Robin	*Turdus migratorius*	Native
Varied Thrush	*Ixoreus naevius*	Native
Wrentit	*Chamaea fasciata*	Native

Common Name	***Scientific Name***	**Origin**
Cedar Waxwing	*Bombycilla cedrorum*	Native
European Starling	*Sternus vulgaris*	Introduced
Cassin's Vireo	*Vireo solitarius*	Native
Hutton's Vireo	*Vireo huttoni*	Native
Warbling Vireo	*Vireo gilvus*	Native
Red-Eyed Vireo	*Vireo olivaceus*	Native
Orange-Crowned Warbler	*Vermivora celata*	Native
Nashville Warbler	*Vermivora ruficapilla*	Native
Yellow Warbler	*Dendroica petechia*	Native
Yellow-Rumped Warbler	*Dendroica coronata*	Native
Black-Throated Gray Warbler	*Dendroica nigrescens*	Native
Townsend's Warbler	*Dendroica townsendi*	Native
Hermit Warbler	*Dendroica occidentalis*	Native
Macgillivray's Warbler	*Oporornis tolmiei*	Native
Common Yellowthroat	*Geothlypis trichas*	Native
Wilson's Warbler	*Wilsonia pusilla*	Native
Yellow-Breasted Chat	*Icteria virens*	Native
Western Tanager	*Piranga ludoviciana*	Native
Black-Headed Grosbeak	*Pheucticus melanocephalus*	Native
Lazuli Bunting	*Passerina amoena*	Native
Spotted Towhee	*Pipilo maculatus*	Native
Chipping Sparrow	*Spizella passerina*	Native
Vesper Sparrow	*Pooecetes gramineus*	Native
Lark Sparrow	*Chondestes grammacus*	Native
Savannah Sparrow	*Passerculus sandwichensis*	Native
Grasshopper Sparrow	*Ammodramus savannarum*	Native
Fox Sparrow	*Passerella iliaca*	Native
Song Sparrow	*Melospiza melodia*	Native
Lincoln's Sparrow	*Melospiza lincolnii*	Native
White-Crowned Sparrow	*Zonotrichia leucophrys*	Native
Dark-Eyed Junco	*Junco hyemalis*	Native
Red-Winged Blackbird	*Agelaius phoeniceus*	Native
Western Meadowlark	*Sturnella neglecta*	Native
Yellow-Headed Blackbird	*Xanthocephalus xanthocephalus*	Native
Brewer's Blackbird	*Euphagus cyanocephalus*	Native
Brown-Headed Cowbird	*Molothrus ater*	Native
Bullock's Oriole	*Icterus galbula*	Native
Purple Finch	*Carpodacus purpureus*	Native
House Finch	*Carpodacus mexicanus*	Native
Red Crossbill	*Loxia curvirostra*	Native
Pine Siskin	*Carduelis pinus*	Native
Lesser Goldfinch	*Carduelis psaltria*	Native
American Goldfinch	*Carduelis tristis*	Native
Evening Grosbeak	*Coccothraustes vespertinus*	Native
House Sparrow	*Passer domesticus*	Introduced

Table 14. Mammals and birds of the Willamette River Basin (PNWERC 2002). Note that extinctions refer to local condition.

Characteristic	Most mussels	Most macroinvertebrates
Life-span Long	(>30 years)	Short (<3 years)
Mobility	Limited	Moderate
Recruitment	Irregular	Regular
Recolonization	Slow	Rapid
Tolerance of adults to flow extremes	High	Low

Table 15. Characteristics of freshwater mussels and most other macroinvertebrates (from Gore et al 2001)

Common Name	***Scientific Name***	**Origin**
Amphibians		
Northwestern Salamander	*Ambystoma gracile*	Native
Long-Toed Salamander	*Ambystoma macrodactylum*	Native
Clouded Salamander	*Aneides ferreus*	Native
Oregon Slender Salamander	*Batrachoseps wrighti*	Native
Ensatina	*Ensatina eschscholtzii*	Native
Dunn's Salamander	*Plethodon dunni*	Native
Western Red-Backed Salamander	*Plethodon vehiculum*	Native
Roughskin Newt	*Taricha granulosa*	Native
Pacific Giant Salamander	*Dicamptodon tenebrosus*	Native
Southern Torrent Salamander	*Rhyacotriton variegatus*	Native
Cascade Torrent Salamander	*Rhyacotriton cascadae*	Native
Tailed Frog	*Ascaphus truei*	Native
Western Toad	*Bufo boreas*	Native
Pacific Treefrog	*Pseudacris regilla*	Native
Red-Legged Frog	*Rana aurora*	Native
Foothill Yellow-Legged Frog	*Rana boylii*	Native
Cascades Frog	*Rana cascadae*	Native
Bullfrog	*Rana catesbeiana*	Introduced
Oregon Spotted Frog	*Rana pretiosa*	Native
Painted Turtle	*Chrysemys picta*	Native
Western Pond Turtle	*Clemmys marmorata*	Native
Reptiles		
Northern Alligator Lizard	*Elgaria coerulea*	Native
Southern Alligator Lizard	*Elgaria multicarinata*	Native
Western Fence Lizard	*Sceloporus occidentalis*	Native
Western Skink	*Eumeces skiltonianus*	Native
Rubber Boa	*Charina bottae*	Native
Racer	*Coluber constrictor*	Native
Sharptail Snake	*Contia tenuis*	Native
Ringneck Snake	*Diadophis punctatus*	Native
Gopher Snake	*Pituophis catenifer*	Native
Western Terrestrial Garter Snake	*Thamnophis elegans*	Native
Northwestern Garter Snake	*Thamnophis ordinoides*	Native
Common Garter Snake	*Thamnophis sirtalis*	Native
Western Rattlesnake	*Crotalus viridis*	Native

Table 16. Amphibian and reptile species of the Willamette Basin..

Common Name	*Scientific Name*	Origin	Coast Fork	Middle Fork	Main-stem
Bullhead Catfishes	**Ictaluridae**				
Black bullhead	*Ameiurus melas*	Introduced			X
Brown bullhead	*Ameiurus nebulosus*	Introduced	X	X	X
Yellow bullhead	*Ameiurus natalis*	Introduced	X		X
Channel catfish	*Ictalurus punctatus*	Introduced			X
Flounders	**Pleuronectidae**				
Starry flounder[1]	*Platichthys stellatus*	Native			X
Herrings	**Clupeidae**				
American shad[2]	*Alosa sapidissima*	Introduced			X
Lampreys	**Petromyzontidae**				
Western brook lamprey	*Lampetra richardsoni*	Native	X	X	X
Pacific lamprey[2]	*Lampetra tridentata*	Native	X	X	X
River lamprey[2]	*Lampetra ayresi*	Native			X
Livebearers	**Poeciliidae**				
Mosquitofish	*Gambusia affinis*	Introduced	X	X	
Minnows	**Cyprinidae**				
Chiselmouth	*Acrocheilus alutaceus*	Native	X	X	X
Common carp	*Cyprinus carpio*	Introduced	X	X	X
Oregon chub	*Oregonichthys crameri*	Native	X	X	
Peamouth	*Mylocheilus caurinus*	Native	X	X	X
Northern pikeminnow	*Ptychocheilus oregonensis*	Native	X	X	X
Goldfish	*Carassius auratus*	Introduced			X
Longnose dace	*Rhinichthys cataractae*	Native	X	X	X
Leopard dace	*Rhinichthys falcatus*	Native	X	X	X
Speckled dace	*Rhinichthys osculus*	Native	X	X	X
Redside shiner	*Richardsonius balteatus*	Native	X	X	X

Common Name	*Scientific Name*	Origin	Coast Fork	Middle Fork	Main-stem
Tench	*Tinca tinca*	Introduced			X
Perches	**Percidae**				
Yellow perch	*Perca flavescens*	Introduced	X		X
Walleye	*Stizostedion vitreum*	Introduced		X	X
Sculpins	**Cottidae**				
Prickly sculpin	*Cottus asper*	Native			X
Mottled sculpin	*Cottus bairdi*	Native		X	
Paiute sculpin	*Cottus beldingi*	Native	X	X	X
Shorthead sculpin	*Cottus confuscus*	Native		X	
Reticulate sculpin	*Cottus perplexus*	Native	X	X	X
Torrent sculpin	*Cottus rhotherus*	Native	X	X	X
Riffle sculpin	*Cottus gulosus*	Native			X
Smelts	**Osmeridae**				
Eulachon	*Thaleichthys pacificus*	Native			X
Sticklebacks	**Gasterosteidae**				
Threespine stickleback	*Gasterosteus aculeatus*	Native	X	X	X
Sturgeons	**Acipenseridae**				
White sturgeon	*Acipenser transmontanus*	Native		X	X
Suckers	**Catostomidae**				
Largescale sucker	*Catostomus macrocheilus*	Native	X	X	X
Mountain sucker	*Catostomus platyrhynchus*	Native	X	X	X
Sunfishes	**Centrarchidae**				
Pumpkinseed	*Lepomis gibbosus*	Introduced	X		X
Warmouth	*Lepomis gulosus*	Introduced	X		X
Bluegill	*Lepomis macrochirus*	Introduced	X	X	X
Redear sunfish	*Lepomis microlophus*	Introduced			X

Common Name	***Scientific Name***	**Origin**	**Coast Fork**	**Middle Fork**	**Main-stem**
Smallmouth bass	*Micropterus dolomieui*	Introduced	X	X	X
Largemouth bass	*Micropterus salmoides*	Introduced	X	X	X
White crappie	*Pomoxis annularis*	Introduced	X	X	X
Black crappie	*Pomoxis nigromaculatus*	Introduced	X	X	X
Topminnows	**Fundulidae**				
Banded killifish	*Fundulus diaphanus*	Introduced			X
Trout and Salmon	**Salmonidae**				
Coho salmon[2]	*Oncorhynchus kisutch*	Introduced[3]			X
Sockeye salmon[2]	*Oncorhynchus nerka*	Introduced			X
Spring chinook salmon[2]	*Oncorhynchus tshawytscha*	Native	X[6]	X	X
Fall chinook salmon[2]	*Oncorhynchus tshawytscha*	Introduced[3]	?X[4]	?X	X
Mountain whitefish	*Prosopium williamsoni*	Native	X	X	X
Coastal cutthroat trout(2)	*Oncorhynchus clarki clarki*	Native	X	X	X
Summer steelhead[2]	*Oncorhynchus mykiss*	Introduced[3]	X	X	X
Winter steelhead[2]	*Oncorhynchus mykiss*	Native	X[4]	X	X
Rainbow trout	*Oncorhynchus mykiss*	Native	X	X	X
Brook trout	*Salvelinus fontinalis*	Introduced	X?	X	
Bull trout	*Salvelinus confluentus*	Native		X	
Trout-Perches	**Percopsidae**				
Sand roller	*Percopsis transmontana*	Native	X	X	X

[1] Marine species.

[2] Anadromous species; (2) includes resident form.

[3] Native to Willamette basin, but introduced upstream of Willamette Falls.

[4] Rare; only a small population exists.

[5] Rearing of fish originating from other subbasins.

[6] Dependent on flows, original population was small (K. Reis, pers. comm.)

Table 17. Fish species present in the Willamette River (from USACE 2000, modified for Coast and Middle Forks, with additional information from K. Reis, ODFW). Note that additional introduced species have since been added to this list, including white catfish (*Ameirus catus*), Oriental weatherfish (*Misgurnus anguillicaudatus*) fathead minnow (*Pimephales promelus*), golden shiner (*Notemigonus chrysoleucas*), grass carp (*Ctenopharyngodon idella*), and green sunfish (*Lepomis cyanelllus*). Most of these are restricted to lakes, excepting the white catfish (mainstem) and the weatherfish (small tributaries).

Species	USACE 2002	NWPPC 2004
Upper Willamette Spring Chinook	X	X
Winter Steelhead (introduced, not part of ESU)	X	X
Upper Willamette Cutthroat Trout	X	X
Bull Trout (reintroduced to Middle Fork)	X	X
Oregon Chub	X	X
Pacific Lamprey		X

Table 18. Fish species needs and impacts addressed by recent reviews and documents.

Minimum instream flow requirements downstream of Willamette Project dams. Subset for Middle and Coast Forks.

Stream / Location	Priority Date	Flow (cfs)	Period	Purpose
Willamette River				
Above Willamette Falls to Mouth	4/20/71	1500	all year	Supporting aquatic life
At USGS gage no. 14-1980 at Wilsonville	6/22/64	1500	all year	Supporting aquatic life
At USGS gage no. 14-1910 at Salem	6/22/64	1300	all year	Supporting aquatic life
At USGS gage no. 14-1740 at Albany	6/22/64	1750	all year	Supporting aquatic life
Between Coast Fork and McKenzie R	11/3/83	2000	Jun 1 - Oct 31	Supporting aquatic life and minimizing pollution
		2500	Nov 1 - May 31	
Fall Creek				
Mouth to RM 1.0	6/22/64 [1]	40	all year	Supporting aquatic life
Middle Fork Willamette River				
Coast Fork confluence to 1 mile upstream	6/22/64 [1]	640	all year	Supporting aquatic life
North Fork confluence to 1 mile upstream	6/22/64 [1]	285	all year	Supporting aquatic life
Coast Fork Willamette River				
Middle Fork confluence to 1 mile upstream	6/22/64 [1]	40	all year	Supporting aquatic life
Row River confluence to 1 mile upstream	6/22/64 [1]	15	all year	Supporting aquatic life
Cottage Grove Dam to Row River	1/16/97	125	Nov 16 - Mar 31	Anadromous and resident fish life
Row River to mouth	1/16/97	200	Nov 16 - Mar 31	Anadromous and resident fish life
Row River				
Coast Fork confluence to 1 mile upstream	6/22/64 [1]	40	all year	Supporting aquatic life
Dorena Dam to mouth	1/16/97	175	Nov 16 - Apr 30	Anadromous and resident fish life
Long Tom River				
At USGS gage no. 14-1700 at Monroe	6/22/64	(not specified)	(all year)	Obtaining the highest and best use of waters from storage

[1] also listed for 5/24/62

Table 19. Mininmum instream flow requirements and purposes below Coast and Middle Fork dams, including mainstem targets (USACE 2000).

Flows recommended for good upstream passage of salmon and steelhead for rivers that are regulated by Willamette Project dams, Oregon. Subset for Coast and Middle Fork Chinook..

Location	Flow (cfs)	Time Period	Species	Regulation Point
Middle Fork Willamette River below Dexter	900	Apr 15-Jun 30	Spring Chinook	Dexter Dam
	700	Mar 1-Apr 15	Steelhead	
Fall Creek [1] below Fall Creek Dam	170	Apr 15-Jun 30	Spring Chinook	Fall Creek Dam
Coast Fork Willamette mouth to Row River	200	Oct 15-Dec 1	Fall Chinook	Just below Row River
	175	Jan 1-May 15	Steelhead	
Row River below Dorena Dam	175	Oct 15-Dec 1	Fall Chinook	Dorena Dam
	150	Jan 1-May 15	Steelhead	

[1] Experience at Fall Creek in 1977 and 1978 showed that 150 cfs is sufficient to provide adult transport, and that this flow should not be interrupted frequently with lower flows. Considerable straying of marked fish was noted to have occurred when a week flow schedule of three days at 150 cfs and four days at 50 cfs was followed.

Table 20. Flows needed for returning adult salmon to pass over dams (USACE 2000). Note that Fall Chinook are an introduced strain. Recommendations for steelhead are included (also introduced) for comparison, and because they may affect dam operations.

Minimum spawning flows recommended below each reservoir for rivers that are regulated by Willamette Project dams, Oregon. Subset for Coast and Middle Forks.

Location	Flow (cfs)	Time Period	Species	Regulation Point
Middle Fork Willamette River below Dexter	1200	Sep 10-Oct 10	Spring Chinook	Dexter Dam
		Mar 1-Jun 1	Steelhead	
Fall Creek below Fall Creek	150	Sep 10-Oct 10	Spring Chinook	Fall Creek Dam
		Mar 1-Jun 1	Steelhead	
Row River below Dorena Dam	200	Oct 15-Dec 10	Fall Chinook	Dorena Dam
		Mar 1-Jun 1	Steelhead	
Coast Fork Willamette River mouth to Row River	250	Oct 15-Dec 10	Fall Chinook	Just below Row River
		Mar 1-Jun 1	Steelhead	
Willamette River McKenzie to Corvallis	6500	Sep 10-Oct 10	Fall Chinook	Harrisburg

Table 21. Flows need for spawning by returning adult salmon (USACE 2000). Note that Fall Chinook are an introduced strain. Recommendations for steelhead are included (also introduced) for comparison, and because they may affect dam operations.

Minimum incubation flows recommended below each reservoir for rivers that are regulated by Willamette Project dams, Oregon. Subset for Coast and Middle Forks.

Location	Flow (cfs)	Time Period	Species	Regulation Point
Middle Fork Willamette River below Dexter	One foot lower than flow level at spawning time	Oct 1-Mar 15 Apr 1-Jun 15	Spring Chinook Steelhead	Jasper
Fall Creek below Fall Creek Dam	150 cfs 75 cfs	Oct 1-Mar 15 Apr 1-Jul 1	Spring Chinook Steelhead	Fall Creek Dam
Row River below Dorena Dam	150 cfs	Nov 15-Apr 1 Apr 1-Jun 15	Fall Chinook Steelhead	Dorena Dam
Coast Fork Willamette River mouth to Row River	250 cfs	Nov 15-Apr 1 Apr 1-Jun 15	Fall Chinook Steelhead	Goshen
Willamette River	One foot lower than flow level at peak spawning	Oct 1-Mar 15	Fall Chinook	Harrisburg

Table 22. Minimum incubation flows for anadromous salmonids. Note that Fall Chinook are an introduced strain. Recommendations for steelhead are included (also introduced) for comparison, and because they may affect dam operations (USACE 2000).

Maximum flow recommended during spawning to keep redds in water during incubation for rivers regulated by Willamette Project dams, Oregon. Subset for Coast and Middle Forks.

Location	Flow (cfs)	Time Period	Species	Regulation Point
Middle Fork Willamette River[1] below Dexter Dam				
Fall Creek[1] below Fall Creek Dam				
Row River below Dorena Dam	690	Oct 15-Dec 10	Fall Chinook	Dorena Dam
Coast Fork Willamette River mouth to Row River	850	Oct 15-Dec 10	Fall Chinook	Goshen
Willamette River McKenzie to Corvallis	7500	Sep 10-Oct 10	Fall Chinook	Harrisburg

[1] Because of large fluctuations of stream levels under normal operations of the reservoirs, it was considered impractical at the time to recommend maximum spawning flows below these reservoirs.

Table 23. “Redd protection flows” (USACE 2000). Note that fall Chinook are an introduced stock.

Minimum flows recommended for salmonid rearing for rivers that are regulated by Willamette Project dams, Oregon. Subset for Coast and Middle Forks.

Location	**Flow (cfs)**	**Time Period**	*Regulation Point*
Middle Fork Willamette River below Dexter Dam	1600	Jun 1-Oct 30	Dexter Dam
	800	Nov 1-Jun 1	
Middle Fork Willamette River from Hills Creek Dam to Lookout Point Reservoir	285	Throughout year	Hills Creek Dam
Fall Creek below Fall Creek Reservoir	150	Jun 1-Oct 30	Fall Creek Dam
	50	Nov 1-May 30	
Row River below Dorena Dam	300	Jun 15-Oct 30	Dorena Dam
	100	Nov 1-Jun 15	
Coast Fork Willamette River mouth to Row River	350	Jun 15-Oct 30	Goshen
	200	Nov 1-Jun 15	

Table 24. Minimum flows for rearing of all salmonids, including both anadromous and resident species (USACE 2000)

Water temperature criteria for listed and candidate fish species potentially influenced the Willamette Project dams (USACE 2000). Subset for Middle and Coast Fork species.

Species	Lifestage	Temperature Criteria (C)			
		Optimum/ Preferred	Avoidance/ Tolerance	Stress/ Delay	Upper Lethal Limit
Chinook Salmon	Adult	H: 8-12.5	All: 9.4, 14.1 F: 10.6, 19.4 Sp: 3.3, 13.3 Su: 13.9, 20.0	M: 21.0; Di: 15.5	25.0
	Spawning		5.6, 12.8	16.0	
	Incubation	4.5-12.8	1.7, 14.4		
	Juvenile	R: 7.2-15.6		R: 19.1 M: 18.3	R: 22.0 M: 18.3
Steelhead Trout	Adult	10.0-12.8	7.2, 14.4		23.9
	Spawning		3.9, 9.4		
	Incubation	10.0			
	Juvenile				
Bull Trout	Adult	M: 10-12 9.0-13.0	4.0, 18.0	20.0	
	Spawning	5.0-8.0	4.0, 10.0		
	Incubation	1.0-6.0			
	Juvenile	4.0-10.0			
Cutthroat Trout	Adult	9.4-12.8			22.8
	Spawning	10.0	6.1-17.2		
	Incubation	4.4-12.8			
	Juvenile				
Oregon Chub	Adult				
	Spawning	>16			31
	Juvenile				

Table 25. Water temperature criteria for listed and sensitive fish species in the Coast and Middle Forks (USACE 2000). Key to abbreviations in table: F=Fall run, Sp=Spring run, Su=Summer run; M=Migration; Di=Disease; R=Rearing; H=Holding. Note that steelhead are likely not native to the Coast and Middle Forks.

Parameter	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
Water Quality				
Temperature	Higher in summer	No impact	No impact	No impact
Nutrients	Rates of primary production and microbial activity increase	Concentrations may increase, especially in early rain events Biological effects less than summer because of lower light and temperature Mobilization from sediment increases	Concentrations may increase and transport from floodplain increases Biological effects less than summer because of lower light and temperature Mobilization from sediment increases	Concentrations may decrease because of dilution Transport from floodplain increases Biological effects less than summer because of lower light, turbidity, and temperature Mobilization from sediment and floodplain increases
Turbidity	Low in summer May increase after drought with first rain events	Increases Timing and magnitude depend on land use and geomorphology	Increases Timing and magnitude depend on land use and geomorphology	Increases Timing and magnitude depend on land use and geomorphology
Toxics/pollutants	Concentrations may increase due to lack of dilution and effect of temperature Biological effects may be greater Mobilization from sediment low	Mobilization from sediment increases	Mobilization from sediment and adjacent floodplain increases	Mobilization from sediment and adjacent floodplain increases
Sediment	Little or no movement or delivery	Input from bank erosion, mostly fine particles(?)	Turnover of some sediment, some gravel bars cleared	Extensive erosion and deposition Scour and formation of gravel bars

Parameter	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
Channel Geomorphology	No major changes Fine sediment deposition in channel	Possible channel downcutting, formation of sediment deposits across side channels	Erosion of oversteepened banks Some channel movement	Change in channel geometry Possible new channels formed
Delivery of large wood	No changes	Possible streamside forest inputs	Adjacent forest inputs Transport from upstream	Adjacent forest inputs Channel avulsion inputs Transport from upstream
Floodplain Structure	No change	Floodplain margins modified by bank failure, especially if flows remain at bankfull for extended periods	Floodplain margins modified by bank failure, especially for steep banks if flows drop rapidly Sediment deposits in secondary channels removed by high flows	Floodplain margins modified by bank failure and channel avulsion New channels may be formed Sediment deposits in secondary channels removed by high flows Relative size of secondary channels may change
Hyporheic	Subsurface exchange may increase because of lower proportion of surface flow Influence of subsurface flow on surface water may be more evident	Water recharge in bars and floodplains increases Surface water may have greater influence on hyporheic zone as surface water head increases Silt and sediment flushed from interstitial spaces, increasing potential	Water recharge in bars and floodplains increases Surface water may have greater influence on hyporheic zone as surface water head increases Silt and sediment flushed from interstitial spaces, increasing potential hyporheic	Water recharge in bars and floodplains increases Surface water may have greater influence on hyporheic zone as surface water head increases Silt and sediment flushed from interstitial spaces, increasing potential hyporheic exchange New channels and bars provide areas of greater

Parameter	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
		hyporheic exchange	exchange	permeability and increased hyporheic exchange

Species	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
Black Cottonwood	Extreme drought decreases seedling survival Young tree survival may decrease Rate of flow decrease critical to seedling survival	New gravel bars create instream colonization sites for next season	Seedlings and young trees on floodplain may be eroded Sediment deposits may benefit young trees New bars and floodplain surfaces create colonization sites for next season	Seedlings and young trees on floodplain may be eroded Vegetative reproduction increases from tree fall and fragmentation Sediment deposits may benefit young trees New bars and floodplain surfaces create colonization sites for next season
Willow	Extreme drought decreases seedling survival Young tree survival may decrease	New gravel bars create instream colonization sites for next season	Seedlings and young trees on floodplain may be eroded Vegetative reproduction increases from tree fall and fragmentation Sediment deposits may benefit young trees New bars and floodplain surfaces create colonization sites for next season	Seedlings and young trees on floodplain may be eroded Vegetative reproduction increases from tree fall and fragmentation Sediment deposits may benefit young trees New bars and floodplain surfaces create colonization sites for next season
Oregon ash	Extreme drought decreases seedling survival Young tree survival may decrease	Inundation and increased soil saturation are favorable to ash establishment and competition with other	Inundation and increased soil saturation are favorable to ash establishment and competition with other	Inundation and increased soil saturation are favorable to ash establishment and competition with other species Seedlings and young trees

Species	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
		species New gravel bars create instream colonization sites for next season	species Seedlings and young trees on floodplain may be eroded Sediment deposits may benefit young trees New bars and floodplain surfaces create colonization sites for next season	on floodplain may be eroded Sediment deposits may benefit young trees New floodplain surfaces create colonization sites for next season
Big-leaf maple	Extreme drought decreases seedling survival Young tree survival may decrease	Little effect	Seedlings and young trees on floodplain may be eroded Sediment deposits may benefit young trees	Seedlings and young trees on floodplain may be eroded Vegetative reproduction increases from tree fall Sediment deposits may benefit young trees
Reed Canarygrass	Drought may allow canarygrass to outcompete other riparian species	Sediment deposits may benefit canarygrass Erosion and redepoistion of grass clumps may increase dispersal	Sediment deposits may benefit canarygrass Erosion may clear some areas of canarygrass Erosion and redeposition of grass clumps may increase dispersal	Sediment deposits may benefit canarygrass Erosion may clear some areas of canarygrass Erosion and redeposition of grass clumps may increase dispersal
Knotweeds	Drought may allow knotweeds to outcompete other riparian species	Sediment deposits may benefit knotweeds Erosion and redeposition of root	Sediment deposits may benefit knotweeds Erosion may clear some areas of knotweeds	Erosion may clear some areas of knotweeds Sediment deposits may benefit knotweeds Erosion and redepoistion of

Species	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
		clumps may increase dispersal	Erosion and redeposition of root clumps may increase dispersal	root clumps may increase dispersal

Species	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
Terrestrial Vertebrates				
Birds	Relatively little effect near river. Shore birds may be affected if area of shoreline habitat diminishes.	Relatively little effect near river.	Patchy changes in habitat by flood alteration of riparian vegetation, gravel bars, and floodplain margin. Scavengers may benefit.	Habitats may be destroyed or created by floodplain change. Scavengers may benefit.
Mammals	Relatively little effect near river.	Relatively little effect near river.	Floods may decrease survival, particularly for less mobile species. Patchy changes in habitat by flood alteration of riparian vegetation, gravel bars, and floodplain margin. Scavengers may benefit	Floods may decrease survival, particularly for less mobile species. Habitats may be destroyed or created by floodplain change. Scavengers may benefit.
Aquatic Invertebrates				
Mussels, long-lived, adults not mobile	Release of larvae which is temperature sensitive	Limited effects of sediment scour or deposition.	May destroy beds in areas of high scour or deposition	May destroy beds in areas of high scour or deposition
Mayflies, short-lived, adults and larvae mobile	Little effect unless riffle habitats decline or area of aquatic habitat is greatly reduced.	Likely to scour new habitat Recolonized by survivors in river bed, downstream larval drift, or aerial	Likely to scour new habitat Recolonized by survivors in river bed, downstream larval drift, or aerial dispersal of	Likely to scour new habitat Recolonized by survivors in river bed, downstream larval drift, or aerial dispersal of egg-laying adults.

Species	Drought/Low Flow	High Flow Pulse (Up to bankfull)	Small Flood (Overbank, 2-10 yr interval)	Large Flood (Floodplain maintenance, >10 yr interval)
		dispersal of egg-laying adults.	egg-laying adults.	
Caddisflies, short-lived adults and larvae limited mobility	Little effect unless riffle habitats decline or area of aquatic habitat is greatly reduced. Survival may decrease if temperatures increase greatly	Likely to scour habitat and cause mortality. Recolonized by survivors in river bed or aerial dispersal of egg-laying adults. Dispersal by drift less important.	Likely to scour habitat and cause mortality. Recolonized by survivors in river bed or aerial dispersal of egg-laying adults. Dispersal by drift less important.	Likely to scour habitat and cause mortality. Recolonized by survivors in river bed or aerial dispersal of egg-laying adults. Dispersal by drift less important.
Aquatic Vertebrates				
Amphibians				
Red-legged frog	May decline if habitat dries up	Likely to scour habitat and cause mortality.	Likely to scour habitat and cause mortality. Survival increased if temporary wetlands created. Adult dispersal and egg production may increase if wetland habitats increase.	Likely to scour habitat and cause mortality. Survival increased if temporary wetlands created, but may also allow bullfrogs to invade. Adult dispersal and egg production may increase if wetland habitats increase.
Bullfrog	May decline if habitat dries up	Likely to scour habitat and cause mortality.	Likely to scour habitat and cause mortality. If flood connects river to deep ponds, could increase. Possible increased mortality in overwintering tadpoles.	Likely to scour habitat and cause mortality. If flood connects river to deep ponds, could increase. Possible increased mortality in overwintering tadpoles. Adult dispersal and egg production may increase if

Species	Drought/Low Flow	High Flow Pulse (Up to bankfull)	Small Flood (Overbank, 2-10 yr interval)	Large Flood (Floodplain maintenance, >10 yr interval)
			Adult dispersal and egg production may increase if wetland habitats increase.	wetland habitats increase.
Reptiles				
Western pond turtle	May decline if habitat dries up	Little effect	If flood connects river to deep ponds, could increase abundance. Possible increased mortality in young. Adult dispersal and reproduction may increase if wetland habitats increase.	If flood creates floodplain ponds or connects river to deep ponds, could increase abundance. Possible increased mortality in young. Adult dispersal and reproduction may increase if wetland habitats increase.
Fish				
Spring Chinook	May decrease summer populations of juveniles in upstream tributaries because of habitat reduction. Spring drought may decrease smolt outmigration or adult upstream migration.	Small floods will have minor impacts. Flushing sediment from sediment may increase spawning success and decrease storage of pathogens in sediments.	Intermediate floods will have minor impacts in early fall or late winter. Spawning success and egg survival in redds may decrease if bed is mobilized. Juvenile survival may be reduced in simplified river reaches. Flushing sediment from sediment may increase spawning success and	Large floods will have moderate impacts in early fall or late winter. Spawning success and egg survival in redds may decrease if bed is mobilized. Juvenile survival may be reduced in simplified river reaches. Flushing sediment from sediment may increase spawning success and decrease storage of

Species	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
			decrease storage of pathogens in sediments.	pathogens in sediments.
Pacific Lamprey	Less affected than other fish because they rear in intergravel environment. As stream habitat shrinks, survival of juveniles may decrease.	Small floods will have minor impacts. Flushing sediment from sediment may increase survival, food supply, and spawning success.	Intermediate floods may decrease survival if gravel deposits are scoured and eliminated. Flushing sediment from sediment may increase survival, food supply, and spawning success.	Large floods may decrease survival if gravel deposits are scoured and eliminated. Flushing sediment from sediment may increase survival, food supply, and spawning success.
Western Brook Lamprey	Less affected than other fish because they rear in intergravel environment. As stream habitat shrinks, survival of juveniles may decrease.	Will have minor impacts. Flushing sediment from sediment may increase survival, food supply, and spawning success.	May decrease survival if gravel deposits are scoured and eliminated. Flushing sediment from sediment may increase survival, food supply, and spawning success.	May decrease survival if gravel deposits are scoured and eliminated. Flushing sediment from sediment may increase survival, food supply, and spawning success.
Cutthroat Trout	Minor impacts in the mainstem river. Adult trout use of tributaries may be reduced by spring drought. If tributary stream habitat diminishes or warms during drought,	Small floods will have minor impacts. Flushing sediment from sediment may increase spawning success and decrease storage of pathogens in sediments.	Intermediate floods may decrease survival slightly, but also may increase survival by increasing transport of food resources from the floodplain. Fish may be able to use tributary junction	Large floods may decrease survival, but also may increase survival by increasing transport of food resources from the floodplain. New riffles and pools may expand available habitat. If channel changes reduce

Species	Drought/Low Flow	High Flow Pulse (Up to bankfull)	Small Flood (Overbank, 2-10 yr interval)	Large Flood (Floodplain maintenance, >10 yr interval)
	juvenile survival may decrease. If temperature increases substantially, survival and distribution may decrease because of thermal tolerance and disease.		environments more extensively. Reduction of warm water non-native species may benefit native species.	available habitat, effects may be negative. Reduction of warm water alien species may benefit native species.
Oregon Chub	May decrease summer populations of juveniles in floodplain tributaries because of habitat reduction as streams and ponds dry up.	Small floods may increase floodplain habitat and increase dispersal.	Intermediate floods will have minor impacts. Reconnected floodplain habitats may benefit dispersal. Negative effects of floods on predators may increase survival of chub.	Large floods may cause mortality and displacement. Reconnected floodplain habitats may benefit dispersal. Negative effects of large floods on predators may increase survival. If floods increase predators, survival may decrease.
Large scale sucker	Minor impacts in the mainstem river. As nearshore habitat shifts and shrinks, larval survival may decrease.	Small floods will have minor impacts. Flushing sediment from gravel may increase spawning success.	Intermediate floods may decrease survival slightly, but also may increase survival by increasing transport of food resources from the floodplain. Fish may be able to use tributary junction environments more extensively.	Large floods may decrease survival, but also may increase survival by increasing transport of food resources from the floodplain. New riffles and pools may expand available habitat. If channel changes reduce available habitat, effects may be negative.

Species	**Drought/Low Flow**	**High Flow Pulse (Up to bankfull)**	**Small Flood (Overbank, 2-10 yr interval)**	**Large Flood (Floodplain maintenance, >10 yr interval)**
Largemouth Bass	Favored by warm water and more lacustrine habitat. Survival may increase during drought.	Small floods will have minor impacts.	Intermediate floods decrease survival for non-native species.	Large floods decrease survival for non-native species.
Smallmouth Bass	Favored by warm water and more lacustrine habitat. Survival may increase during drought.	Small floods will have minor impacts.	Intermediate floods decrease survival for non-native species.	Large floods decrease survival for non-native species.

Table 26. Summary of impacts of different flow regimes on ecosystem parameters and exemplar species. Note the different sections of this table are also included in the main text.

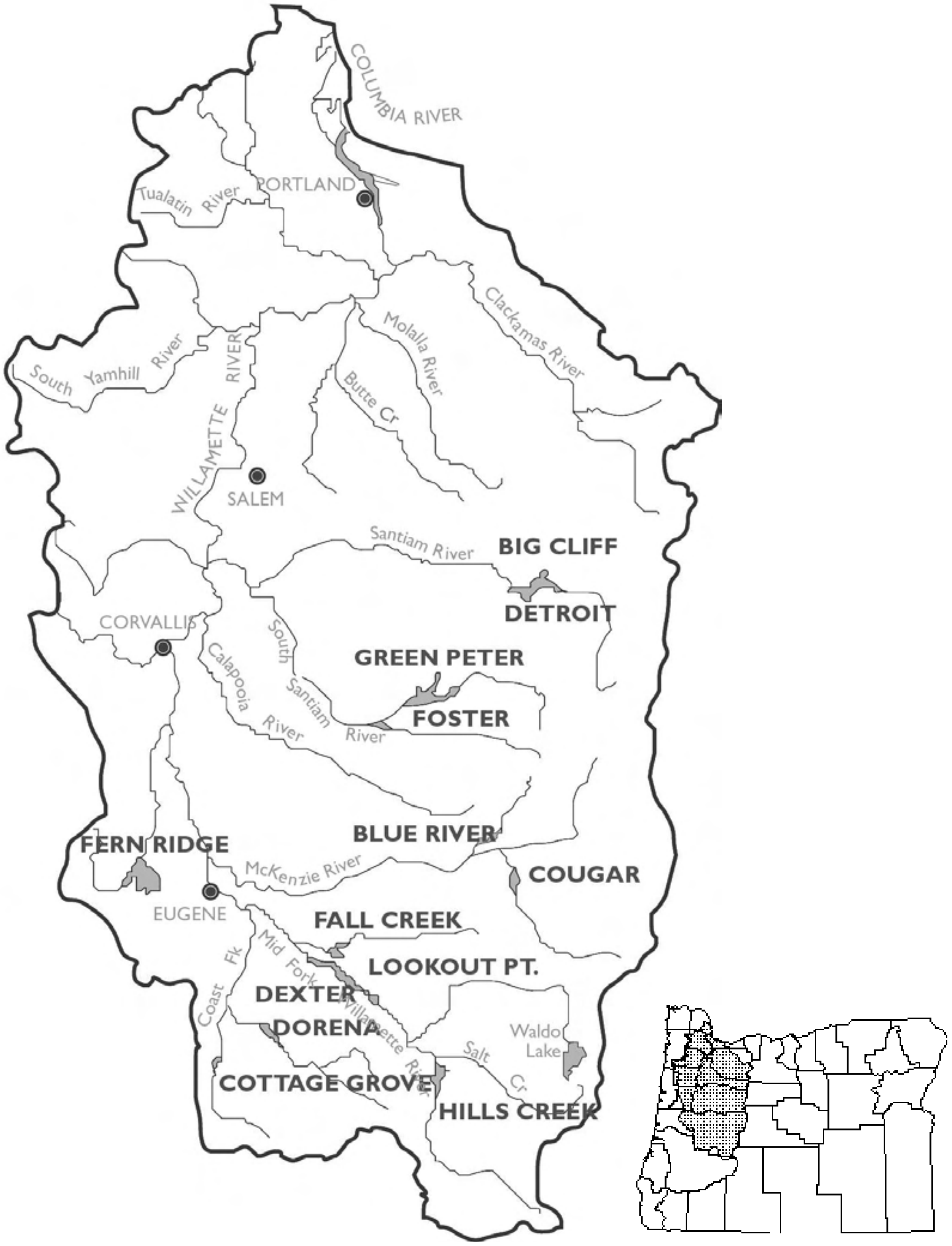


Figure 1. Map of the Willamette River basin showing major tributaries and the locations of the thirteen USACE flood control projects (USACE, 2000).

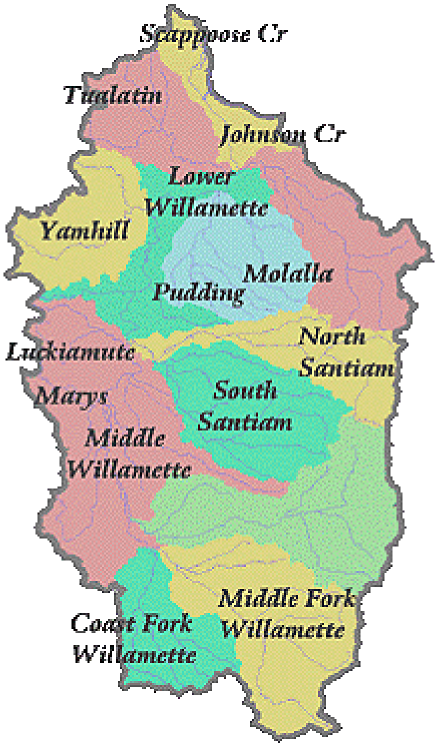
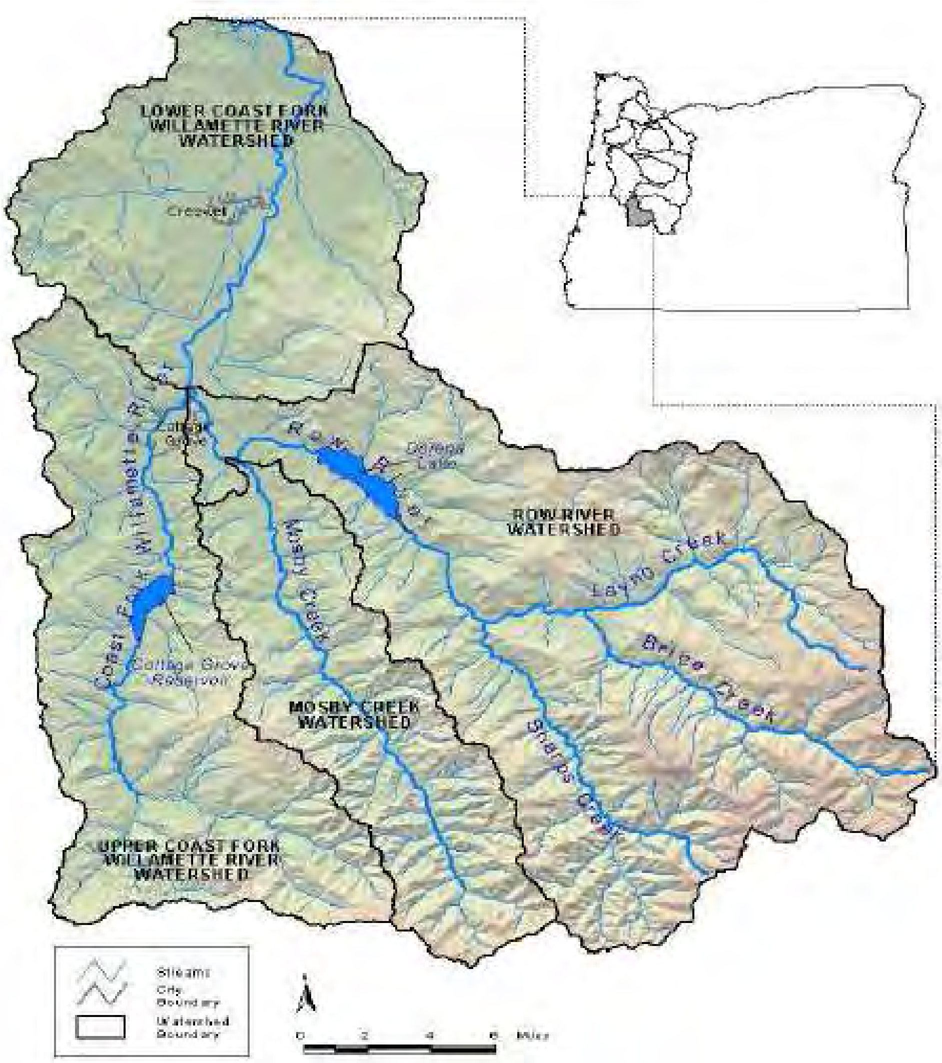


Figure 2 Subbasins of the Willamette River (from Oregon Water Resources Department at, http://www.wrd.state.or.us/OWRD/SW/streamflow_will.shtml).


LOWER COAST FORK WILLAMETTE RIVER WATERSHED
Creswell
Coast Fork Willamette River
Cottage Grove
Row River
Dorena Lake
ROW RIVER WATERSHED
Mosby Creek
Layng Creek
Brice Creek
Cottage Grove Reservoir
MOSBY CREEK WATERSHED
Sharps Creek
UPPER COAST FORK WILLAMETTE RIVER WATERSHED
Streams
City Boundary
Watershed Boundary
0
2
4
6
Miles

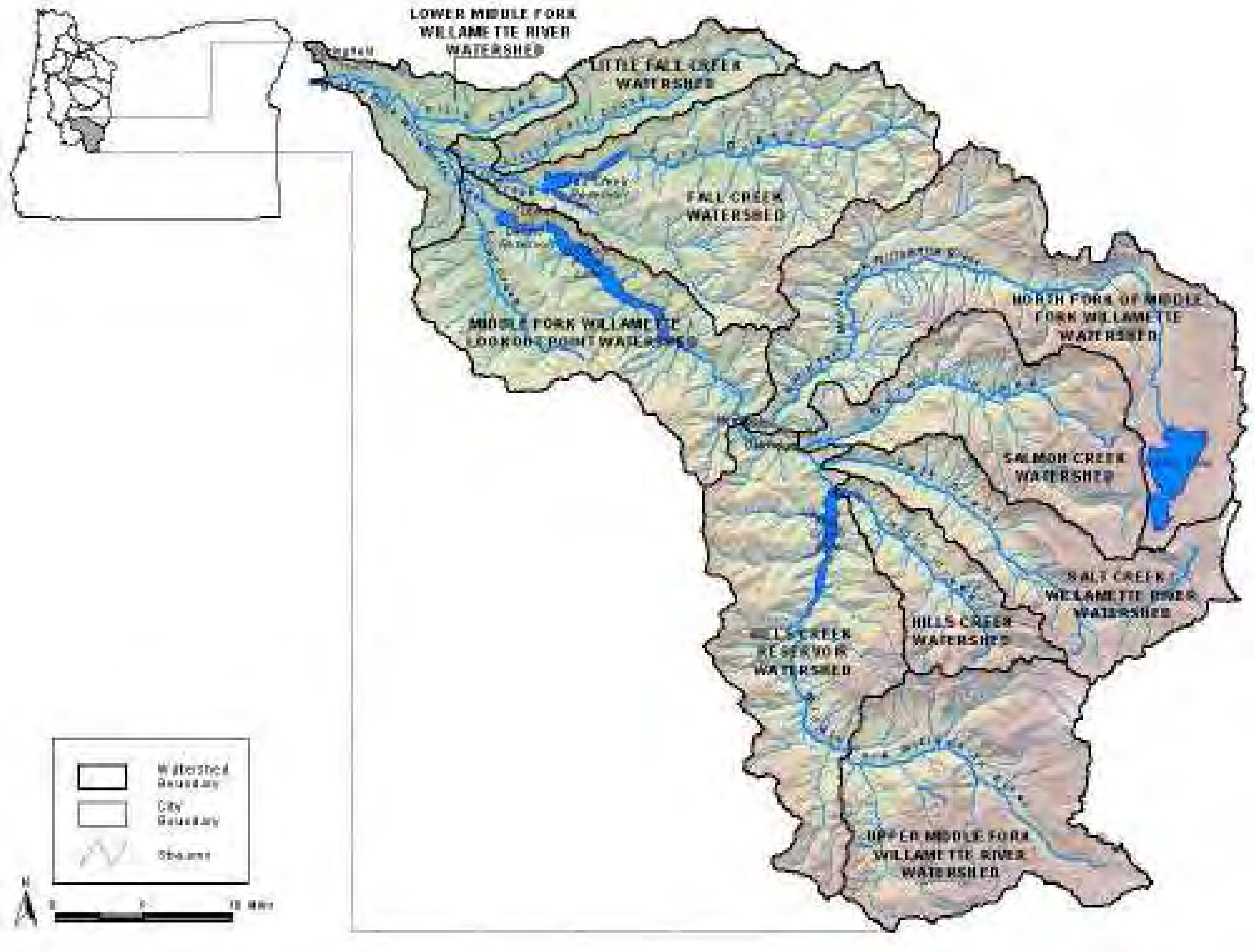


Figure 3a & b: Coast Fork (3a, upper panel) and Middle Fork (3b, lower panel) drainage networks and topography (ODEQ 2006).

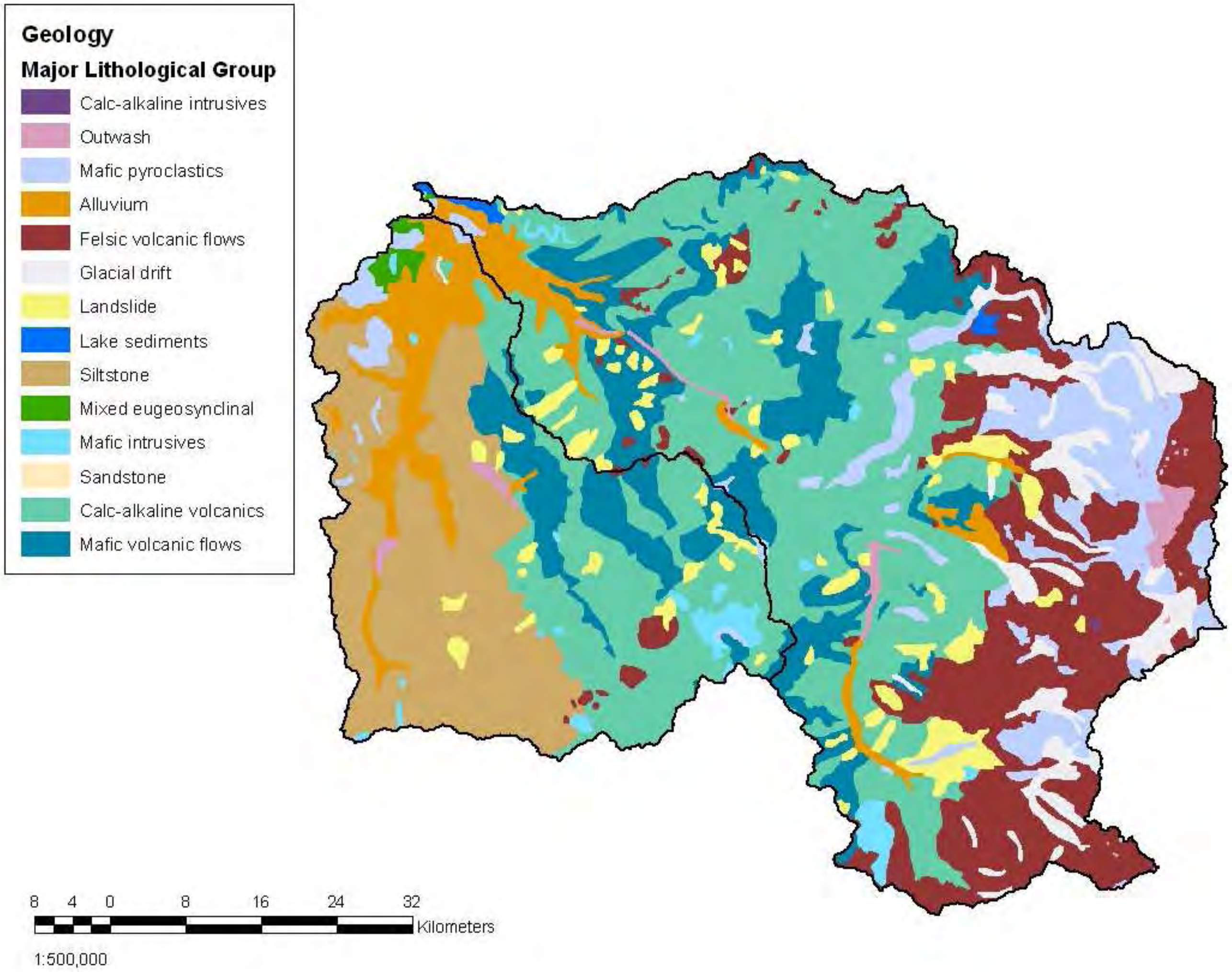


Figure 4. Coast and Middle Fork Geology (adapted from PNWERC 2002).

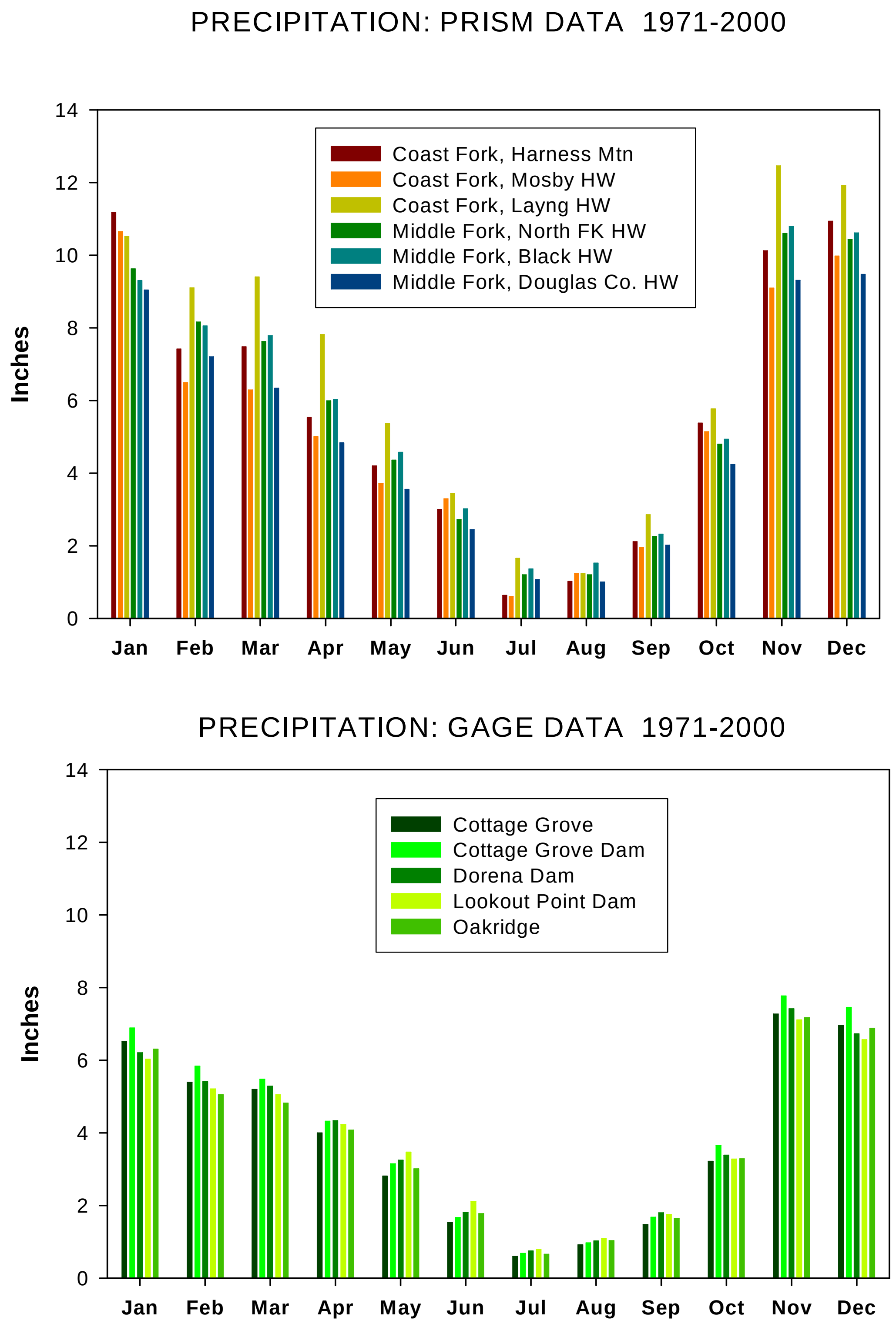


Figure 5a & b: Precipitation as rainfall. PRISM data (5a) are derived from a spatially explicit model. See http://www.ocs.oregonstate.edu/prism/index.phtml for more details. Gage data are shown in Figure 5b.

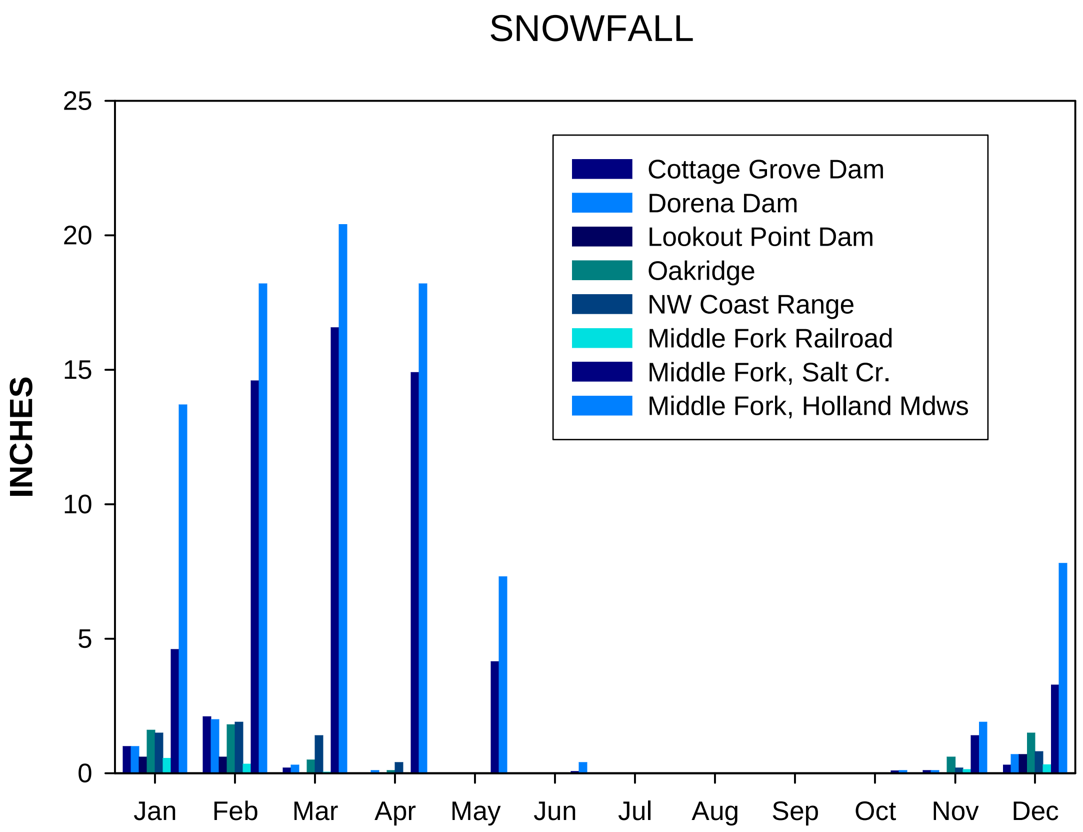


Figure 6: Precipitation as snowfall. The only snow gage (SNOTEL) site in the Coast Range is east of Portland: the Coast Fork mountains do not receive sufficient snow to warrant a SNOTEL. Elevations (in feet) of the SNOTEL sites are: NW Coast, 2000; Middle Fork Railroad, 2750; Middle Fork Salt Cr., 4000; Middle Fork Holland Meadows, 4900.

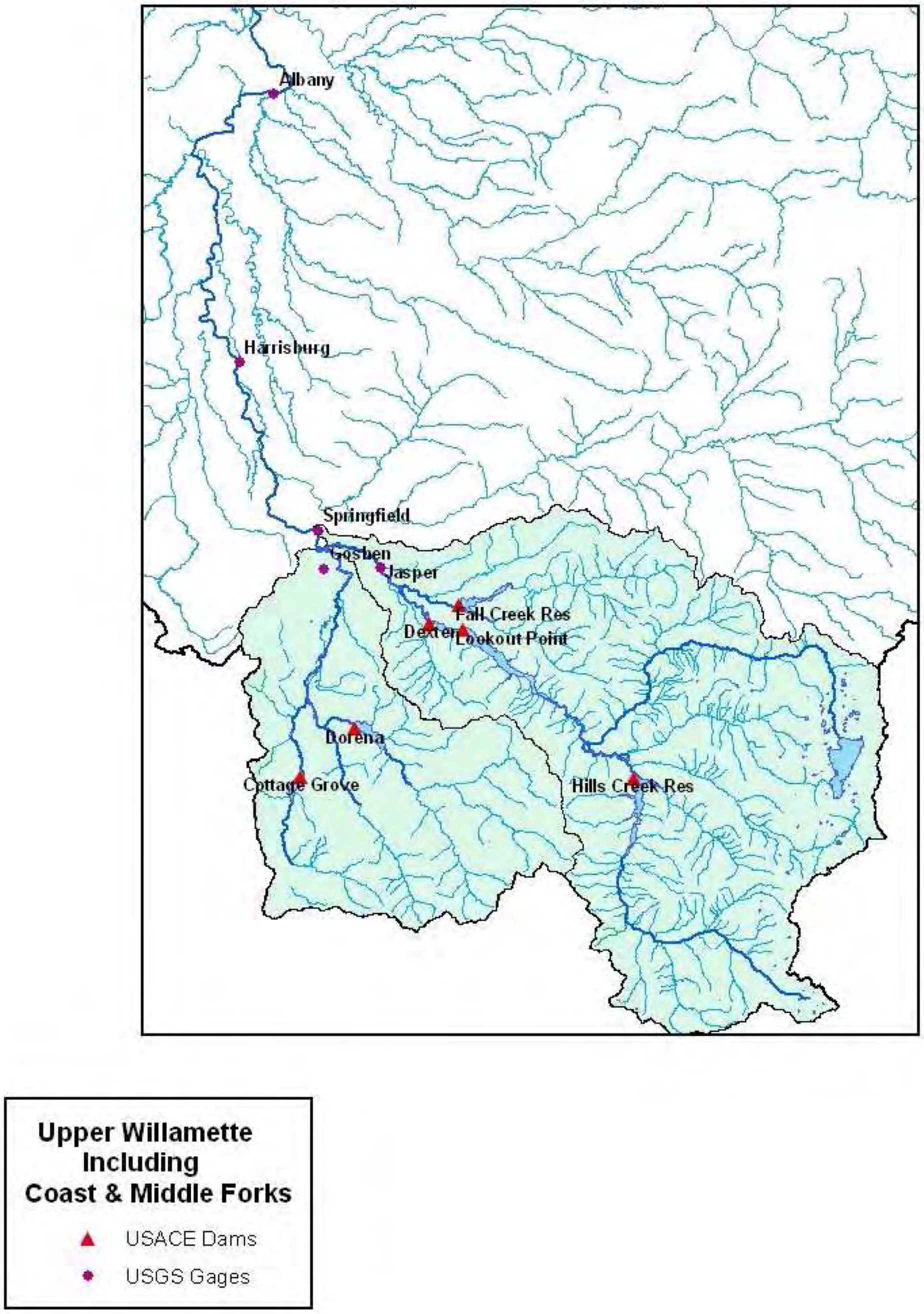


Figure 7. Coast and Middle Forks drainage network with locations of USACE dams and USGS gages used in this report.

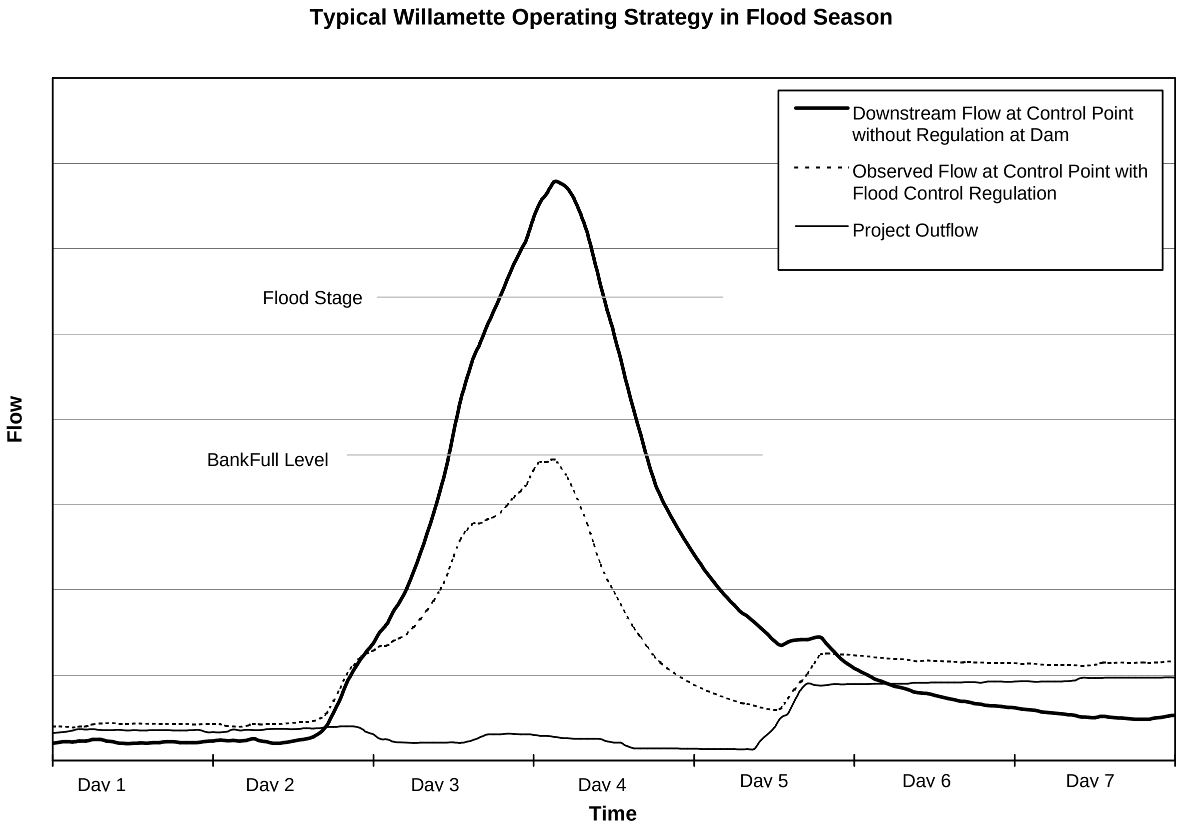
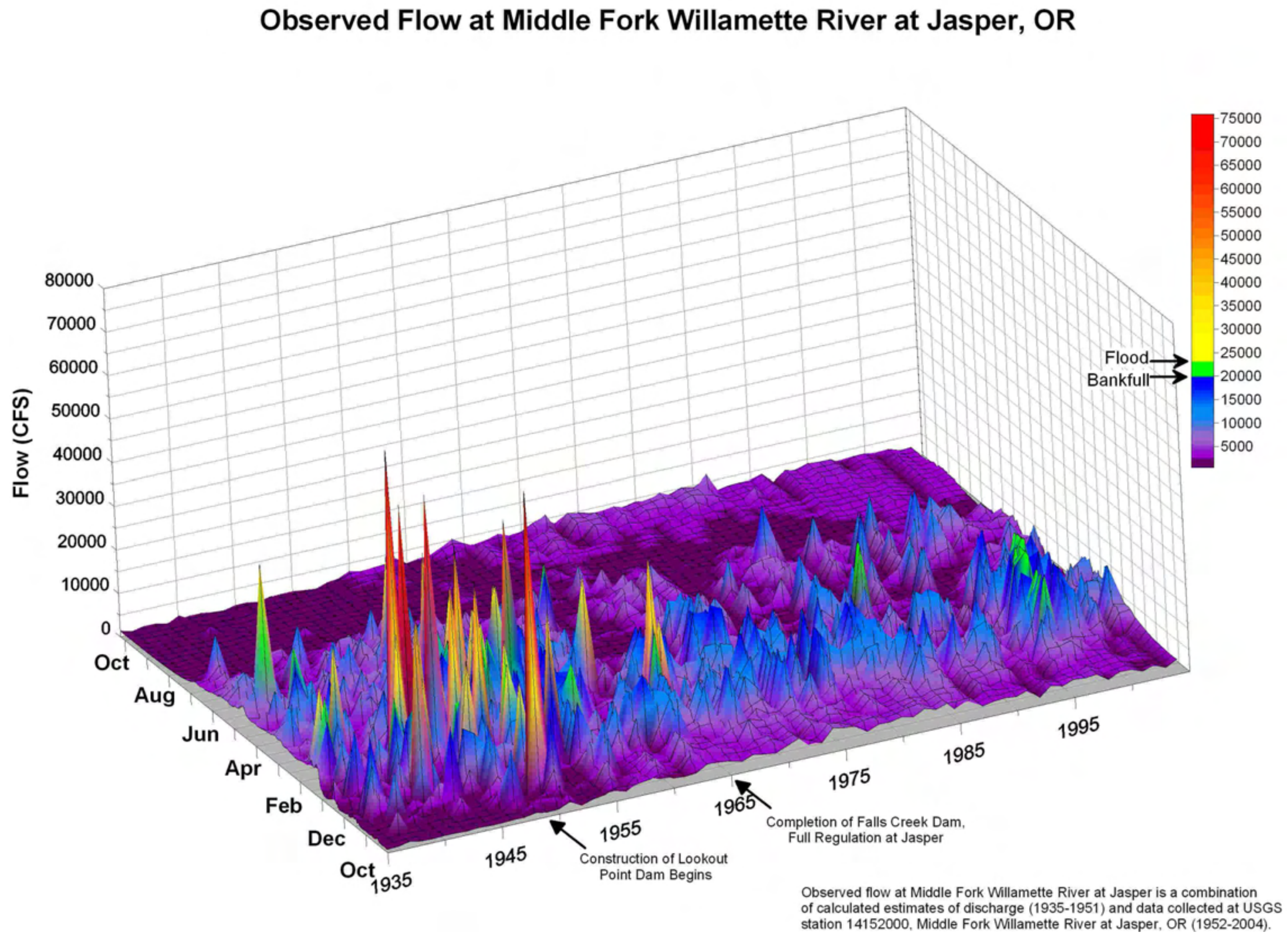


Figure 8. Typical dam operation for flood control in the Willamette Basin (USACE 2000).

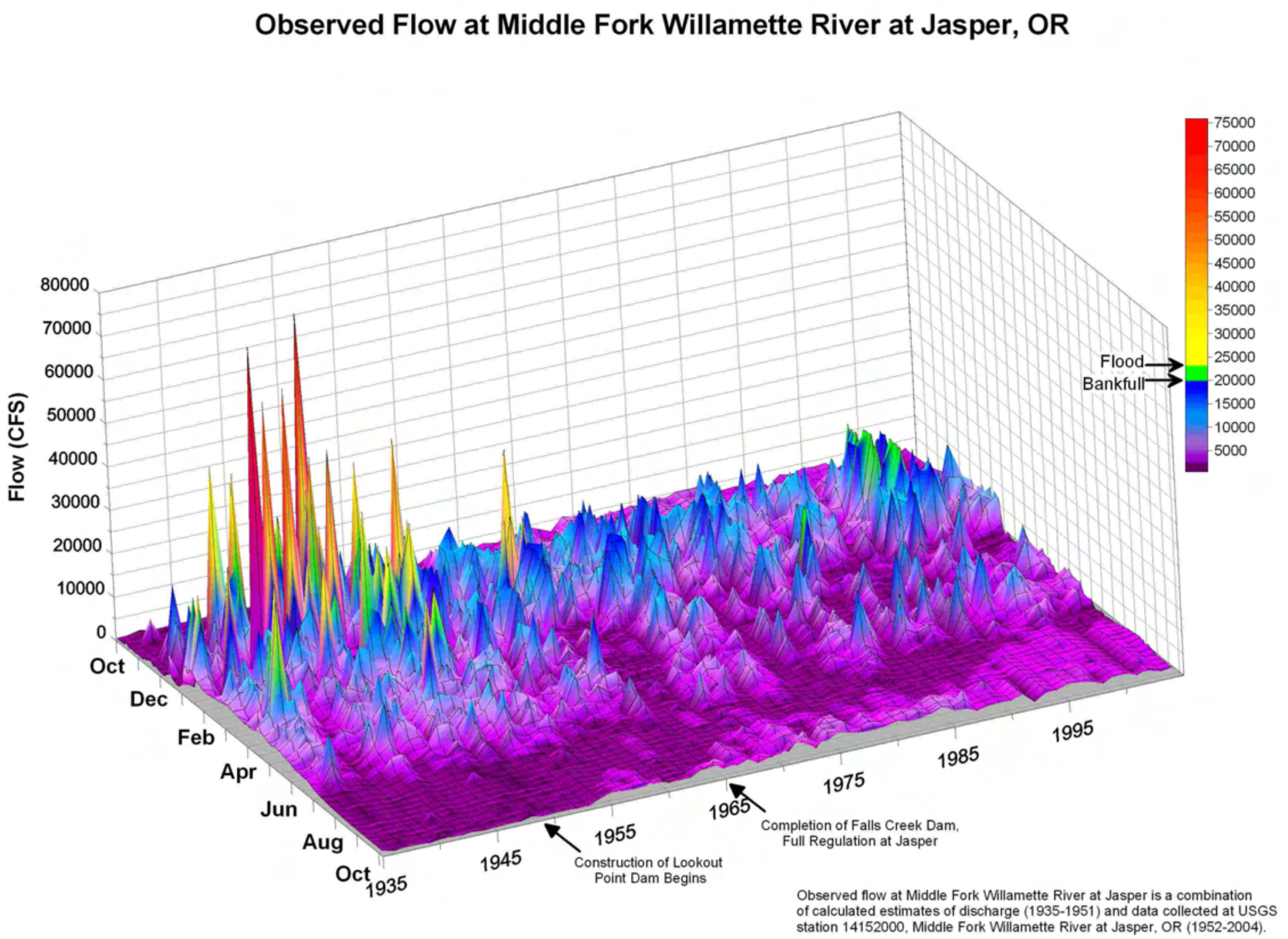

Observed Flow at Middle Fork Willamette River at Jasper, OR

Construction of Lookout Point Dam Begins

Completion of Falls Creek Dam, Full Regulation at Jasper

Observed flow at Middle Fork Willamette River at Jasper is a combination of calculated estimates of discharge (1935-1951) and data collected at USGS station 14152000, Middle Fork Willamette River at Jasper, OR (1952-2004).

Figure 9. Observed flows at the Jasper gage, Middle Fork Willamette River, 1936 – 2004. Months run from right to left to highlight peak flows. Figure prepared by Chris Nygaard, USACE, Portland, OR.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Construction of Lookout Point Dam Begins

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Observed flow at Middle Fork Willamette River at Jasper is a combination of calculated estimates of discharge (1935-1951) and data collected at USGS station 14152000, Middle Fork Willamette River at Jasper, OR (1952-2004).

Figure 10. Observed flows at the Jasper gage, Middle Fork Willamette River, 1936 – 2004. Months run from left to right to highlight summer low flows. Figure prepared by Chris Nygaard, USACE, Portland, OR.

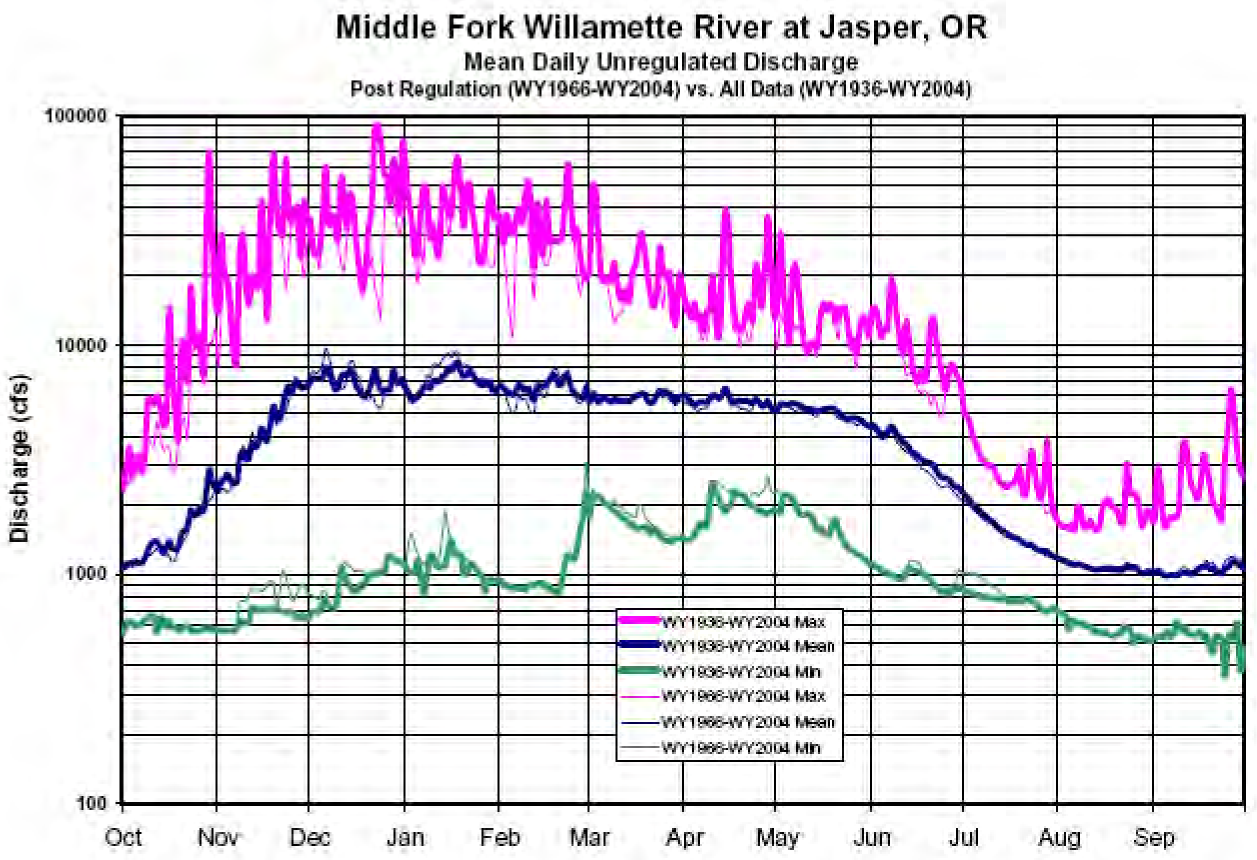


Figure 11. Mean daily discharges (maxima, minima and averages) at the Jasper gage, Middle Fork Willamette River for entire period of record (thick bars, 1936-2004) vs. post-dam completion (thinner bars, 1966-2004). Figure prepared by Chris Nygaard, USACE, Portland, OR.

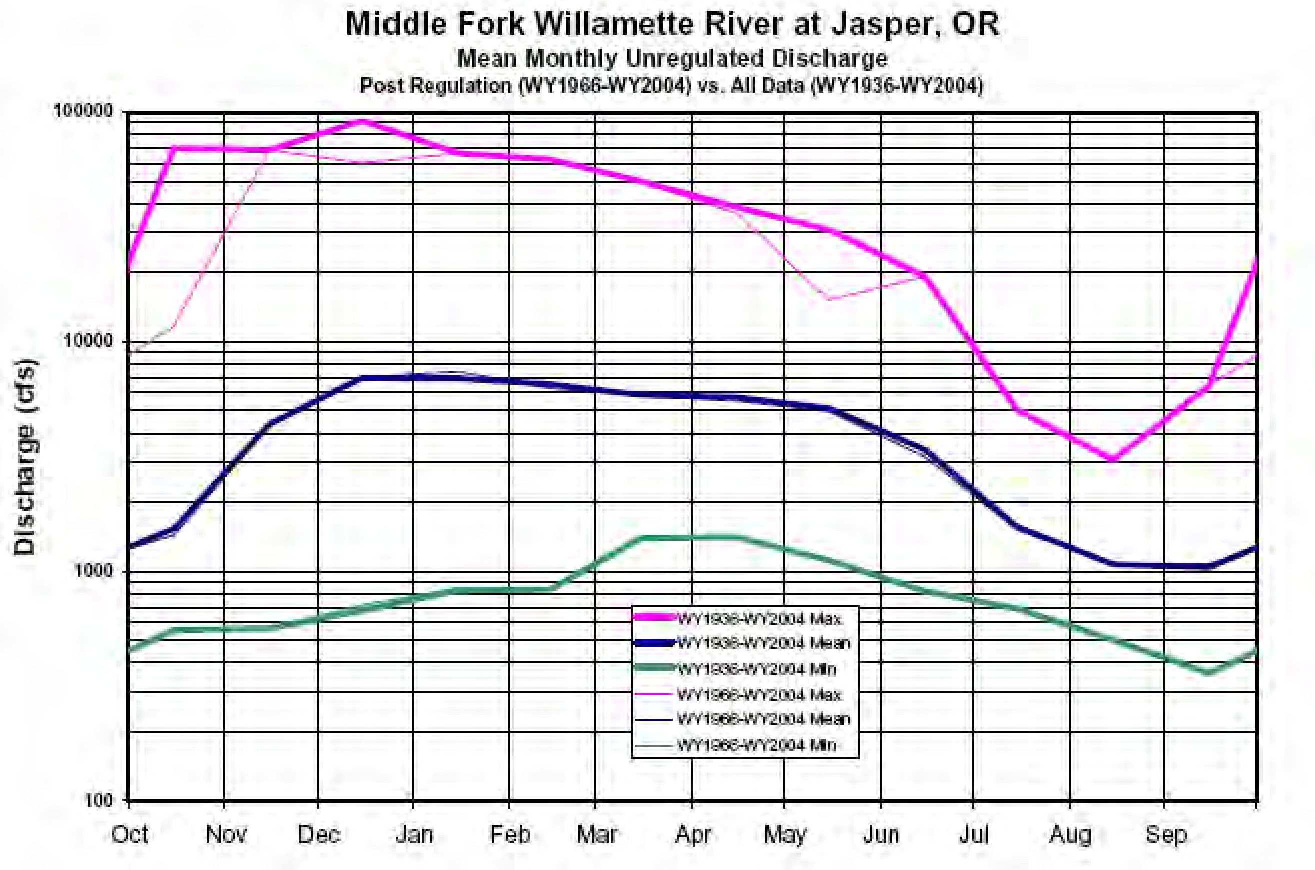


Figure 12. Mean monthly discharges (maxima, minima and averages) at the Jasper gage, Middle Fork Willamette River for entire period of record (thick bars, 1936-2004) vs. post-dam completion (thinner bars, 1966-2004). Figure prepared by Chris Nygaard, USACE, Portland, OR.

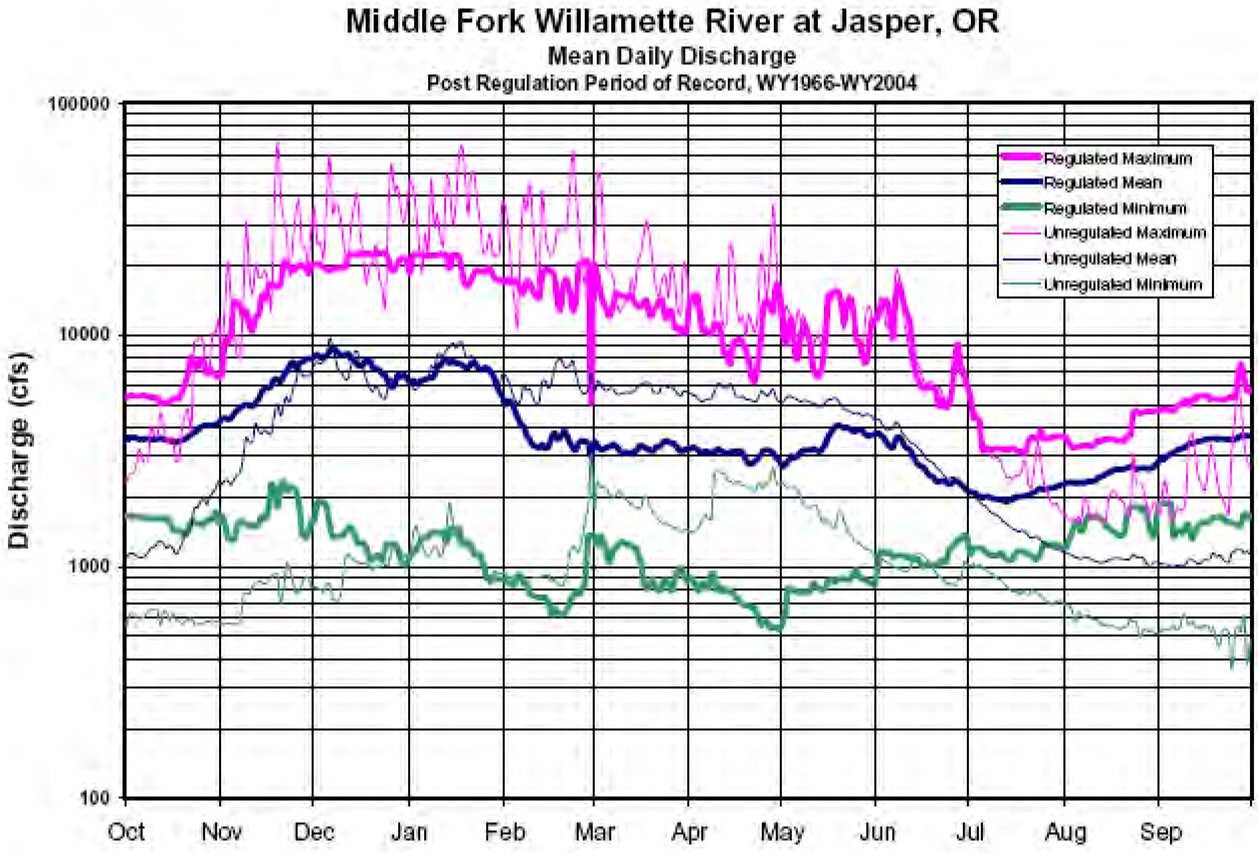


Figure 13. Mean daily discharges (maxima, minima and averages) at the Jasper gage, Middle Fork Willamette River for period of post-dam completion (1966-2004). Regulated flows are those observed at the gage; unregulated flows are derived from USACE models. Figure prepared by Chris Nygaard, USACE, Portland, OR.

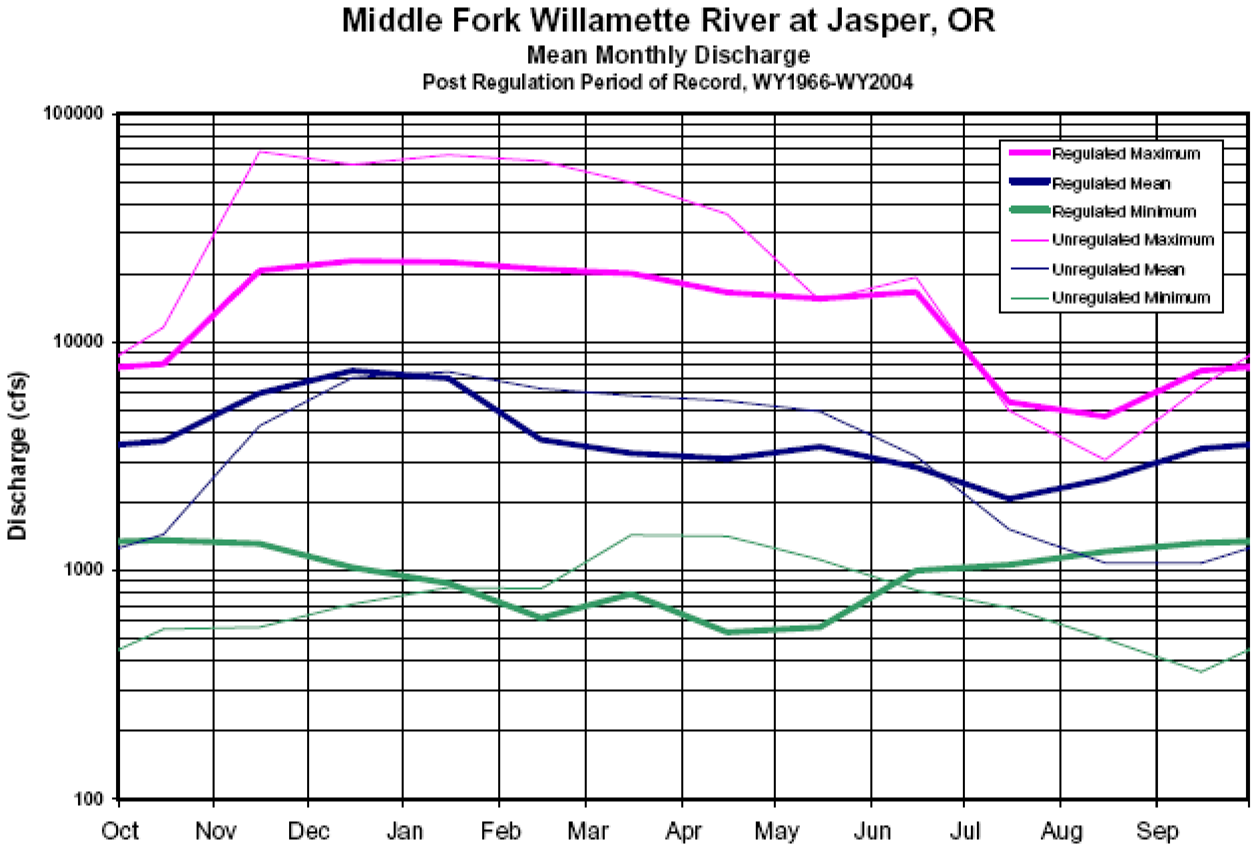


Figure 14. Mean monthly discharges (maxima, minima and averages) at the Jasper gage, Middle Fork Willamette River for period of post-dam completion (1966-2004). Regulated flows are those observed at the gage; unregulated flows are derived from USACE models. Figure prepared by Chris Nygaard, USACE, Portland, OR.

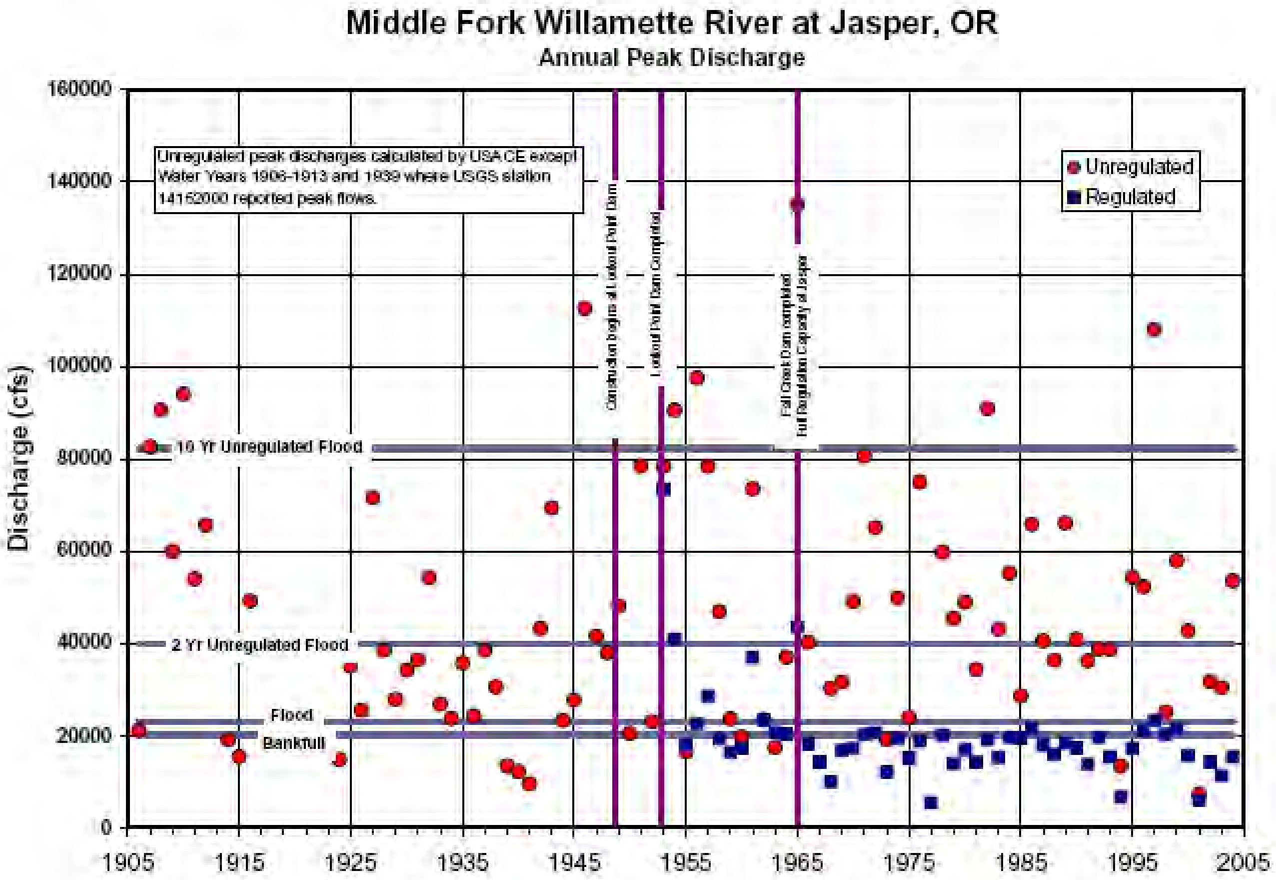
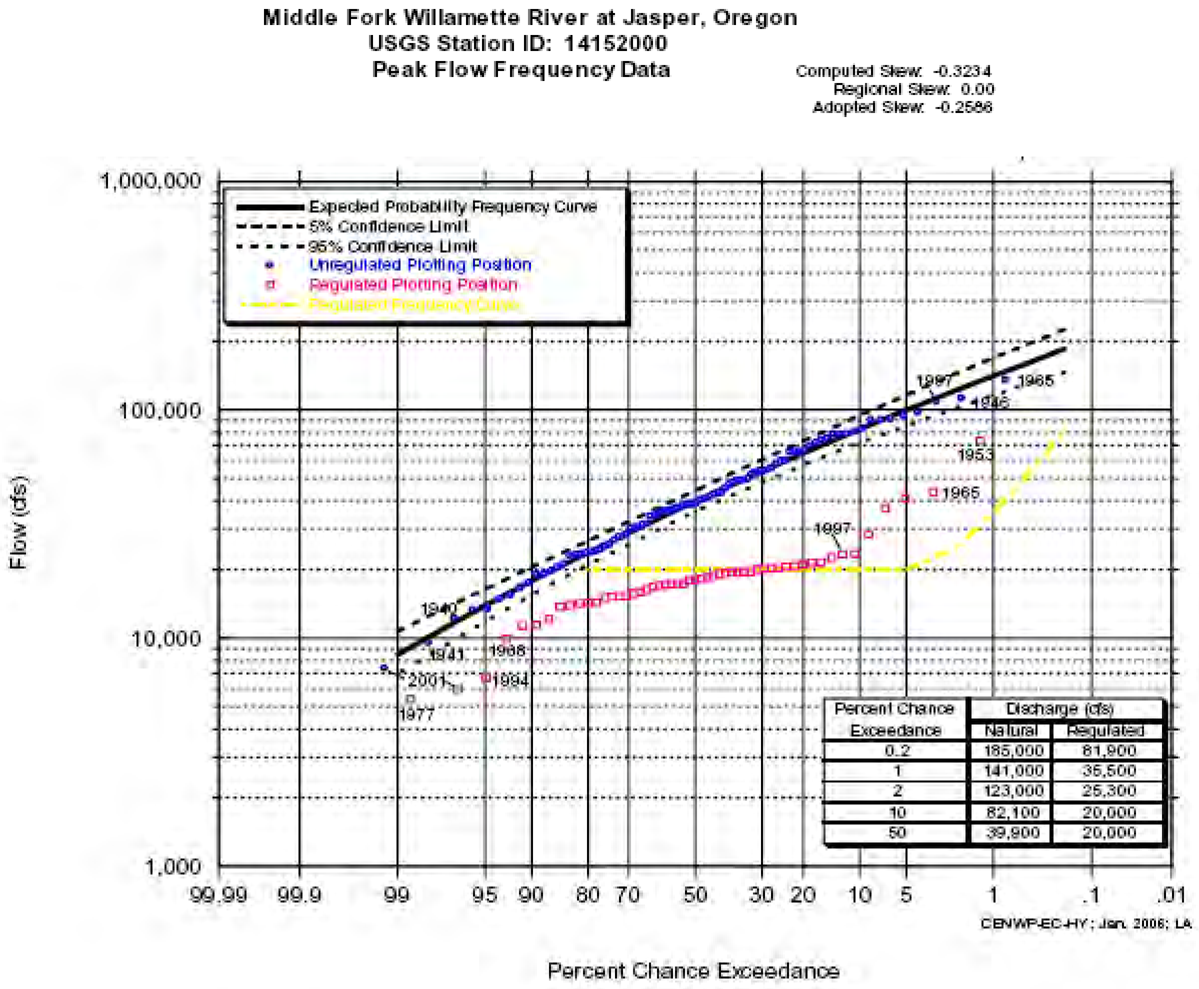
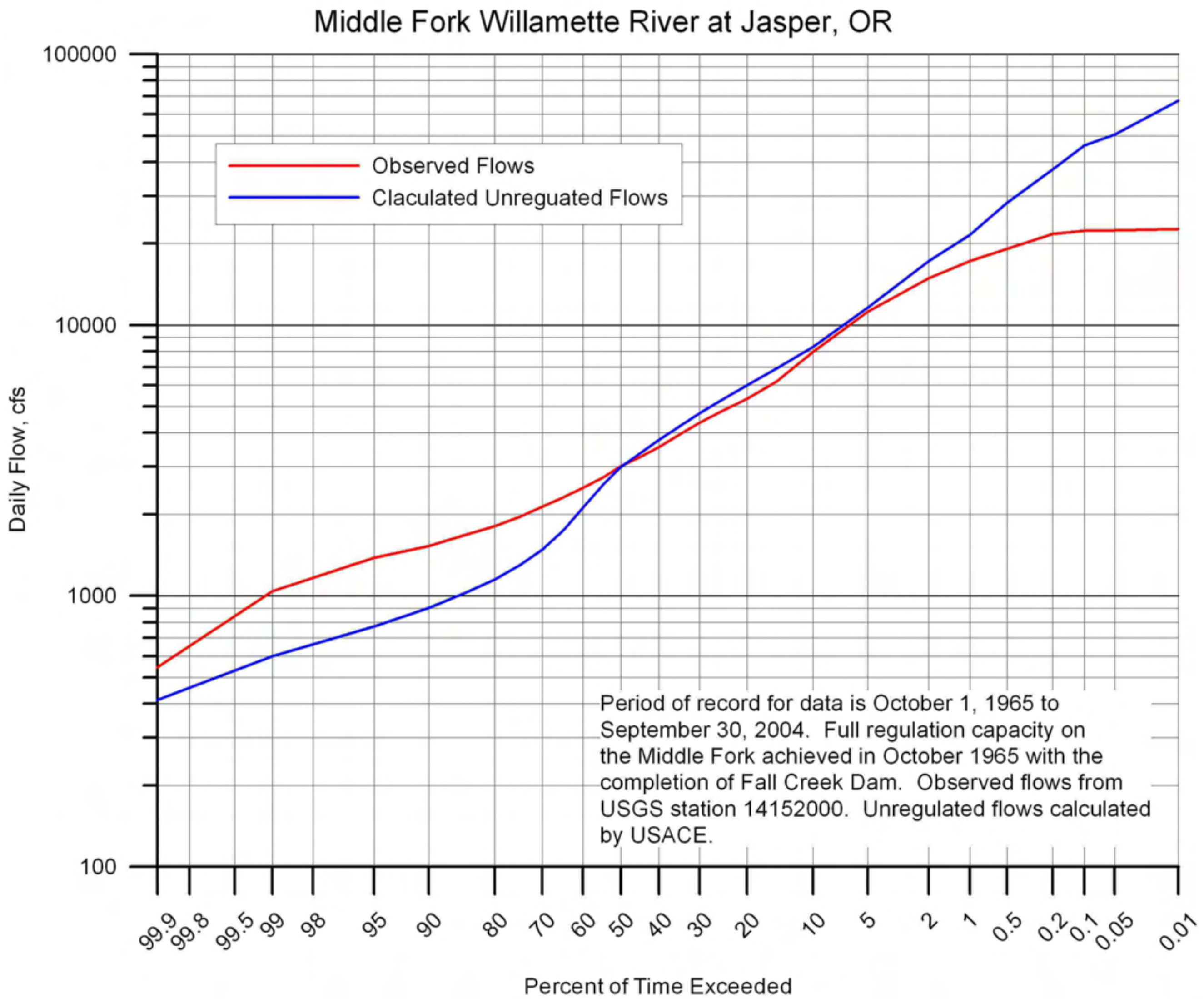


Figure 15. Annual peak discharges at the Jasper gage, Middle Fork of the Willamette River. Blue bars indicate the four environmental flow levels. Figure prepared by Chris Nygaard, USACE, Portland, OR.



Percent Chance Exceedance	Discharge (cfs)	
	Natural	Regulated
0.2	185,000	81,900
1	141,000	35,500
2	123,000	25,300
10	82,100	20,000
50	39,900	20,000

Figure 16. Draft flood frequency (exceedance curves) for the Middle Fork Willamette River at Jasper. Flood frequency data are preliminary and have not received final approval. Subsequent review may result in significant revisions to the data. Figure prepared by Chris Nygaard, USACE, Portland, OR.



Period of record for data is October 1, 1965 to September 30, 2004. Full regulation capacity on the Middle Fork achieved in October 1965 with the completion of Fall Creek Dam. Observed flows from USGS station 14152000. Unregulated flows calculated by USACE.

Figure 17. Flow duration curve for the Middle Fork Willamette River at Jasper. Figure prepared by Chris Nygaard, USACE, Portland, OR.

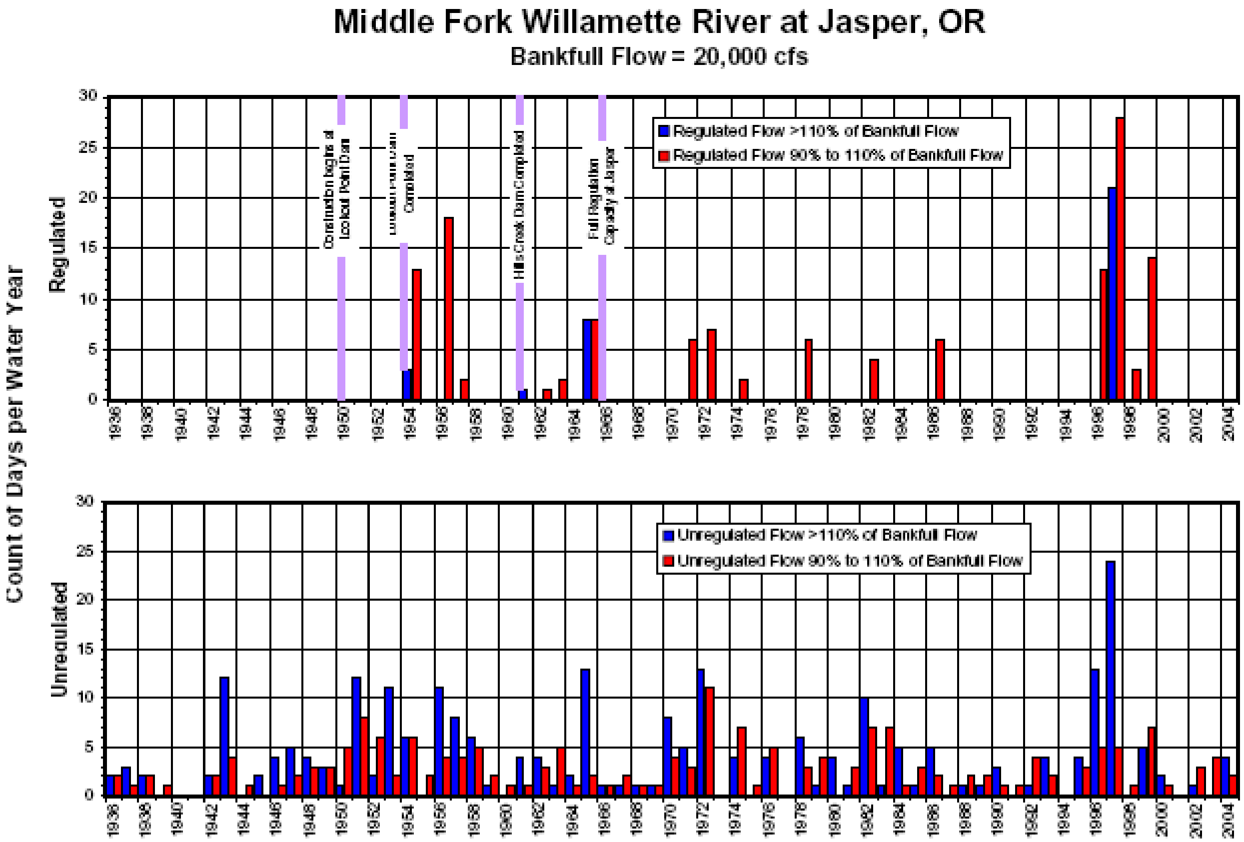


Figure 18. Number of days discharges are at bankfull levels for the Middle Fork of the Willamette River at Jasper. Comparison of regulated and unregulated flows by water year. Figure prepared by Chris Nygaard, USACE, Portland, OR.

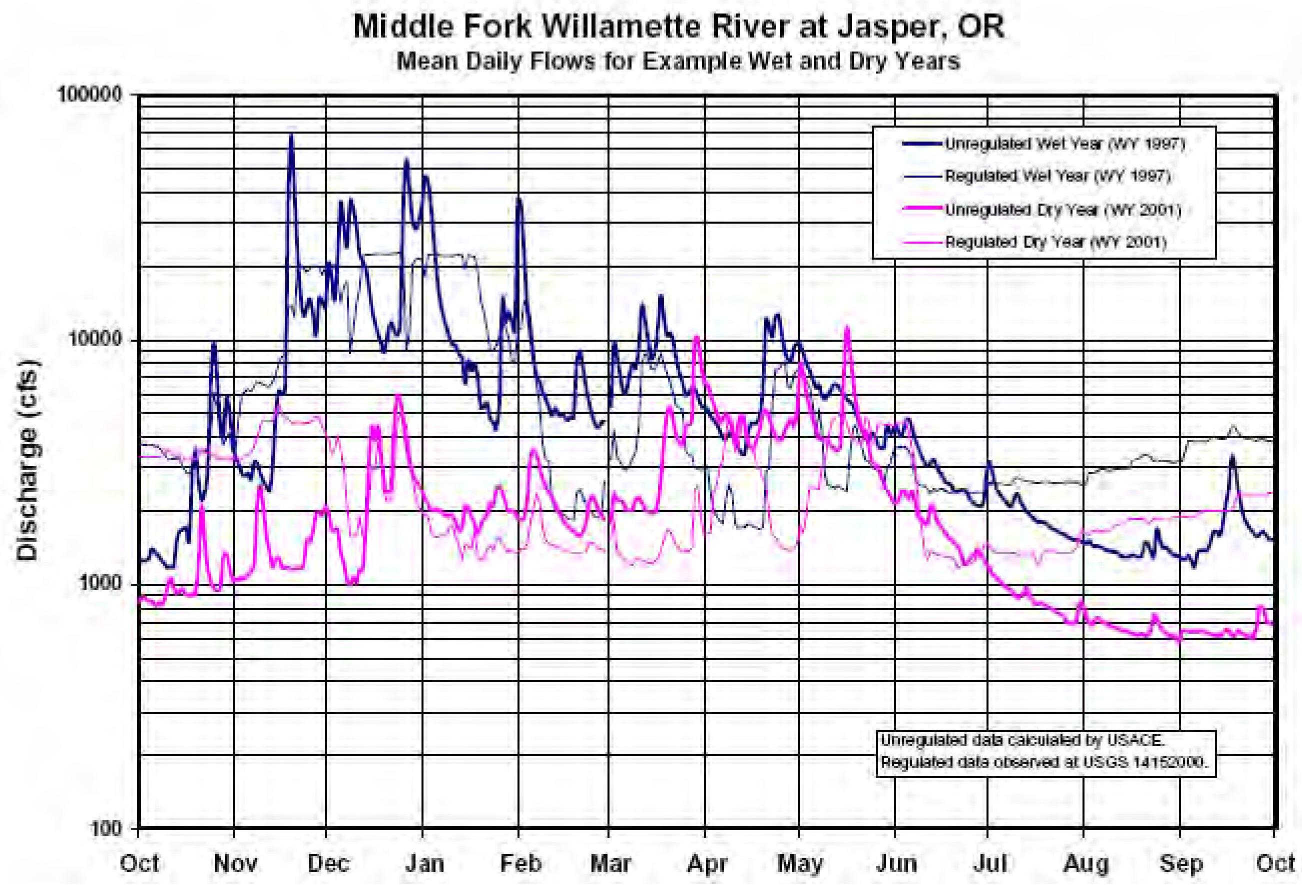


Figure 19. Mean daily flows for exemplar wet (1997) and dry (2001) water years under regulated and unregulated conditions for the Middle Fork of the Willamette River at Jasper. Figure prepared by Chris Nygaard, USACE, Portland, OR.

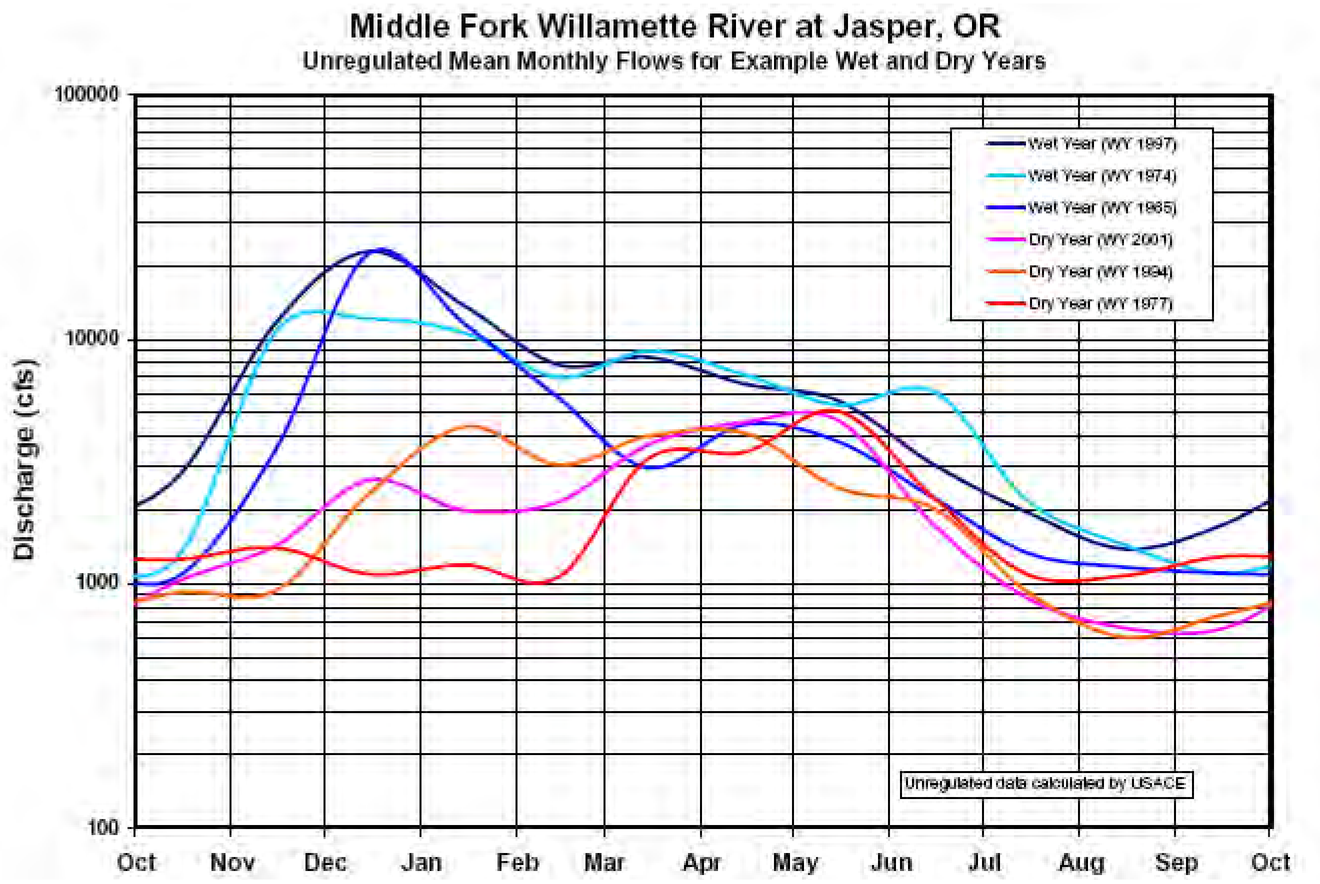
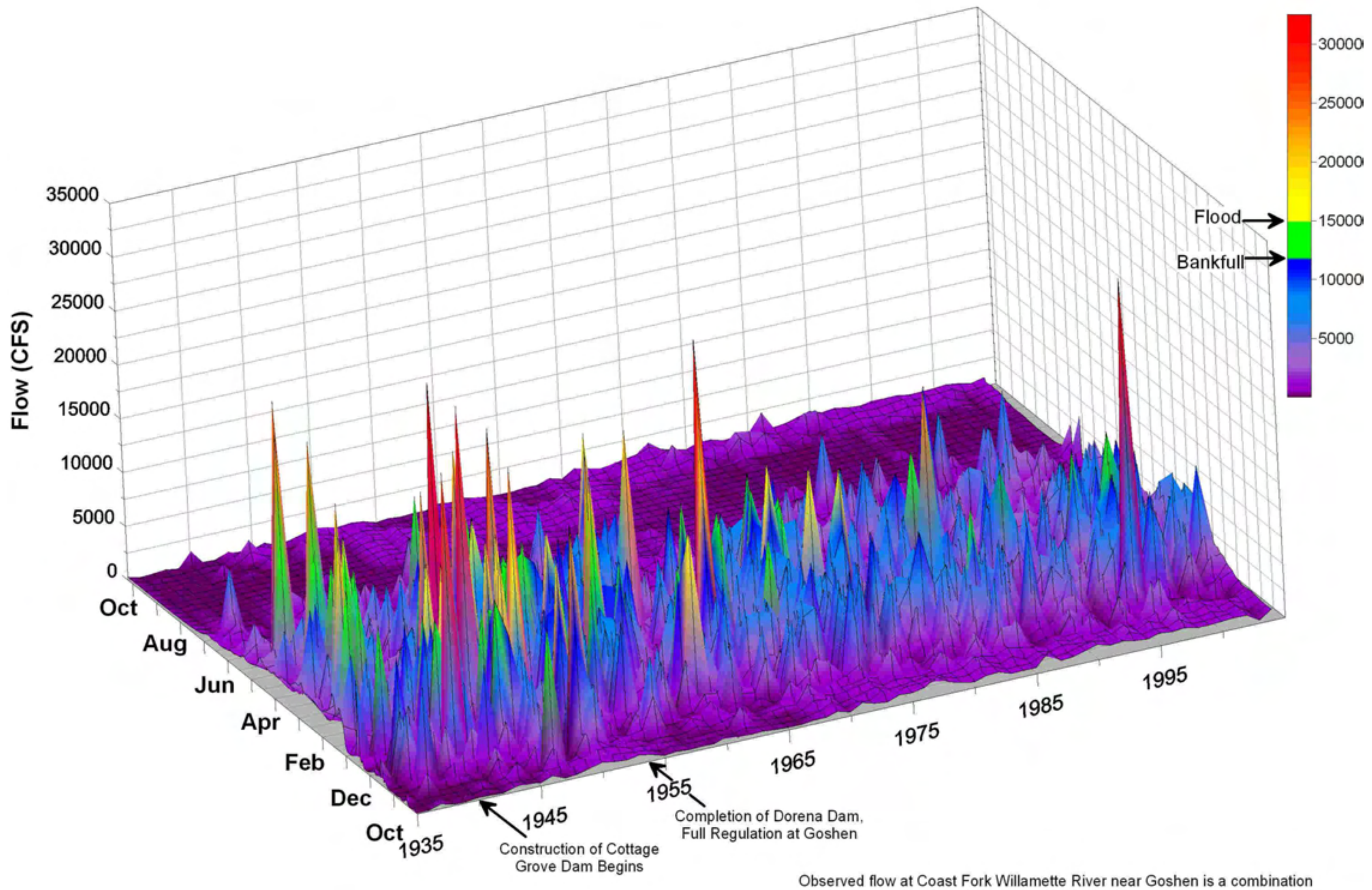


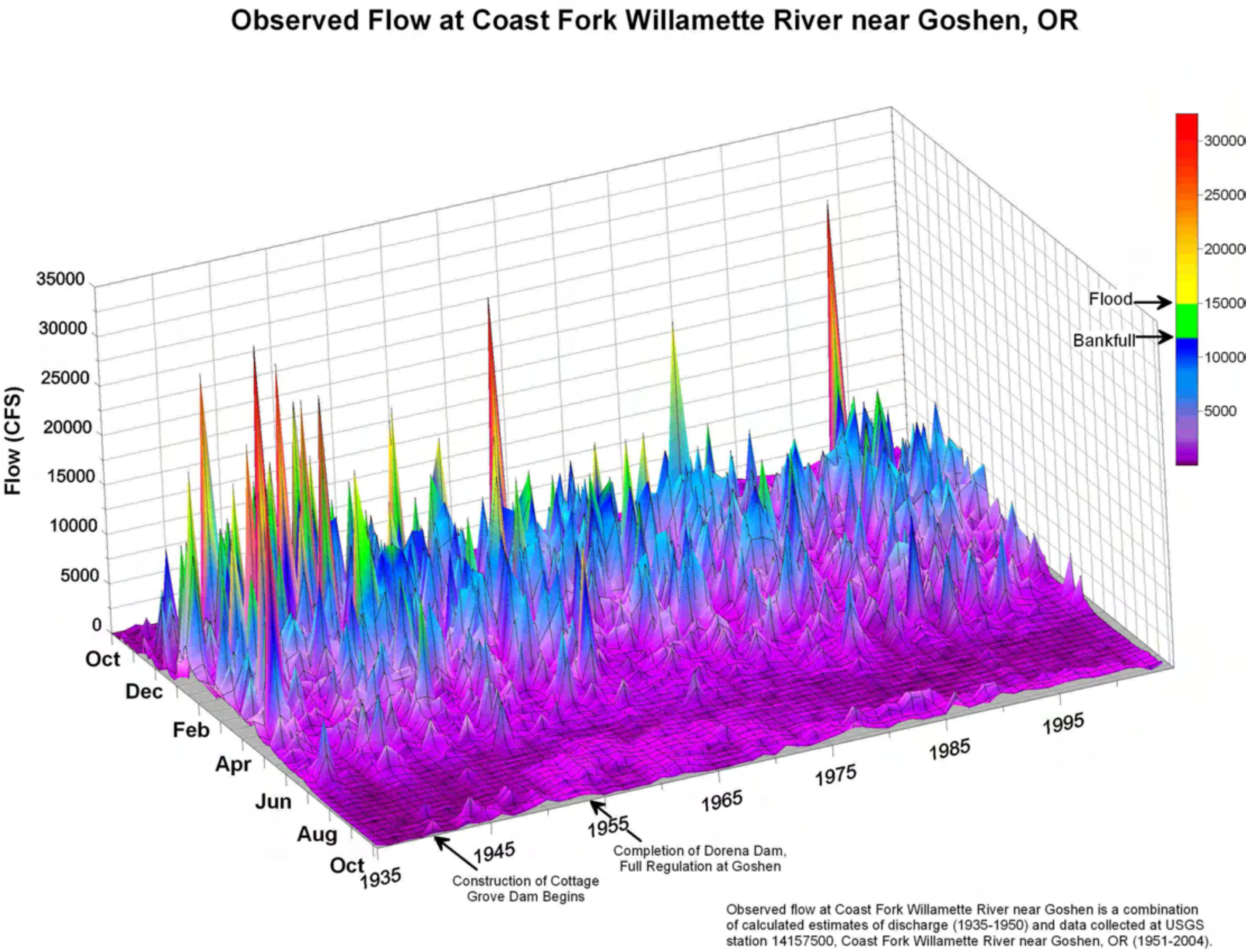
Figure 20. Mean monthly flows for exemplar wet (1997, 1974, and 1965) and dry (2001, 1994 and 1977) water years under unregulated conditions for the Middle Fork of the Willamette River at Jasper. Figure prepared by Chris Nygaard, USACE, Portland, OR.

Observed Flow at Coast Fork Willamette River near Goshen, OR



Observed flow at Coast Fork Willamette River near Goshen is a combination of calculated estimates of discharge (1935-1950) and data collected at USGS station 14157500, Coast Fork Willamette River near Goshen, OR (1951-2004).

Figure 21. Observed flows at the Goshen Gage, Coast Fork Willamette River, 1935 – 2004. Months run from right to left to highlight peak flows. Figure prepared by Chris Nygaard, USACE, Portland, OR.



Observed flow at Coast Fork Willamette River near Goshen is a combination of calculated estimates of discharge (1935-1950) and data collected at USGS station 14157500, Coast Fork Willamette River near Goshen, OR (1951-2004).

Figure 22. Observed flows at the Goshen Gage, Coast Fork Willamette River, 1935 – 2004. Months run from left to right to highlight summer low flows. Figure prepared by Chris Nygaard, USACE, Portland, OR.

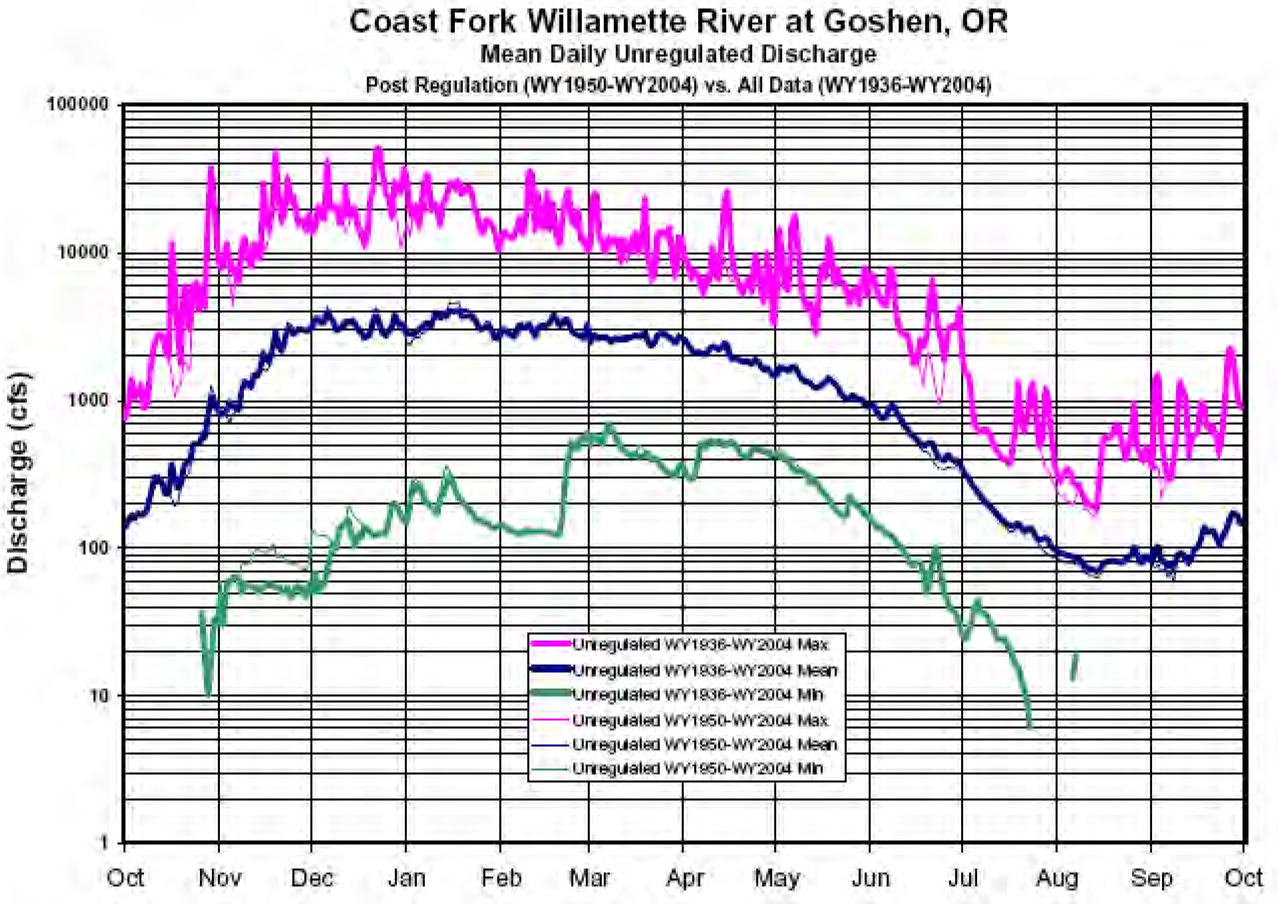


Figure 23. Mean daily discharges (maxima, minima and averages) at the Goshen gage, Coast Fork Willamette River for entire period of record (thick bars, 1936-2004) vs. post-dam completion (thinner bars, 1950-2004). Figure prepared by Chris Nygaard, USACE, Portland, OR.

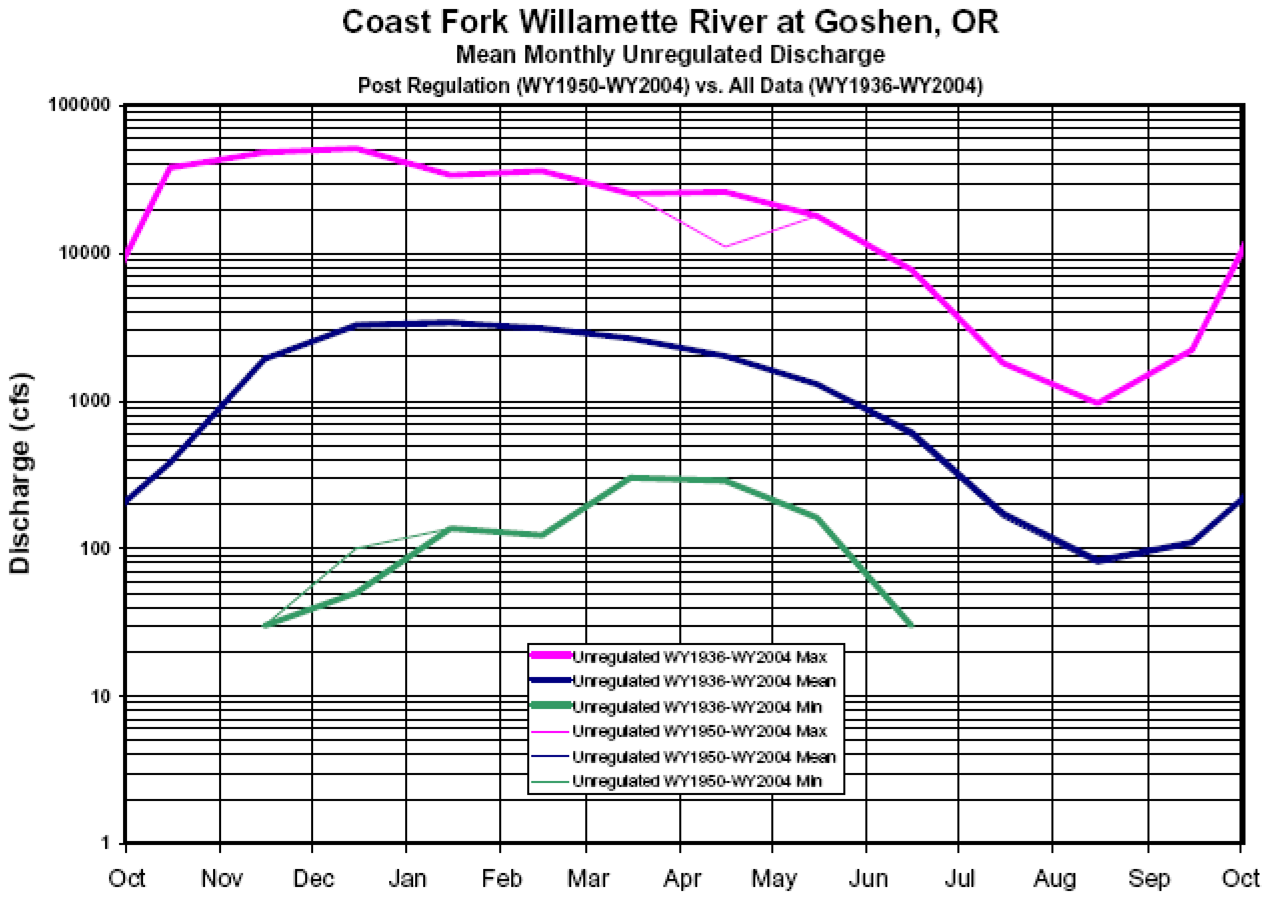


Figure 24. Mean monthly discharges (maxima, minima and averages) at the Goshen gage, Coast Fork Willamette River for entire period of record (thick bars, 1936-2004) vs. post-dam completion (thinner bars, 1950-2004). Figure prepared by Chris Nygaard, USACE, Portland, OR.

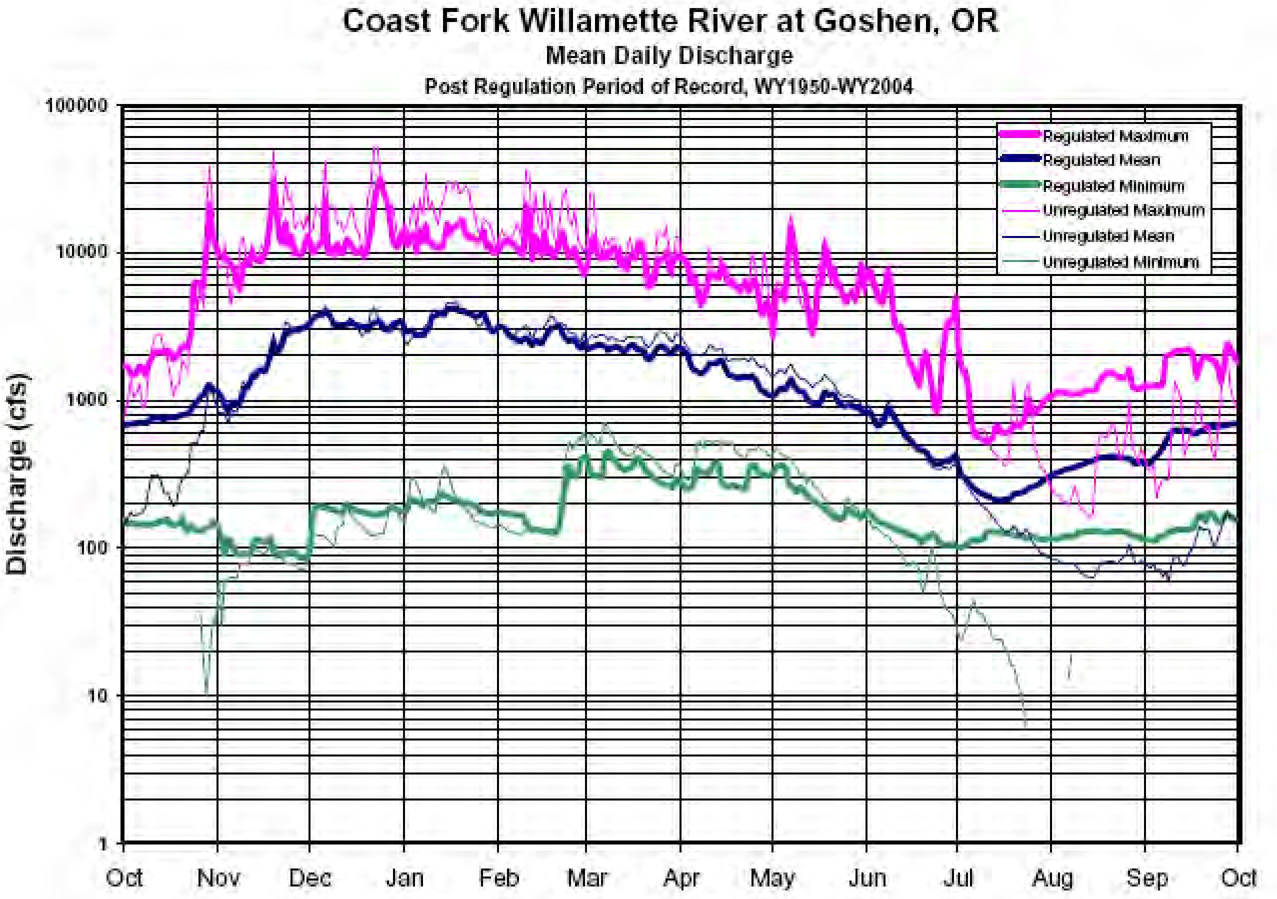


Figure 25. Mean daily discharges (maxima, minima and averages) at the Goshen gage, Coast Fork Willamette River for period of post-dam completion (1950-2004). Regulated flows are those observed at the gage; unregulated flows are derived from USACE models. Figure prepared by Chris Nygaard, USACE, Portland, OR.

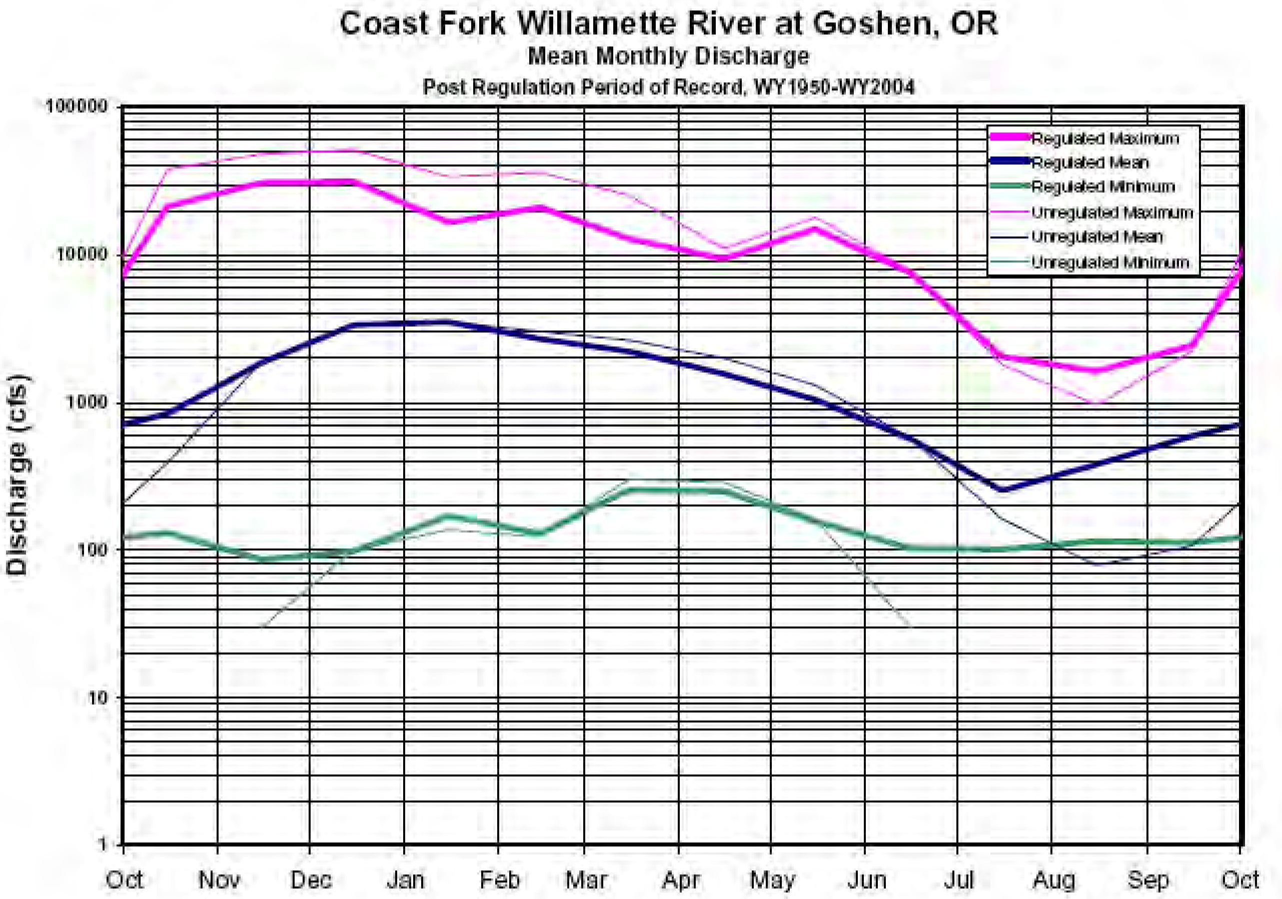


Figure 26. Mean monthly discharges (maxima, minima and averages) at the Goshen gage, Coast Fork Willamette River for period of post-dam completion (1950-2004). Regulated flows are those observed at the gage; unregulated flows are derived from USACE models. Figure prepared by Chris Nygaard, USACE, Portland, OR.

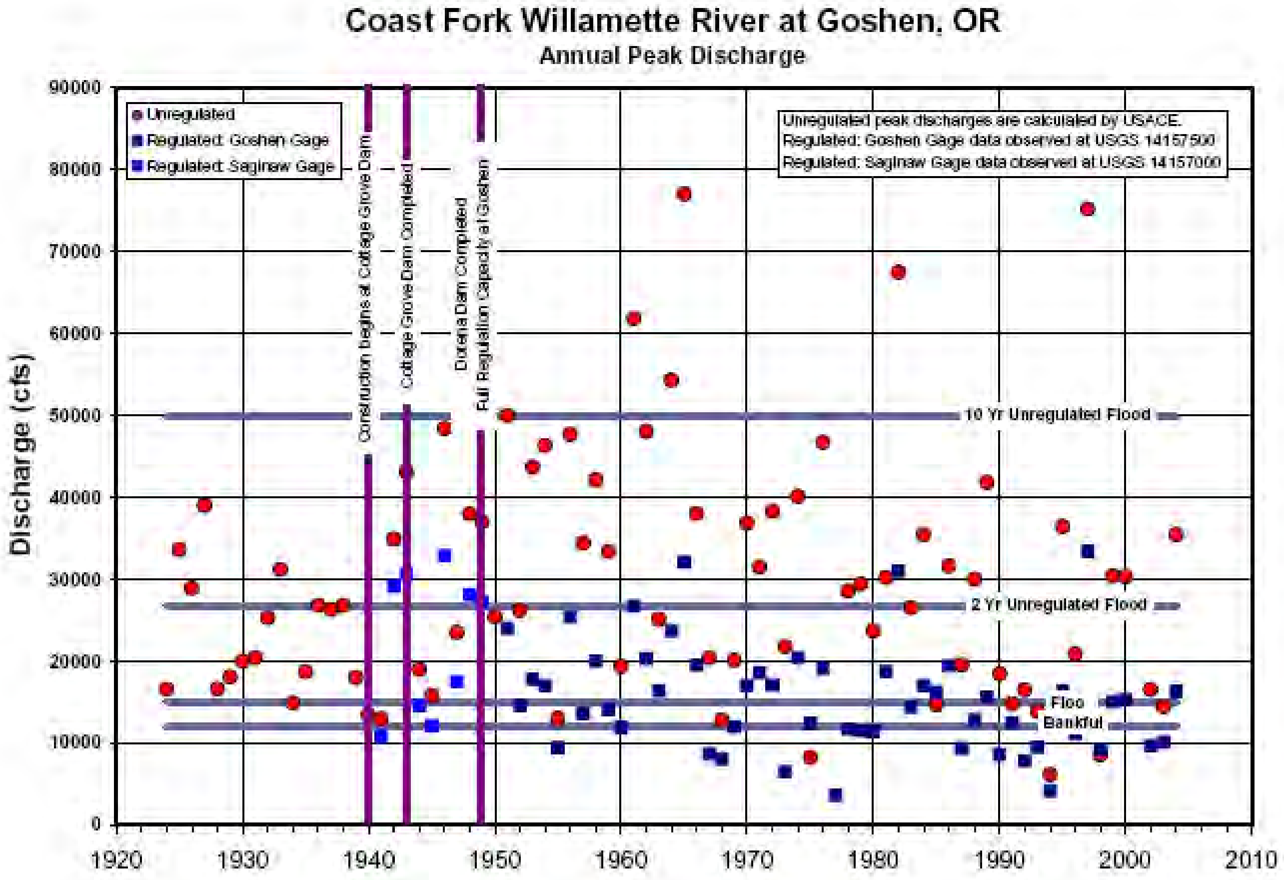
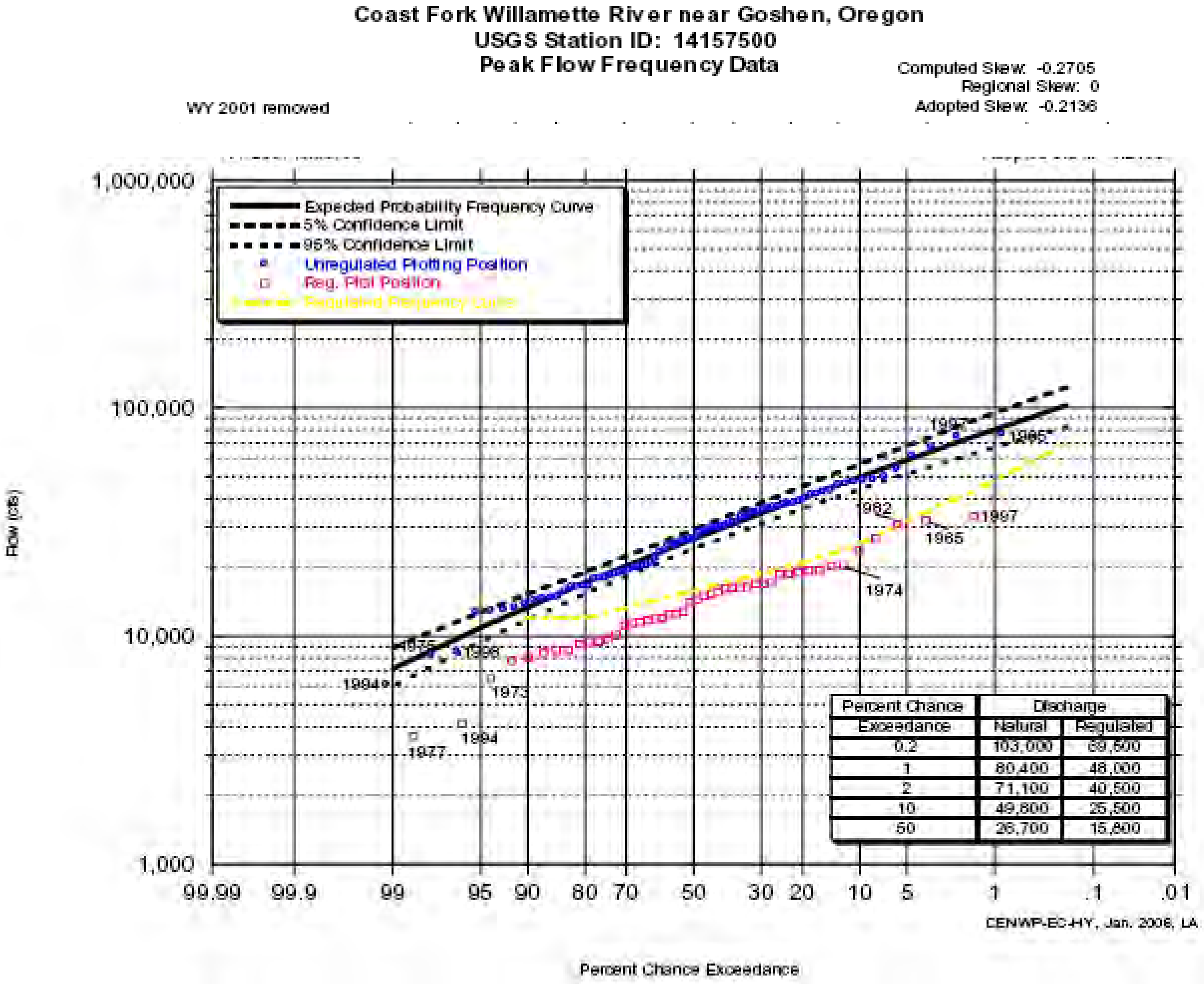


Figure 27. Annual peak discharges at the Goshen gage, Coast Fork of the Willamette River. Blue bars indicate the four environmental flow levels. Figure prepared by Chris Nygaard, USACE, Portland, OR.



Percent Chance	Discharge	
Exceedance	Natural	Regulated
0.2	103,000	69,600
1	80,400	48,000
2	71,100	40,500
10	49,800	25,500
50	26,700	15,800

Figure 28. Draft flood frequency (exceedance curves) for the Coast Fork Willamette River at Goshen. Flood frequency data are preliminary and have not received final approval. Subsequent review may result in significant revisions to the data. Figure prepared by Chris Nygaard, USACE, Portland, OR.

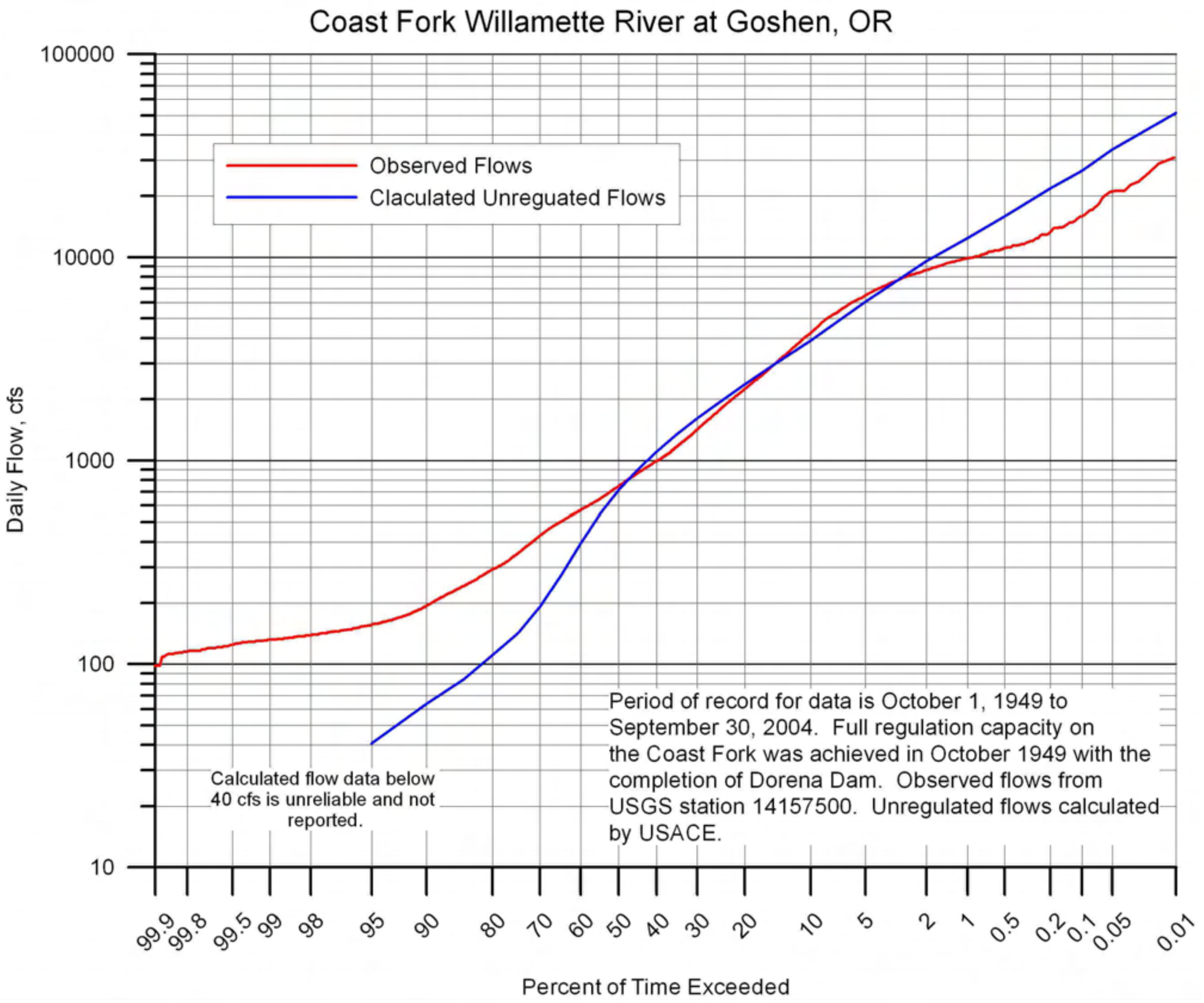


Figure 29. Flow duration curve for the Coast Fork Willamette River at Goshen. Figure prepared by Chris Nygaard, USACE, Portland, OR.

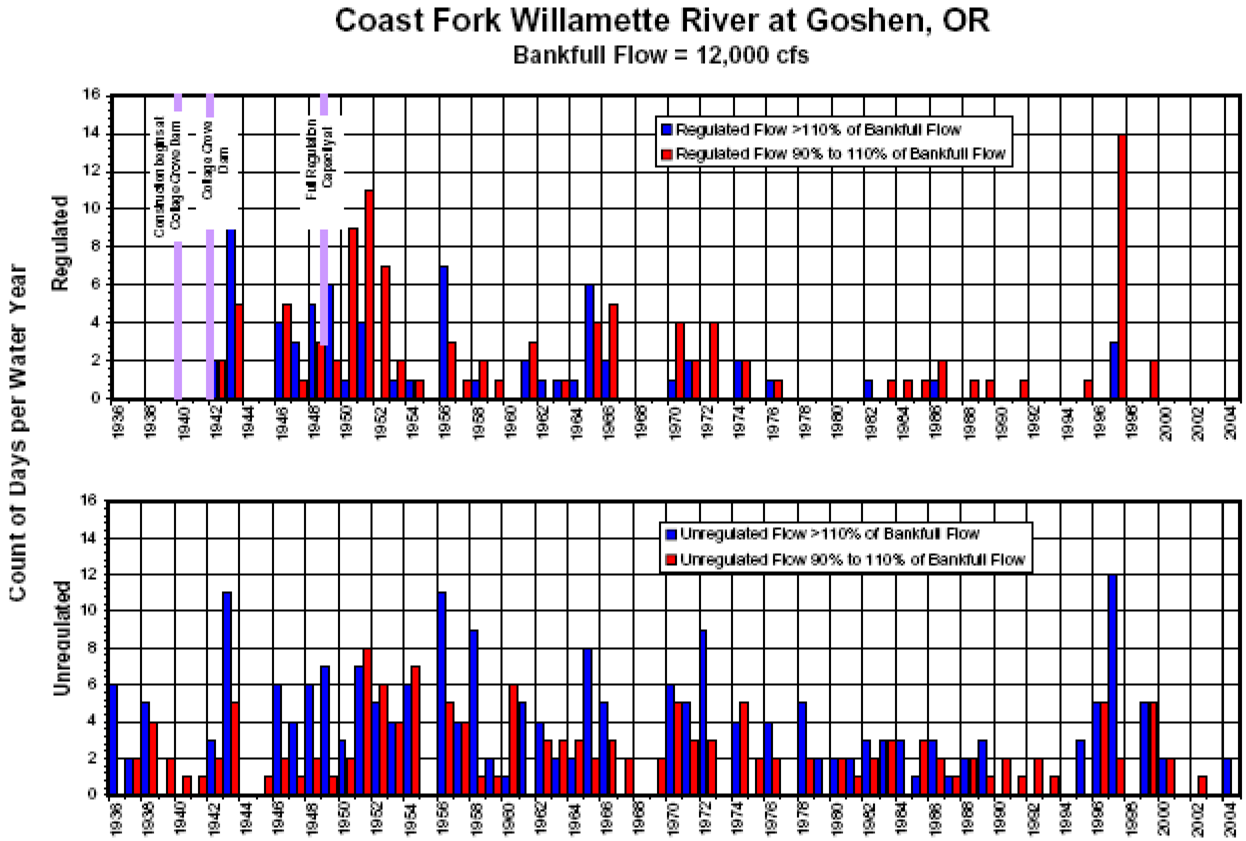


Figure 30. Number of days discharges are at bankfull levels for the Coast Fork of the Willamette River at Goshen. Comparison of regulated and unregulated flows by water year. Figure prepared by Chris Nygaard, USACE, Portland, OR.

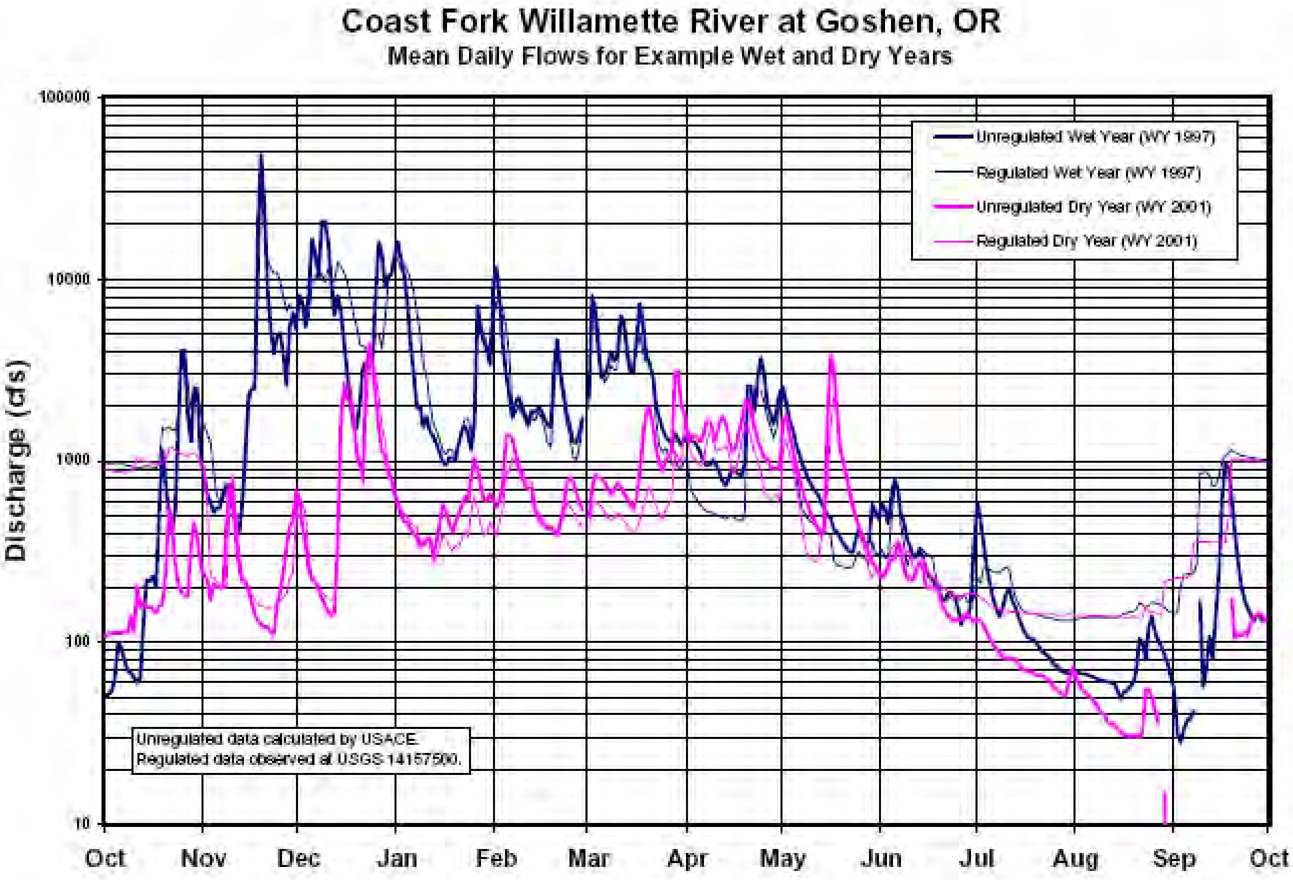


Figure 31. Mean daily flows for exemplar wet (1997) and dry (2001) water years under regulated and unregulated conditions for the Coast Fork of the Willamette River at Goshen. Figure prepared by Chris Nygaard, USACE, Portland, OR.

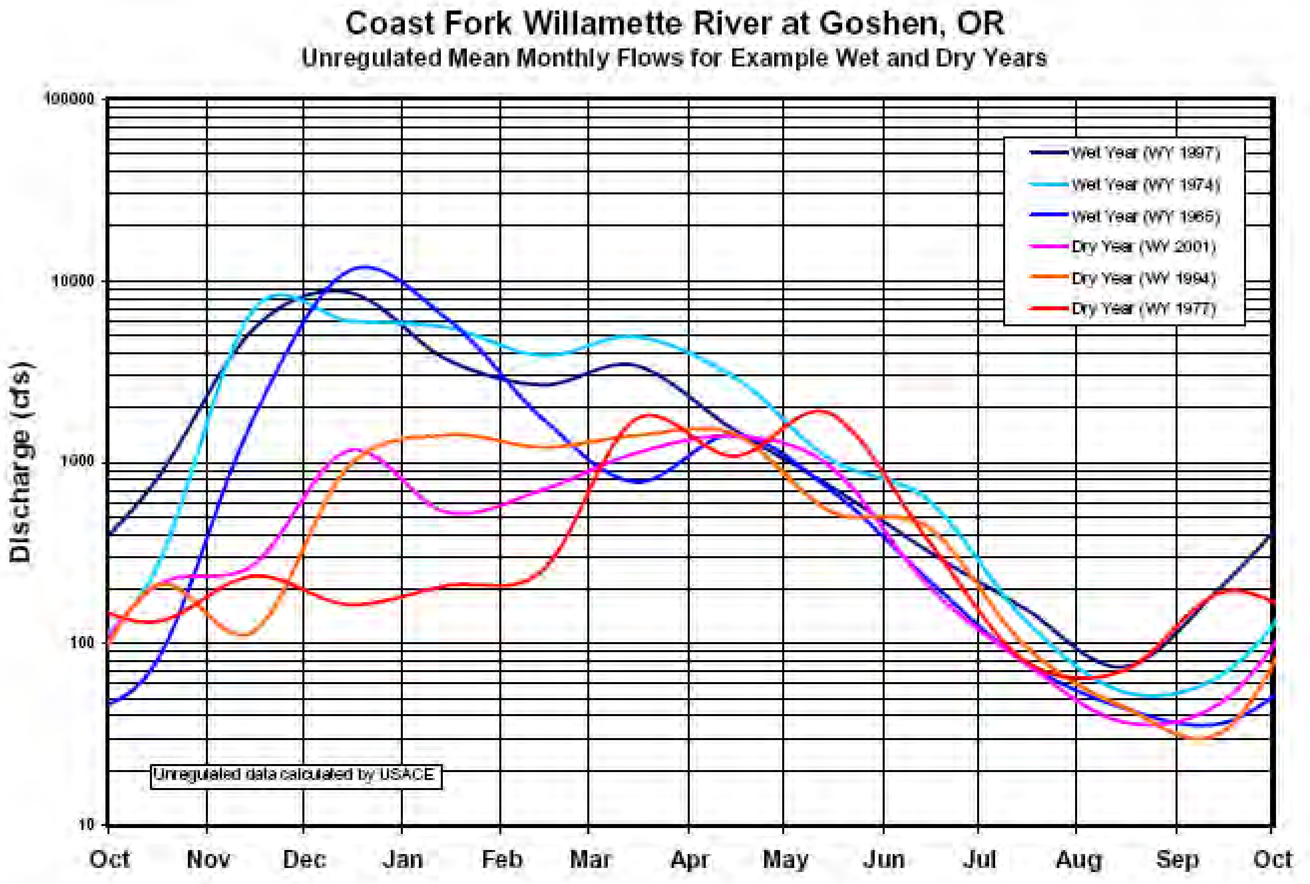
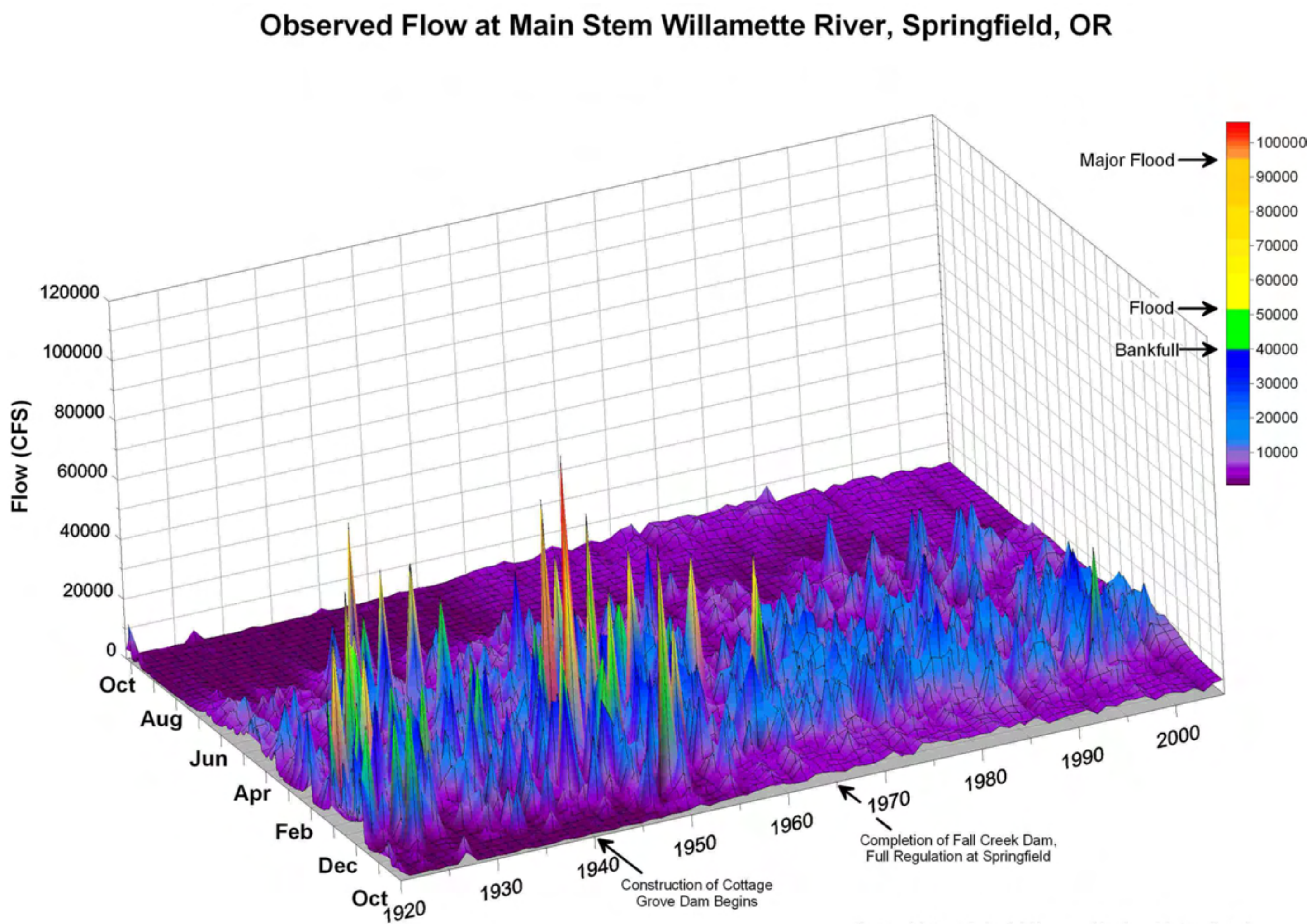


Figure 32. Mean monthly flows for exemplar wet (1997, 1974, and 1965) and dry (2001, 1994 and 1977) water years under unregulated conditions for the Coast Fork of the Willamette River at Goshen. Figure prepared by Chris Nygaard, USACE, Portland, OR.

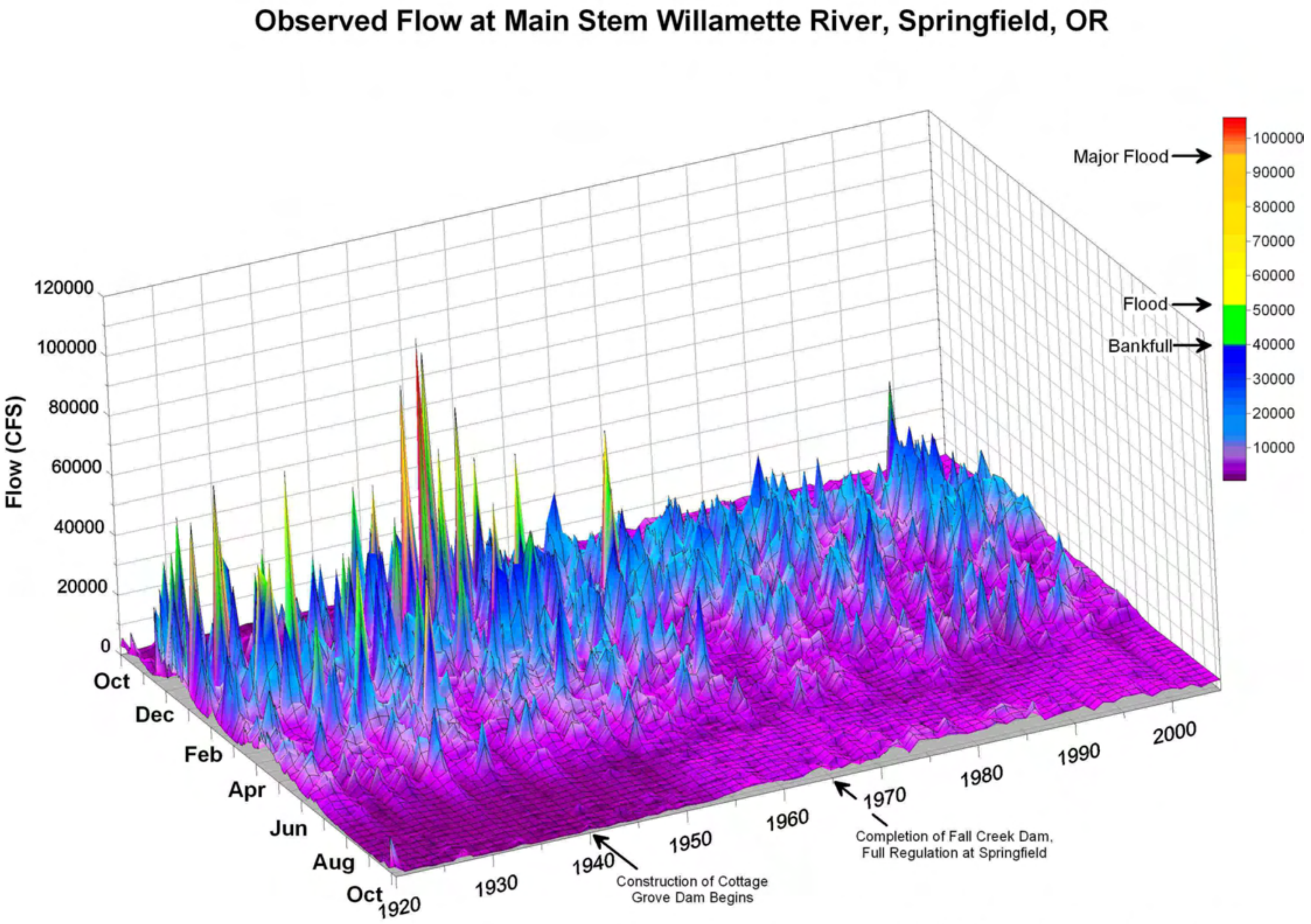


Construction of Cottage Grove Dam Begins

Completion of Fall Creek Dam, Full Regulation at Springfield

Observed data at Springfield is a combination of data collected at USGS station 14158000, Willamette River at Springfield (1920-1957), and calculated estimates of discharge (1958-2004).

Figure 33. Observed flows at the Springfield gage Willamette River, 1920 – 2004. Months run from right to left to highlight peak flows. Figure prepared by Chris Nygaard, USACE, Portland, OR.



Observed data at Springfield is a combination of data collected at USGS station 14158000, Willamette River at Springfield (1920-1957), and calculated estimates of discharge (1958-2004).

Figure 34. Observed flows at the Springfield gage, Willamette River, 1920 – 2004. Months run from left to right to highlight summer low flows. Figure prepared by Chris Nygaard, USACE, Portland, OR.

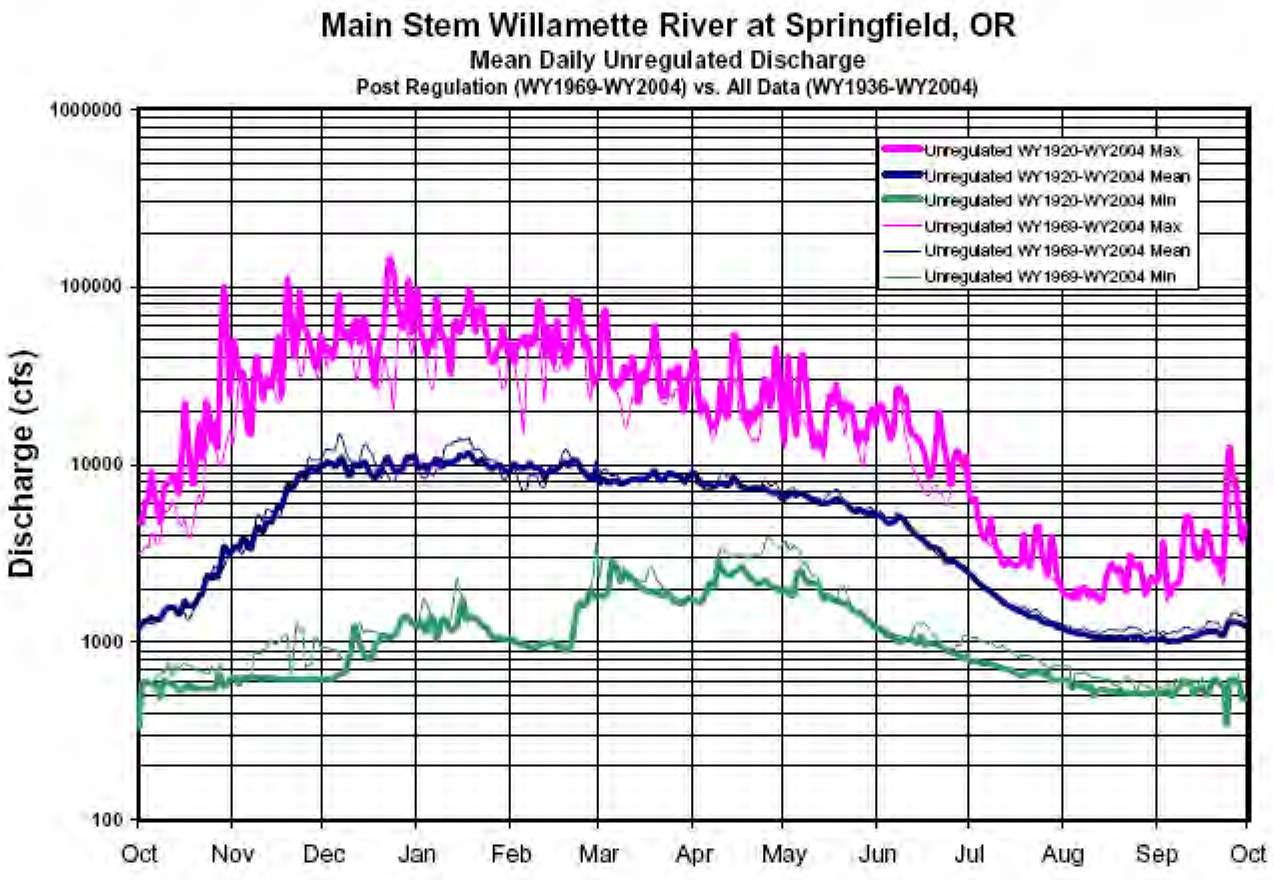


Figure 35. Mean daily discharges (maxima, minima and averages) at the Springfield gage, Willamette River for entire period of record (thick bars, 1920-2004) vs. post-dam completion (thinner bars, 1969-2004). Figure prepared by Chris Nygaard, USACE, Portland, OR.

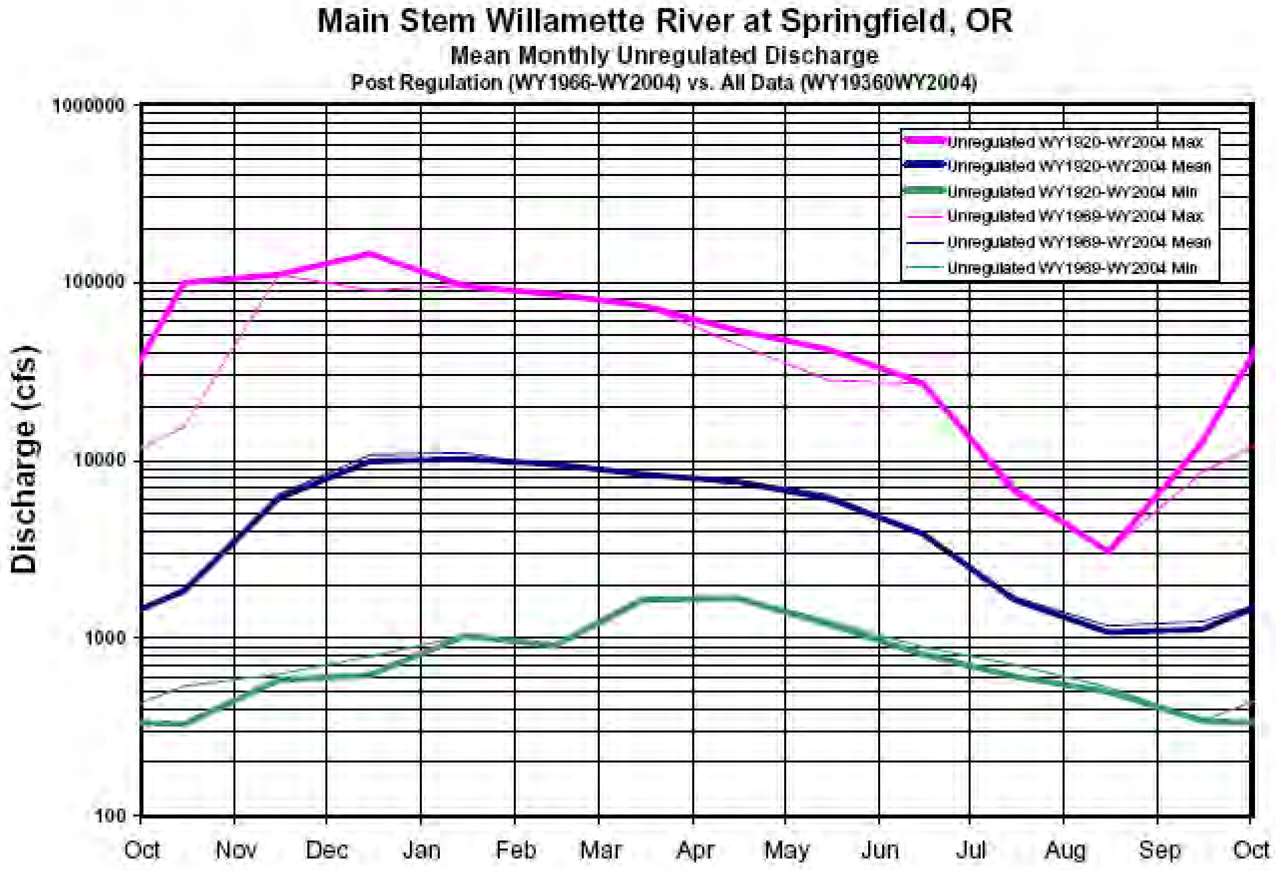


Figure 36. Mean monthly discharges (maxima, minima and averages) at the Springfield gage, Willamette River for entire period of record (thick bars, 1920-2004) vs. post-dam completion (thinner bars, 1969-2004). Figure prepared by Chris Nygaard, USACE, Portland, OR.

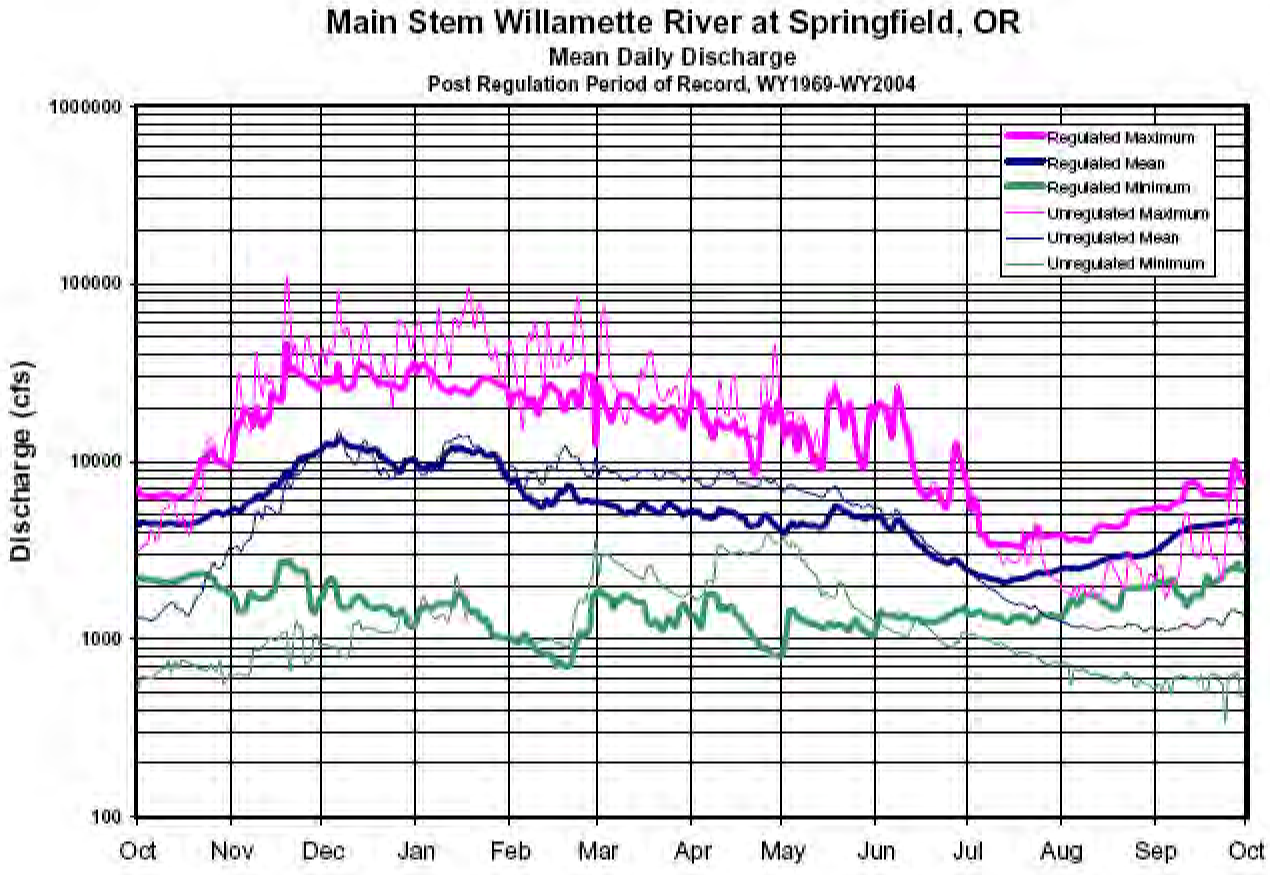


Figure 37. Mean daily discharges (maxima, minima and averages) at the Springfield gage, Willamette River for period of post-dam completion (1969-2004). Regulated flows are those observed at the gage; unregulated flows are derived from USACE models. Figure prepared by Chris Nygaard, USACE, Portland, OR.

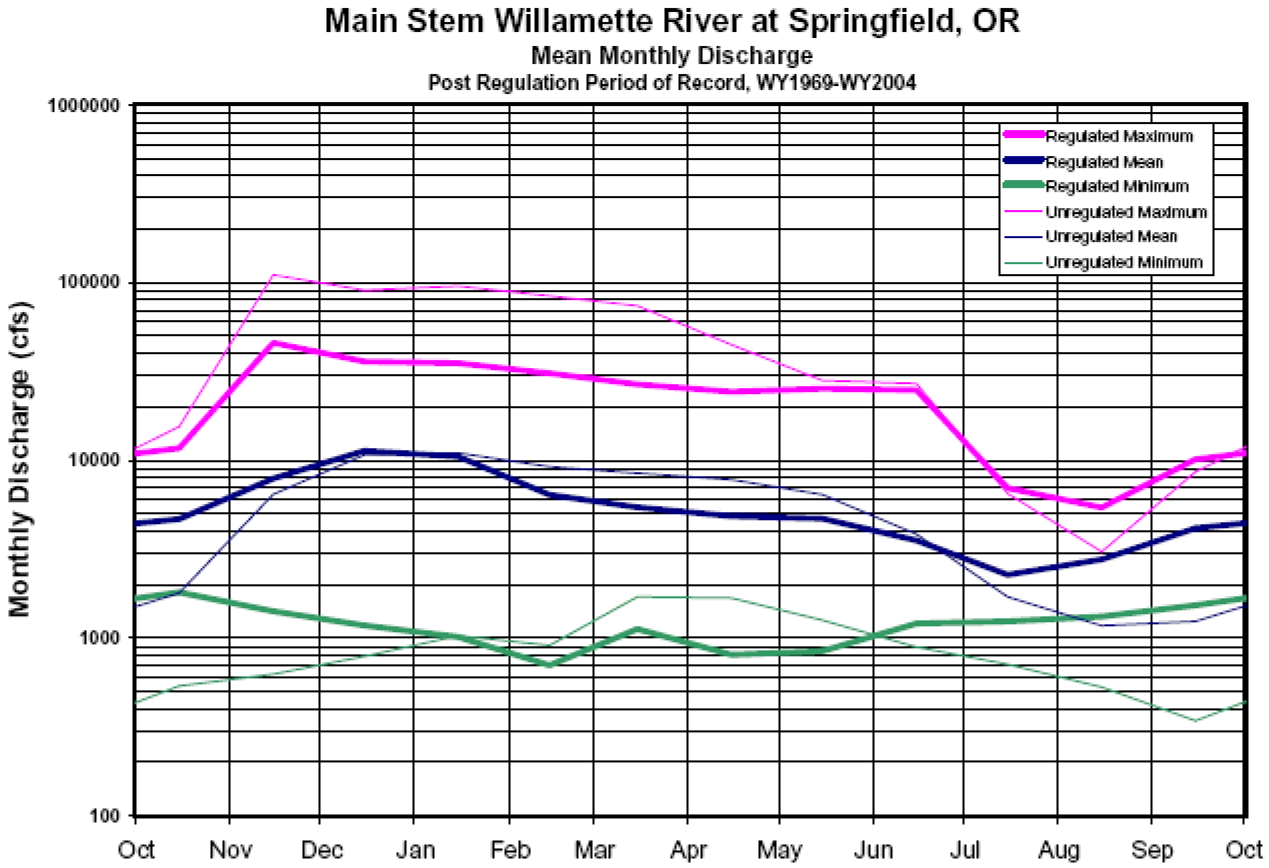


Figure 38. Mean monthly discharges (maxima, minima and averages) at the Springfield gage, Willamette River for period of post-dam completion (1969-2004). Regulated flows are those observed at the gage; unregulated flows are derived from USACE models. Figure prepared by Chris Nygaard, USACE, Portland, OR.

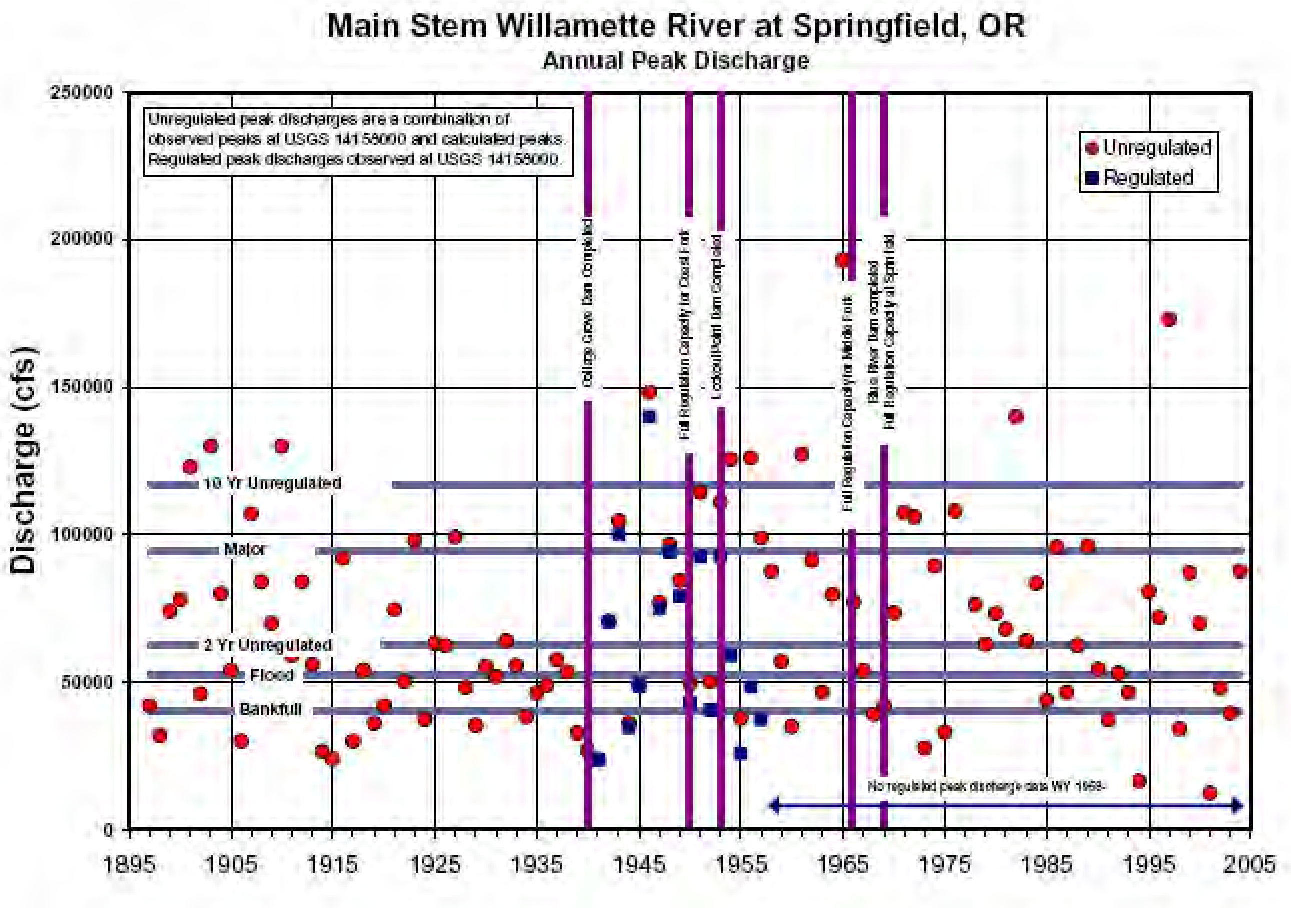
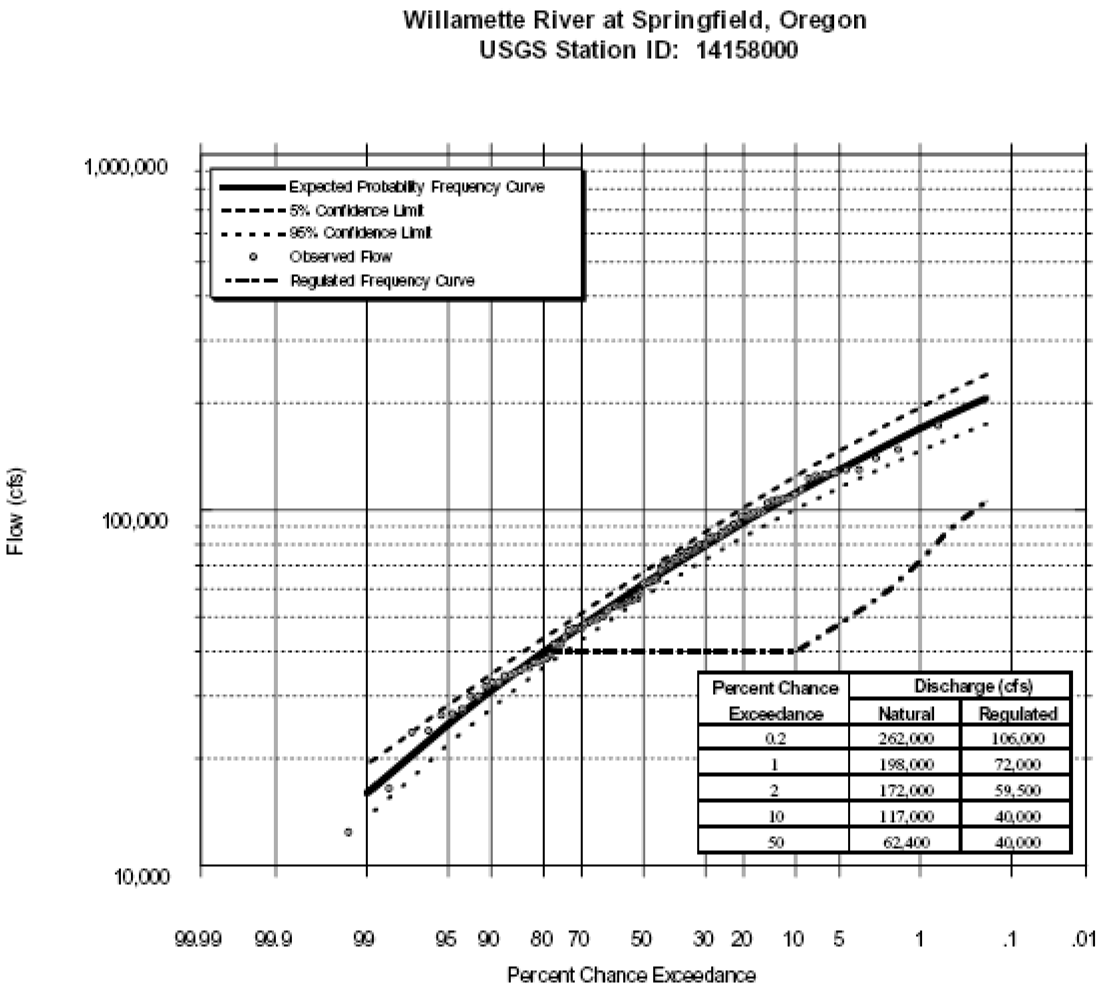
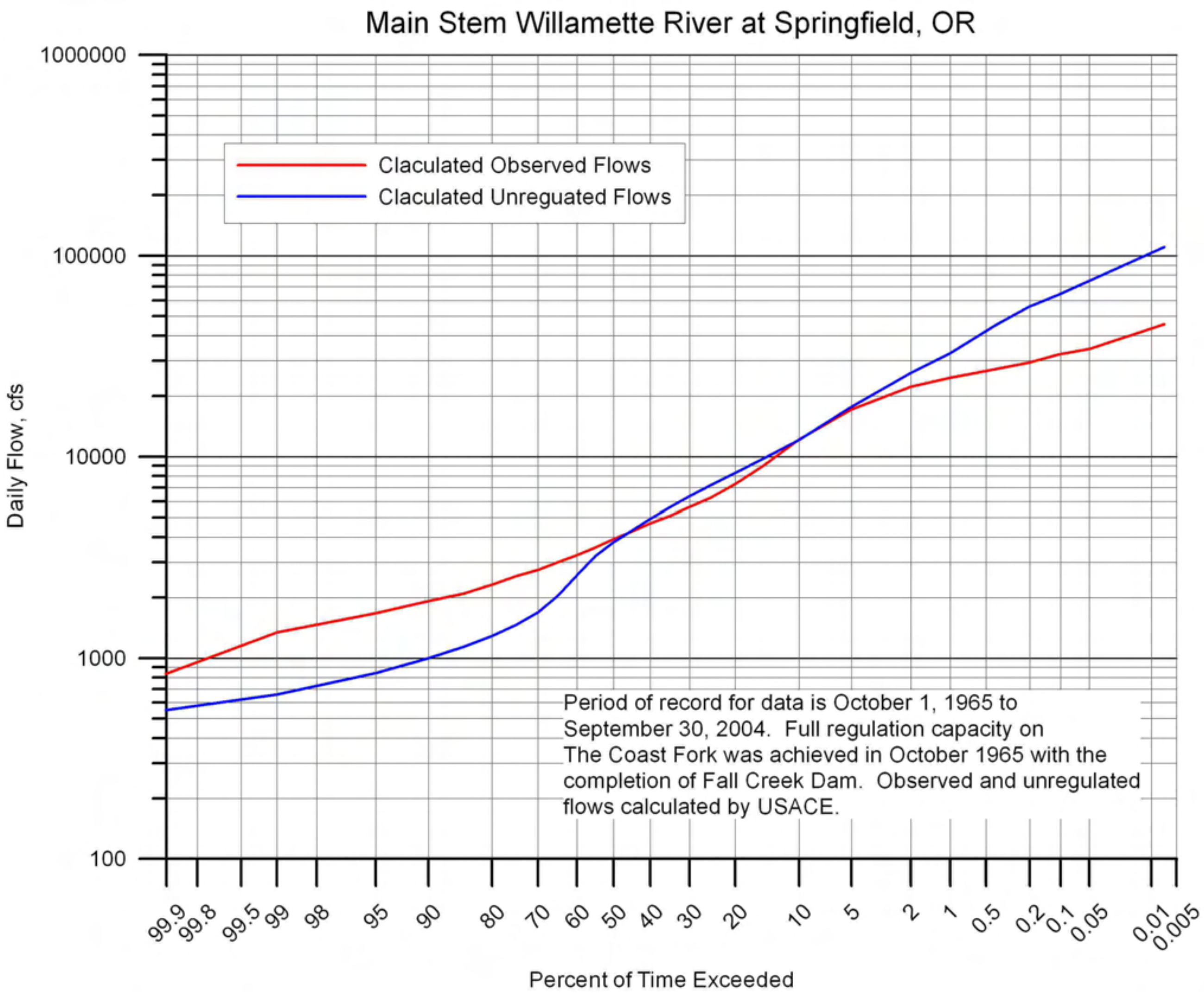


Figure 39. Annual peak discharges at the Springfield gage, Willamette River. Blue bars indicate the four environmental flow levels. Figure prepared by Chris Nygaard, USACE, Portland, OR.



Percent Chance Exceedance	Discharge (cfs)	
	Natural	Regulated
0.2	262,000	106,000
1	198,000	72,000
2	172,000	59,500
10	117,000	40,000
50	62,400	40,000

Figure 40. Draft flood frequency (exceedance curves) for the Willamette River at Springfield. Flood frequency data are preliminary and have not received final approval. Subsequent review may result in significant revisions to the data. Figure prepared by Chris Nygaard, USACE, Portland, OR.



Period of record for data is October 1, 1965 to September 30, 2004. Full regulation capacity on The Coast Fork was achieved in October 1965 with the completion of Fall Creek Dam. Observed and unregulated flows calculated by USACE.

Figure 41. Flow duration curve for the Willamette River at Springfield. Figure prepared by Chris Nygaard, USACE, Portland, OR.

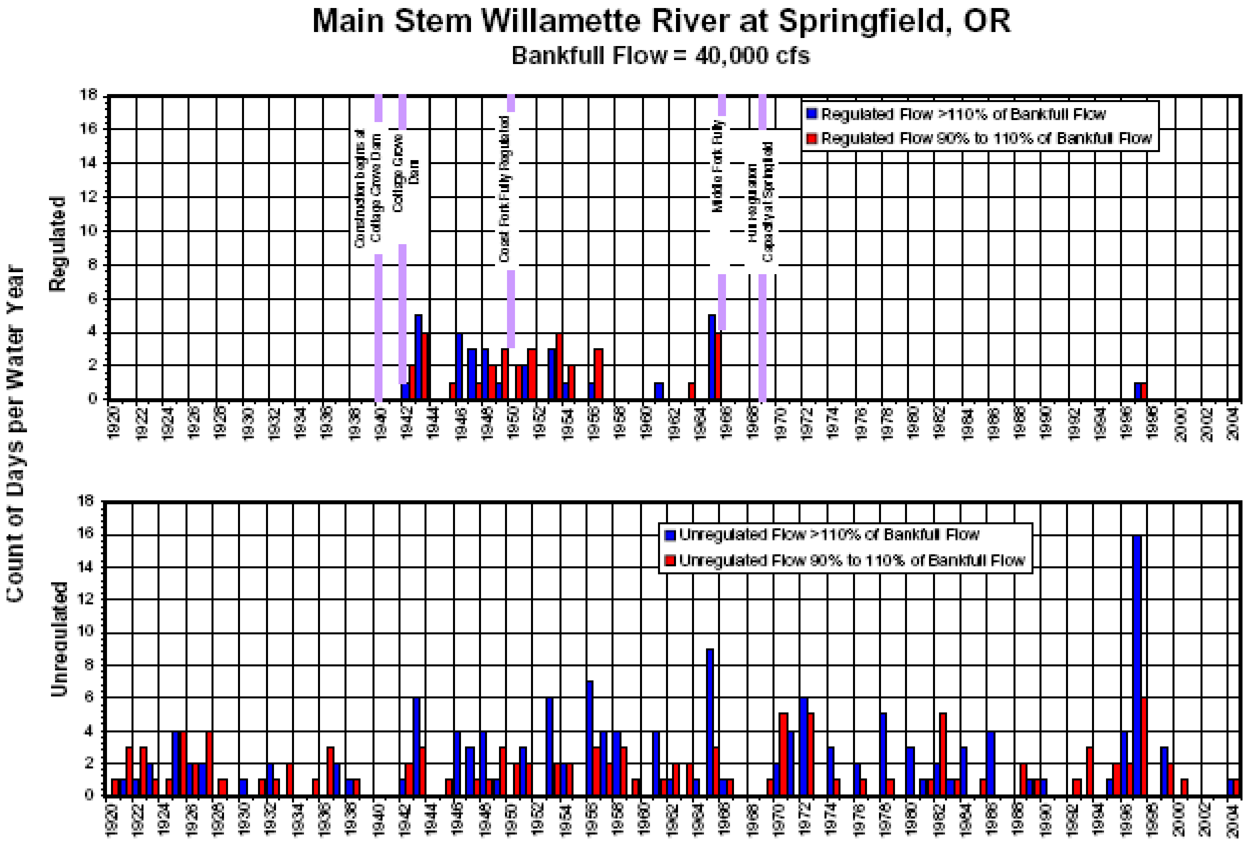


Figure 42. Number of days discharges are at bankfull levels for the Willamette River at Springfield. Comparison of regulated and unregulated flows by water year. Figure prepared by Chris Nygaard, USACE, Portland, OR.

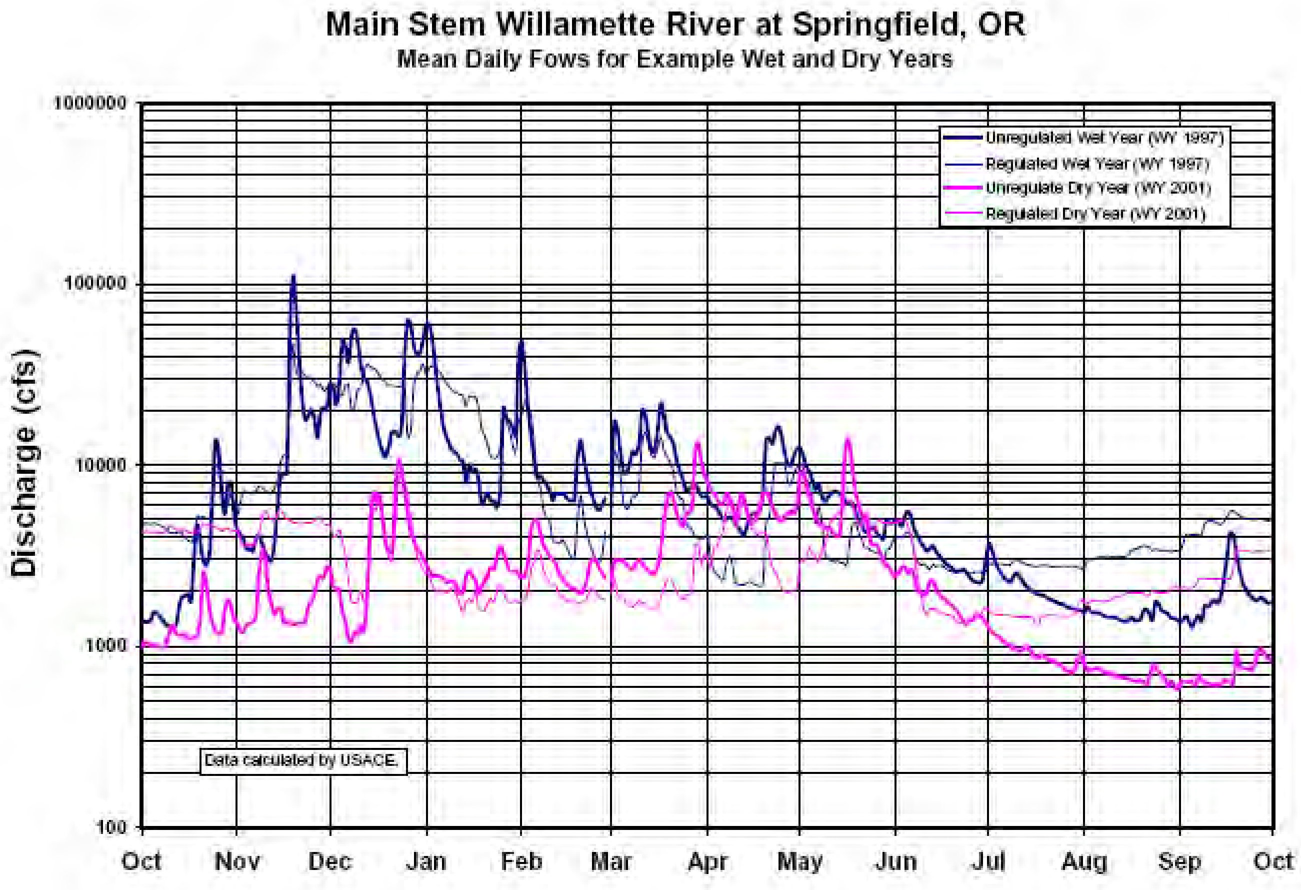


Figure 43. Mean daily flows for exemplar wet (1997) and dry (2001) water years under regulated and unregulated conditions for the Willamette River at Springfield. Figure prepared by Chris Nygaard, USACE, Portland, OR.

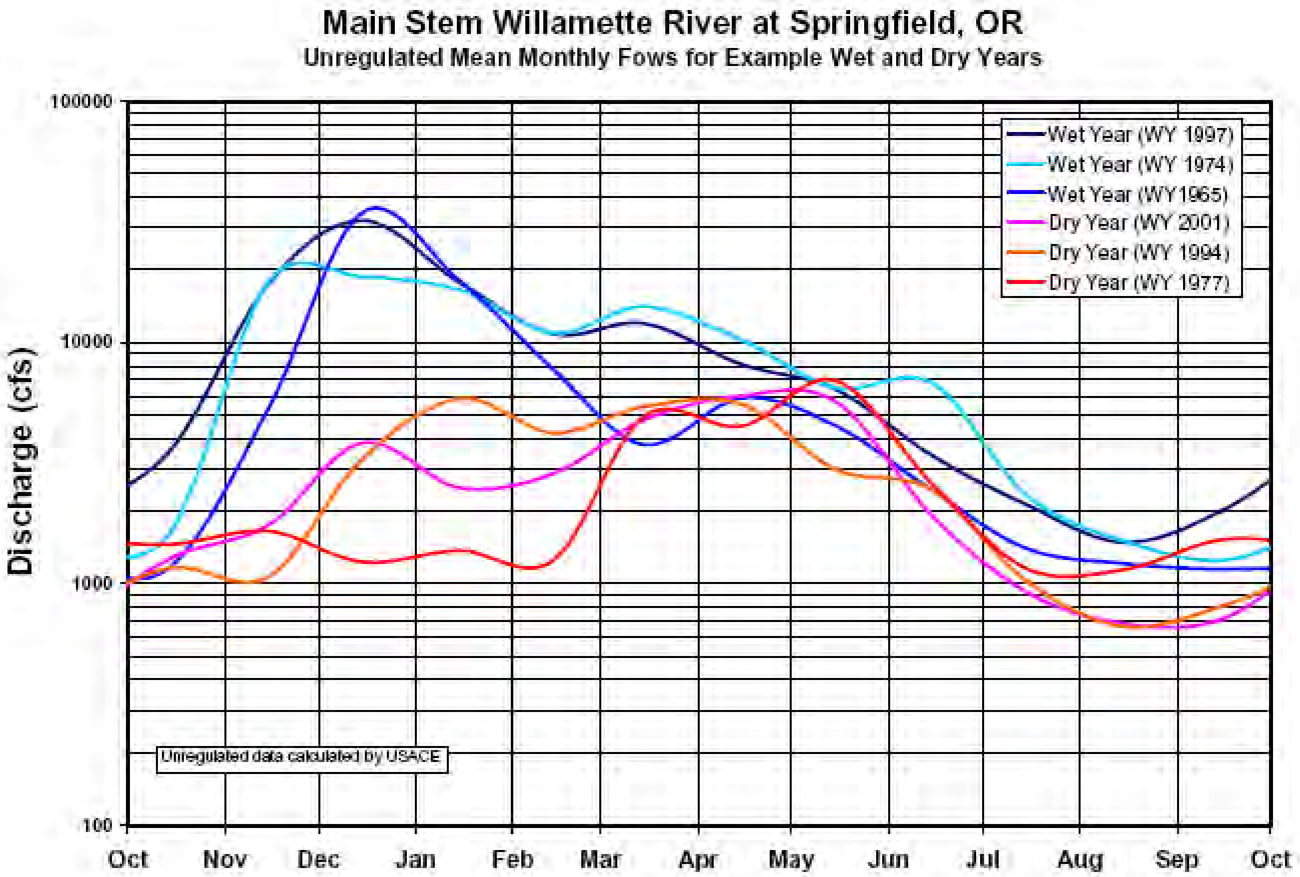


Figure 44. Mean monthly flows for exemplar wet (1997, 1974, and 1965) and dry (2001, 1994 and 1977) water years under unregulated conditions for the Willamette River at Springfield. Figure prepared by Chris Nygaard, USACE, Portland, OR.

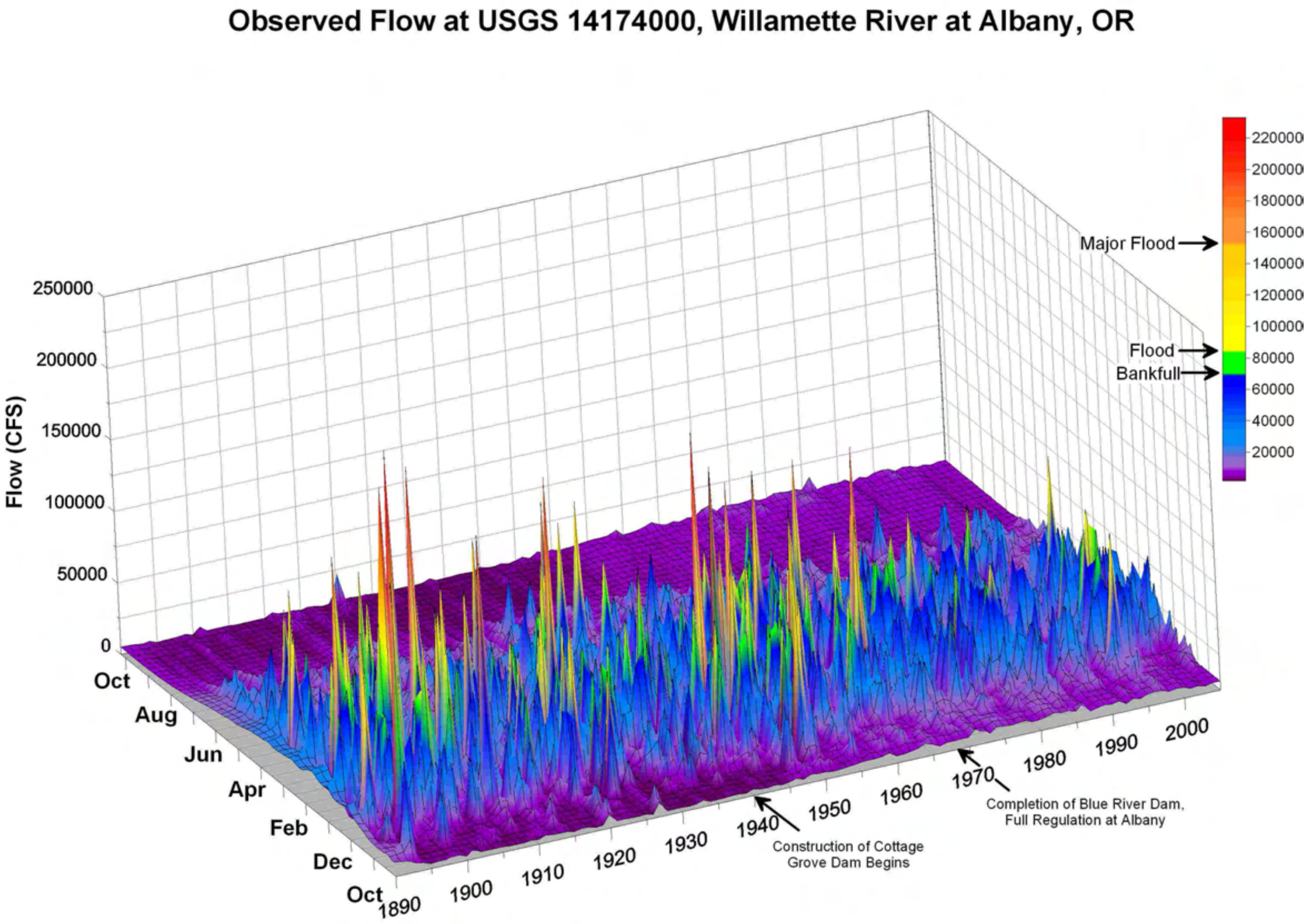


Figure 45. Observed flows at the Albany gage Willamette River, 1893 – 2004. Months run from right to left to highlight peak flows. Figure prepared by Chris Nygaard, USACE, Portland, OR.

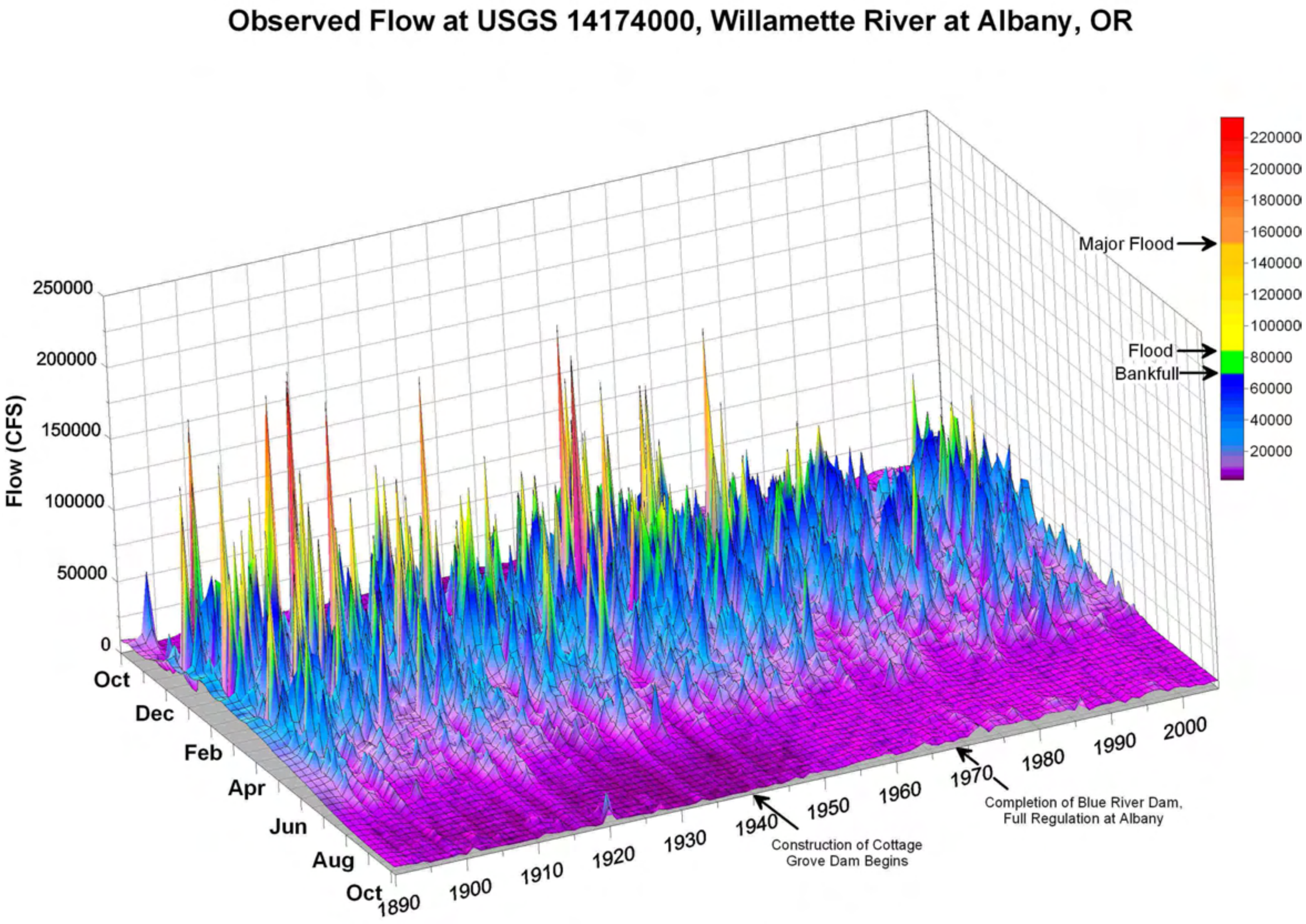


Figure 46. Observed flows at the Albany gage, Willamette River, 1893 – 2004. Months run from left to right to highlight summer low flows. Figure prepared by Chris Nygaard, USACE, Portland, OR.

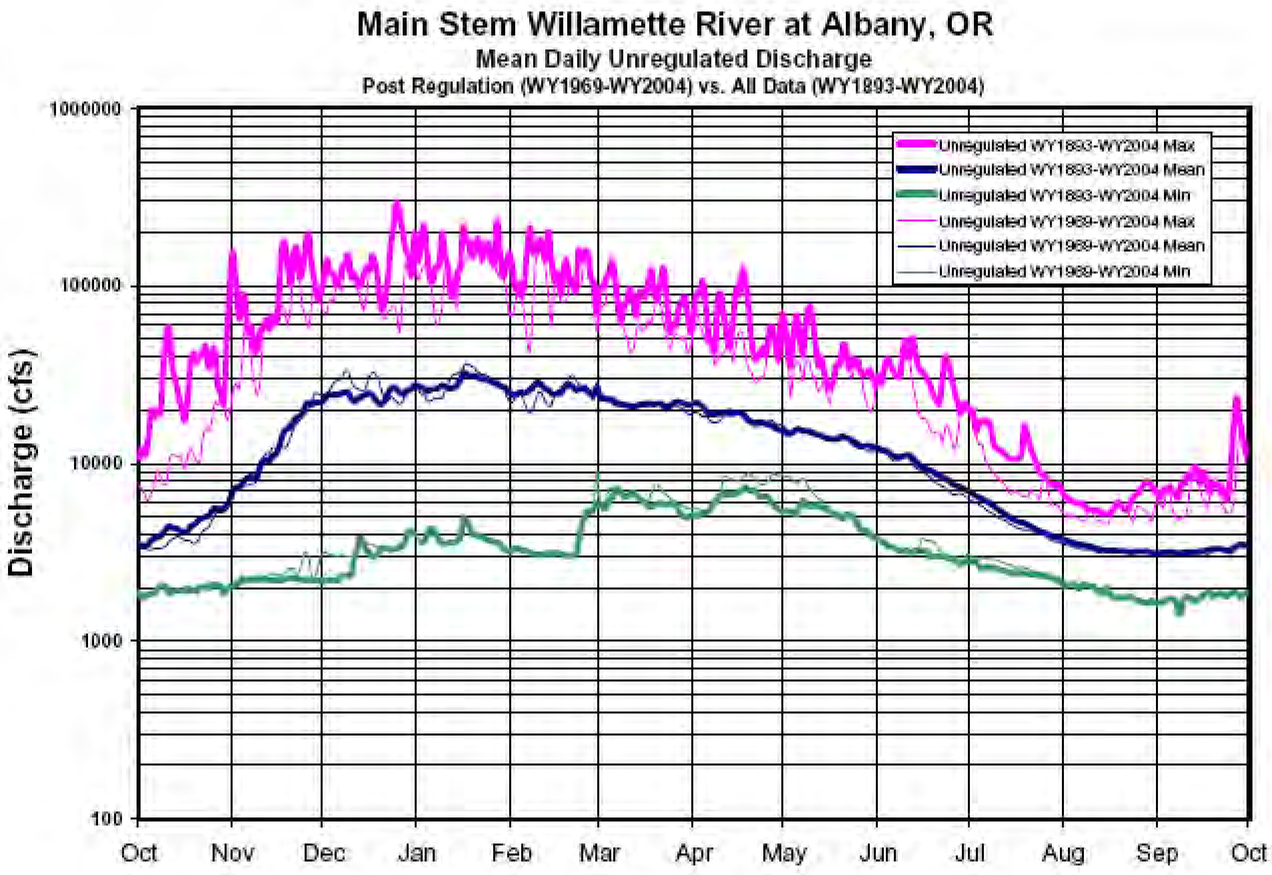


Figure 47. Mean daily discharges (maxima, minima and averages) at the Albany gage, Willamette River for entire period of record (thick bars, 1893-2004) vs. post-dam completion (thinner bars, 1969-2004). Figure prepared by Chris Nygaard, USACE, Portland, OR.

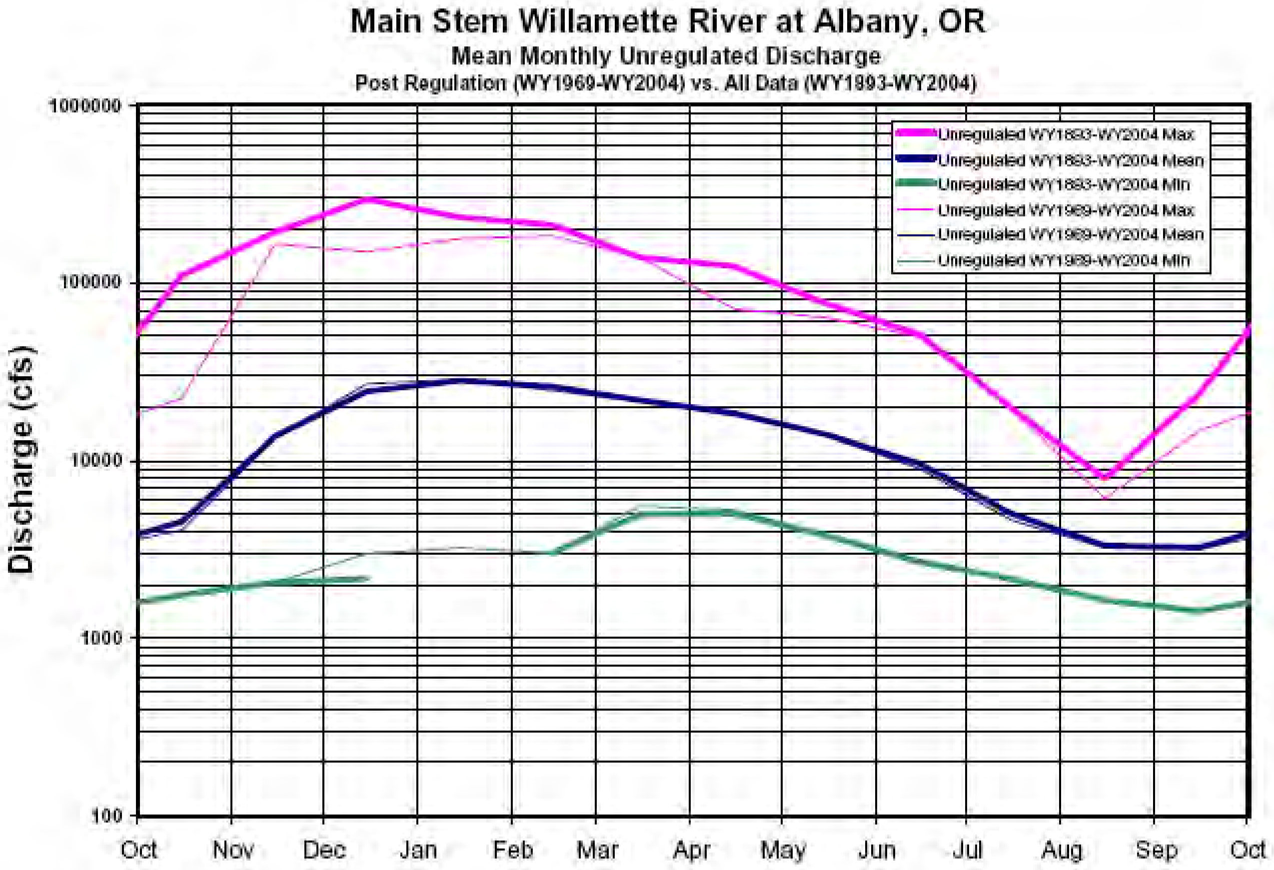


Figure 48. Mean monthly discharges (maxima, minima and averages) at the Albany gage, Willamette River for entire period of record (thick bars, 1893-2004) vs. post-dam completion (thinner bars, 1969-2004). Figure prepared by Chris Nygaard, USACE, Portland, OR.

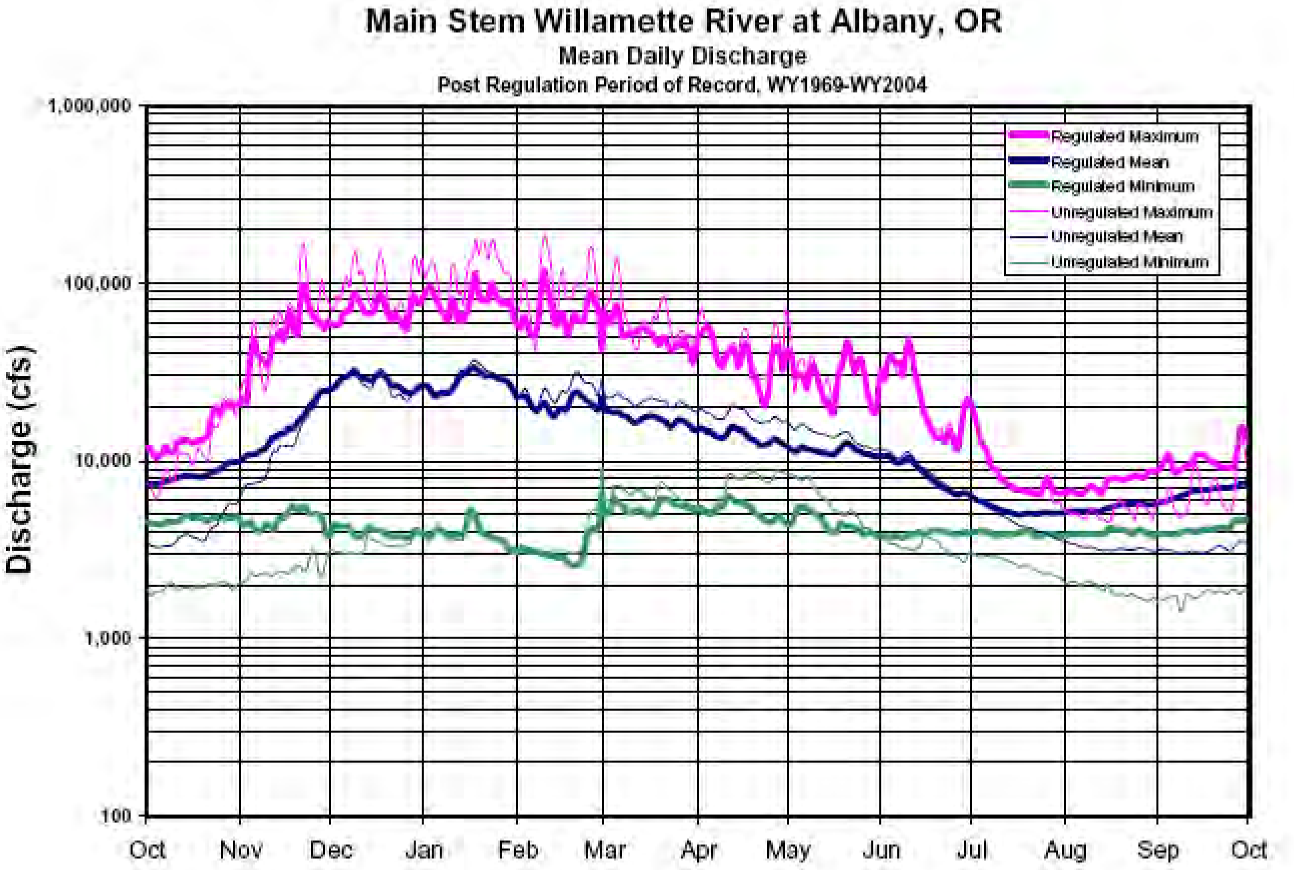


Figure 49. Mean daily discharges (maxima, minima and averages) at the Albany gage, Willamette River for period of post-dam completion (1969-2004). Regulated flows are those observed at the gage; unregulated flows are derived from USACE models. Figure prepared by Chris Nygaard, USACE, Portland, OR.

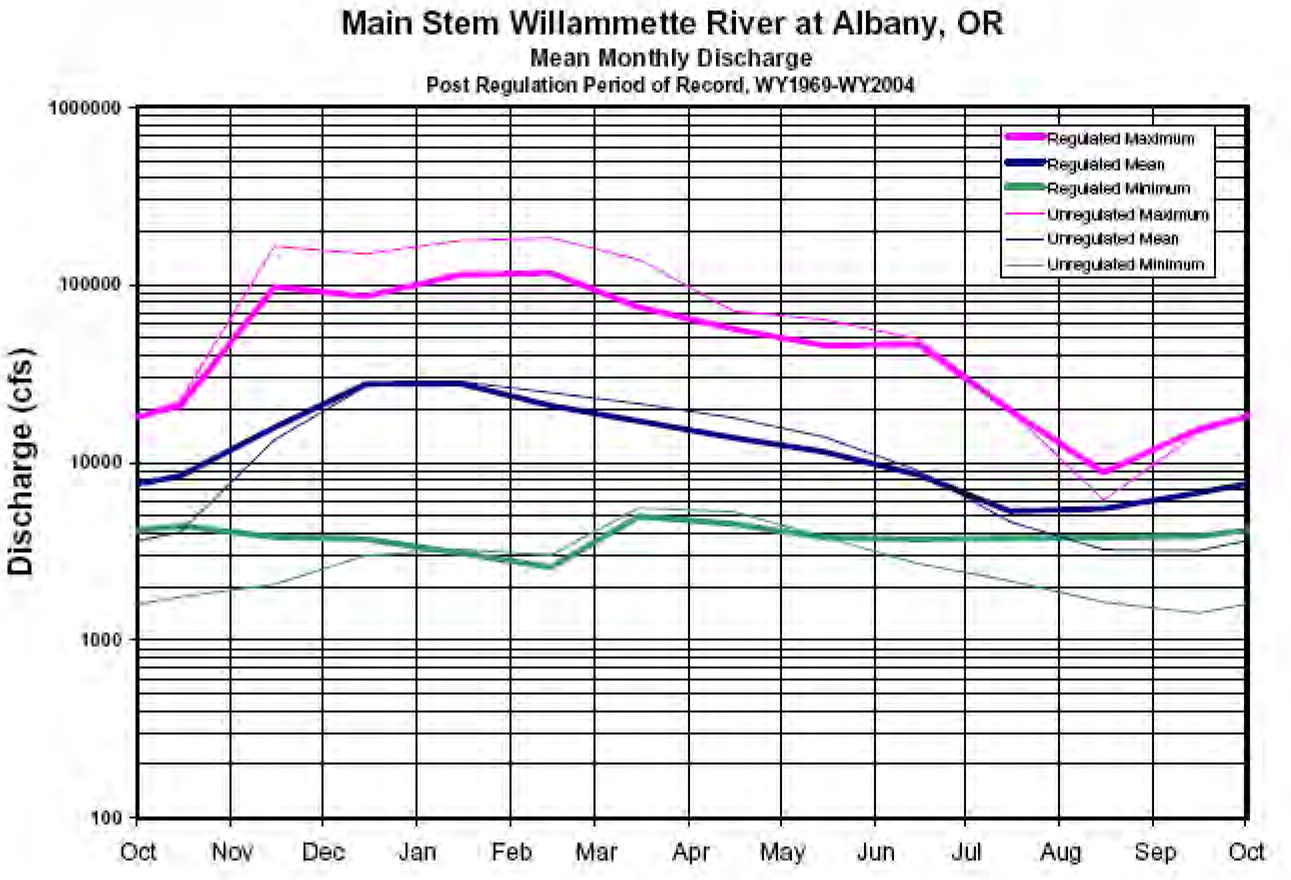


Figure 50. Mean monthly discharges (maxima, minima and averages) at the Albany gage, Willamette River for period of post-dam completion (1969-2004). Regulated flows are those observed at the gage; unregulated flows are derived from USACE models. Figure prepared by Chris Nygaard, USACE, Portland, OR.

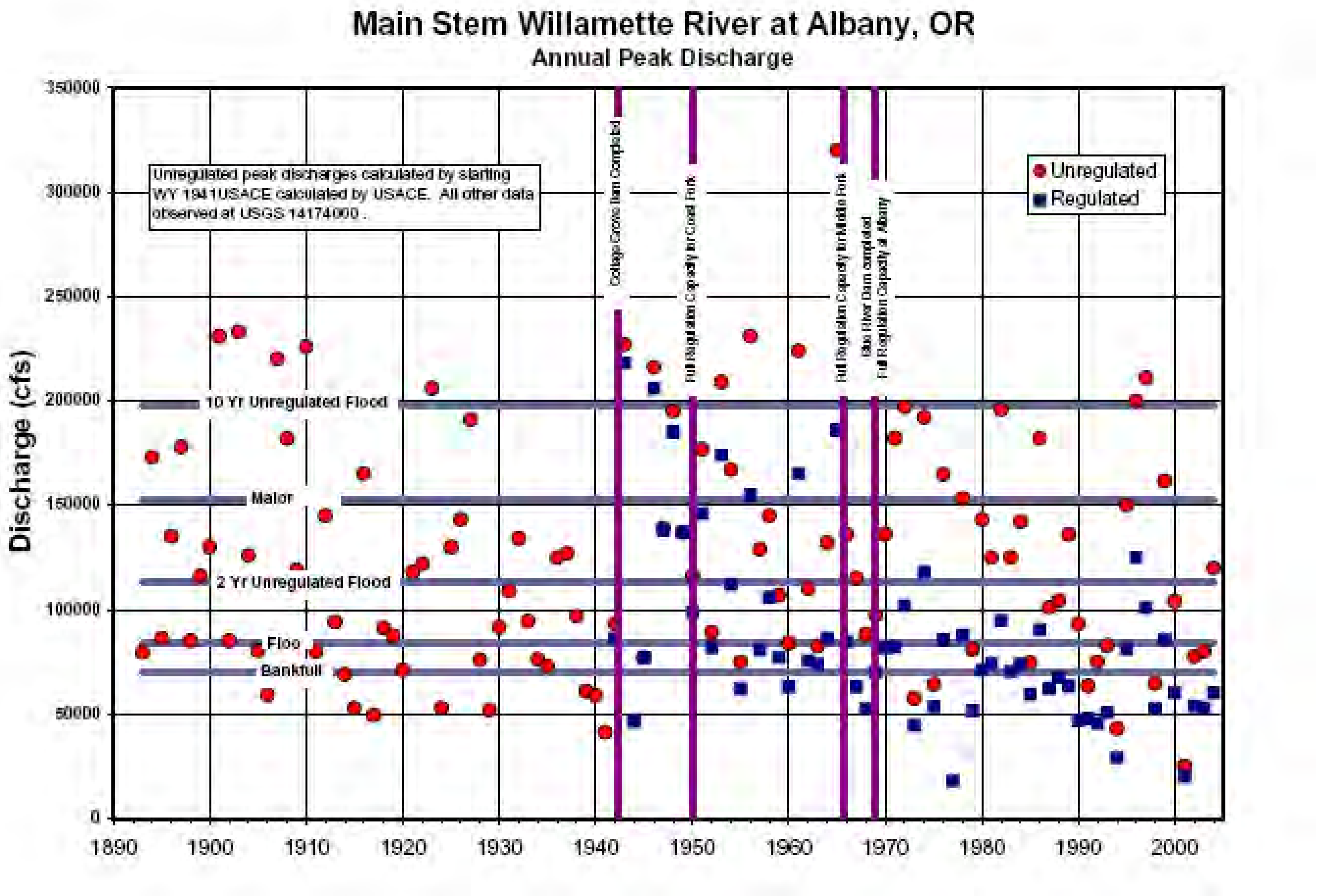
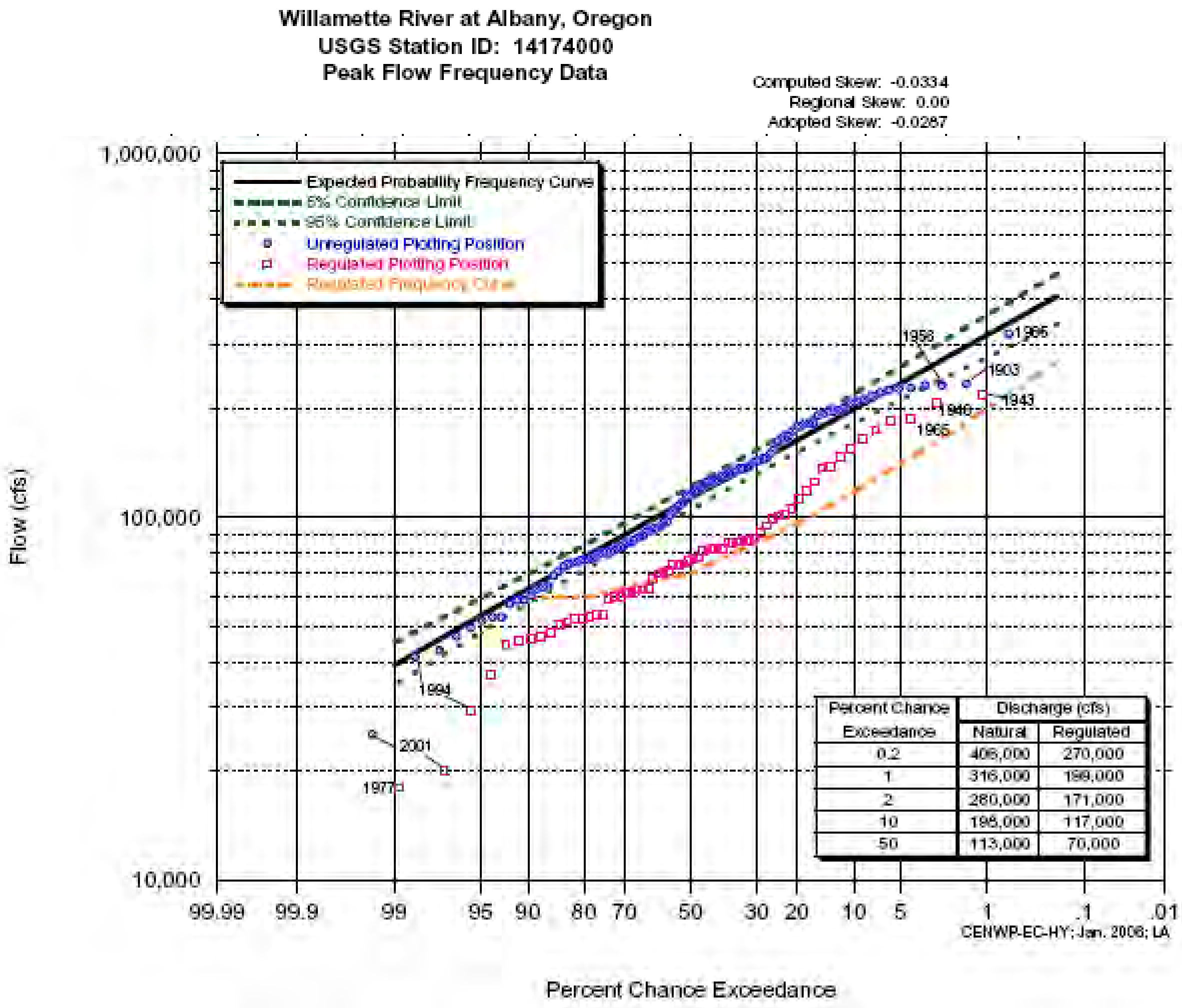
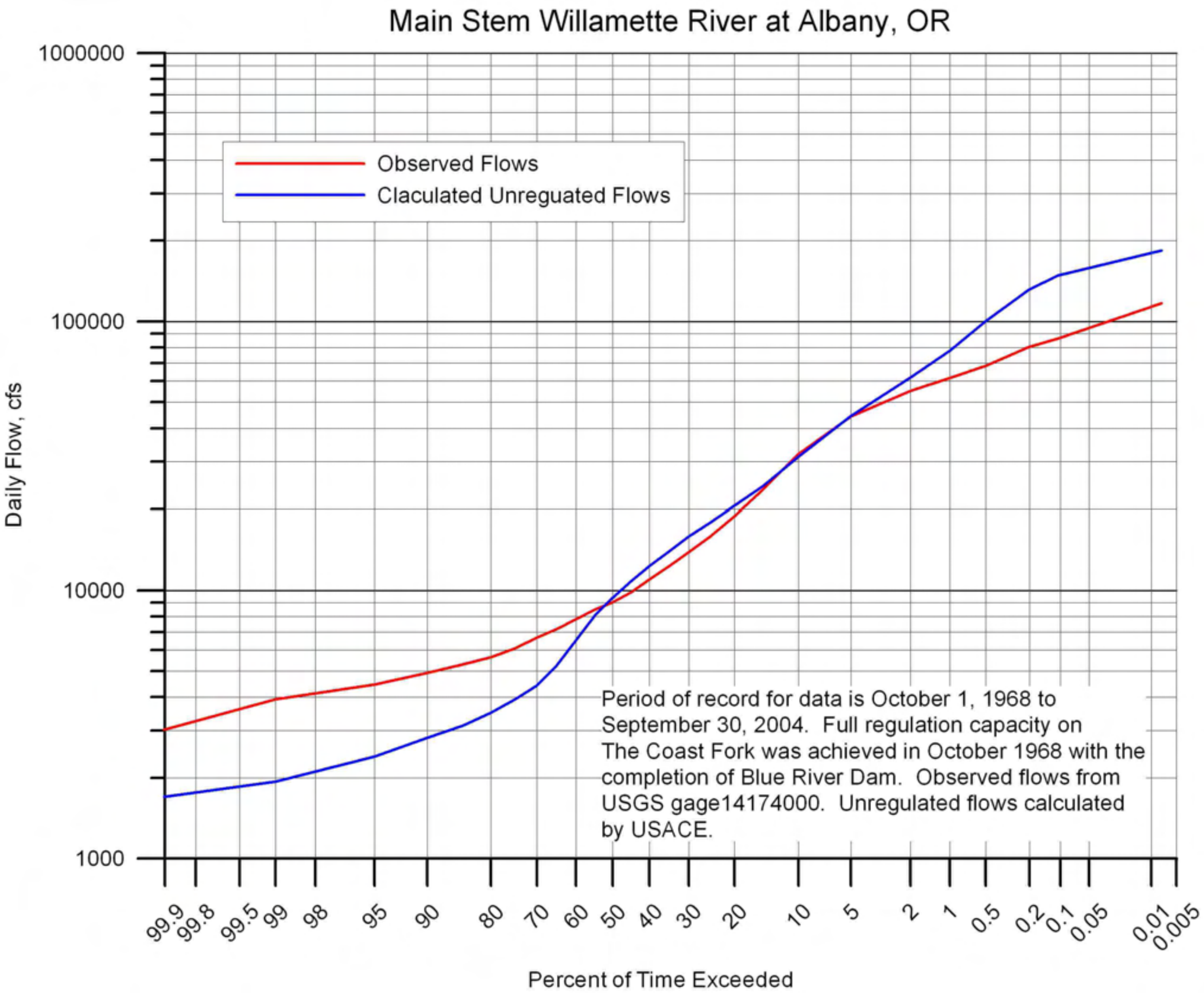


Figure 51. Annual peak discharges at the Albany gage, Willamette River. Blue bars indicate the four environmental flow levels. Figure prepared by Chris Nygaard, USACE, Portland, OR.



Percent Chance Exceedance	Discharge (cfs)	
	Natural	Regulated
0.2	406,000	270,000
1	316,000	199,000
2	280,000	171,000
10	196,000	117,000
50	113,000	70,000

Figure 52. Draft flood frequency (exceedance curves) for the Willamette River at Albany. Flood frequency data are preliminary and have not received final approval. Subsequent review may result in significant revisions to the data. Figure prepared by Chris Nygaard, USACE, Portland, OR.



Period of record for data is October 1, 1968 to September 30, 2004. Full regulation capacity on The Coast Fork was achieved in October 1968 with the completion of Blue River Dam. Observed flows from USGS gage14174000. Unregulated flows calculated by USACE.

Figure 53. Flow duration curve for the Willamette River at Albany. Figure prepared by Chris Nygaard, USACE, Portland, OR.

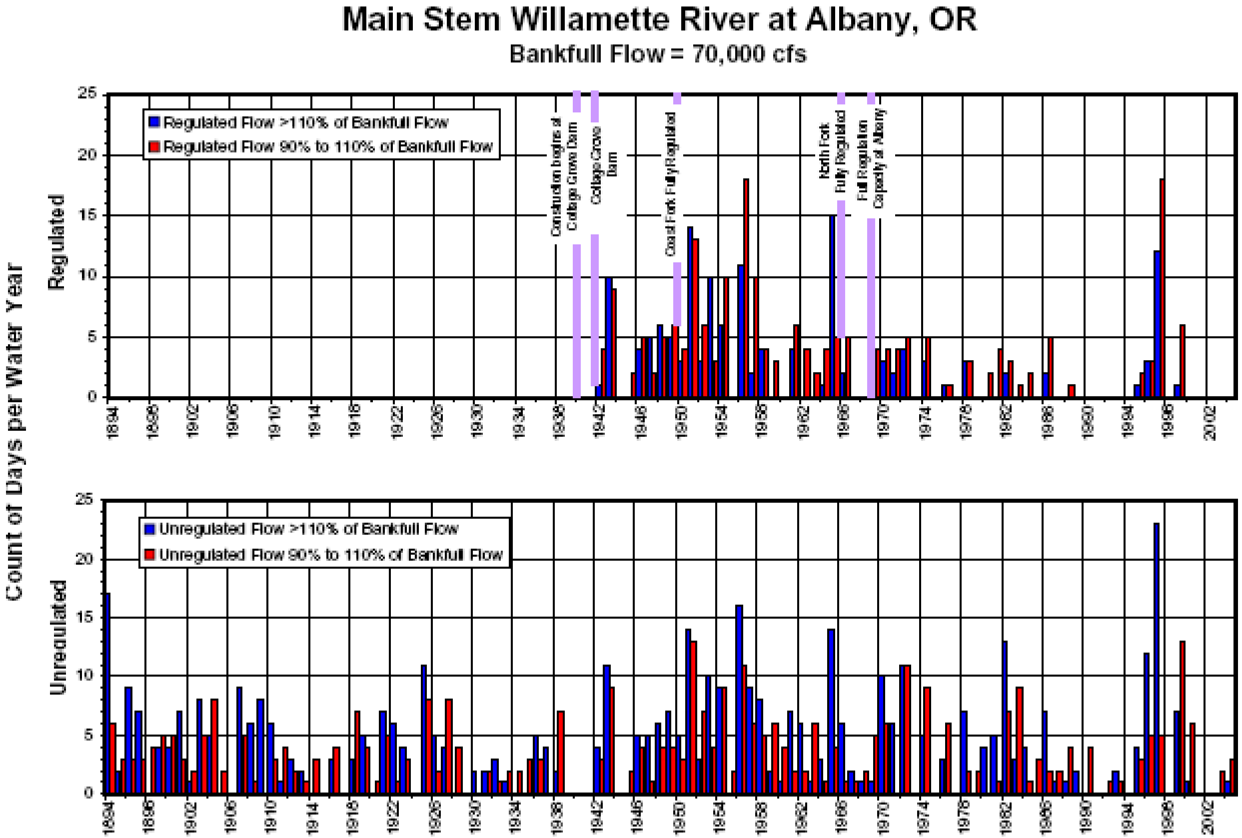


Figure 54. Number of days discharges are at bankfull levels for the Willamette River at Albany. Comparison of regulated and unregulated flows by water year. Figure prepared by Chris Nygaard, USACE, Portland, OR.

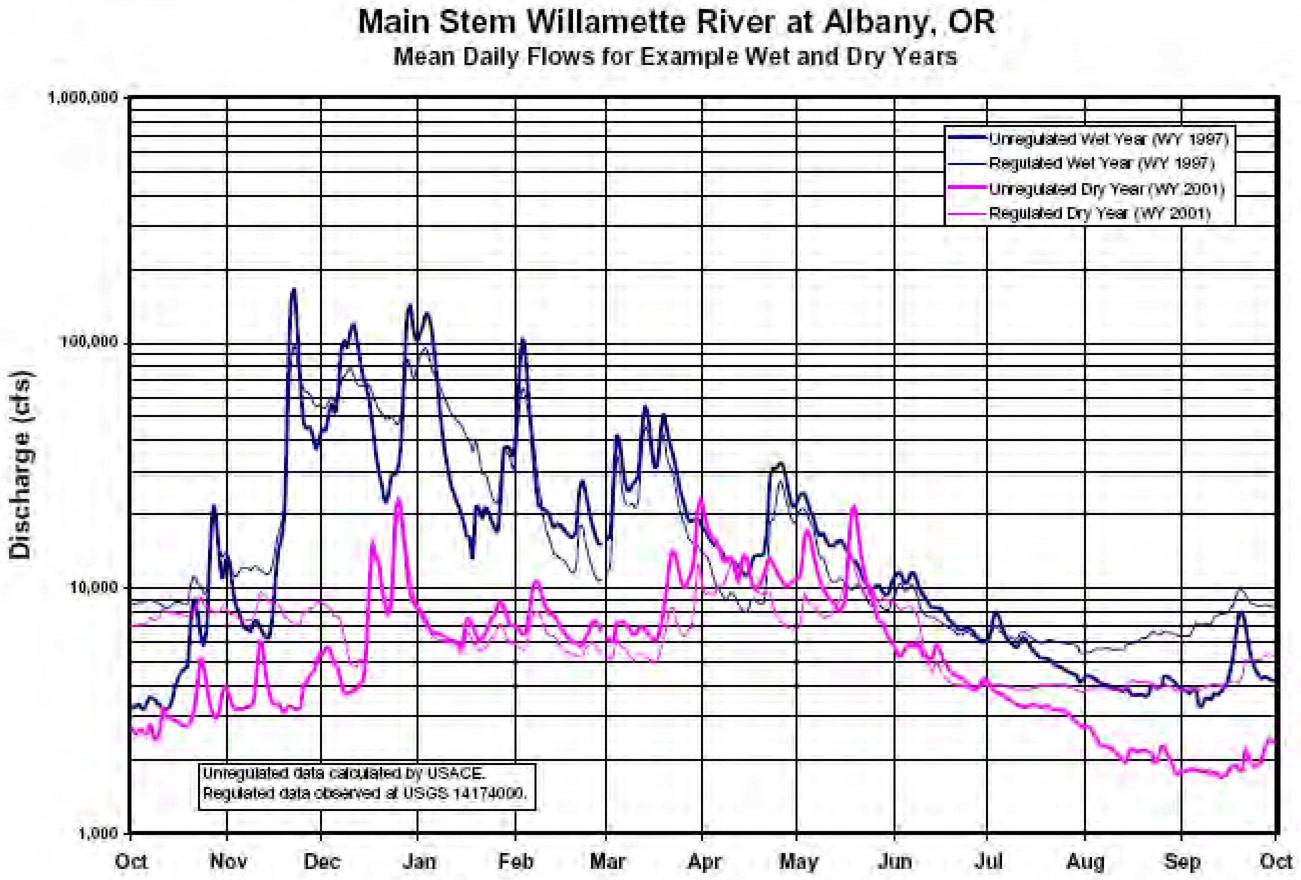


Figure 55. Mean daily flows for exemplar wet (1997) and dry (2001) water years under regulated and unregulated conditions for the Willamette River at Albany. Figure prepared by Chris Nygaard, USACE, Portland, OR.

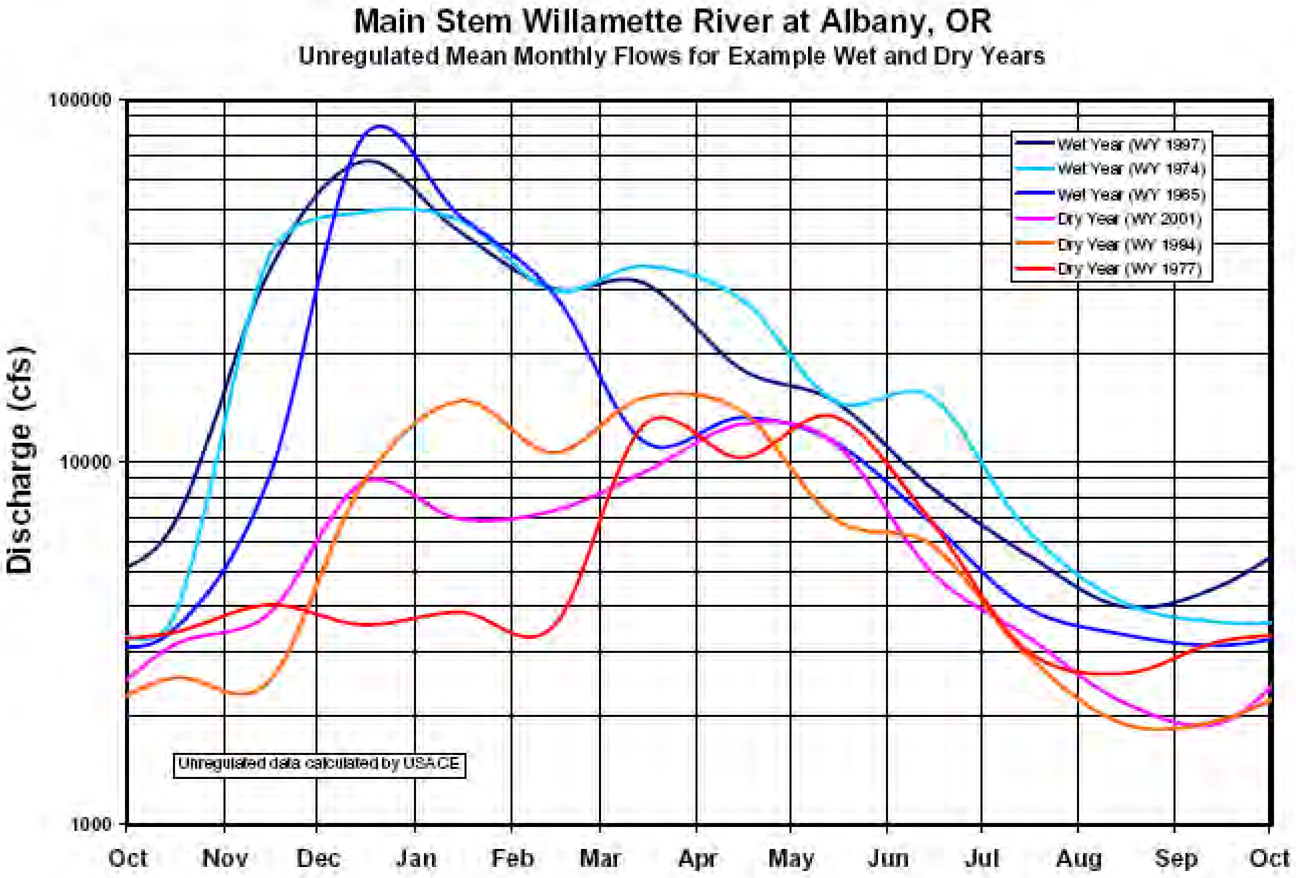


Figure 56. Mean monthly flows for exemplar wet (1997, 1974, and 1965) and dry (2001, 1994 and 1977) water years under unregulated conditions for the Willamette River at Albany. Figure prepared by Chris Nygaard, USACE, Portland, OR.

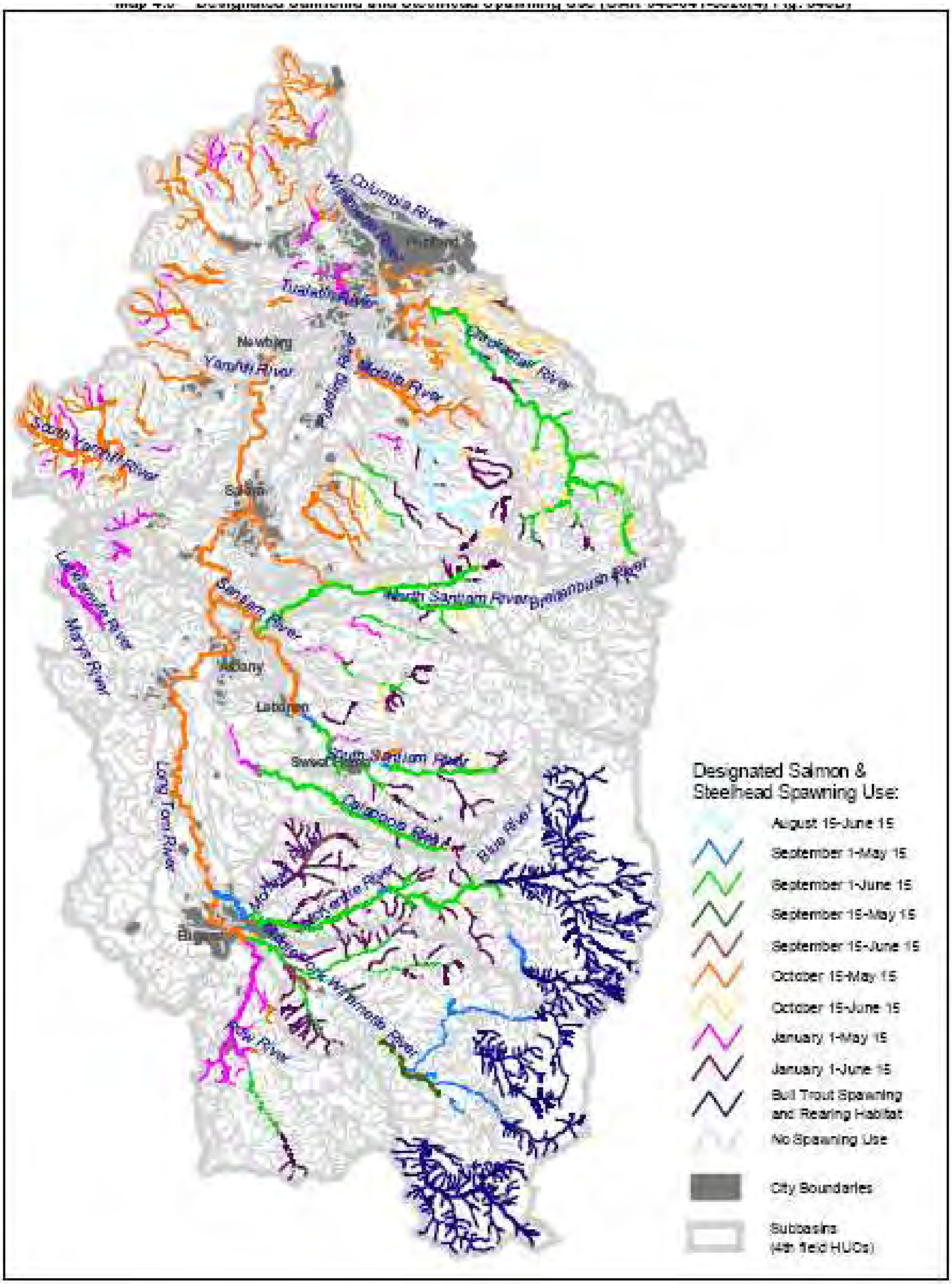


Figure 57. Stream segments designated for salmonid spawning in the Willamette River basin (ODEQ 2006).

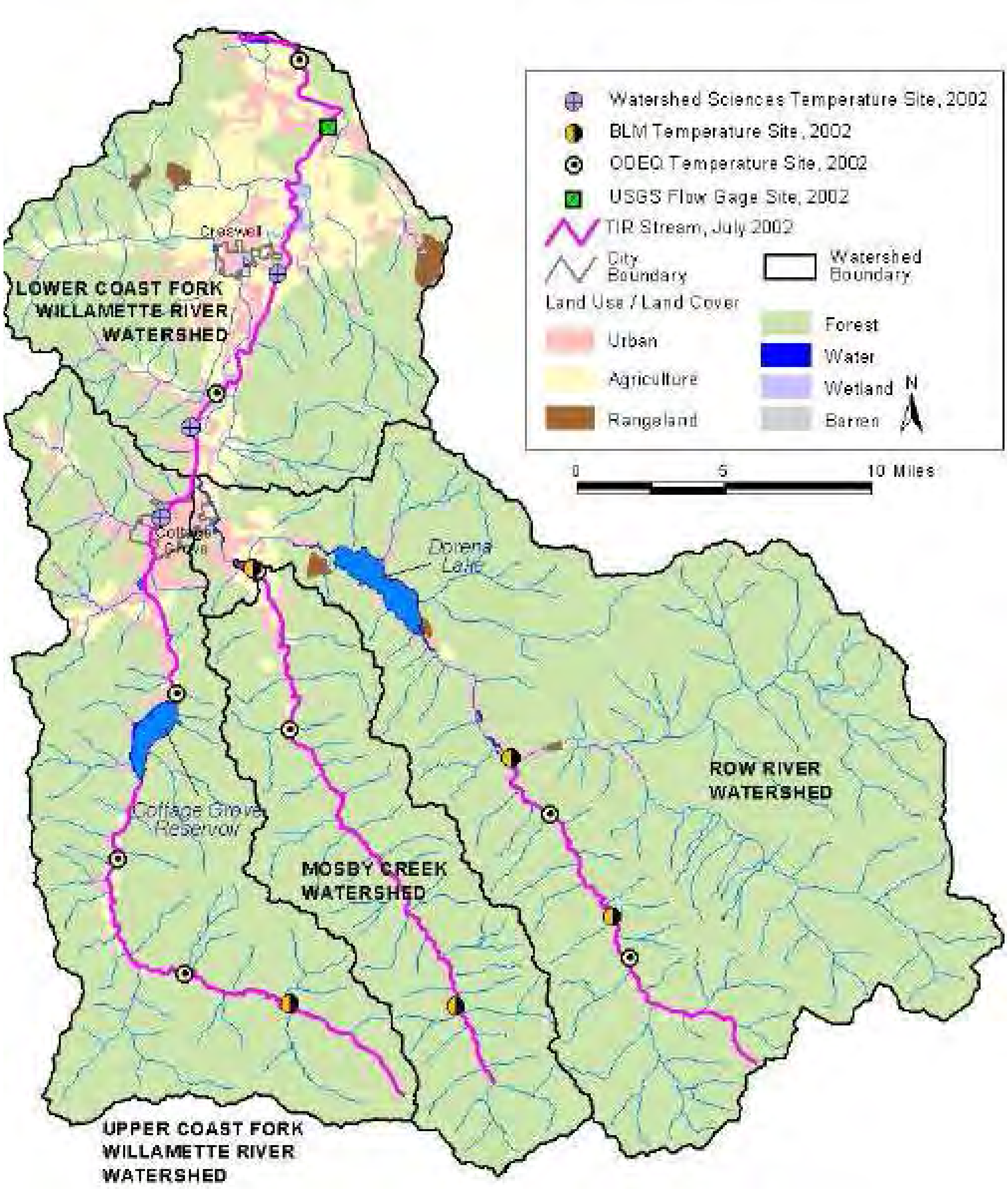


Figure 58. Temperature monitoring locations within the Coast Fork subbasin (ODEQ 2006).

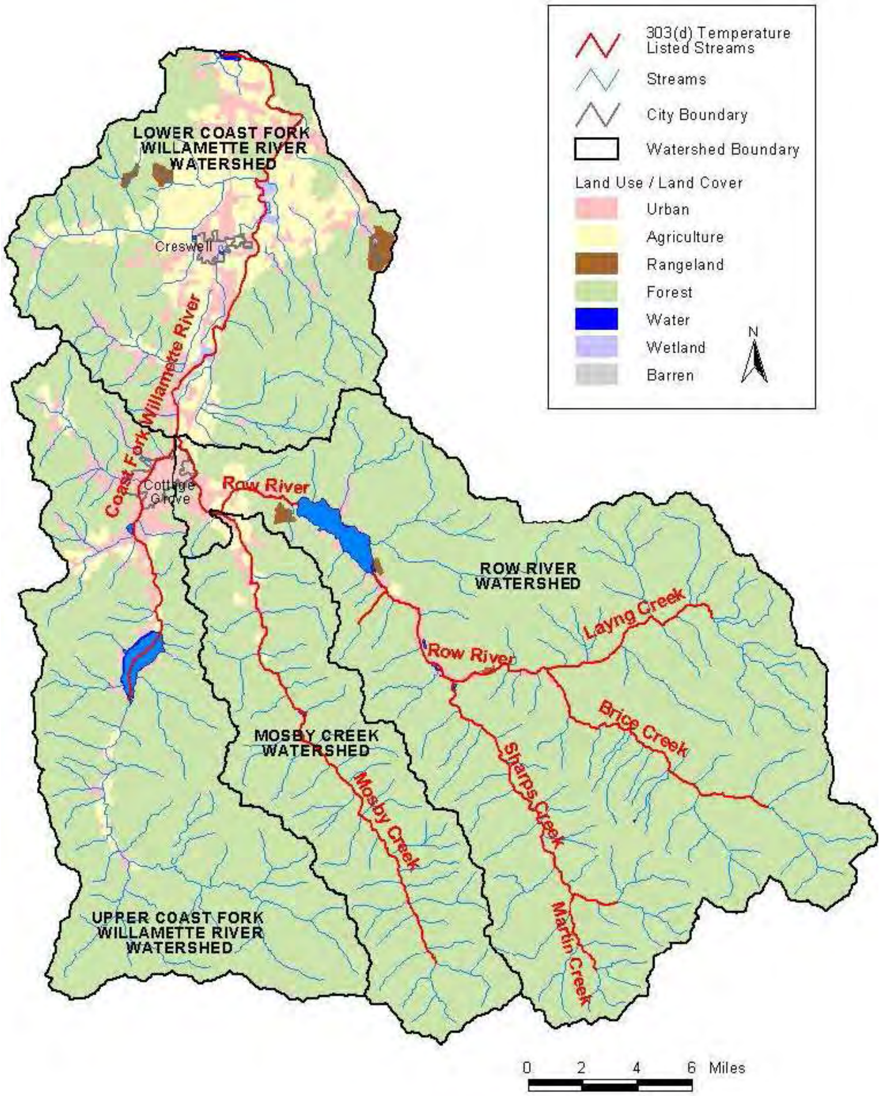


Figure 59. 303(d) listed streams for temperature in the Coast Fork subbasin (ODEQ 2006).

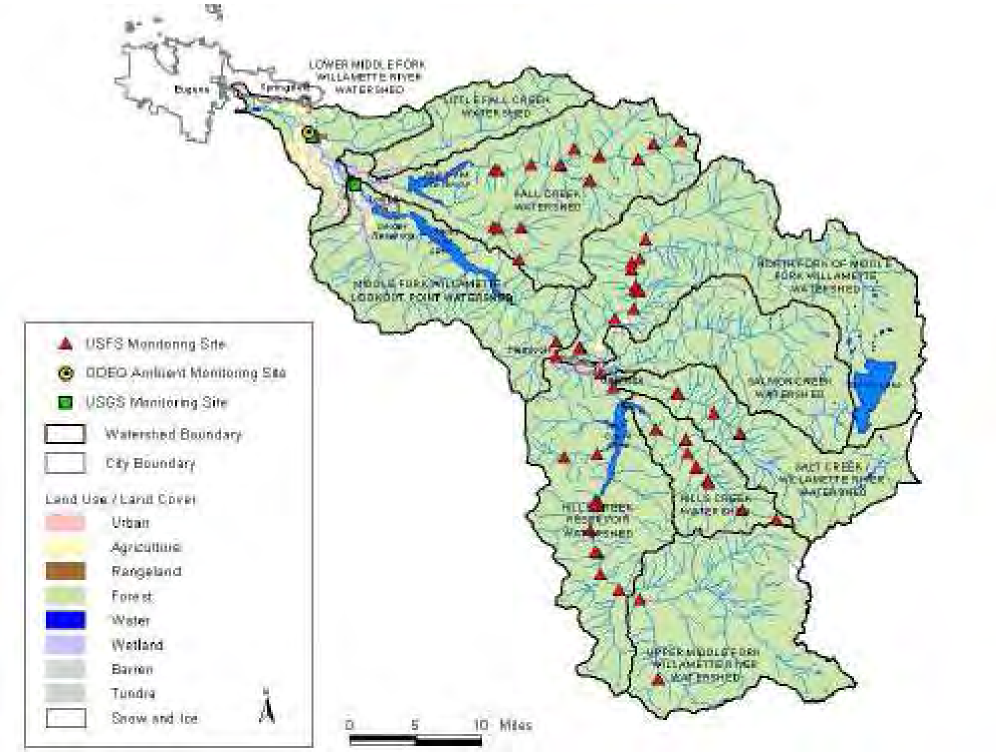


Figure 60. Temperature monitoring locations within the Middle Fork subbasin (ODEQ 2006).

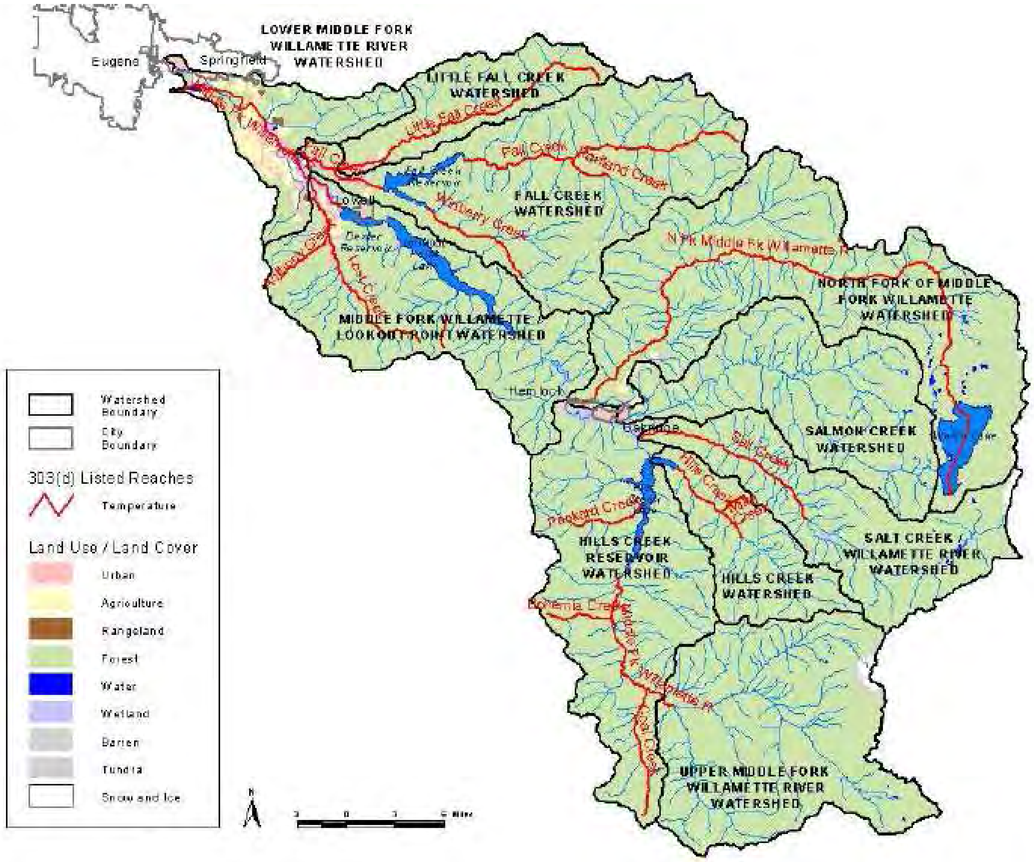


Figure 61. 303(d) listed streams for temperature in the Middle Fork subbasin (ODEQ 2006).

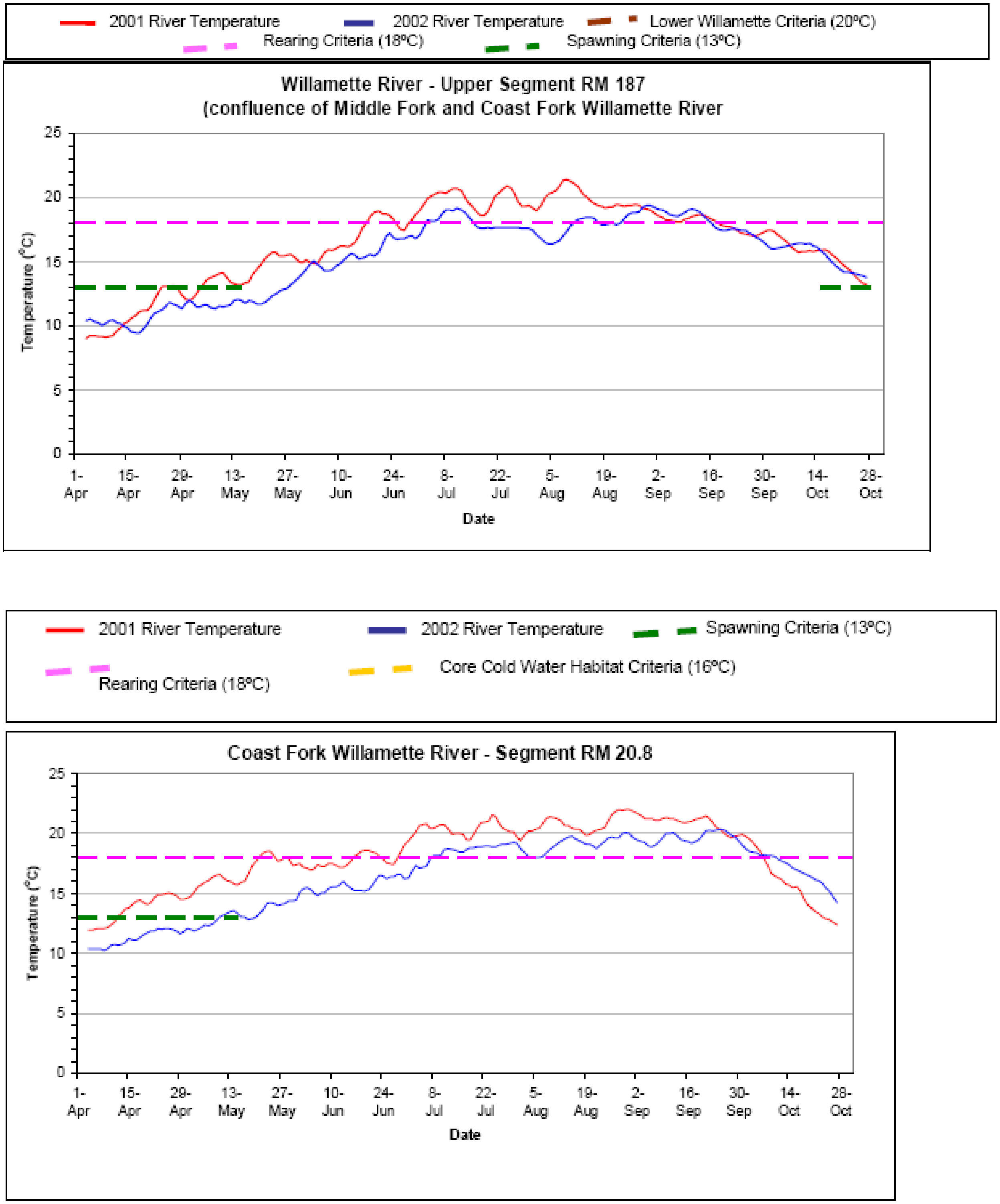


Figure 62. Coast Fork and mainstem Willamette observed temperatures compared to target temperatures (ODEQ 2006).

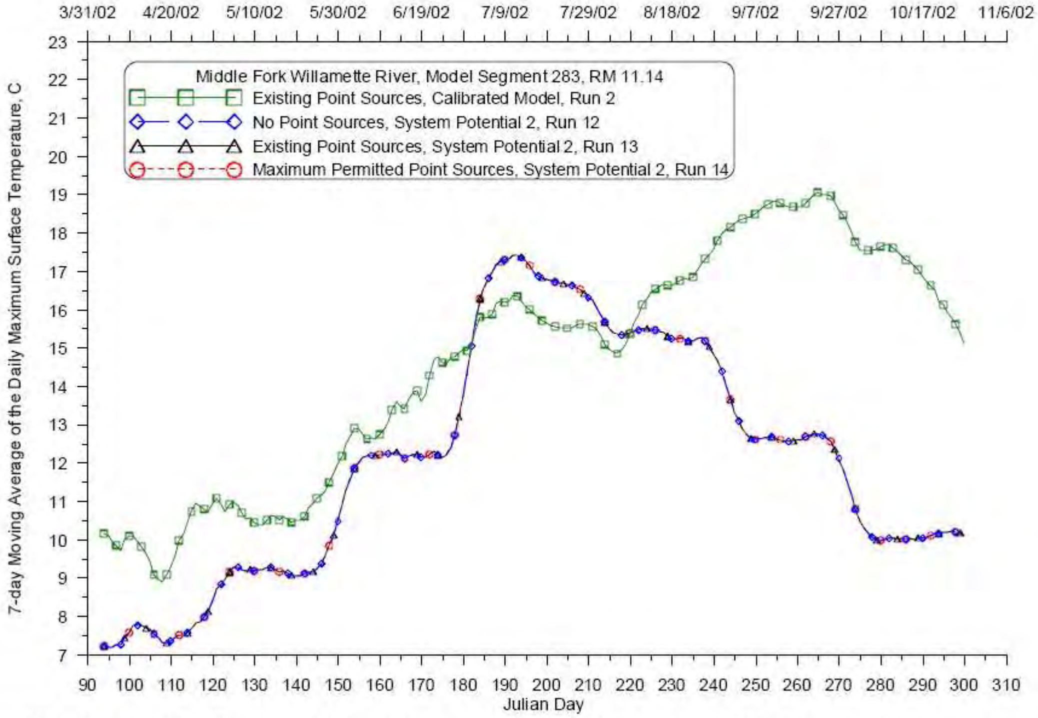


Figure 372: Calibrated model and System Potential 2 (varying point source discharges) 7-day moving average of the daily maximum temperature comparison for 2002 for the Middle Fork Willamette River at RM 11.14

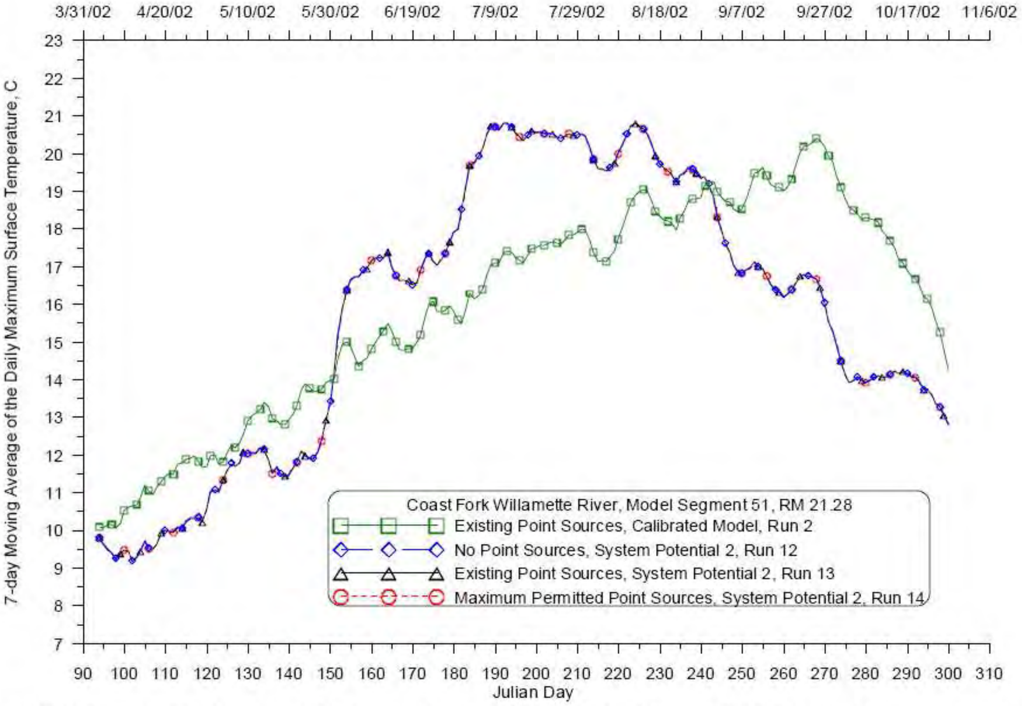


Figure 368: Calibrated model and System Potential 2 (varying point source discharges) 7-day moving average of the daily maximum temperature comparison for 2002 for the Coast Fork Willamette River at RM 21.28

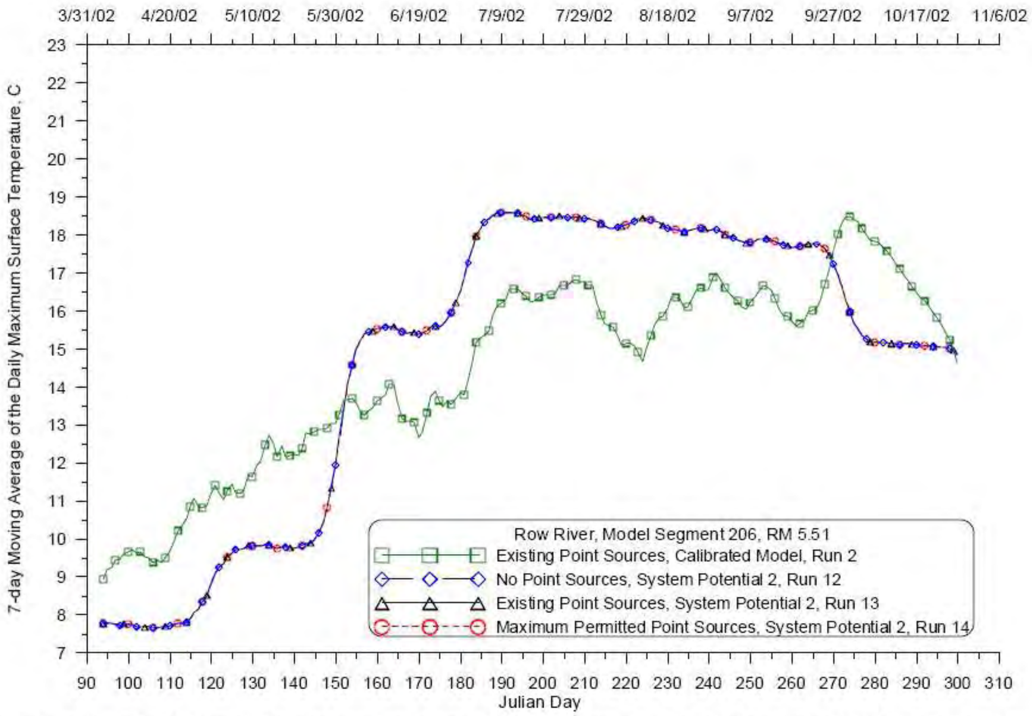


Figure 370: Calibrated model and System Potential 2 (varying point source discharges) 7-day moving average of the daily maximum temperature comparison for 2002 for the Row River at RM 5.51

Figure 63. Modeled changes in temperature under proposed changes and existing conditions in the Row River, Coast Fork and Middle Fork of the Willamette River (Annear et al 2004).

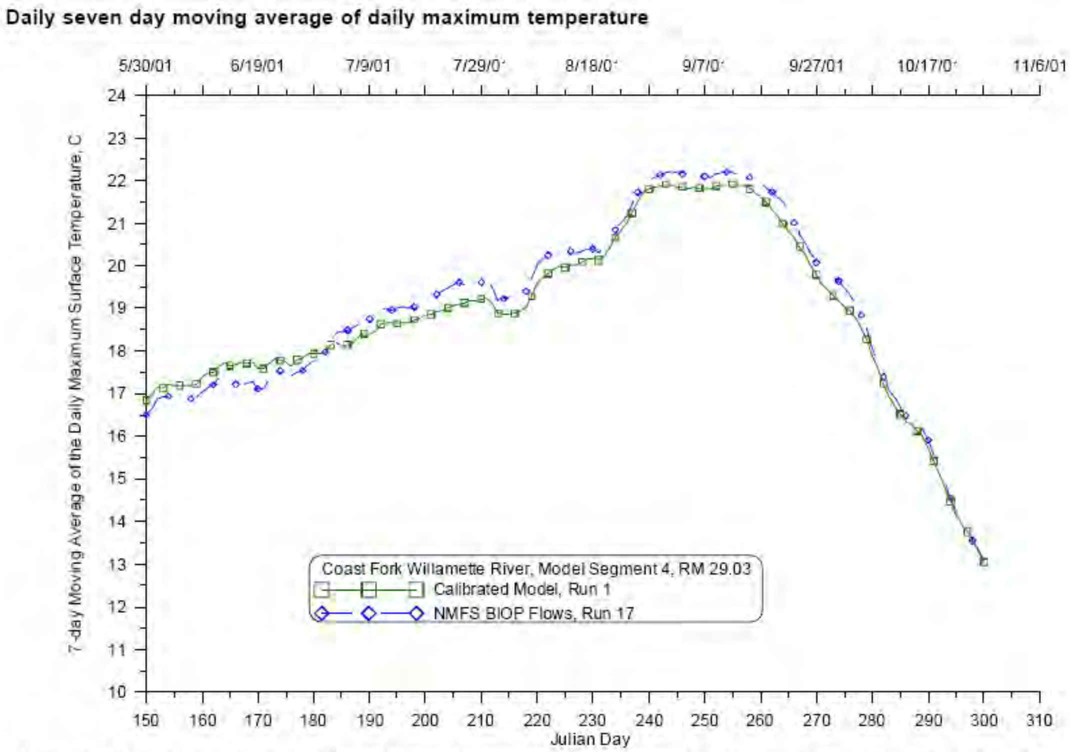


Figure 783: Calibrated model compared with NMFS Biological Opinion flows, 7-day average of the daily maximum temperature for 2001 for the Coast Fork Willamette River at RM 29.03

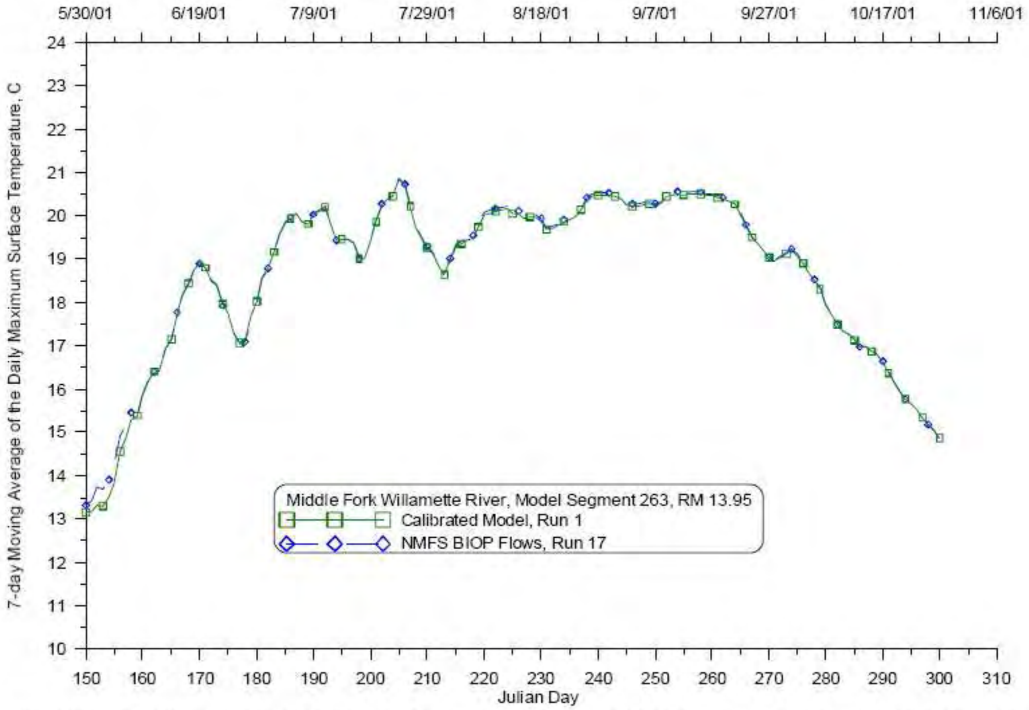
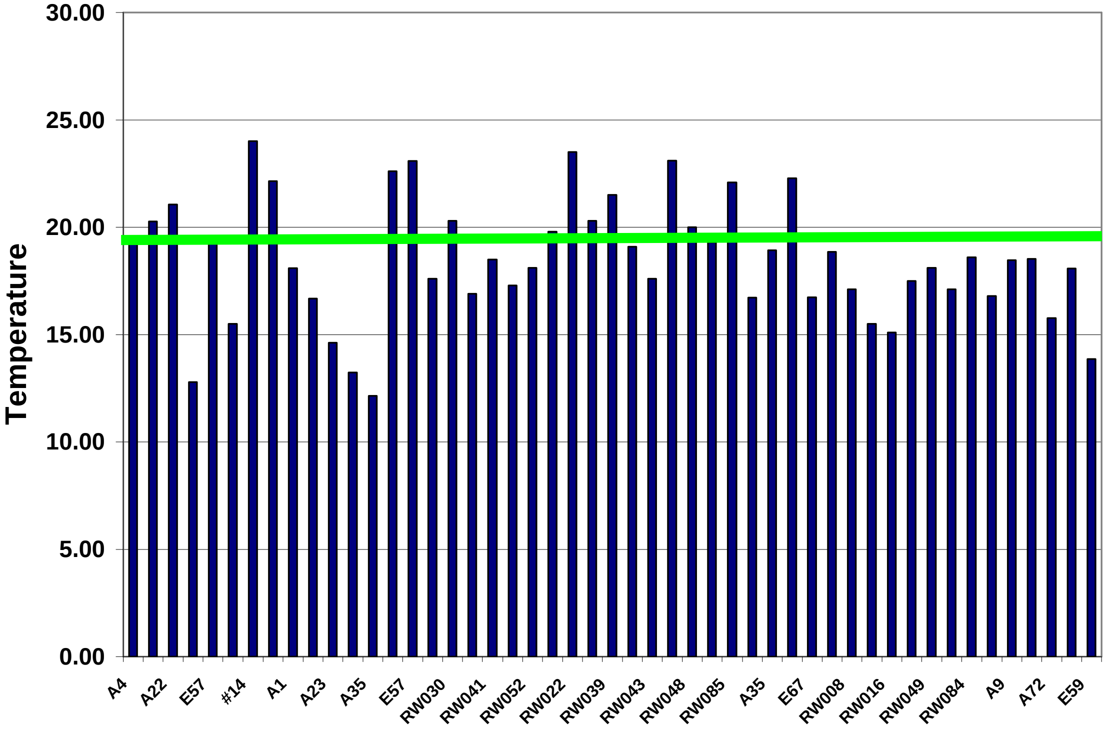


Figure 787: Calibrated model compared with NMFS Biological Opinion flows, 7-day average of the daily maximum temperature for 2001 for the Middle Fork Willamette River at RM 13.95

Figure 64. Modeled effects of NMFS Biological Opinion on stream temperatures for the Coast Fork and Middle Fork Willamette (Annear et al 2004).



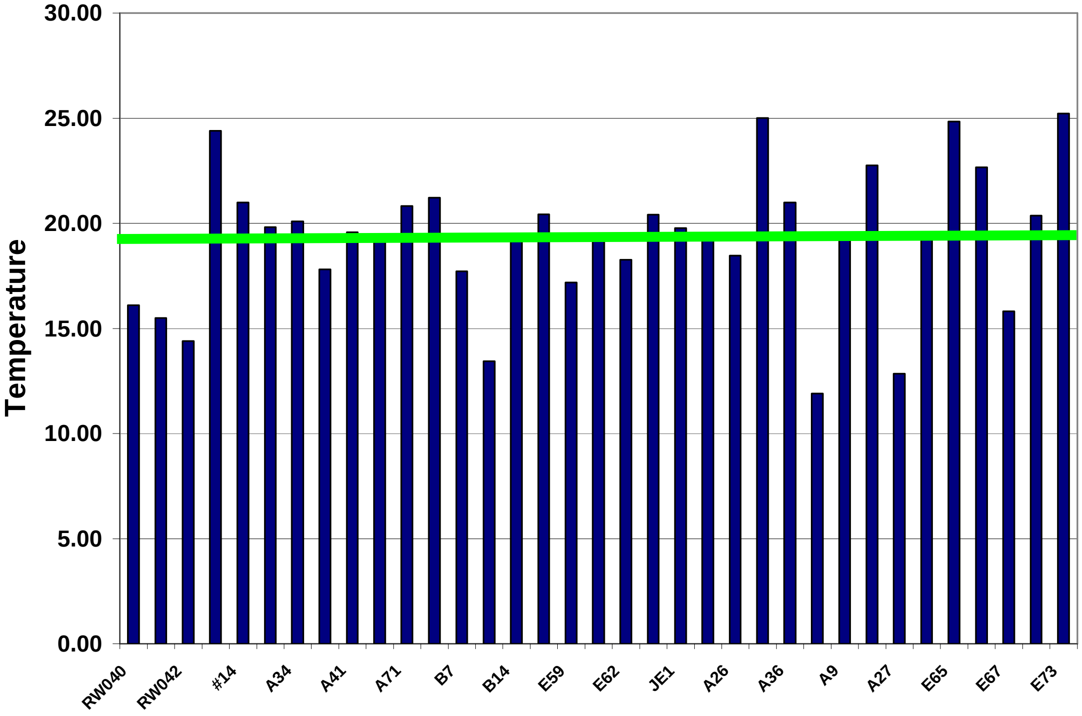


Figure 65. Temperatures of small (upper panel) and large (lower panel) off-channel alcoves on floodplains along the Willamette River (Gregory et al unpublished data).

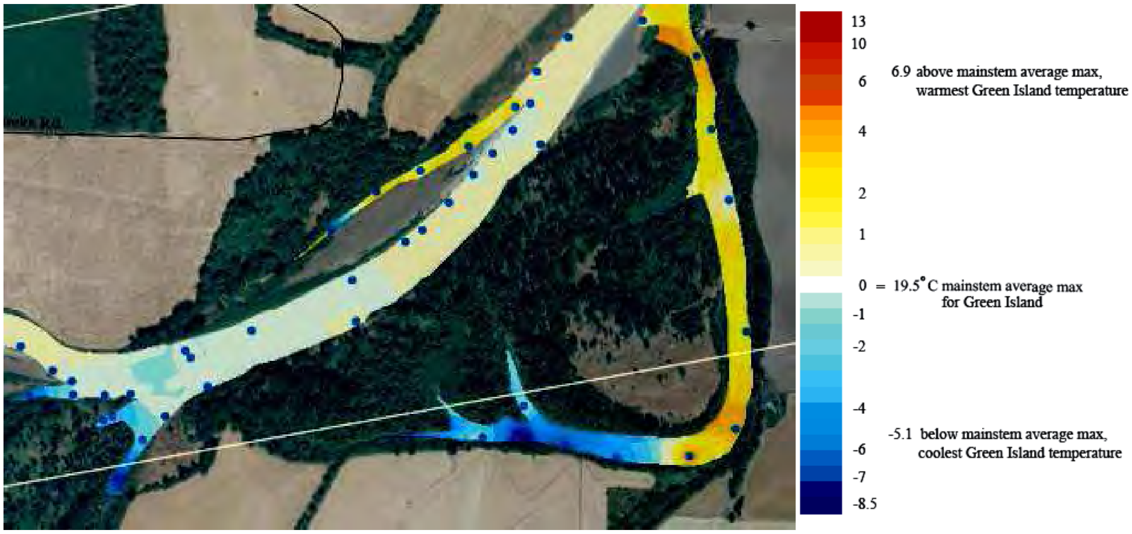


Figure 66. Norwood Island illustrating thermal gradients in off-channel habitats (Gregory et al unpublished data).

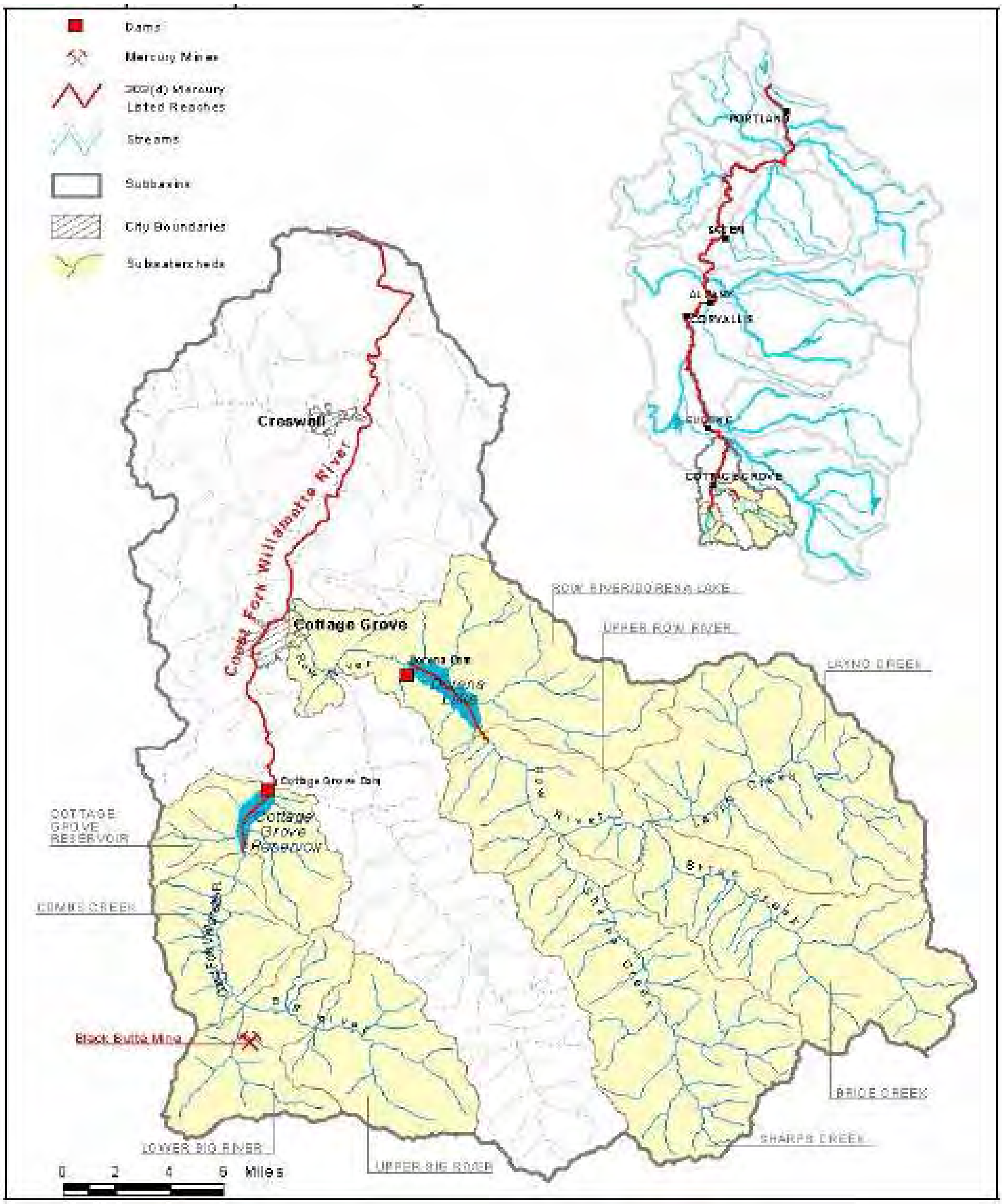


Figure 67. Mercury-contaminated reaches in the Coast Fork Willamette (ODEQ 2006).

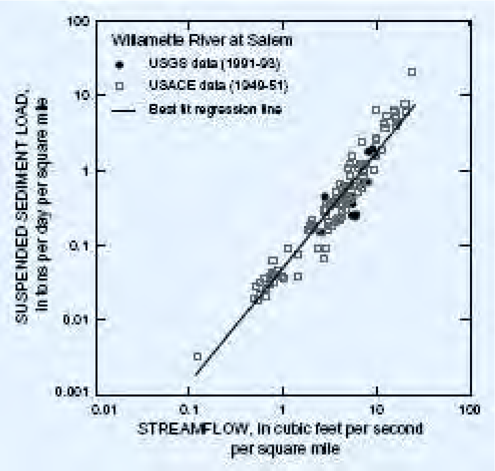


Figure 68. Relationship between suspended sediment transport and streamflow before and after dam construction (Wentz et al 1998, Laenen 1995).

U. S. ARMY, CORPS OF ENGINEERS **PORTLAND DISTRICT**

COAST FORK WILLAMETTE RIVER, OREGON MOUTH TO COTTAGE GROVE LAKE 13 JULY 1999 APPROXIMATE SCALE 1:12,000 SHEET 3 OF 8

Figure 69 a & b. Examples of revetment locations on the Coast (a, upper) and Middle Fork (b, lower) Willamette. (USACE 1999 Riverbook).

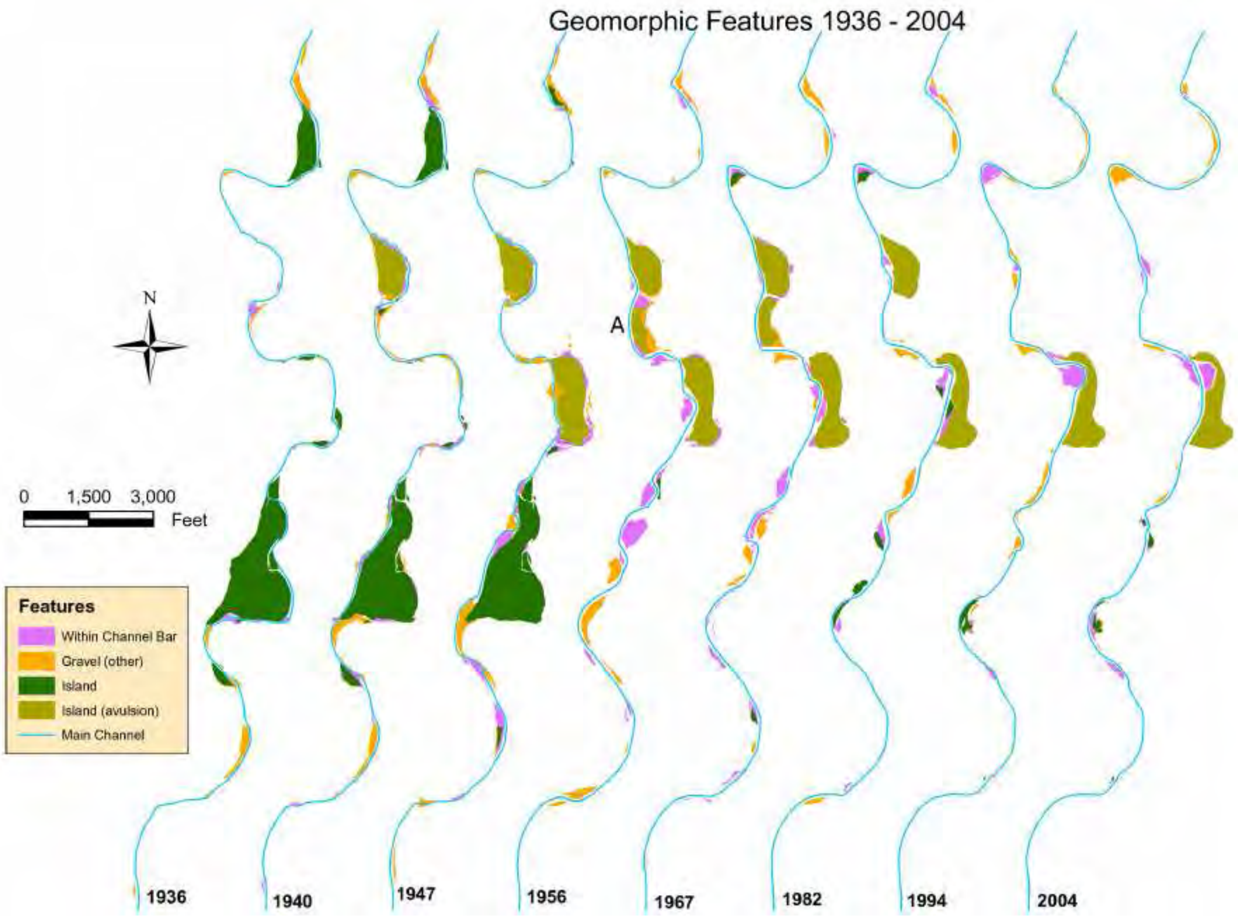


Figure 70. Coast Fork Willamette channel change between 1936 and 2004 (Dykaar 2005)

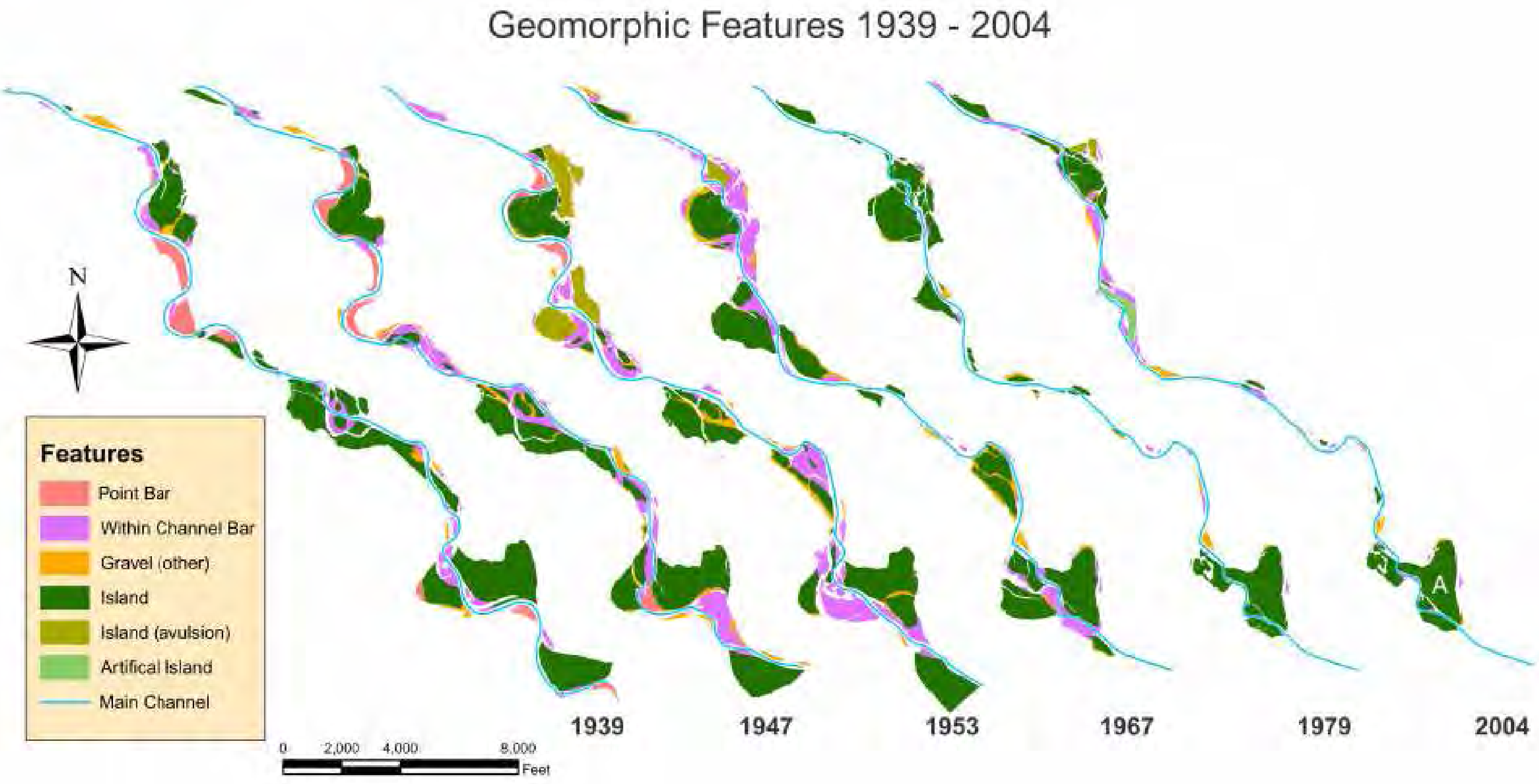


Figure 71. Middle Fork Willamette channel change 1939-2004 (Dykaar 2005).

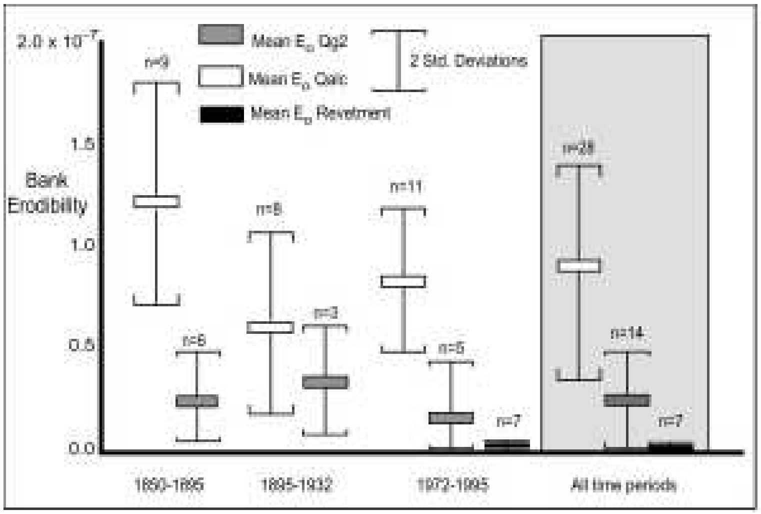


Figure 72. Bank Erodibility Trends for upper Willamette River 1850–1995. For all time intervals, Holocene Alluvium (Qalc) is on average 2–5 times more erodible than partially cemented Pleistocene Gravels (Qg2). Revetment installed along Qalc banks in the 1930's through 1970's is highly resistant to erosion. (Wallick et. al. 2006).

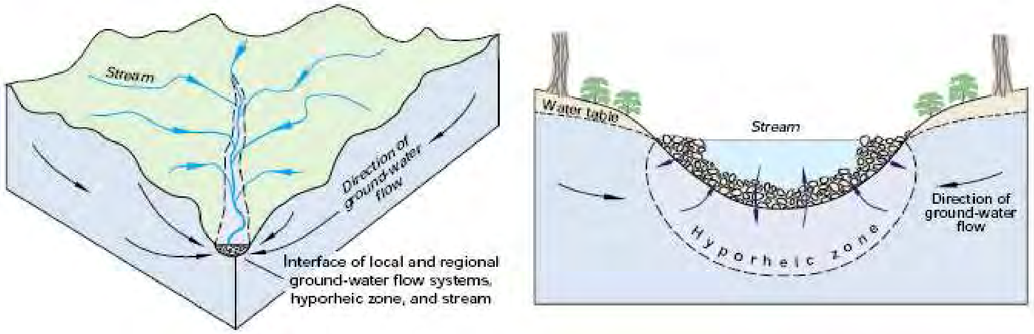


Figure 73. Relationship between surface water, groundwater, and hyporheic zones (Winter et al 1998).

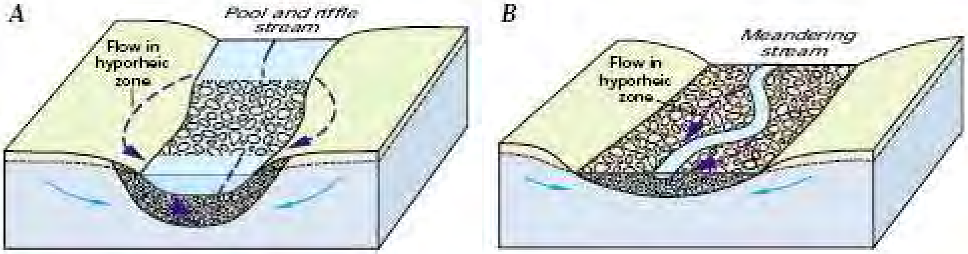


Figure 74. Effects of slope (left panel) and stream meanders (right panel) on hyporheic connections (Winter et al 1998).

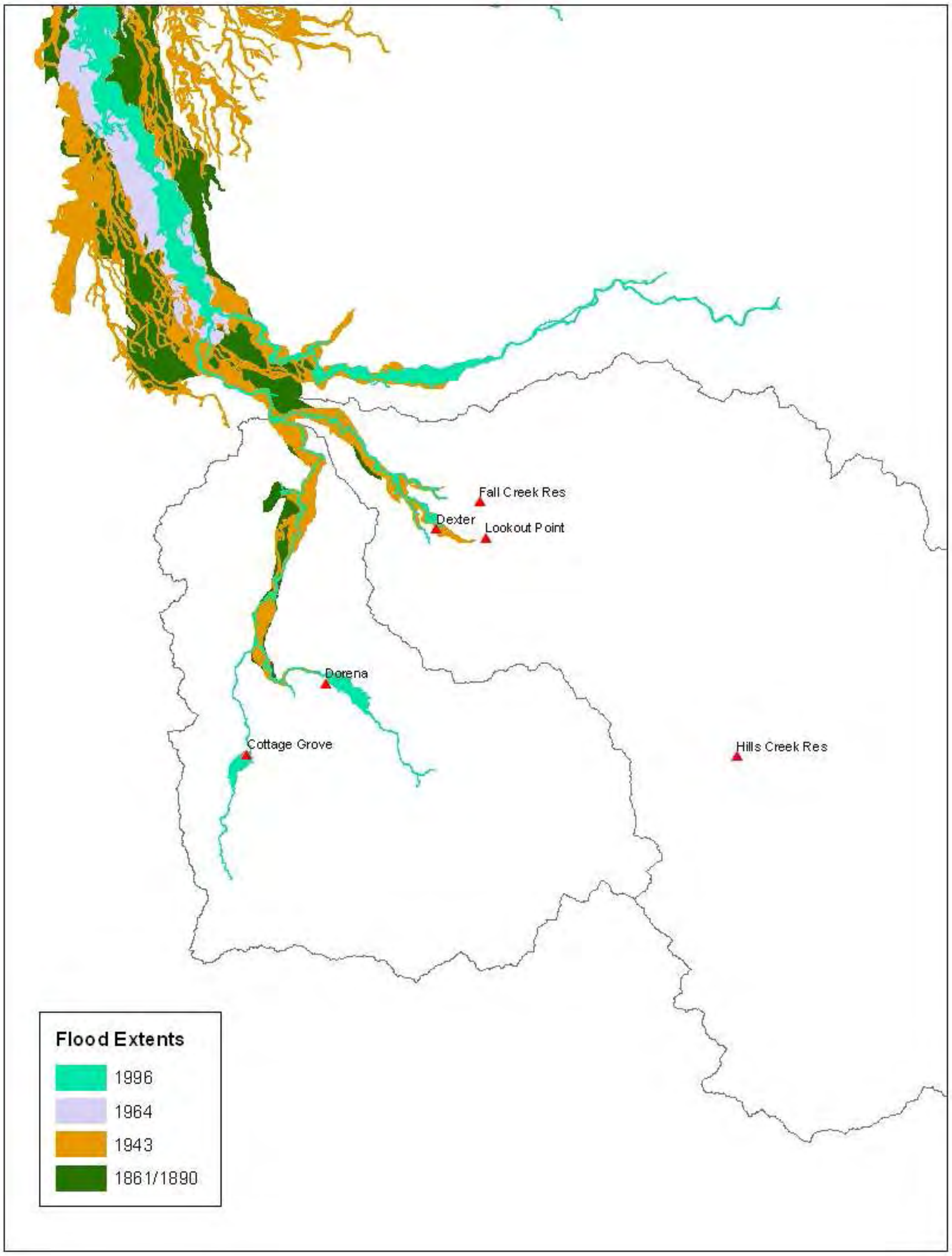


Figure 75. Historical flood extents. Note that imagery for 1964 flood was not collected above Eugene. During 1996 flood, maximum extents of high water had receded slightly above Eugene by the time air photos were taken. Extents of 1943/45 and 1861/90 based on USACE historical maps. See PNWERC 2002 for more detail.

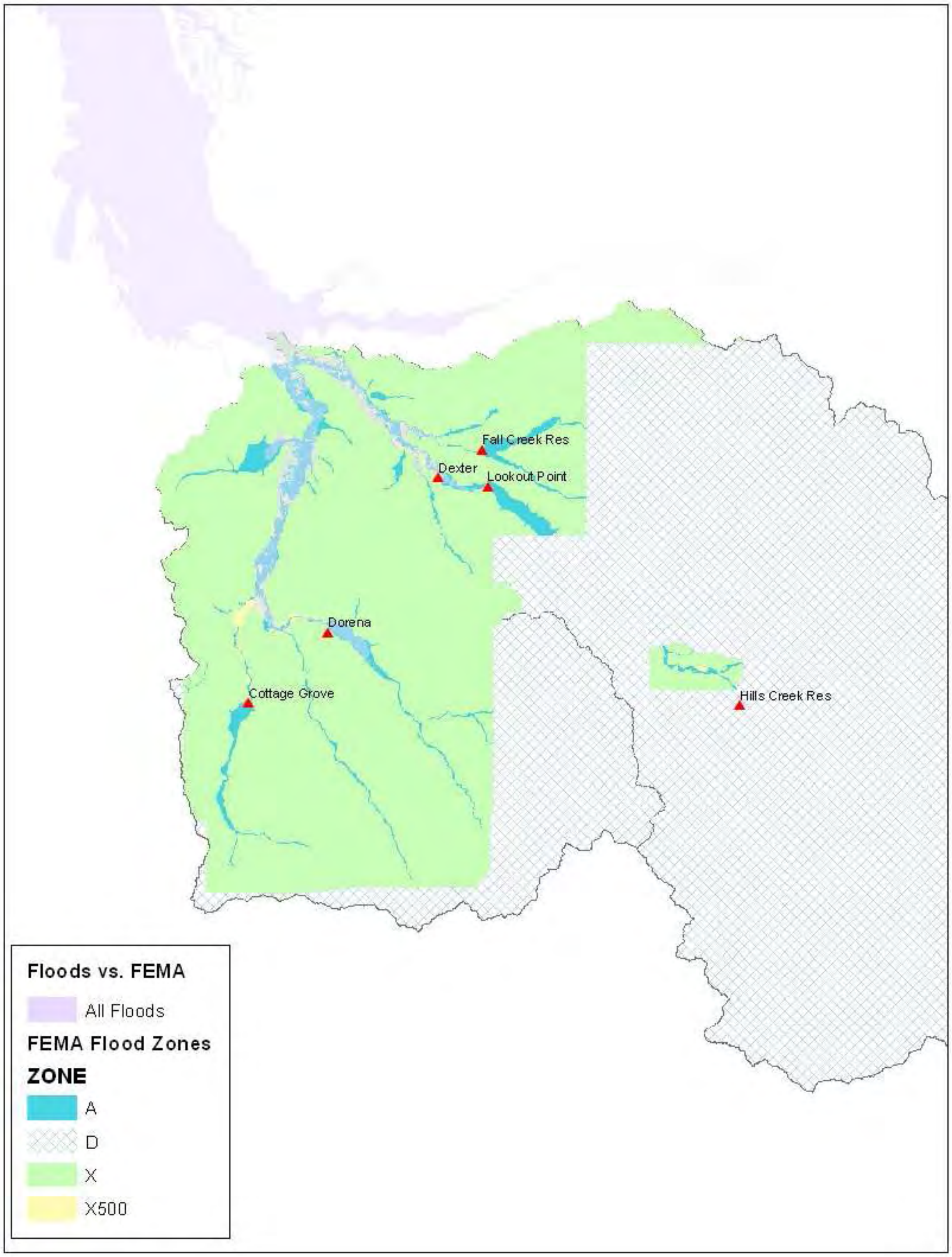


Figure 76. FEMA flood extents in Coast and Middle Forks and maximum extent of historical floods.

FEMA Zone Codes:

A = 100 yr flood zone; D = Flood hazard undetermined; X= Outside 100 & 500 year floodplain; X500 = 500 year flood zone; or 100 year floodplain of <1 ft depth; or levee protected from 100 yr flood

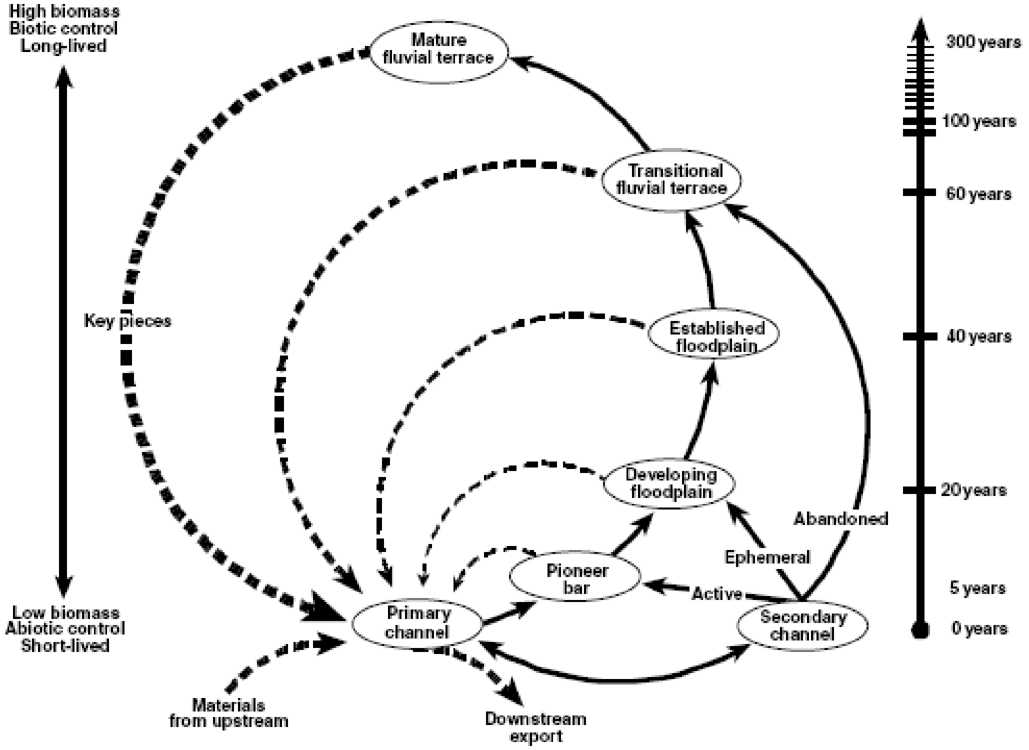


Figure 77. The cycle of channel and floodplain creation and destruction in the Pacific Northwest (Latrelle et al 2006).

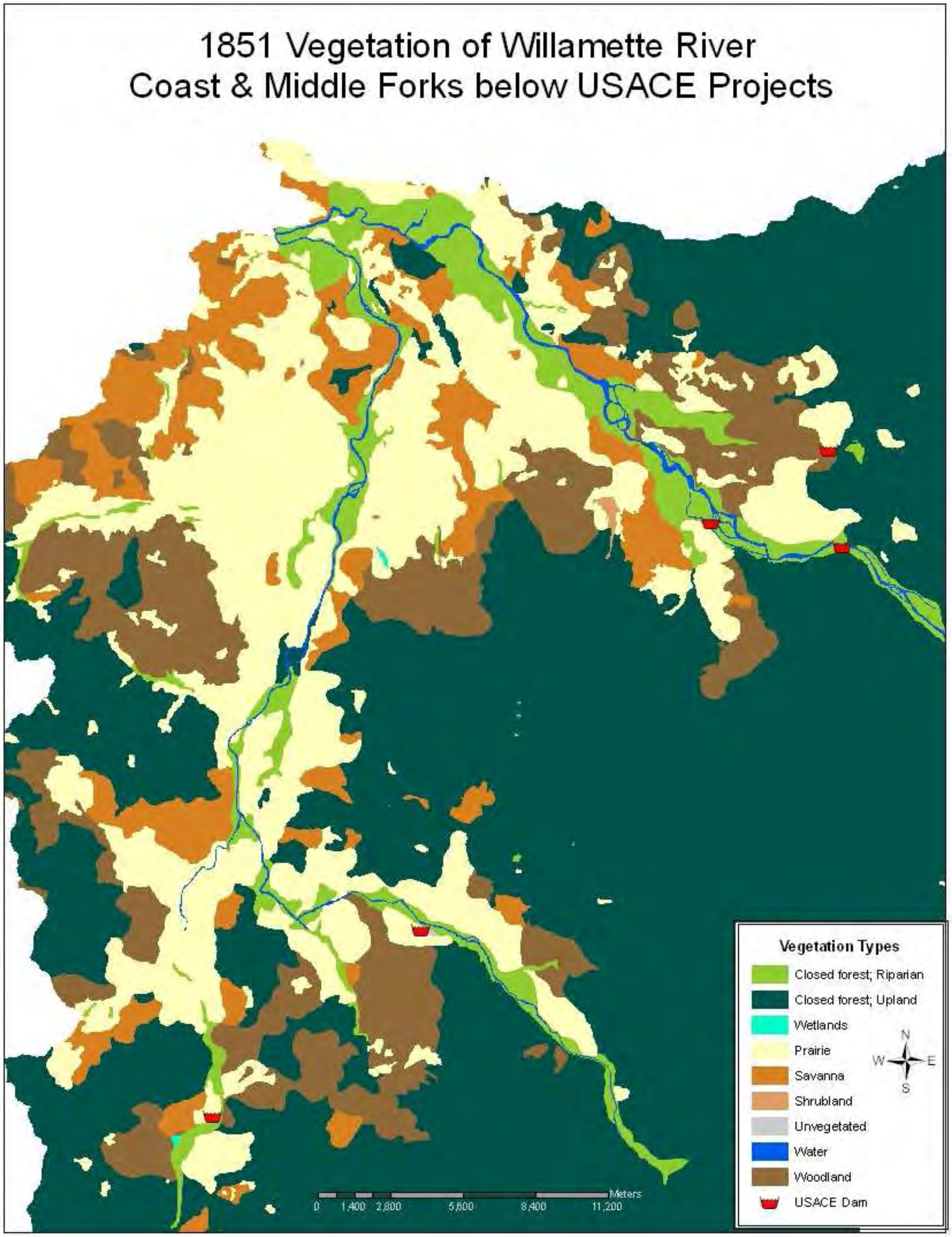


Figure 78. Pre-settlement vegetation (ca. 1850) within and adjacent to the floodplain, Coast and Middle Forks of the Willamette River (PNWERC 2002).

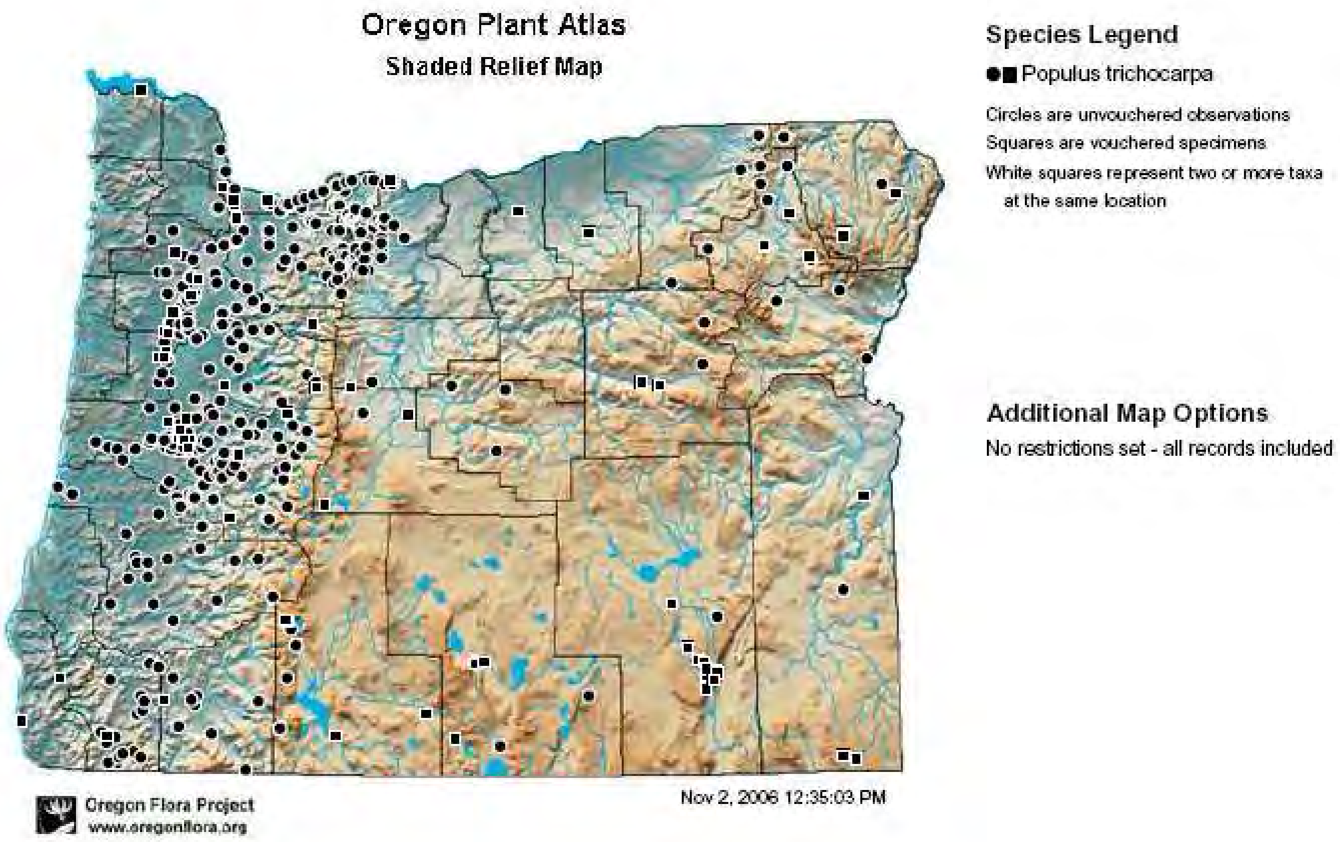


Figure 79. Black cottonwood collected in Oregon: OSU Herbarium records, Oregon Flora Project.

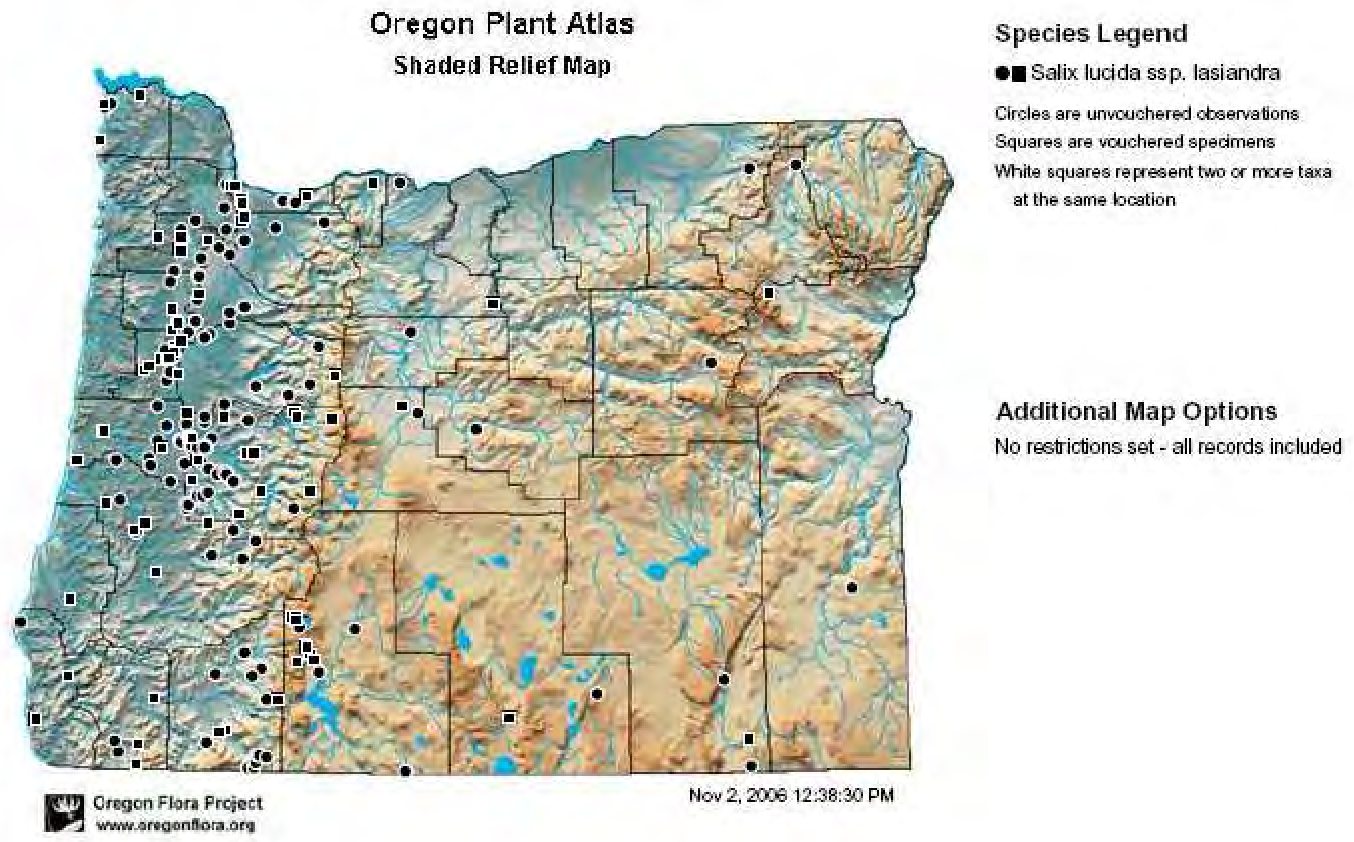


Figure 80. Pacific willow collected in Oregon: OSU Herbarium records, Oregon Flora Project

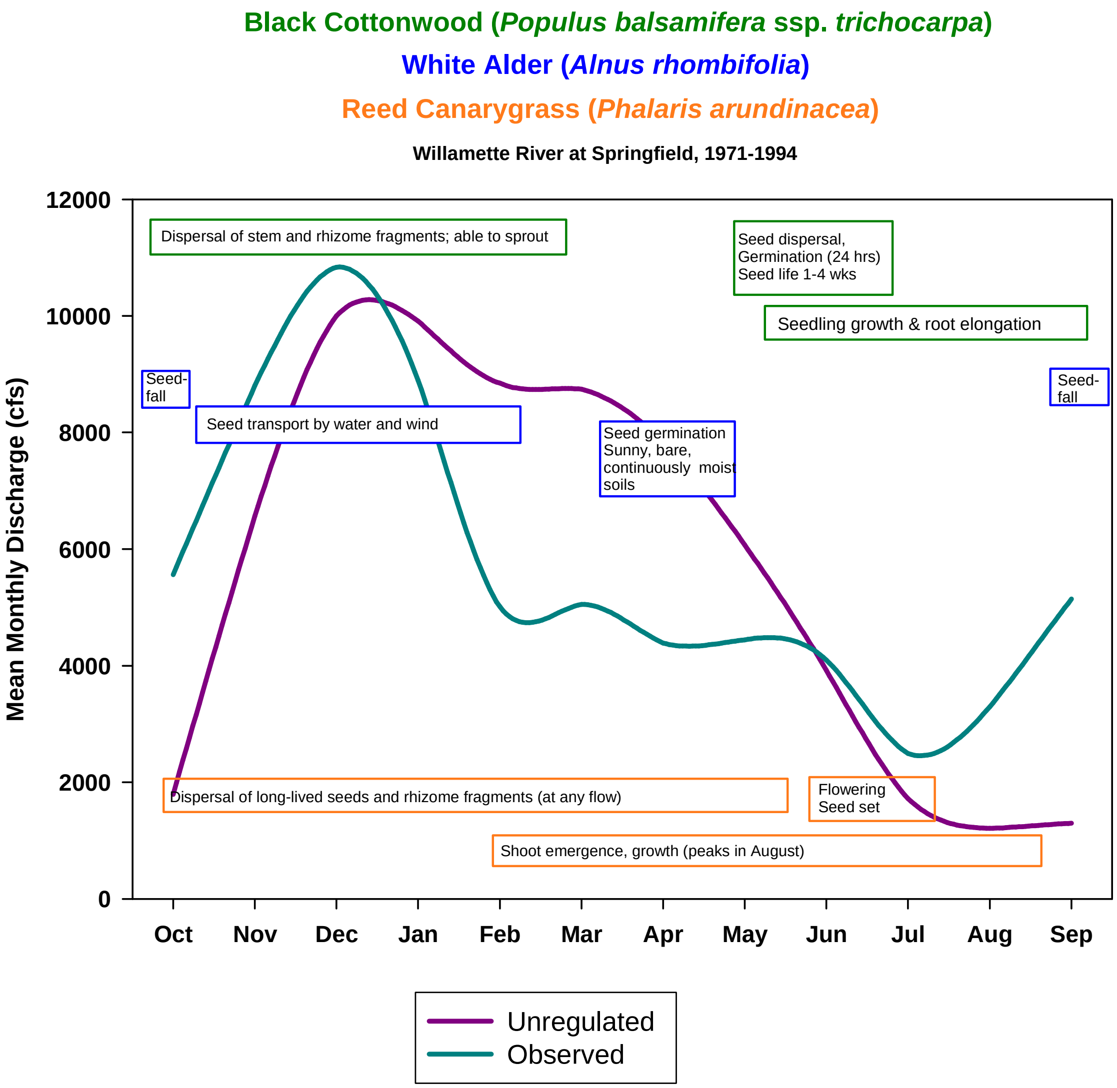


Figure 81. Life history stages and timing of three floodplain plant species (two trees and one grass) in relation to discharge (observed and unregulated).

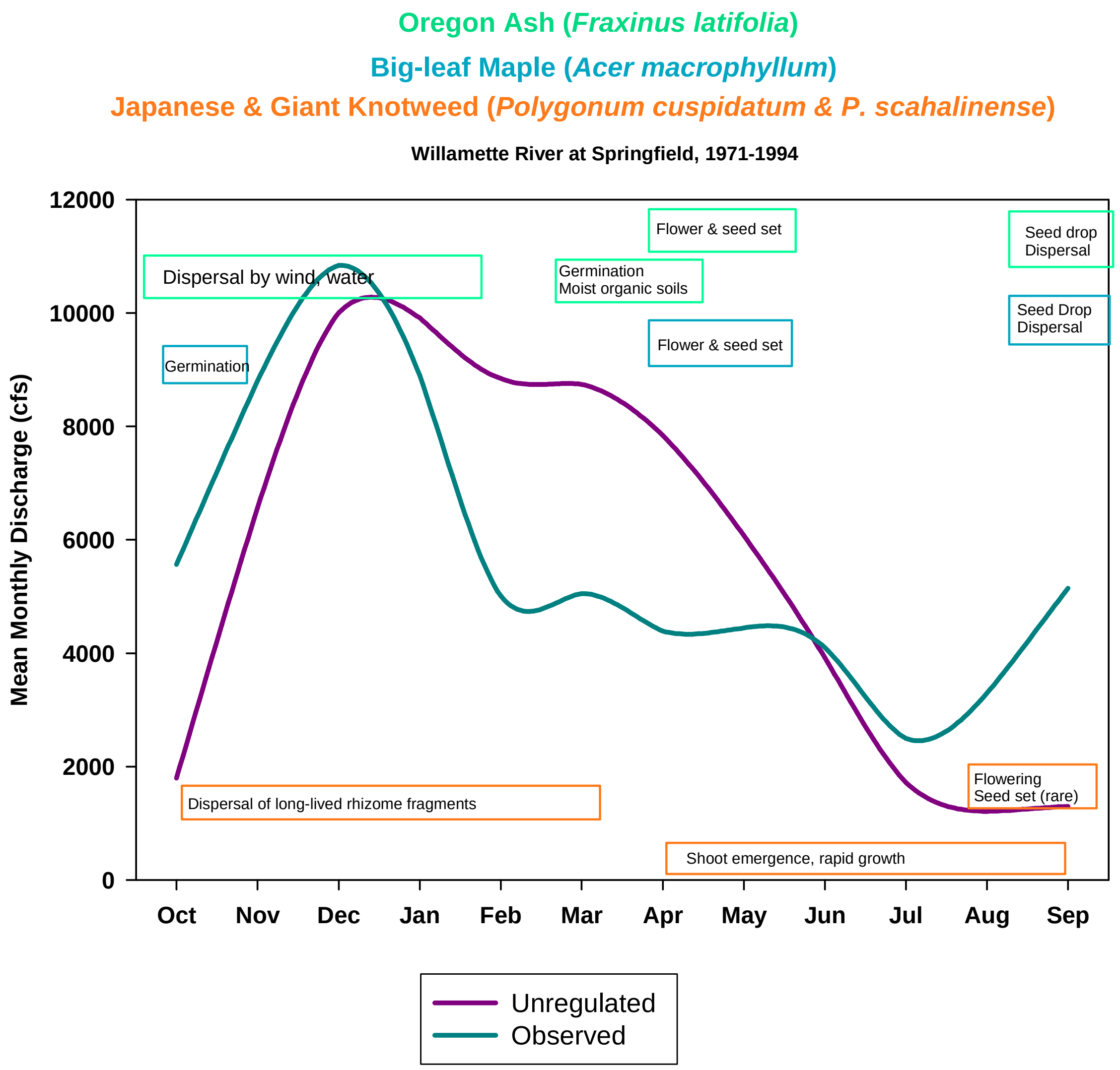


Figure 82. Life history stages and timing of four floodplain plant species (two trees and two invasive perennials) in relation to discharge (observed and unregulated).

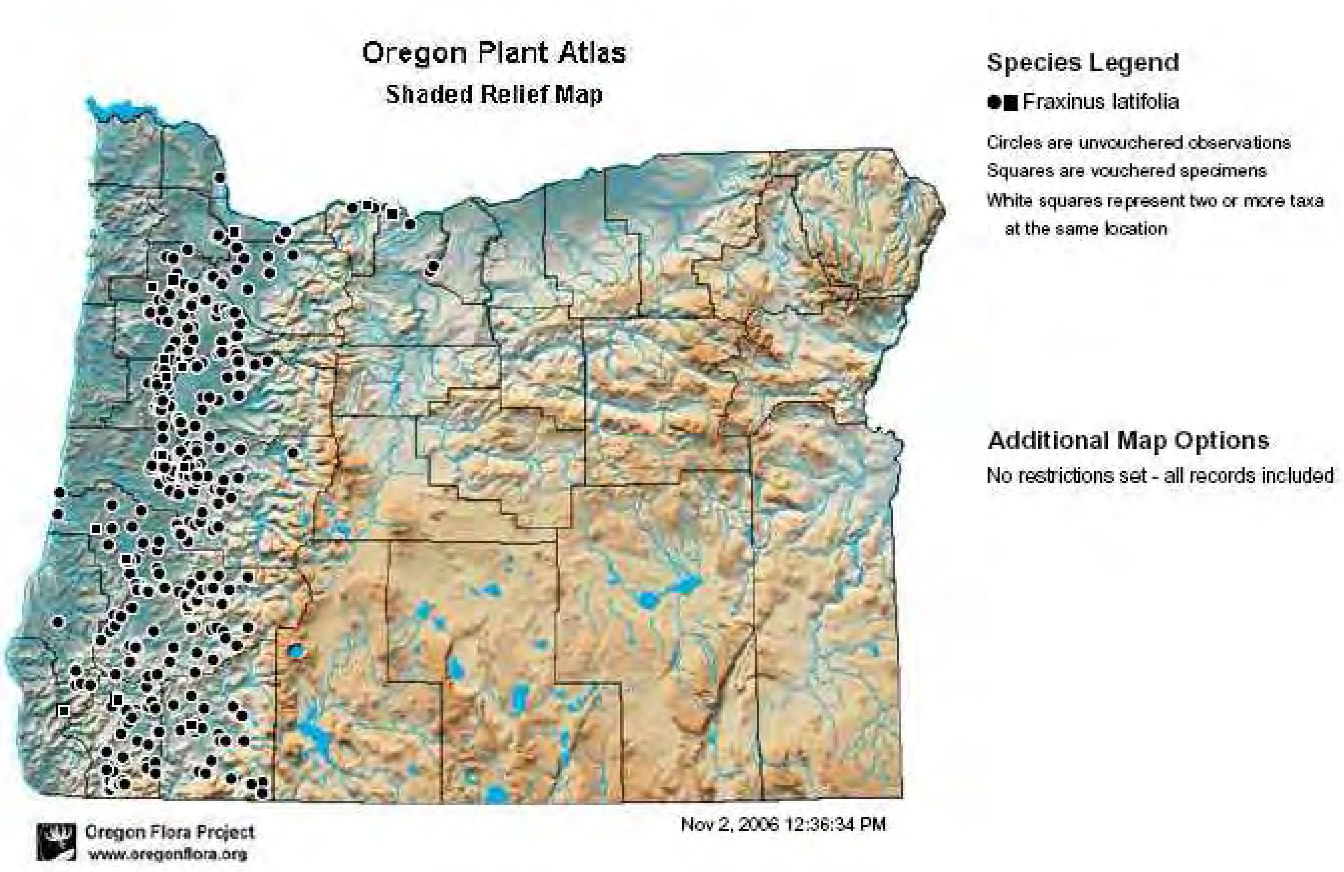


Figure 83. Oregon ash collected in Oregon: OSU Herbarium records, Oregon Flora Project.

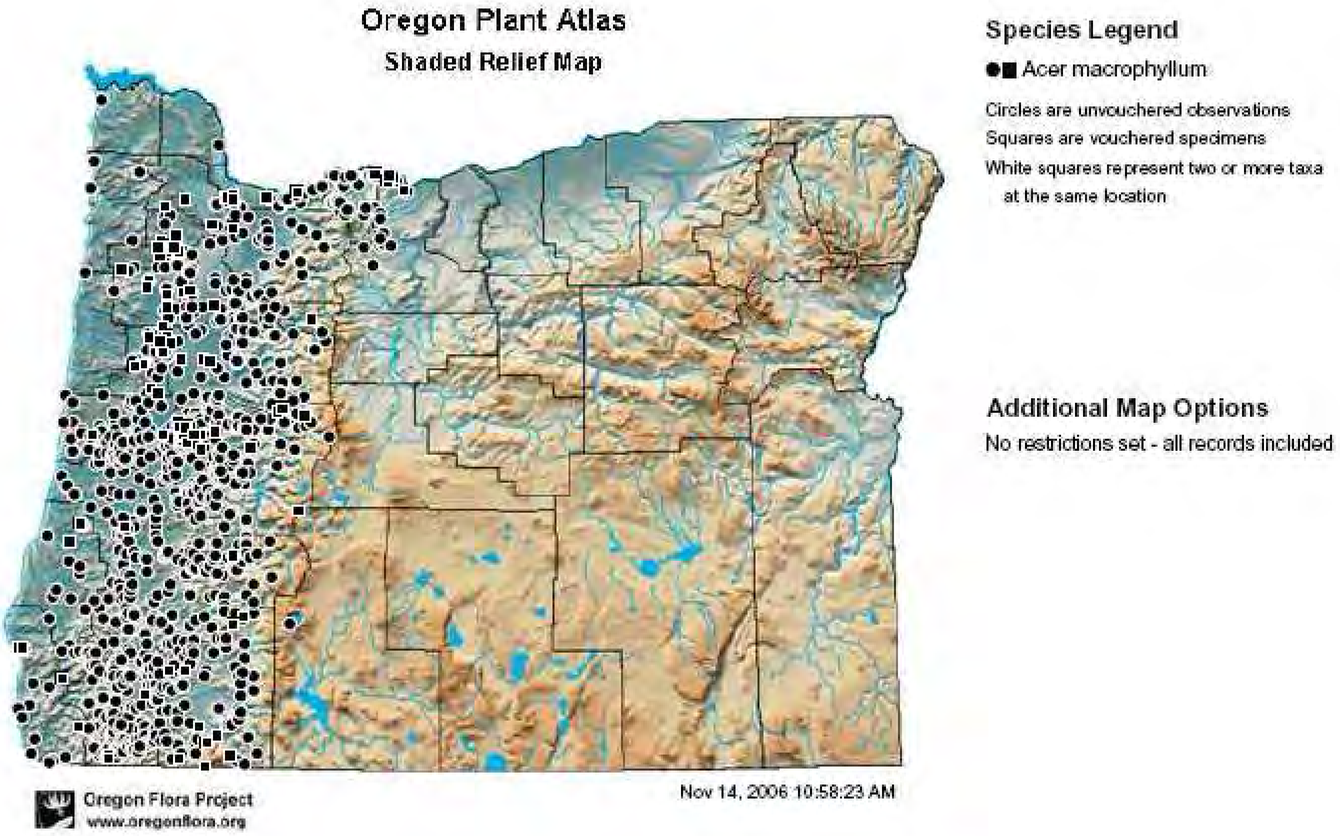


Figure 84. Big-leaf maple collected in Oregon: OSU Herbarium records, Oregon Flora Project.

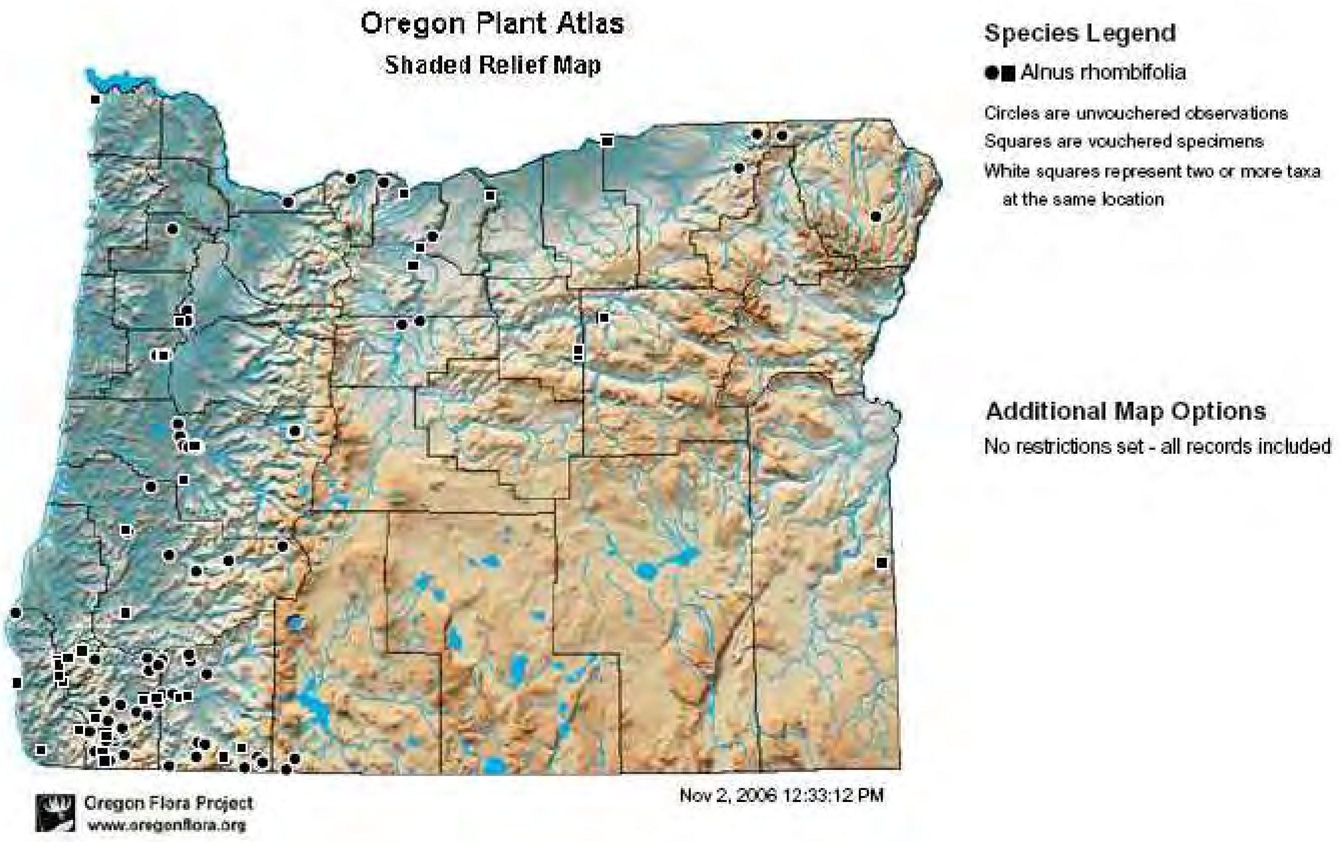


Figure 85. White alder collected in Oregon: OSU Herbarium records, Oregon Flora Project.

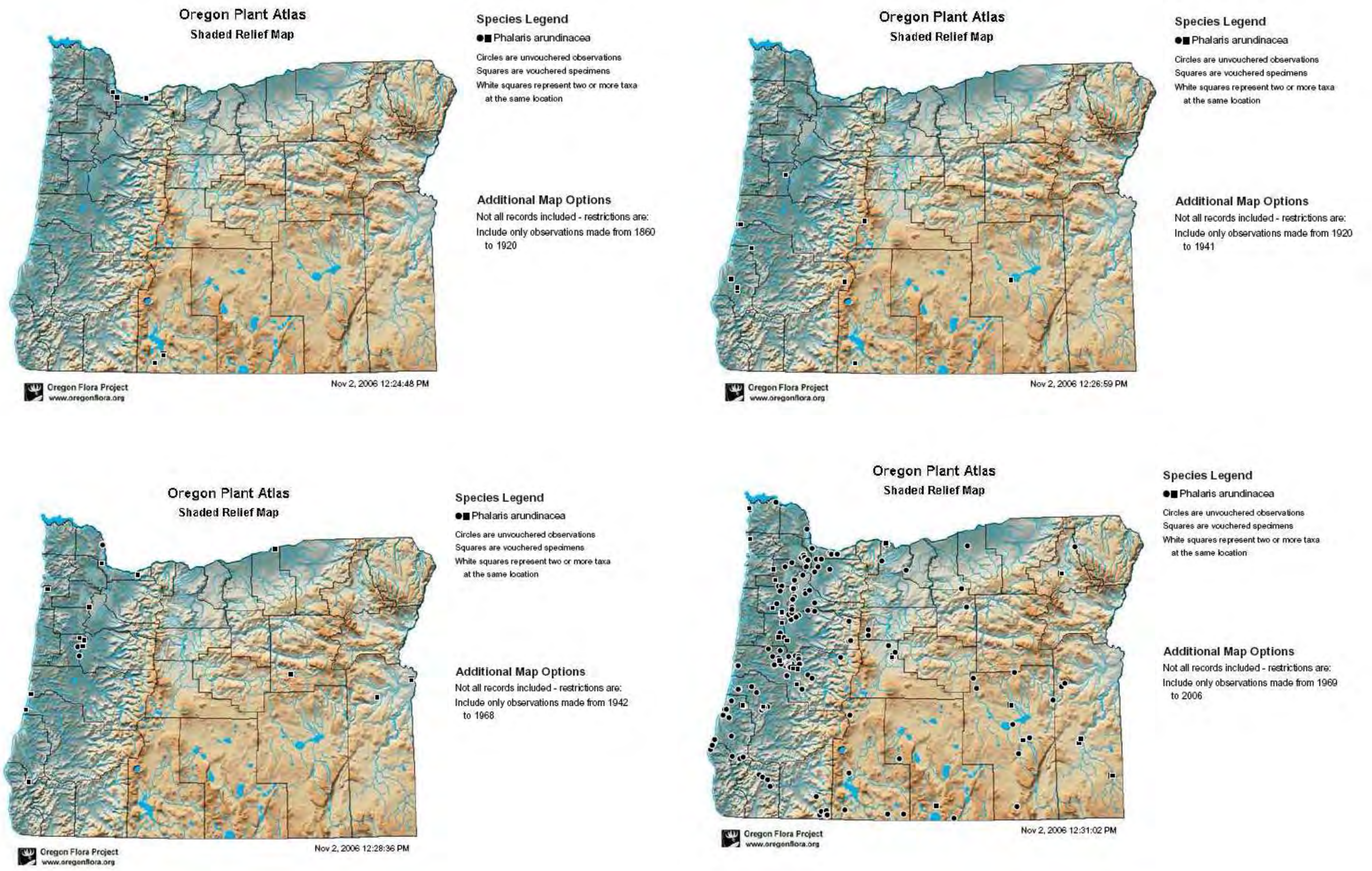


Figure 86: Change in distribution of reed canarygrass as indicated by collections in the OSU Herbarium, Oregon Flora Project.

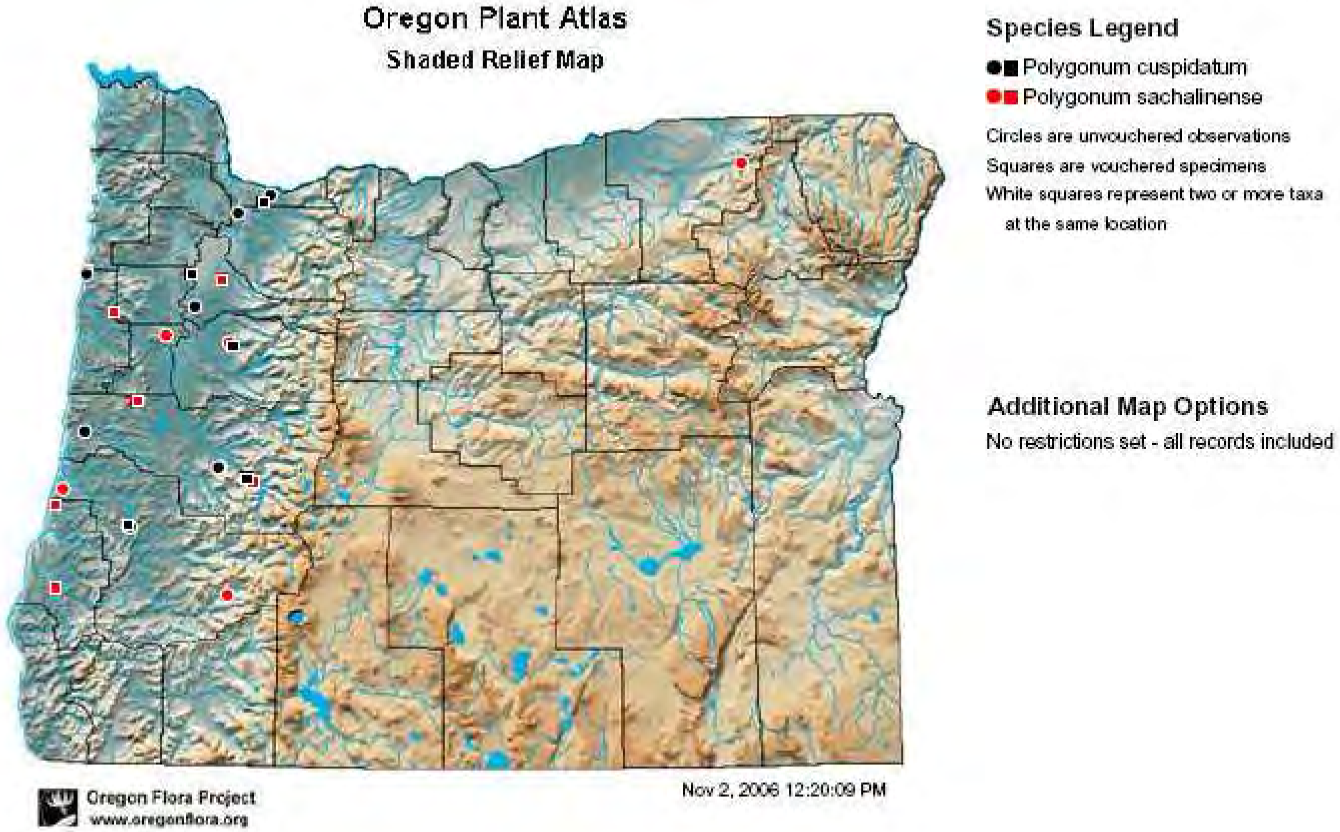
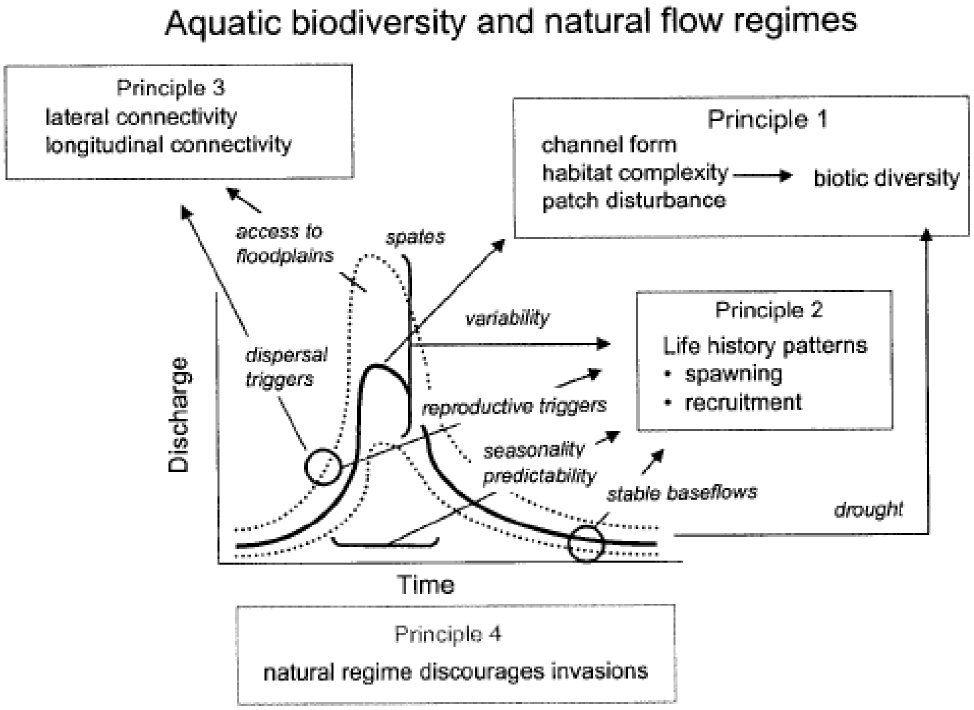


Figure 40: Distribution of knotweed species as indicated by collections in the OSU Herbarium, Oregon Flora Project.



The natural flow regime of a river influences aquatic biodiversity via several interrelated mechanisms that operate over different spatial and temporal scales. The relationship between biodiversity and the physical nature of the aquatic habitat is likely to be driven primarily by large events that influence channel form and shape (principle 1). However, droughts and low-flow events are also likely to play a role by limiting overall habitat availability. Many features of the flow regime influence life history patterns, especially the seasonality and predictability of the overall pattern, but also the timing of particular flow events (principle 2). Some flow events trigger longitudinal dispersal of migratory aquatic organisms and other large events allow access to otherwise disconnected floodplain habitats (principle 3). The native biota have evolved in response to the overall flow regime. Watershed land-use change and associated water resource development inevitably lead to changes in one or more aspects of the flow regime resulting in declines in aquatic biodiversity via these mechanisms. Invasions by introduced or exotic species are more likely to succeed at the expense of native biota if the former are adapted to the modified flow regime (principle 4). (Bunn & Athington 2002).

Figure 88. The role of discharge regime in aquatic biodiversity—note this encompasses more than just invertebrates.

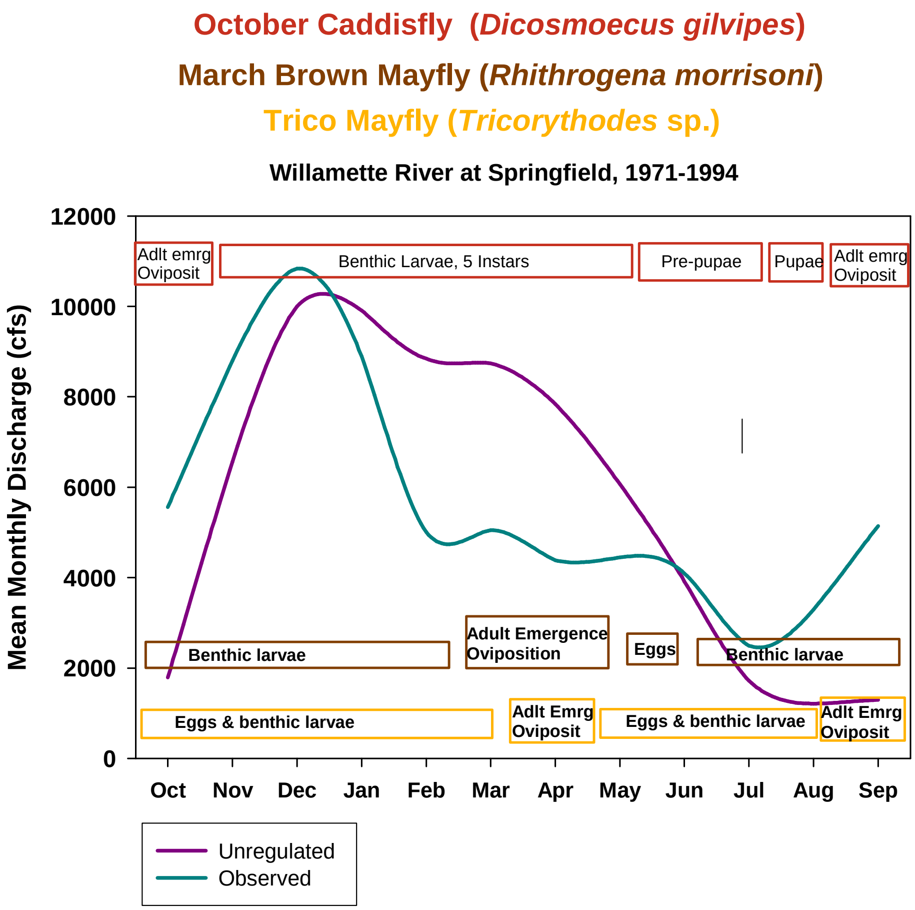


Figure 89. Examples of aquatic insect life histories from three relatively short-lived species in relation to discharge regime (unregulated and observed).

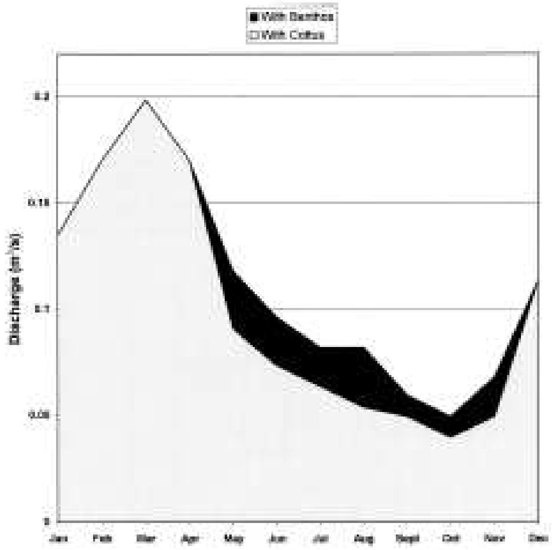
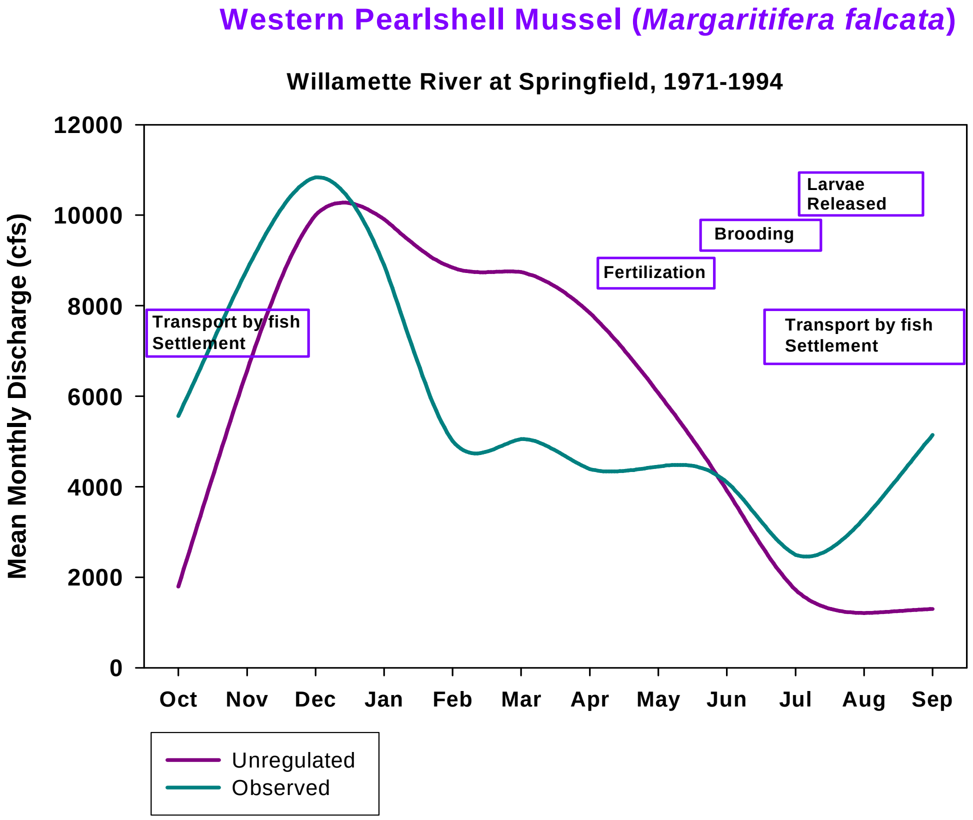


Figure 90. A comparison of recommended monthly minimum releases on Queens Creek, North Carolina, with a 20% reduction in habitat allowed. Based on predictions using only a benthic fish (Cottus bairdi) and including benthic macroinvertebrate diversity. This results in a 4.3% annual volumetric increase to protect benthos. (Gore et al. 2001).


Western Pearlshell Mussel (*Margaritifera falcata*)

Willamette River at Springfield, 1971-1994

Figure 91. Freshwater mussel life history in relation to flow regime (unregulated and observed).

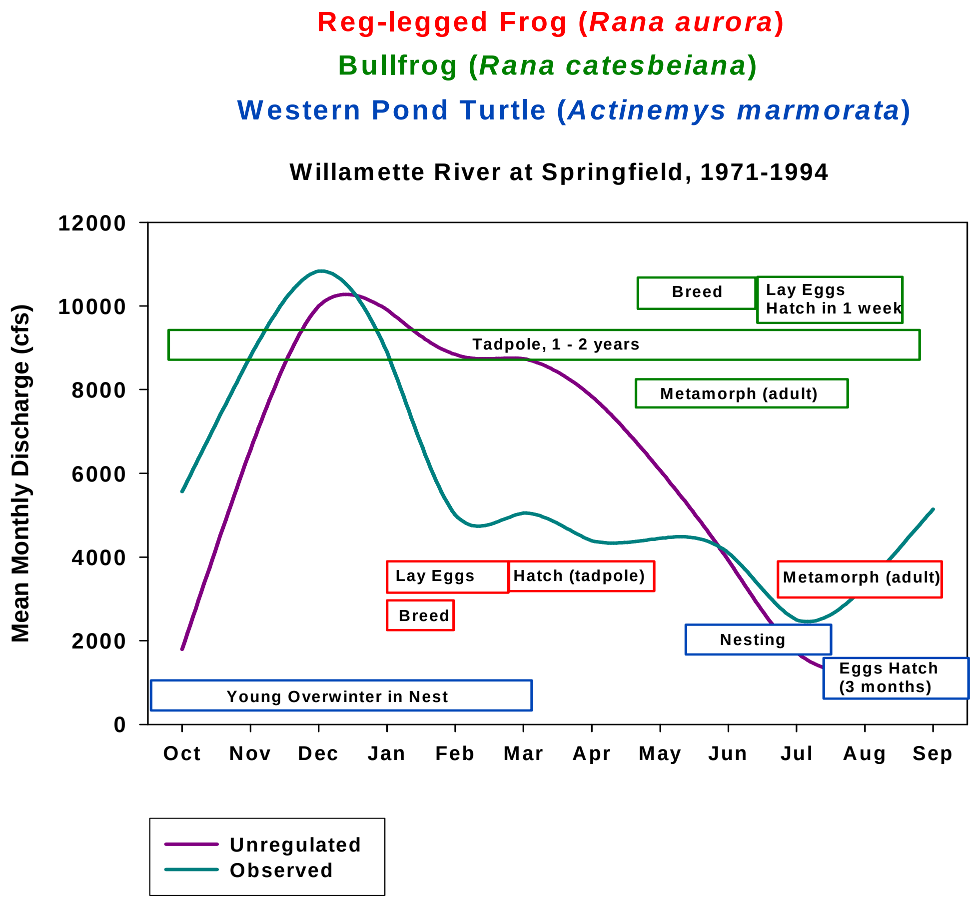


Figure 92. Native frog (*Rana aurora*) and turtle (*Actinemys marmorata*) and introduced (*R. catesbeiana*) frog life histories in relation to flow regime (unregulated and observed).

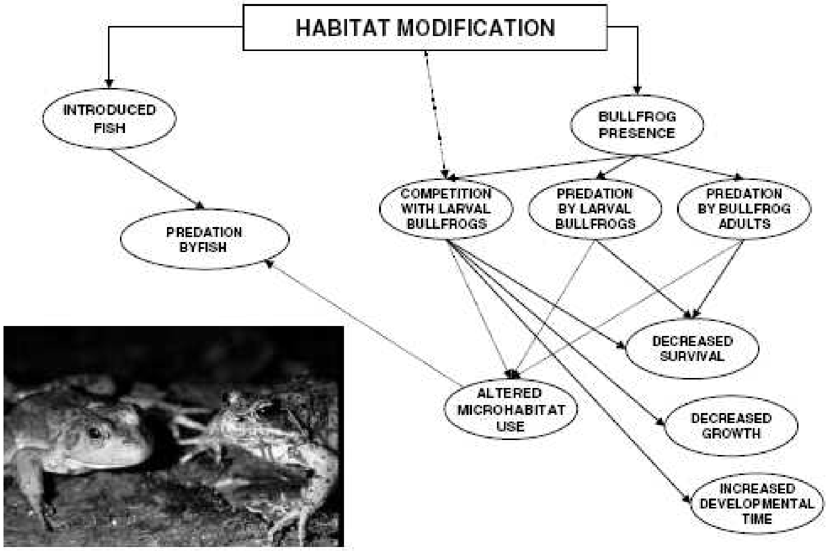


Figure 93. Interaction web for impacts of habitat modification, introduced bullfrogs, *Rana catesbeiana* (left), and predatory fish on red-legged frogs, *Rana aurora* (right), in the western United States. Arrows represent direct (solid) and indirect (dashed) interactions that have been tested in experimental studies in Oregon, Washington, and California. Other direct and indirect interactions are possible but have not been tested experimentally. (Blaustein & Kiesecker 2002).

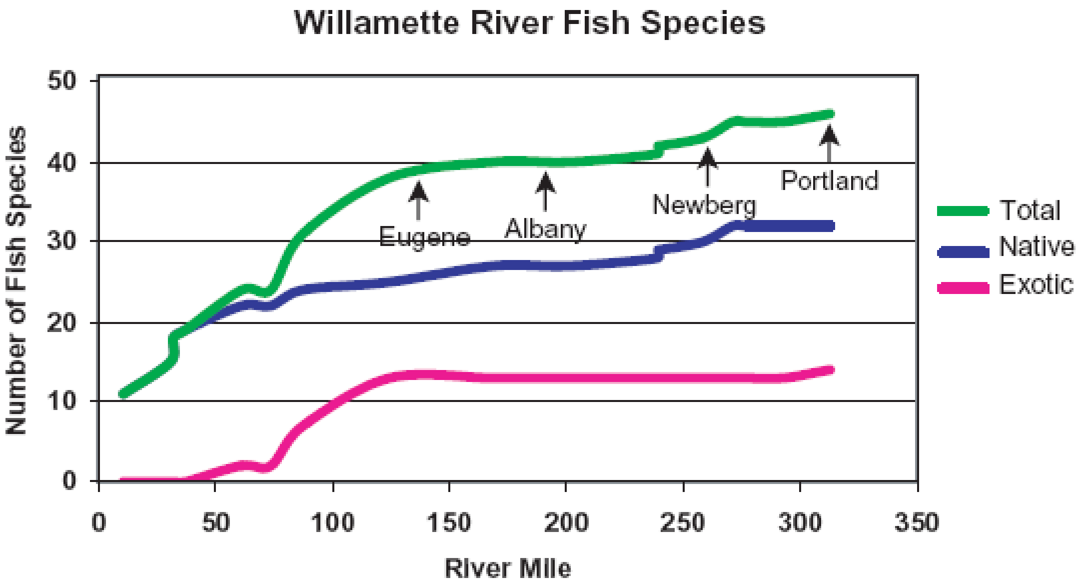


Figure 94. Longitudinal pattern of cumulative number of fish species (native, introduced, total) from the headwaters of the Middle Fork of the Willamette River to the mouth in Portland. Fish species presence is projected between points of known species occurrence. (PNWERC 2002)

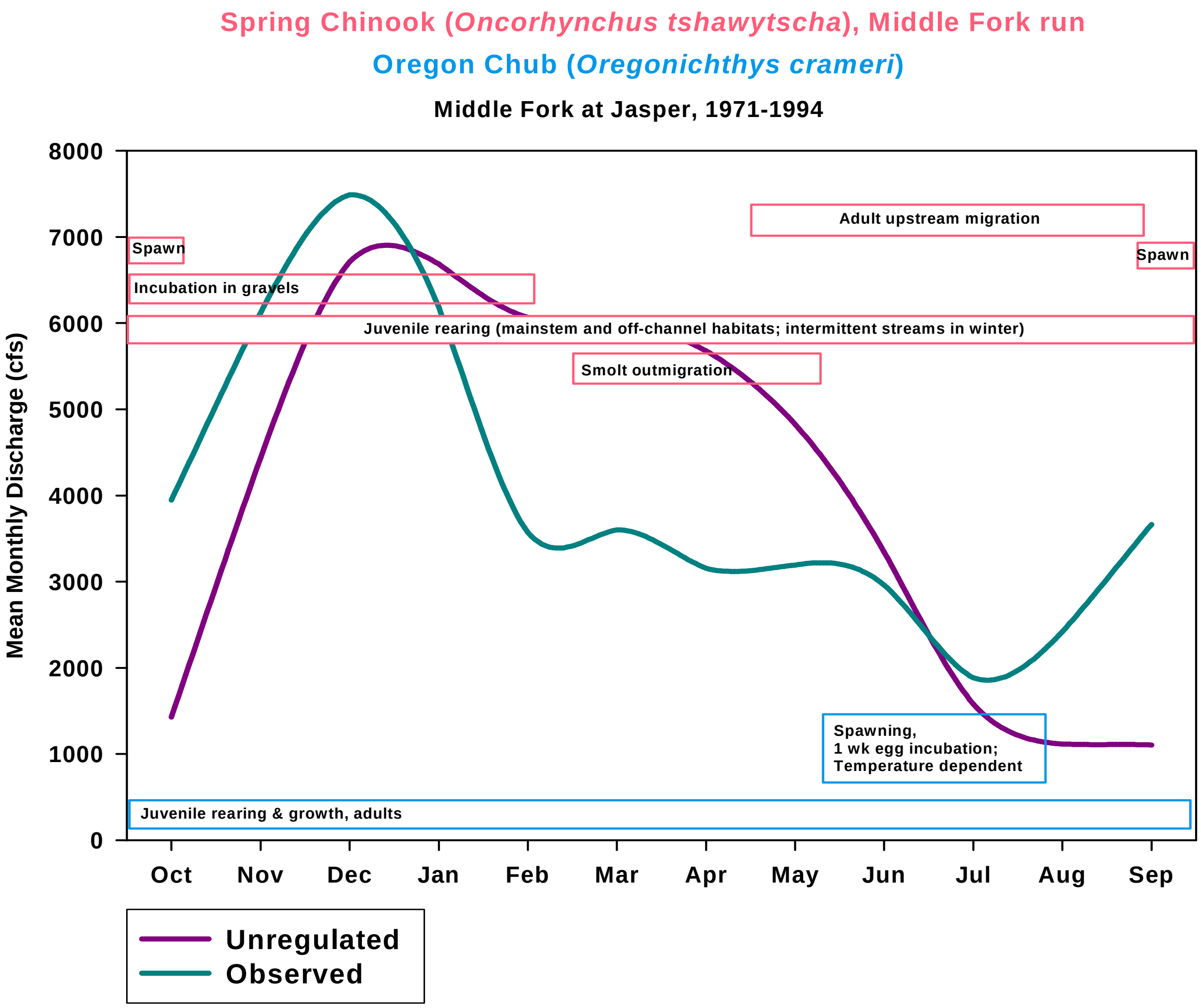


Figure 95. Life history of two native fish species, one anadromous (Chinook) and one resident (chub) in relation to discharge regime (observed vs. unregulated).

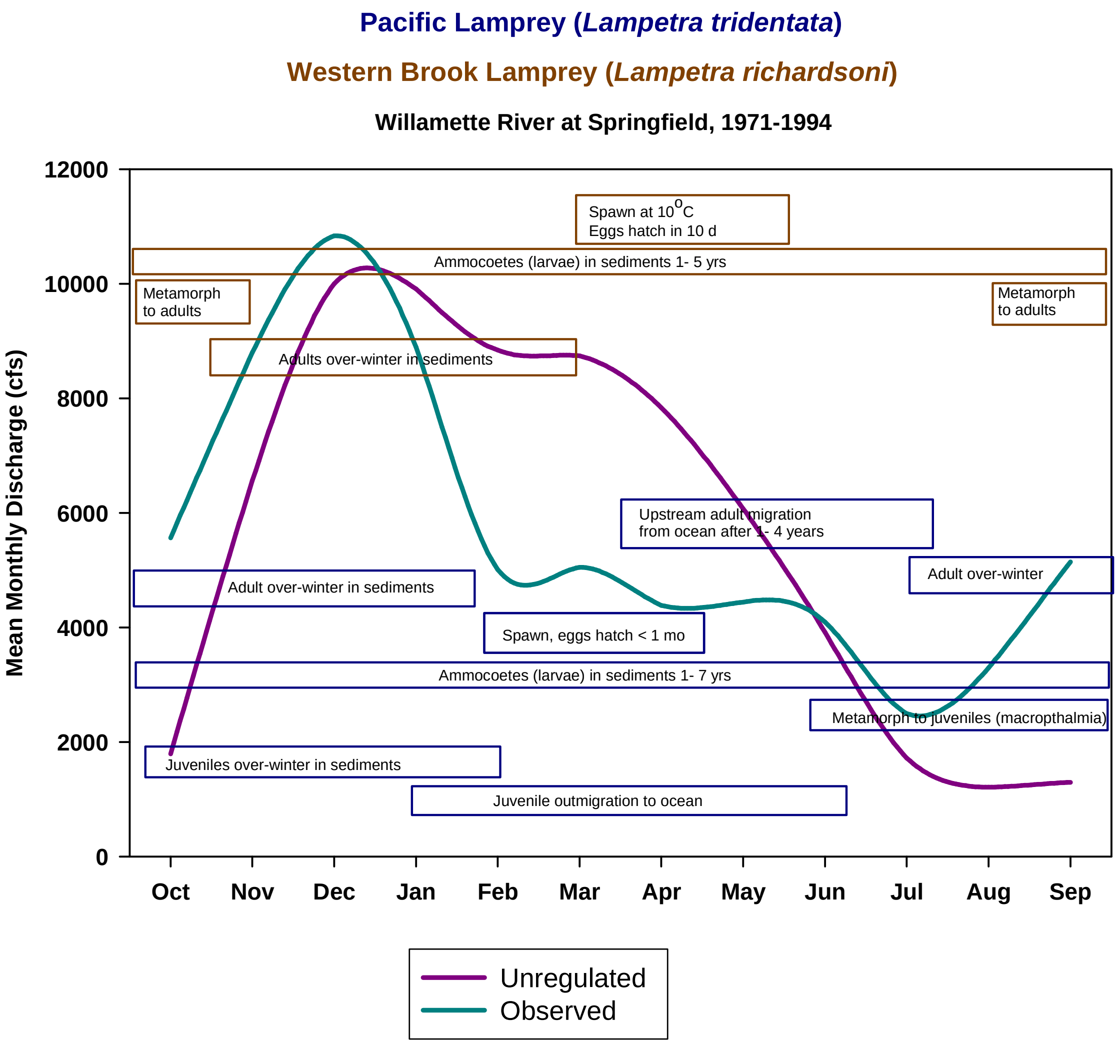


Figure 96. Life history stages of lamprey species in relation to discharge regime (unregulated and observed).

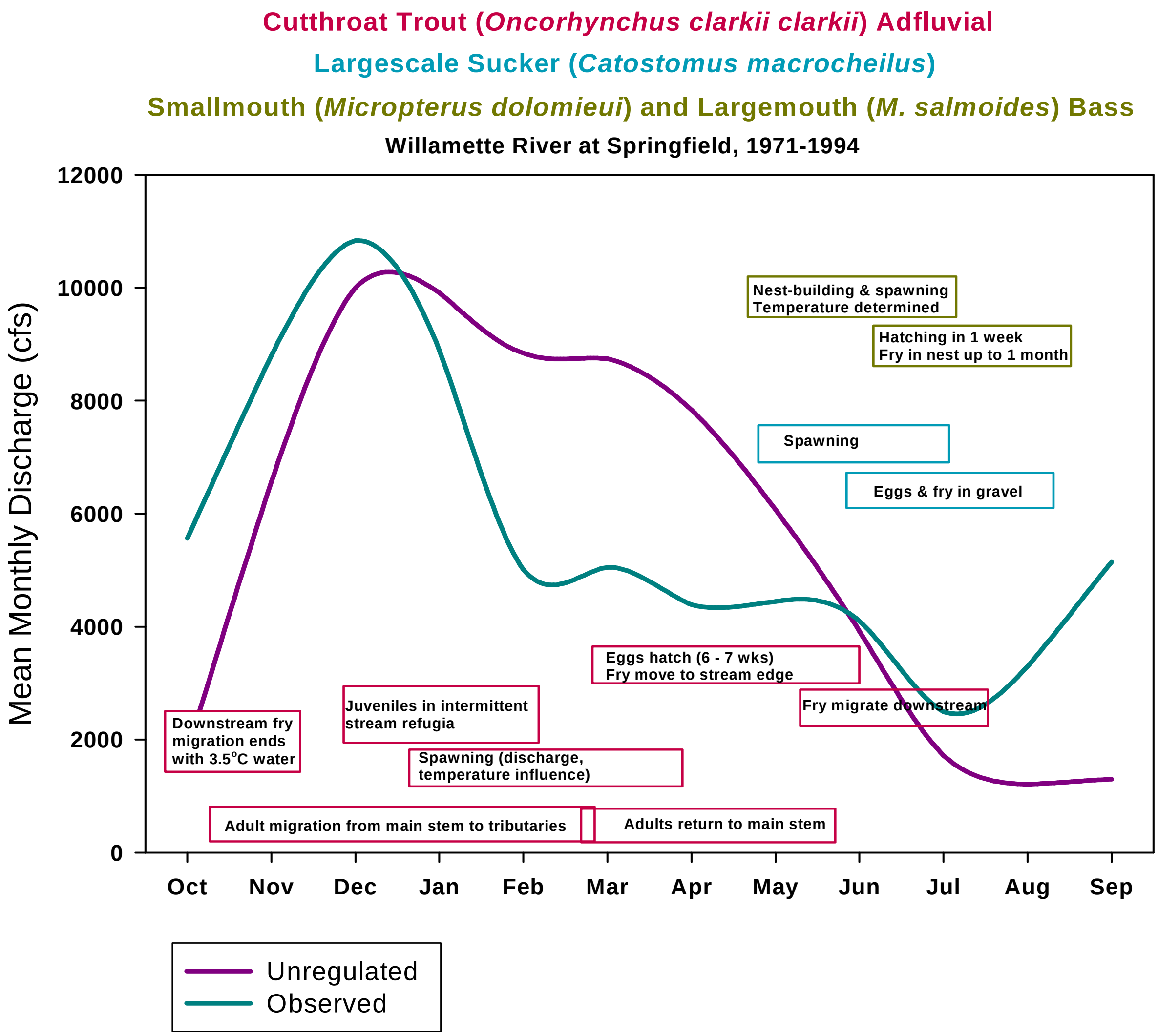


Figure 97. Life histories of resident native and invasive fish species in relation to discharge regime (unregulated and observed).

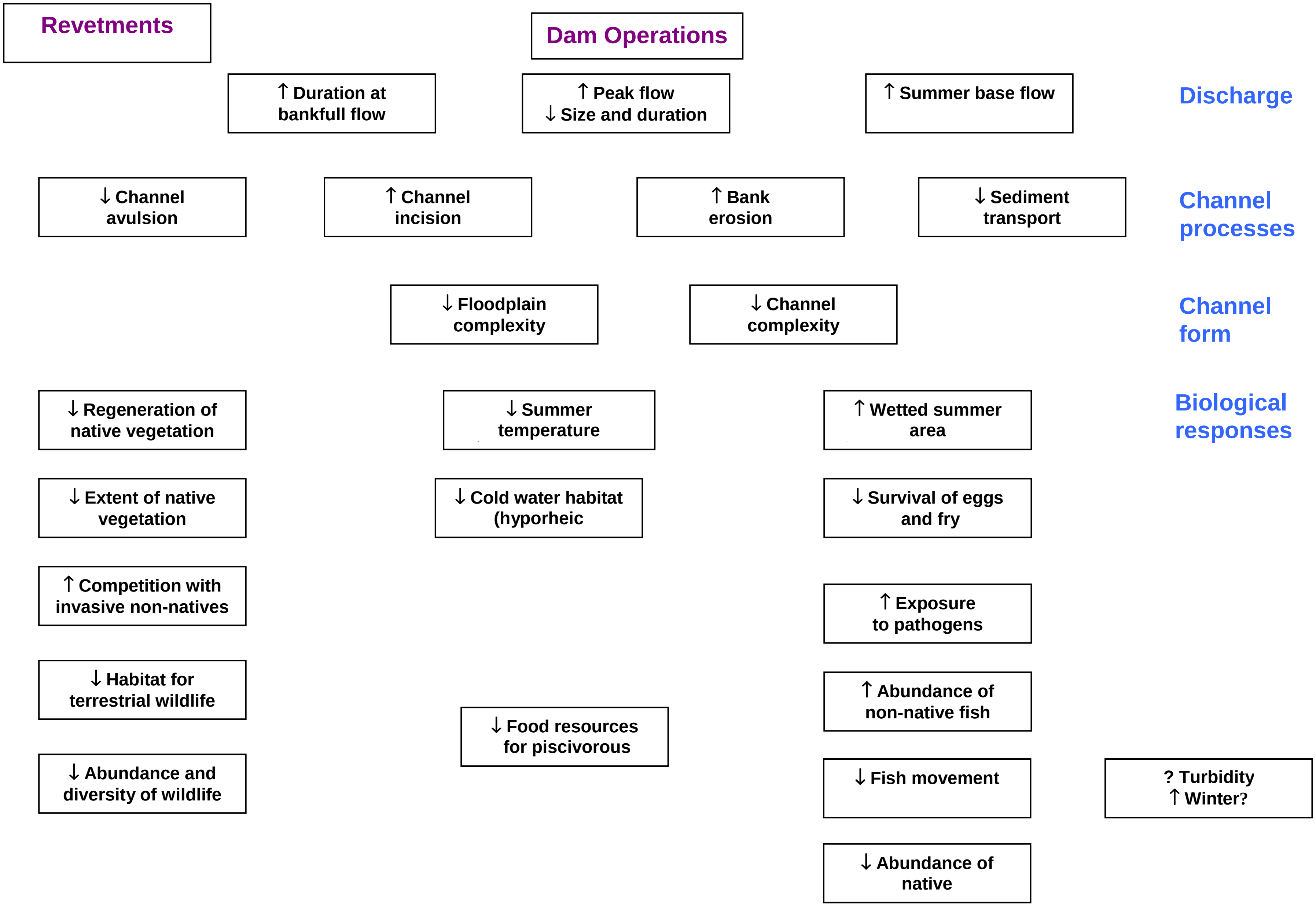


Figure 98. Effects of dam operations and revetments on physical and biological processes in the Coast Fork, Middle Fork, and Upper mainstem Willamette River.

APPENDIX 1

Preliminary IHA Analysis for the Middle Fork Willamette River at Jasper OR

Jeff Opperman (jopperman@tnc.org)
September 27, 2006

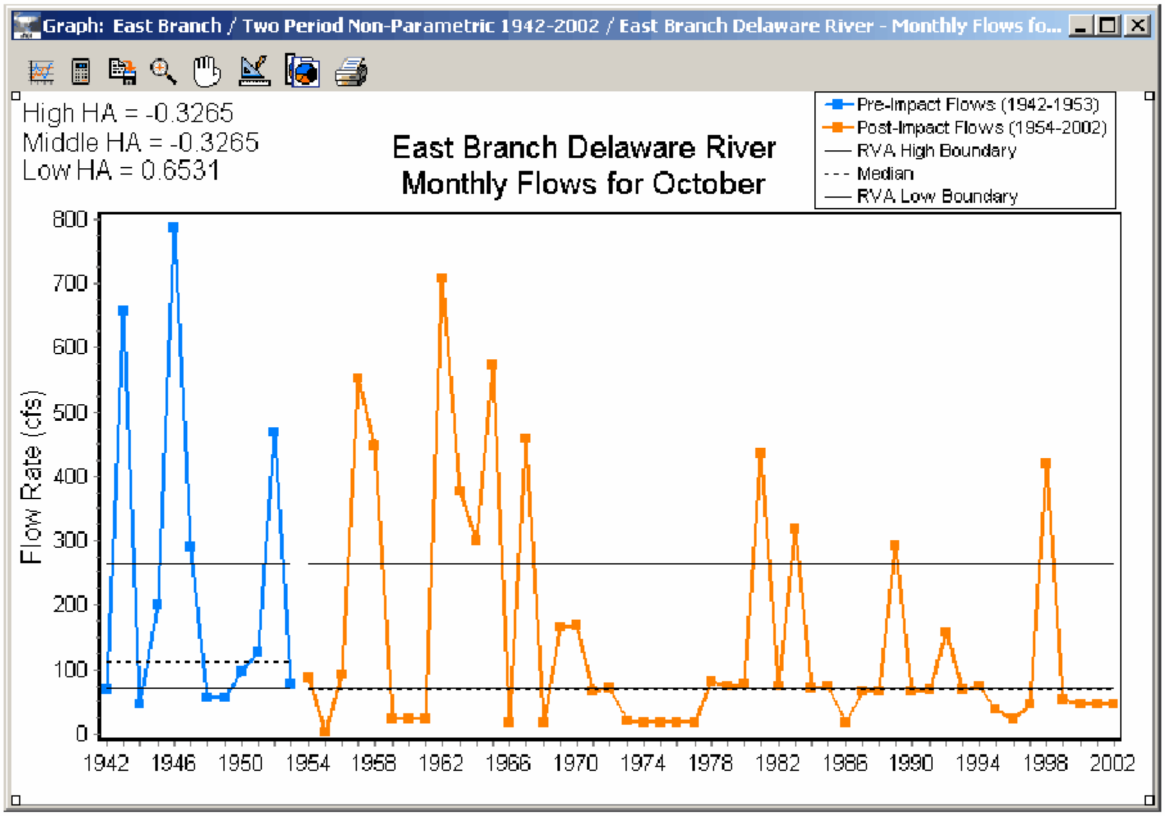
Indicators of Hydrologic Alteration

The Indicators of Hydrologic Alteration software (IHA) organizes long periods of hydrological data into sets of ecologically important parameters. The scientific basis of this program is summarized in several papers (Richter et al. 1996, Richter et al. 1997). These papers and the IHA software itself can be downloaded from the web site: nature.org/freshwater (specifically: http://www.nature.org/initiatives/freshwater/conservationtools/index.html).

Thirty-three IHA parameters can be lumped into five groups: (1) magnitude of monthly flow conditions; (2) magnitude and duration of extreme flow events (e.g. high and low flows); (3) the timing of extreme flow events; (4) frequency and duration of high and low flow pulses; and (5) the rate and frequency of changes in flows. For these parameters, the IHA can perform a Range of Variability Analysis. For each of the parameters, IHA calculates a Hydrologic Alteration factor, which is calculated as follows:

1. For each parameter, IHA divides the full range of ‘pre-impact data’ into three different categories, generally percentiles (e.g., lowest third, middle third, highest third).
2. The program then analyzes the ‘post-impact’ data and compares the observed distribution of data with the distribution expected from the pre-impact data.
3. HA factor = (observed frequency-expected frequency)/expected frequency
4. A positive HA factor means that the frequency of values in the category (percentile grouping) has increased in the post-impact period, while a negative HA factor means that the frequency of values in the category (percentile grouping) has decreased in the post-impact period

For example, if a dam was able to store and attenuate all high flow events, then, for floods, the HA factor for the ‘high category’ (highest third of all flows from pre-impact data) would be negative, while the ‘low category’ (lowest third of all flows from pre-impact data) would be positive. For a second example, see the figure below. In this example, there are fewer than expected October flows in the ‘high’ category (highest third of pre-impact flows): during the 48 years post impact, one would expect 16 years to fall into the ‘high’ category, but only 11 do. Thus, the High HA factor is negative.



Ecosystem Flow Components

The IHA also calculates 34 parameters that relate to Ecosystem Flow Components (EFCs): low flows, extreme low flows, high flow pulses, small floods and large floods. The IHA default for defining floods is that small floods have a recurrence interval ≥ 2 years and < 10 years and large floods are those with a recurrence interval ≥ 10 years.

Methods for Jasper

For this IHA analysis, unregulated flow data were provided by the Army Corps of Engineers. I acquired regulated flow data from the USGS website for gauge 14152000. Based on information on the website that the last major dam upstream was completed in 1966, I began the analysis on 10/1/1967 (water year 1968) for both the unregulated and regulated data. The unregulated flow data spanned from 10/01/1967 to 9/30/2004 while the regulated flow data spanned from 10/01/1967 to 8/31/2006.

A primary function of the IHA software is to compare to hydrological data sets and calculate a variety of statistics to assess the degree of hydrological alteration between them. The program is set up to process a single data set and the user is asked to input the year of the 'impact.' The simplest case is for a long hydrological record that has a single dam built at some point of time; the IHA then divides the data set into a 'pre-impact' period (before the year of dam completion) and 'post-impact' period. The Willamette data sets represent a different approach: comparing unregulated and regulated hydrological data from the same period of record. Within the IHA I defined the unregulated data as ‘pre-impact’ and the regulated data as ‘post-impact.’ However, because the IHA requires a single data set with a user-defined year of impact, I created ‘dummy’ years for the post-impact data (regulated data) with an impact date of 10/1/2004. Within the analysis you will see that the post-impact flows are represented by the water years 2005 to 2043. Keep in mind that theses post-impact years are the same years as the pre-impact data (with two extra years in post-impact) but for the purposes of the IHA analysis they’ve been labeled with future years.

Results

The regulated Middle Fork has higher monthly flows from the summer to early winter (July through December) and then, beginning in January, considerably lower monthly flows in the winter and spring (Figure 1). These changes are also reflected in Figure 2, which shows all Hydrologic Alteration (HA) factors, and Figure 3, which emphasizes the highest HA factor for each parameter. Monthly flows from July to December show that the regulated flows have large positive values in the high RVA category (i.e., the regulated period of record has more than the expected number of years in the high range of variability category based on the unregulated flows). Conversely, monthly flows from February to May have large positive values in the low RVA category.

Figure 4 partitions the hydrograph into Ecosystem Flow Components for the total period of record (pre-impact and post-impact) with the arrow indicating the division between the unregulated and regulated flows (remember that the years after 2005 are ‘dummy’ years and actually represent the regulated flows over the same time period as the unregulated, or pre-impact flows). What IHA defined as small and large floods from the unregulated data no longer occur within the regulated data, as indicated by the lack of green and red spikes after the arrow. This is also reflected in the HA values for the one-day and three-day maximum flows, which have large positive values in the low RVA category and large negative values in the middle and high RVA categories (Figure 2). In fact, for one-day maximum floods, the high and middle RVA categories have the maximum possible negative value of -1, indicating that flows in these RVA categories never occurred in the regulated data. This can also be visualized examining Figure 5 which shows the distribution of one-day maximum flow values. The highest one-day maximum flow in the regulated data set was 22,700 cfs, which is just below the 25th percentile of the distribution of one-day maximum flows from the unregulated data. The highest one-day maximum flow in the unregulated data was 68,350 cfs. The median one-day maximum flow dropped in half, from 30,800 cfs in the unregulated data to 16,300 cfs in the regulated data.

The seven-day maximum flows are also reduced in the regulated data, though not as dramatically as the one-day maximum flows (Figure 6). However, no flows in the regulated data are found within the high RVA category.

The 30-day maximum flow has changed little between the unregulated and regulated data sets (Figure 7). (Note that in Figures 5 and 6 the two solid lines for the post-impact data were showing the RVA category boundaries, which are determined by the pre-impact data; this is to emphasize the absence of regulated flows in the high RVA category (7-day maximums) and the high and middle RVA categories (one-day maximums). Here in Figure 7 the two solid lines are the 25th and 75th percentiles from the regulated data; this is to emphasize that the distributions have changed very little).

As stated earlier, the EFCs ‘small floods’ and ‘large floods’ do not occur in the regulated data set (Figure 8). The peak of high flow pulses are somewhat diminished in the regulated data compared to the unregulated data (Figure 9) while the duration of high flow pulses is similar between the data sets (Figure 10).

Low flows in the summer and fall are elevated in the regulated data compared to the unregulated data (Figures11-13). The median of monthly flows increased from 1000 cfs for unregulated flows in August to 2500 cfs for regulated flows (Figure 11) and from 1000 cfs for unregulated flows in October to 3500 cfs for regulated flows(Figure 12). The seven-day minimum flows have approximately doubled from the unregulated data (median = 737 cfs) to the regulated data (median = 1459 cfs) (Figure 13).

Information from USGS website for Jasper:

Station operated in cooperation with the U.S. Army Corps of Engineers.

14152000 MIDDLE FORK WILLAMETTE RIVER AT JASPER, OR

LOCATION.--Lat 43° 59'54", long 122° 54'17", in SW 1/4 SW 1/4 sec.14, T.18 S., R.2 W., Lane County, Hydrologic Unit 17090001, on right bank 25 ft downstream from highway bridge at Jasper, 0.1 mi downstream from Hills Creek, and at mile 195.0.

DRAINAGE AREA.--1,340 mi^2.

PERIOD OF RECORD.--September 1905 to February 1912, July 1913 to March 1917, October 1952 to current year. Monthly discharge only for some periods, published in WSP 1318.

GAGE.--Water-stage recorder. Datum of gage is 513.45 ft above NGVD of 1929. September 1905 to February 1912 and July 1913 to March 1917, nonrecording gage at approximately same site at datum about 1.5 ft higher. Oct. 22, 1952, to Sept. 30, 1953, nonrecording gage at site 25 ft upstream at same datum.

REMARKS.--Flow regulated since 1953 by Lookout Point Lake (station 14149000), since 1961 by Hills Creek Lake (station 14145100), and since 1966 by Fall Creek Lake (station 14150900). Continuous water-quality records for the period October 1953 to September 1987 have been collected at this location.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 94,000 ft^3/s Nov. 23, 1909, gage height, 17.4 ft, datum then in use, from graph based on gage readings, from rating curve extended above 42,000 ft^3/s; minimum discharge, 366 ft^3/s Dec. 5, 1954.

EXTREMES FOR CURRENT YEAR.--Maximum discharge, 15,700 ft^3/s Jan. 18, gage height, 8.36 ft; minimum discharge, 1,460 ft^3/s May 6, July 4.

Figure 1. Monthly flows for unregulated (pre-impact) and regulated (post-impact) flows on the Middle Fork Willamette, Jasper (OR). Plotted points are median monthly flow values for the period of record. The pre-impact flows are bracketed by the 25th and 75th percentiles.

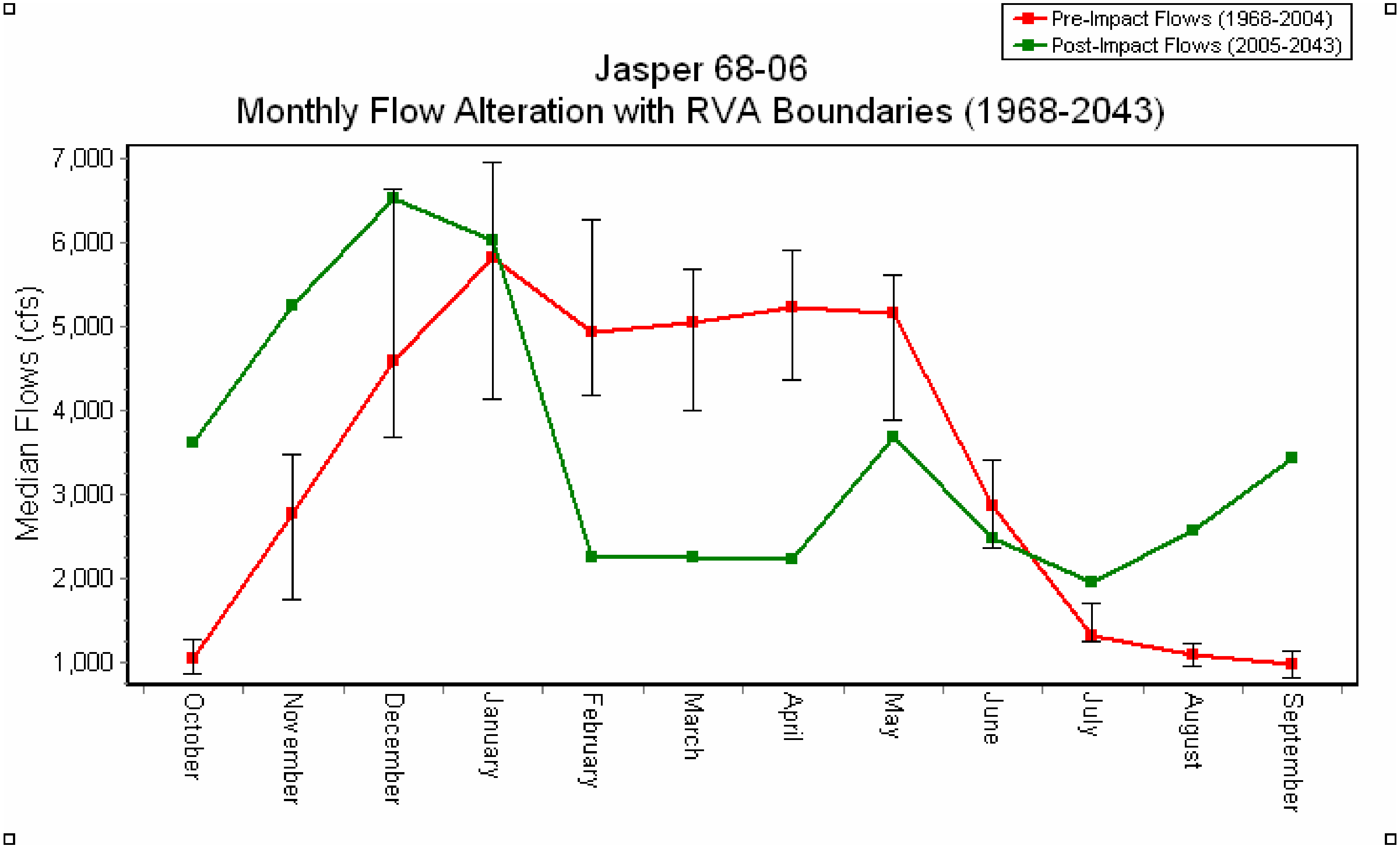


Figure 2. Hydrologic alteration factors for the Middle Fork Willamette River.

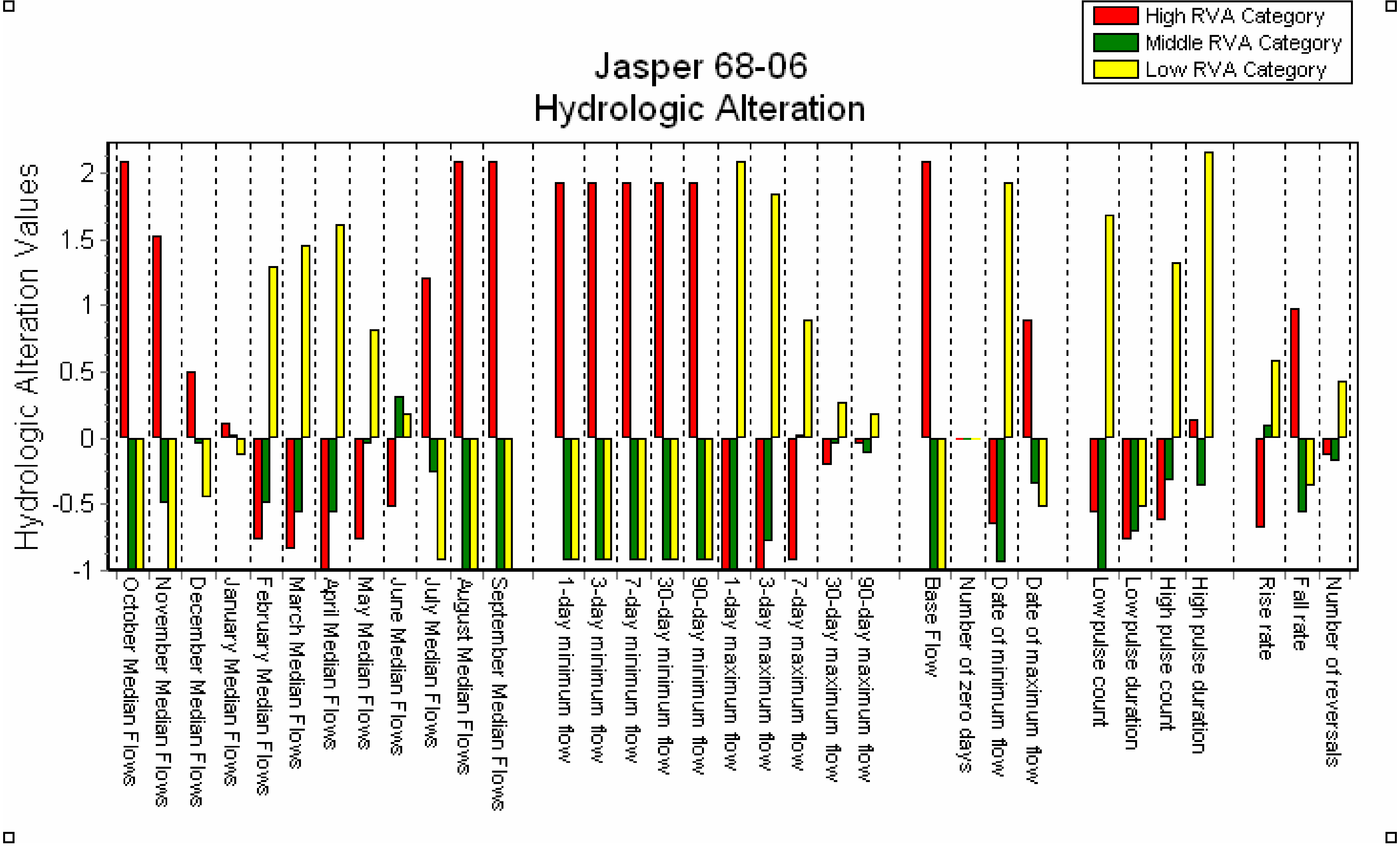


Figure 3. The greatest HA factors for each parameter on the Middle Fork Willamette River.

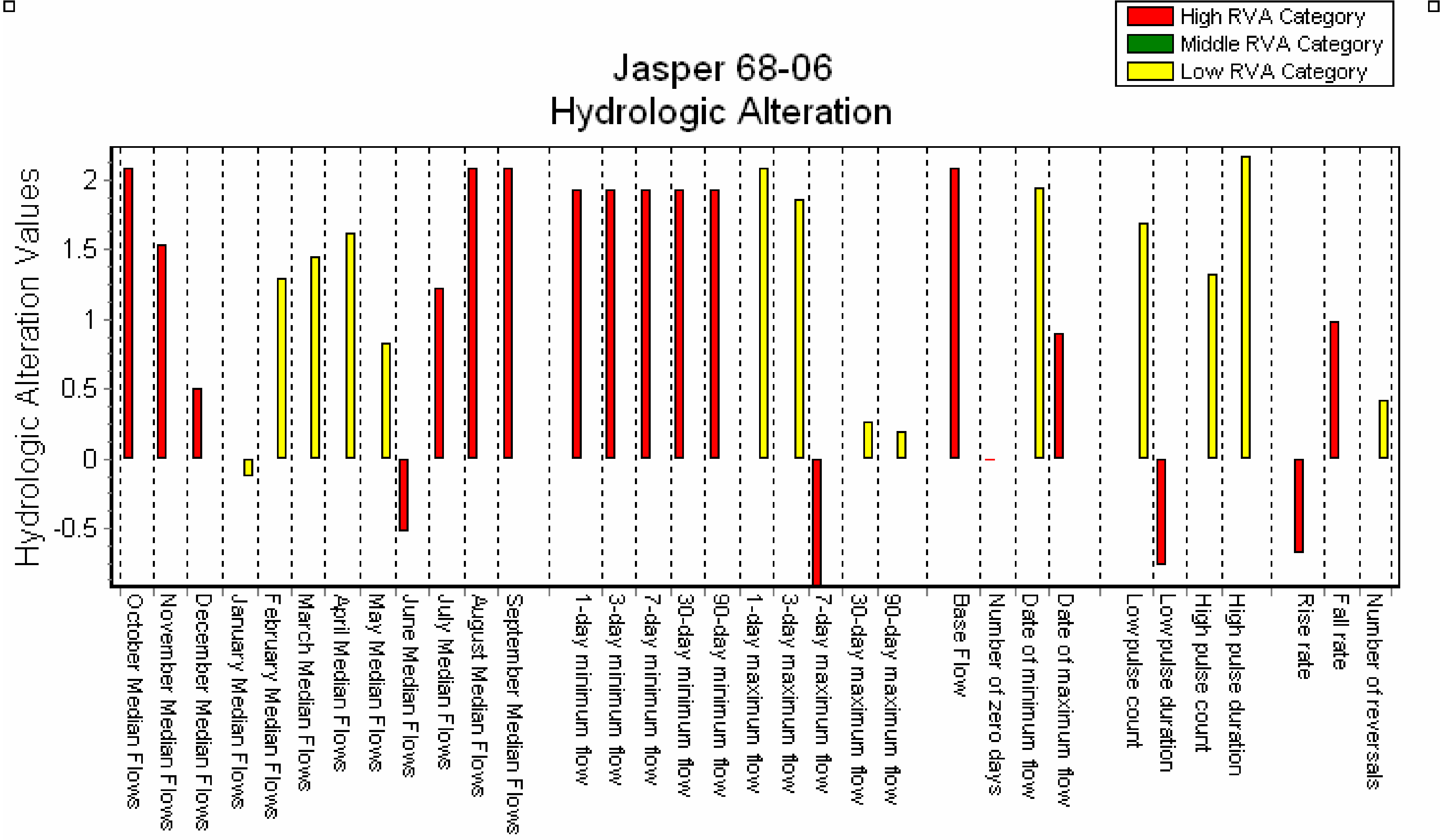


Figure 4. Ecosystem flow components for unregulated (left of the arrow) and regulated flows on the Middle Fork Willamette River.

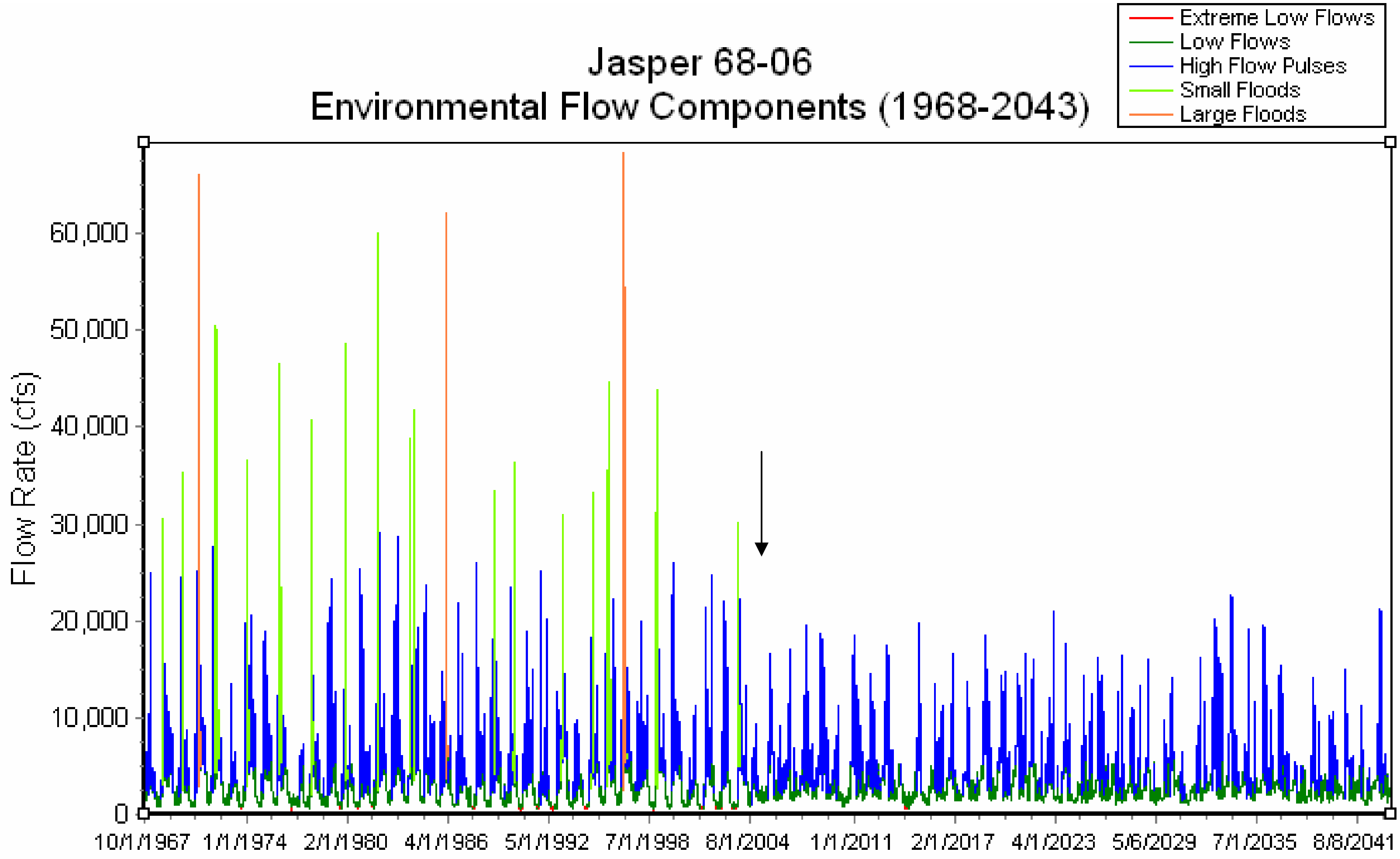


Figure 5. One-day maximum flows for Middle Fork Willamette River.

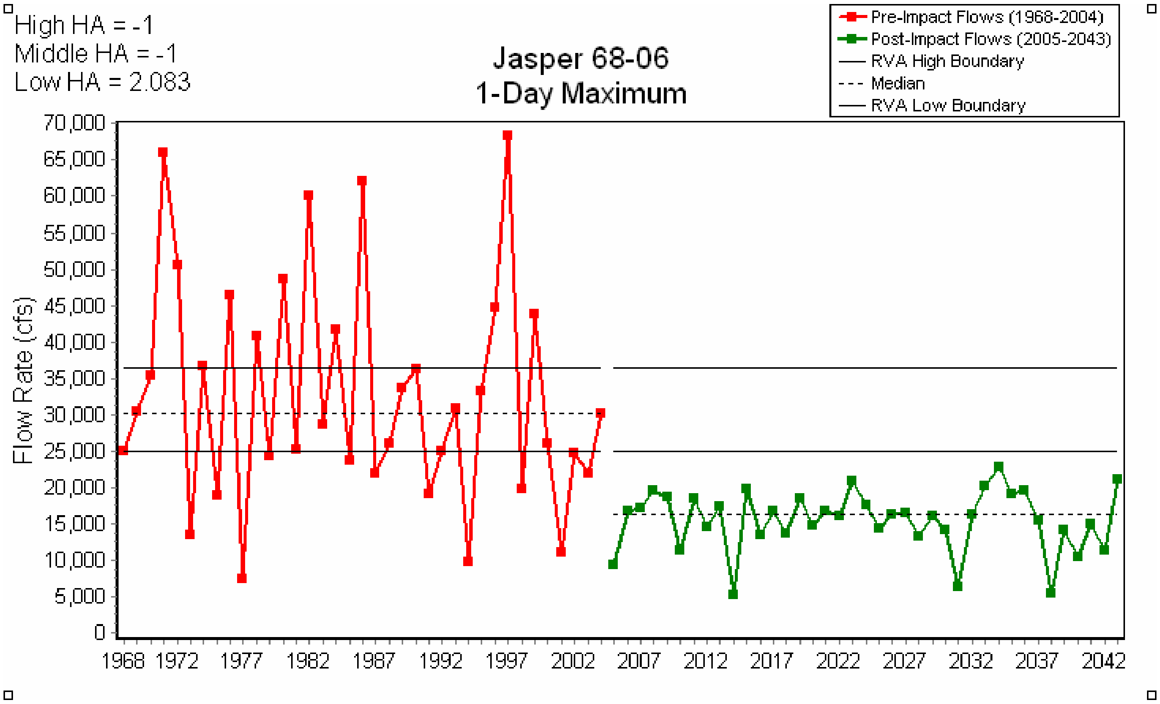


Figure 6. Seven-day maximum flows for Middle Fork Willamette River.

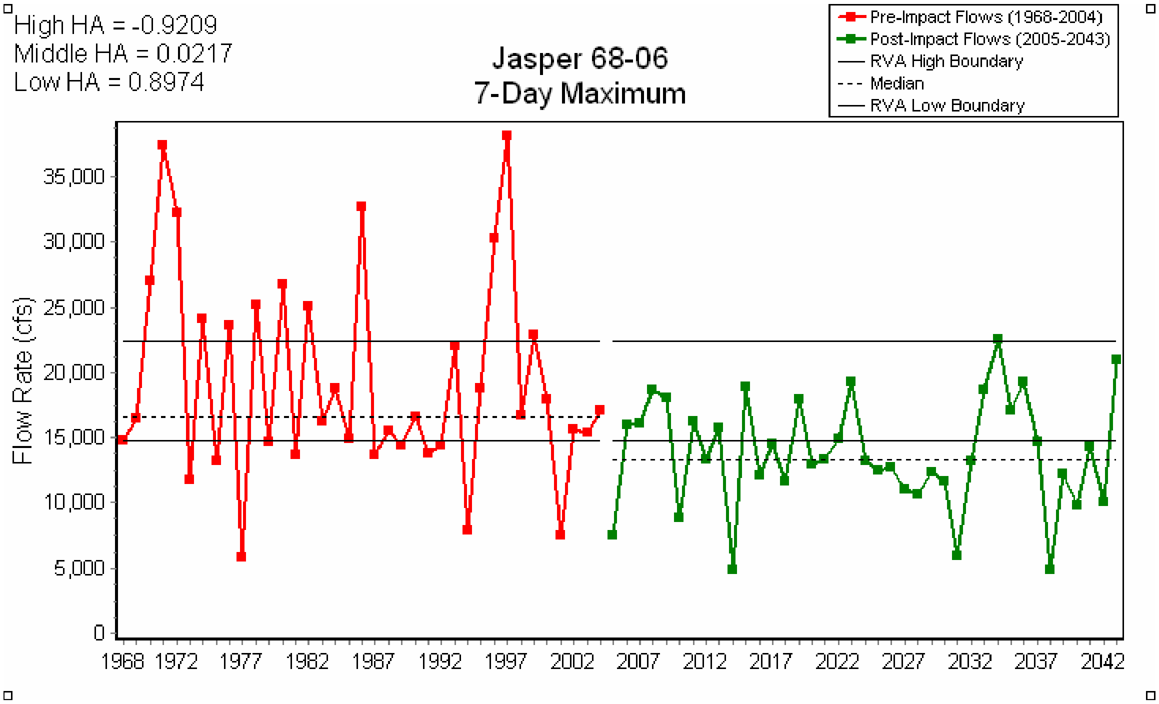


Figure 7. 30-day maximum flows for Middle Fork Willamette River.

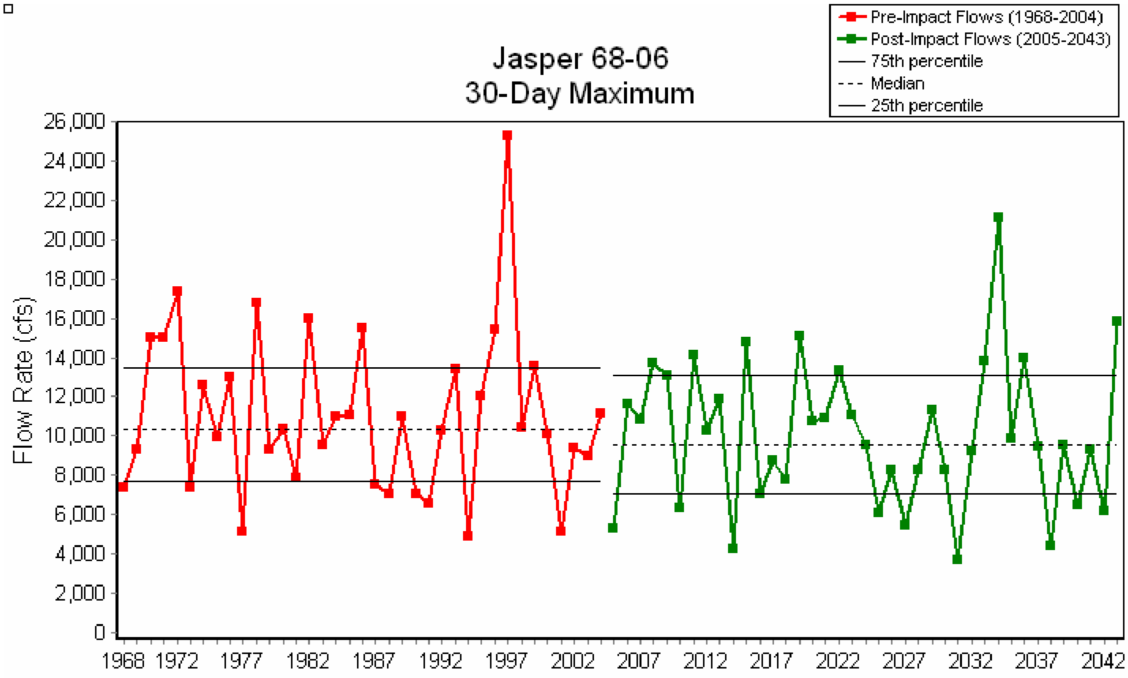


Figure 8. Small floods, peak magnitude for Middle Fork Willamette River.

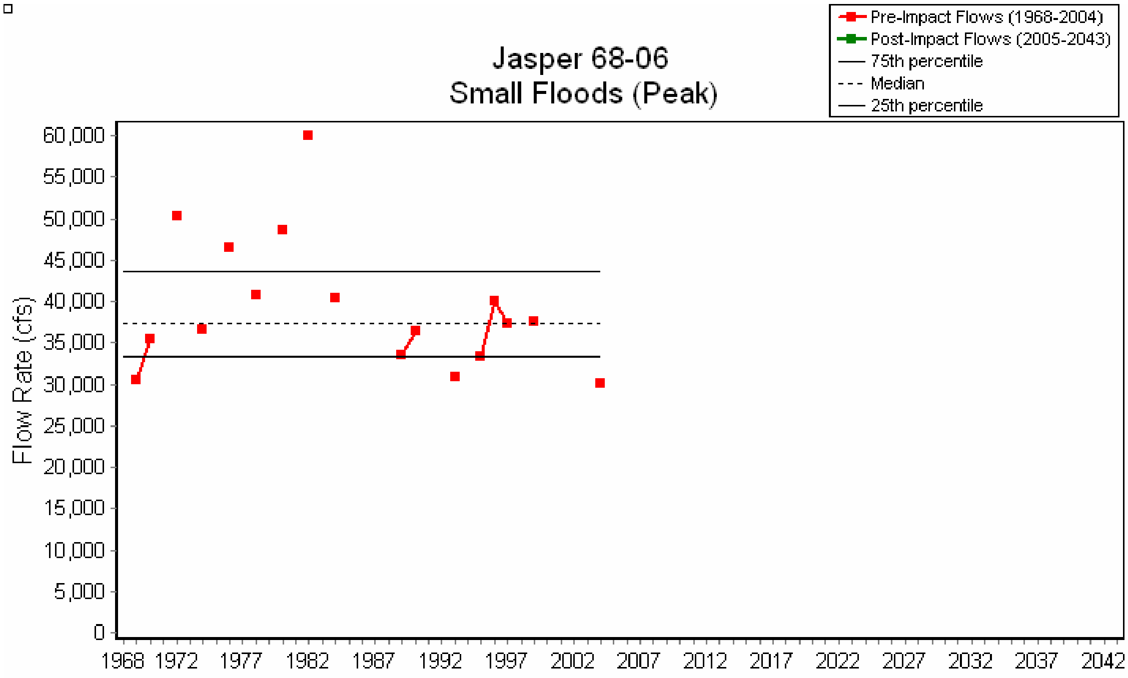


Figure 9. Peak of high flow pulses for Middle Fork Willamette River.

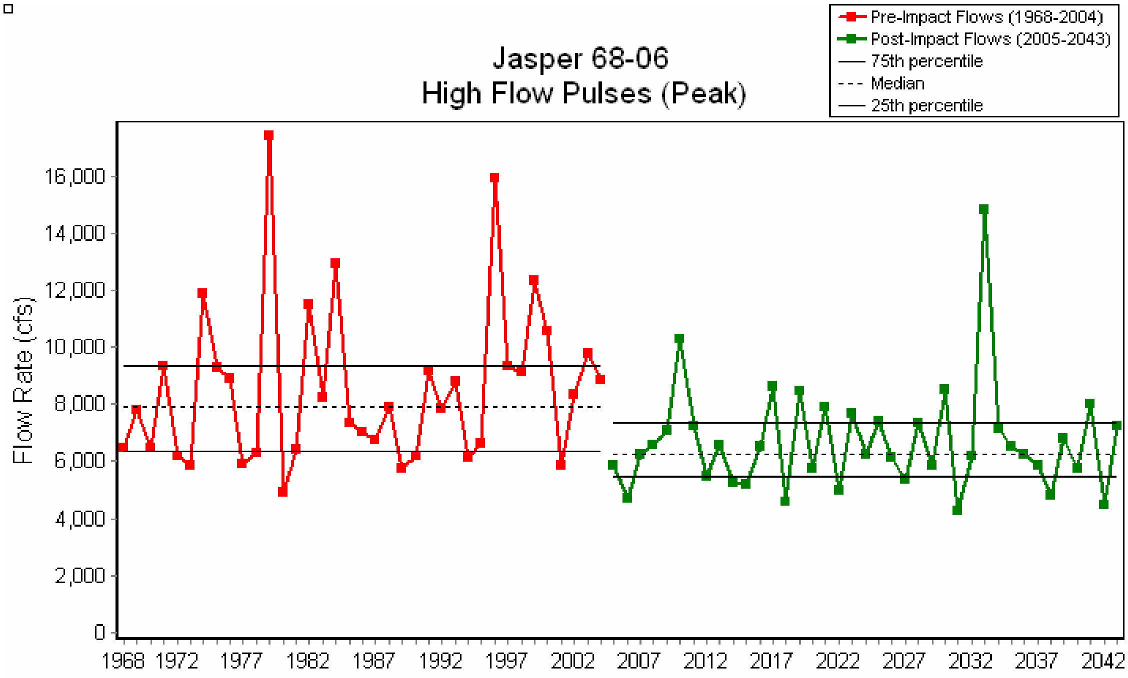


Figure 10. Duration of high flow pulses for Middle Fork Willamette River.

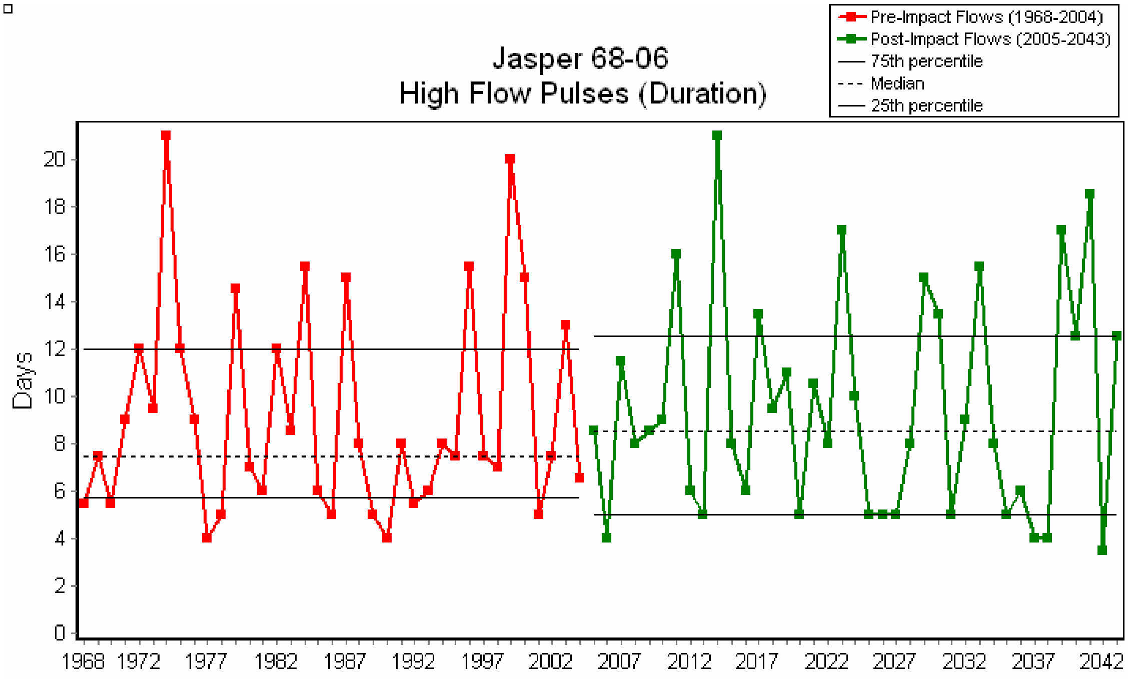


Figure 11. Monthly flows for August for Middle Fork Willamette River.

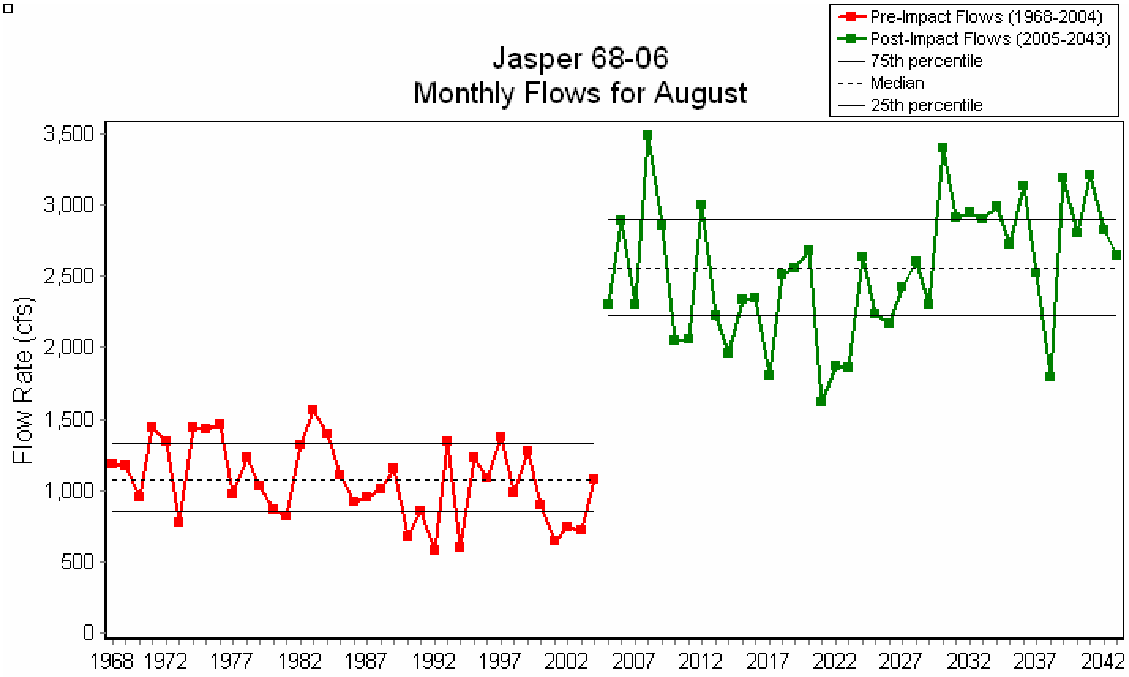


Figure 12. Monthly flows for October for Middle Fork Willamette River.

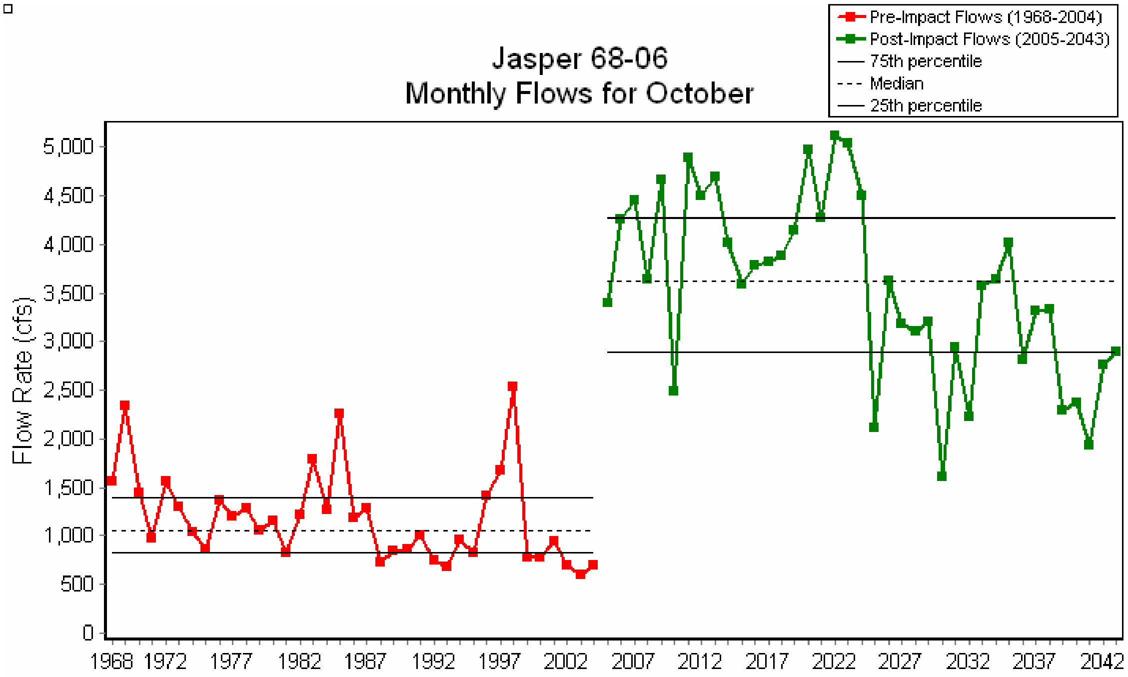
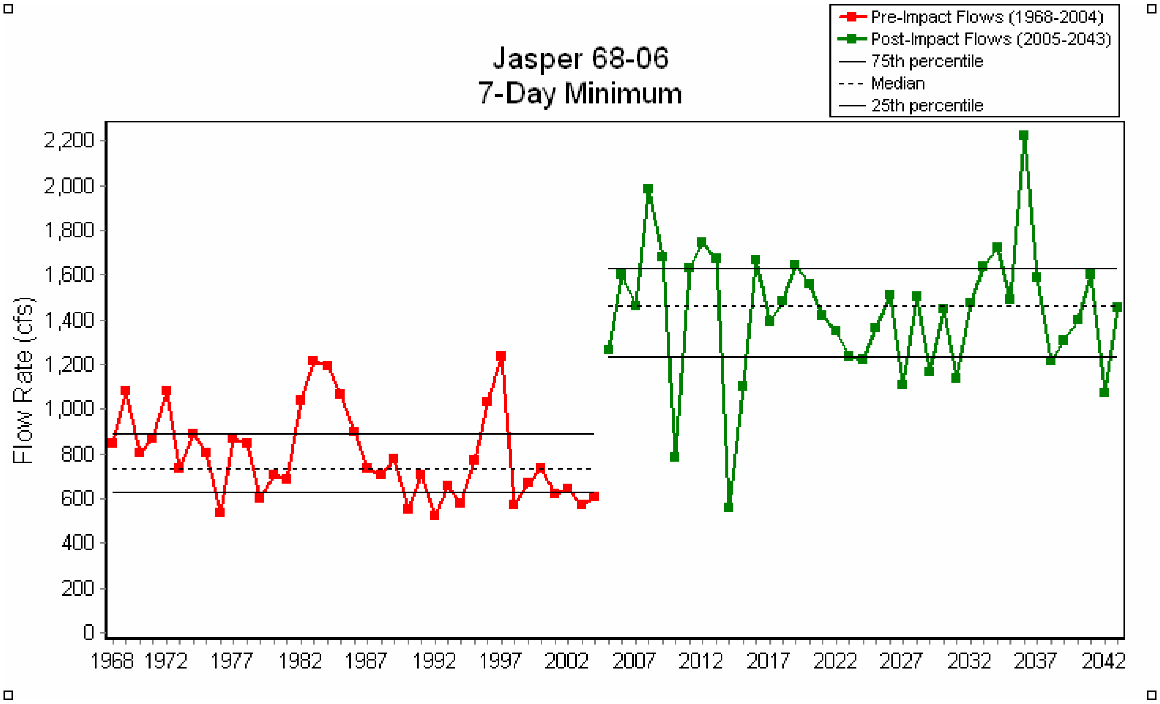


Figure 13. 7 day minimum flows for Middle Fork Willamette River.



APPENDIX 2

Preliminary IHA Analysis for the Coast Fork Willamette River at Goshen OR

Jeff Opperman (jopperman@tnc.org)

September 28, 2006

Background on IHA (please refer to report on Jasper for description of IHA)

Methods for Goshen

For this IHA analysis, unregulated flow data were provided by the Army Corps of Engineers. I acquired regulated flow data from the USGS website for gauge 14157500 (background information for this gauge is appended to the end of this report). Based on information on the website that the last major dam upstream was completed in 1949, I began the analysis for both the unregulated and regulated data on 10/1/1950 (water year 1951; this is also the beginning of the continuous data from USGS). The unregulated flow data spanned from 10/01/1950 to 9/30/2004 while the regulated flow data spanned from 10/01/1950 to 8/31/2006.

A primary function of the IHA software is to compare to hydrological data sets and calculate a variety of statistics to assess the degree of hydrological alteration between them. The program is set up to process a single data set and the user is asked to input the year of the 'impact.' The simplest case is for a long hydrological record that has a single dam built at some point of time; the IHA then divides the data set into a 'pre-impact' period (before the year of dam completion) and 'post-impact' period. The Willamette data sets represent a different approach: comparing unregulated and regulated hydrological data from the same period of record. Within the IHA I defined the unregulated data as 'pre-impact' and the regulated data as 'post-impact.' However, because the IHA requires a single data set with a user-defined year of impact, I created 'dummy' years for the post-impact data (regulated data) with an impact date of 10/1/2004. Within the analysis you will see that the post-impact flows are represented by the water years 2005 to 2060. Keep in mind that theses post-impact years are the same years as the pre-impact data (with two extra years in post-impact) but for the purposes of the IHA analysis they've been labeled with future years.

Results

Regulated monthly flows have relatively small deviations from unregulated flows (Figure 1). Regulated monthly flows are higher than unregulated flows in the late summer to early fall (August through October), similar for November and December, and are greater than unregulated flows in January and then similar again in February. Unregulated flows are higher than regulated flows in the spring.

Median regulated October monthly flows are four times greater than unregulated flows (Figure 2). No regulated flows occur within the low RVA category (as calculated from unregulated or 'pre-impact' flow data) and only once within the middle RVA category (note that nearly all flows are above the two black lines for the 'post-impact' data).

Regulated and unregulated flows have similar medians and variability in February (Figure 3), while regulated flows are somewhat lower in April (Figure 4).

These trends are also evident in Figures 5 and 6 which show the Hydrologic Alteration factors: November through June show relatively small HA values, while July through October have large positive values for the high HA category and large negative values for the middle and low HA categories.

Figures 5 and 6 also indicate that regulated flows have elevated minimum flows relative to unregulated flows (large positive values for high HA category, large negative values for middle and low HA categories). Seven-day minimum regulated flows (median = 150 cfs) are five times greater than unregulated flows (median = 30 cfs; Figure 7). Regulated low flows in September (median = 490) are also five times greater than unregulated low flows (median = 93 cfs; Figure 8) with similar trends for monthly low flows from August through October. The Environmental Flow Component of ‘extreme low flows,’ as determined based on unregulated data, does not occur with regulated flows (Figure 9).

Figure 10 shows the unregulated and regulated flow data categorized by Environmental Flow Components. Large floods (red spikes), as defined by the unregulated data as flows > 10 year recurrence interval, no longer occur in the regulated flow data. However, small floods (green spikes) continue to occur.

The median one-day maximum regulated flow (11,000 cfs) is about half of the median one-day maximum unregulated flow (19,000 cfs; Figure 11). Most regulated one-day maximum flows fall into the low RVA category with only three occurring in the high RVA category. The highest one-day maximum regulated flow is 31,500 cfs compared to the highest one-day maximum unregulated flow of 51,500 cfs. Thirty-day maximum flows were very similar between the two data sets (Figure 12).

Small flood events had similar magnitudes but occurred much less frequently in the regulated data set (six times compared to 23 times; Figure 13). The duration of regulated small flood events approximately doubled compared to unregulated small flood events (Figure 14). Large flood events did not occur in the regulated data set.

High flow pulses had similar magnitude (Figure 15) and duration (Figure 16) in the two data sets. The frequency of high flow pulses was essentially unchanged.

From USGS website:

Station operated in cooperation with the U.S. Army Corps of Engineers.

14157500 COAST FORK WILLAMETTE RIVER NEAR GOSHEN, OR

LOCATION.--Lat 43° 58'50", long 122° 57'55", in NW 1/4 sec.29, T.18 S., R.2 W.,
Lane County, Hydrologic Unit 17090002, on right bank at downstream side of

bridge on State Highway 58, 2.5 mi southeast of Goshen, and at mile 6.4.

DRAINAGE AREA.--642 mi^2.

PERIOD OF RECORD.--August 1905 to February 1912, October 1950 to current year. Monthly discharge only for some periods, published in WSP 1318.

GAGE.--Water-stage recorder. Datum of gage is 473.80 ft above NGVD of 1929. Aug. 23, 1905 to Feb. 7, 1912, nonrecording gage at site 600 ft upstream at different datum.

REMARKS.--Flow regulated since 1942 by Cottage Grove Lake station 14153000) and since 1949 by Dorena Lake (station 14155000). Several small diversions for logponds and irrigation upstream from station. Continuous water-quality records for the period October 1961 to September 1975 have been collected at this location. Periodic suspended sediment data are available for the period October 1991 to September 1993.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 58,500 ft^3/s Nov. 22, 1909, gage height, 19.5 ft, site and datum then in use, from rating curve extended above 15,000 ft^3/s; minimum discharge, 36 ft^3/s Sept. 29, 30, Oct. 11, 12, 1908.

Figures: <u>Throughout, red represents unregulated flows and green represents regulated flows.</u>

Figure 1. Monthly flows for Coast Fork Willamette River near Goshen, OR.

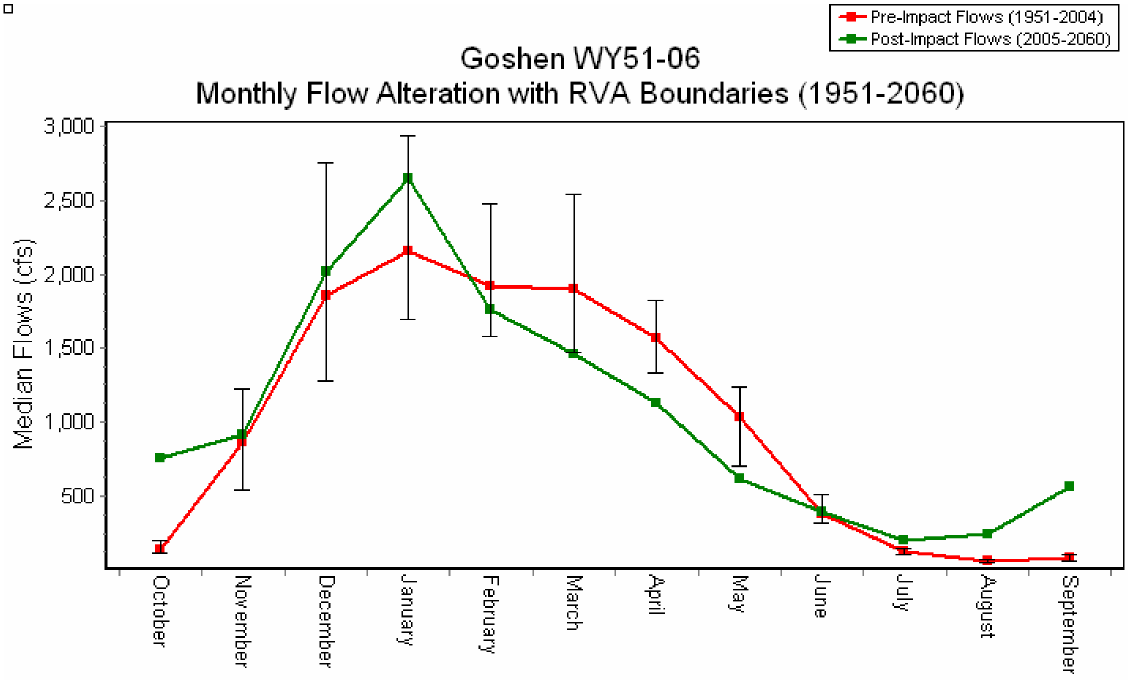


Figure 2. Monthly flows for October, Coast Fork Willamette River.

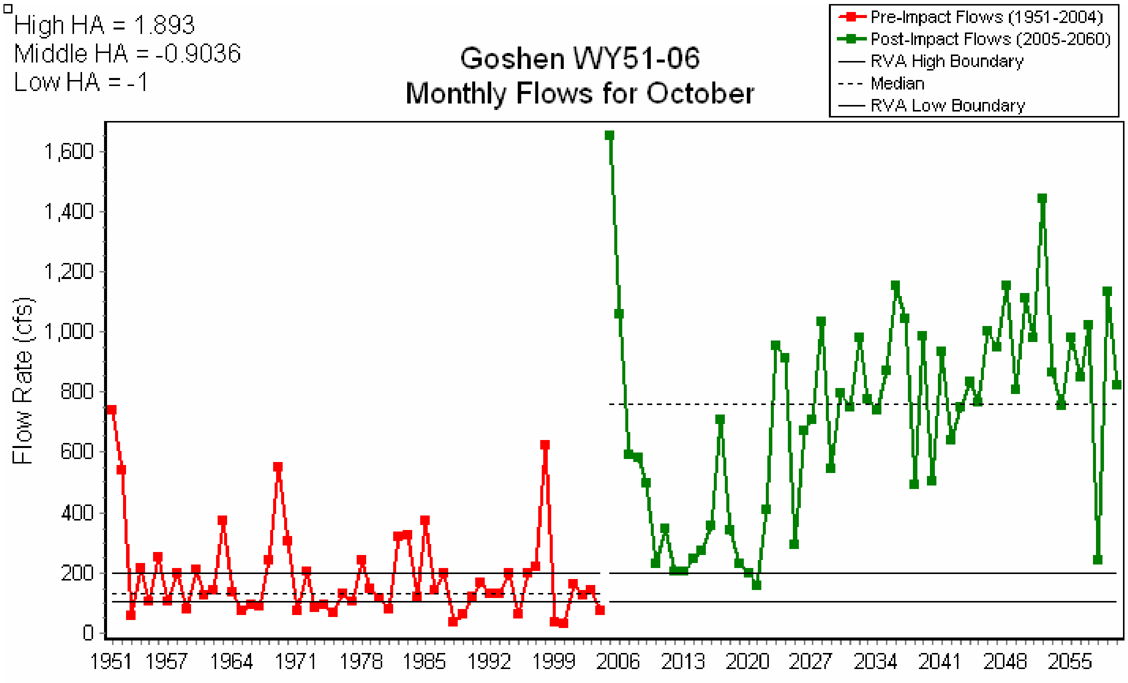


Figure 3. Monthly flows for February, Coast Fork Willamette River.

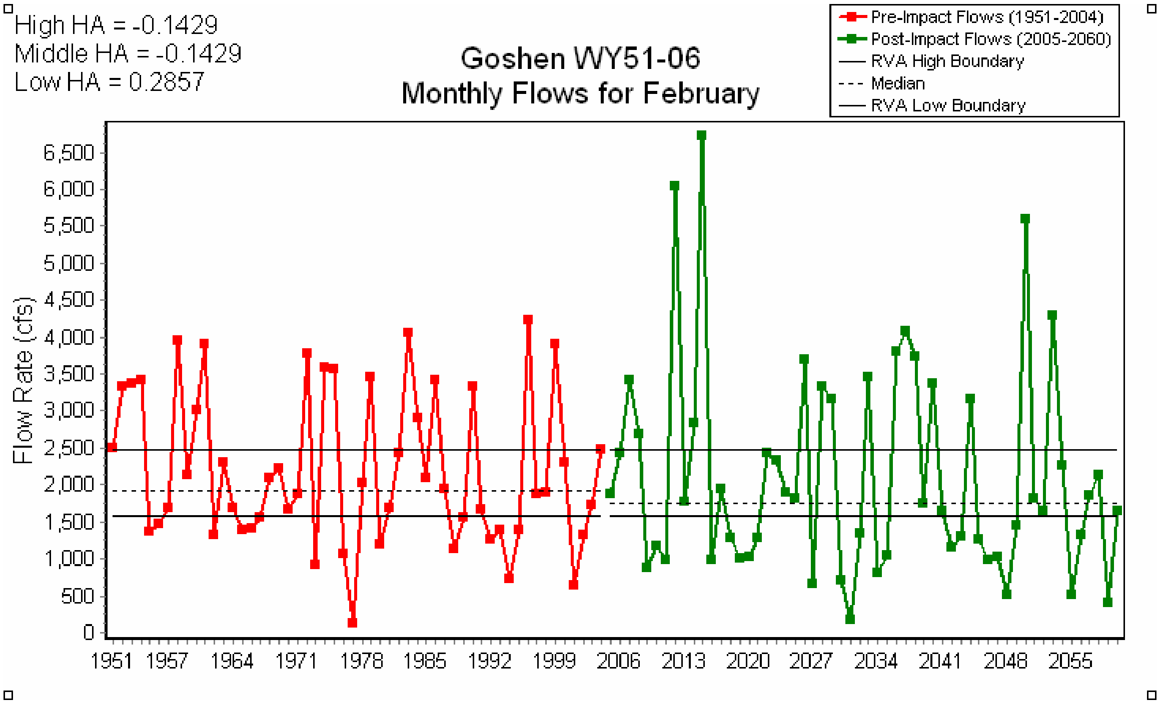


Figure 4. Monthly flows for April, Coast Fork Willamette River.

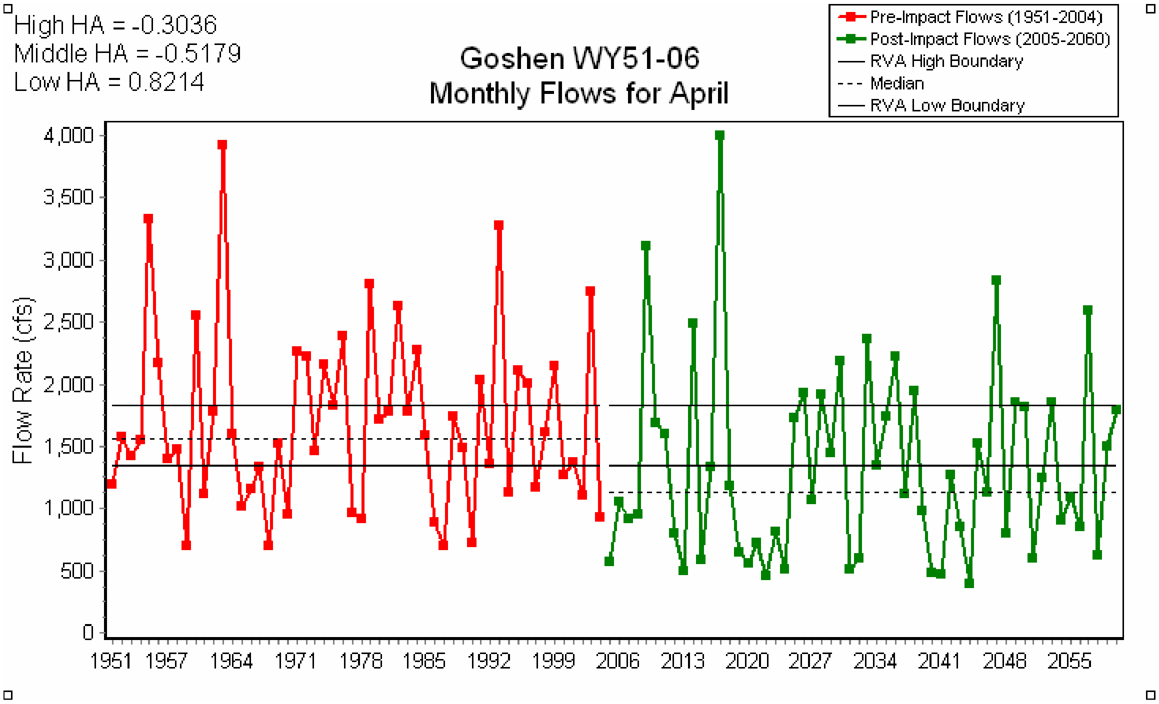


Figure 5. Hydrologic alteration values, Coast Fork Willamette River.

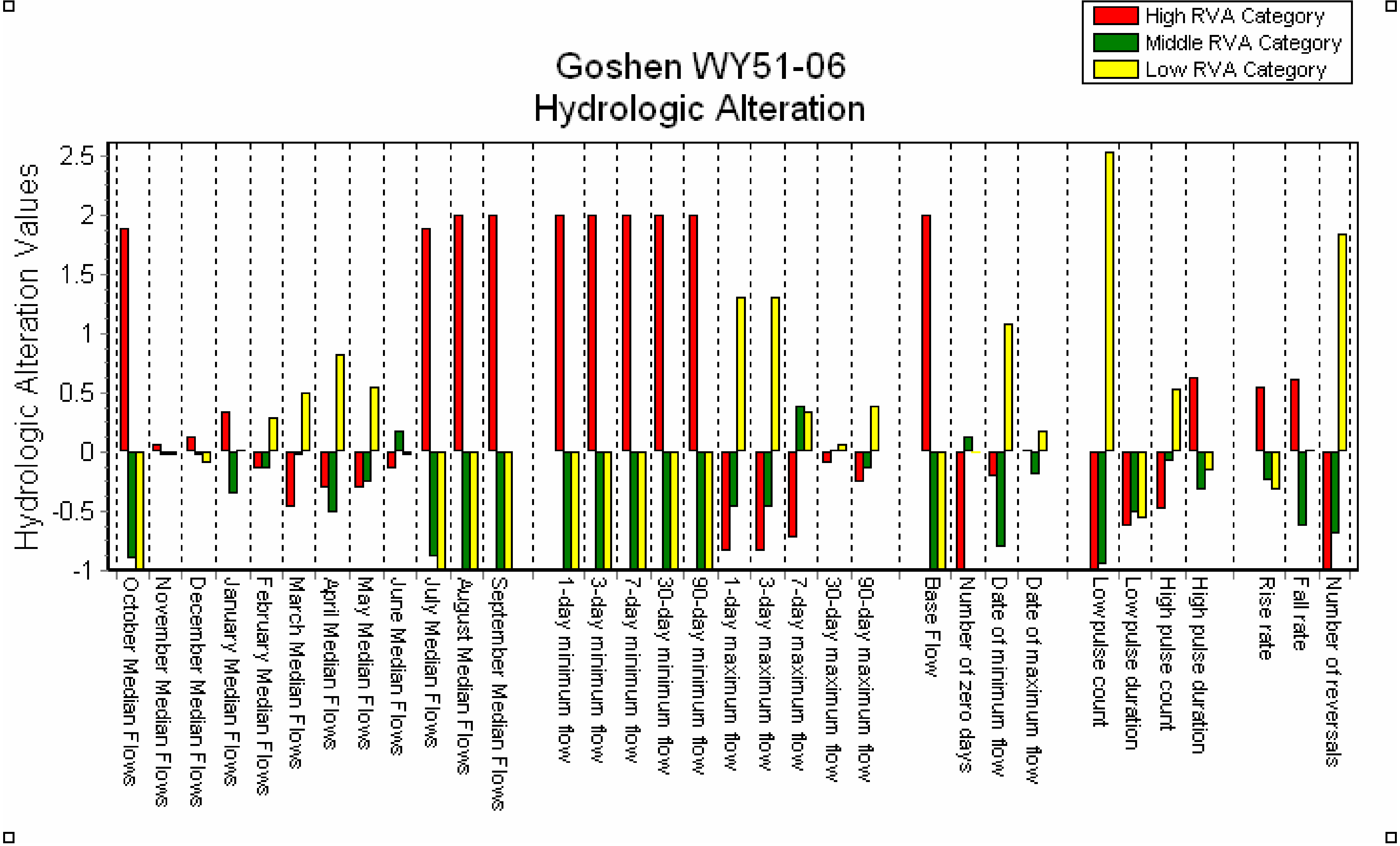


Figure 6. The greatest HA value for each parameter, Coast Fork Willamette River.

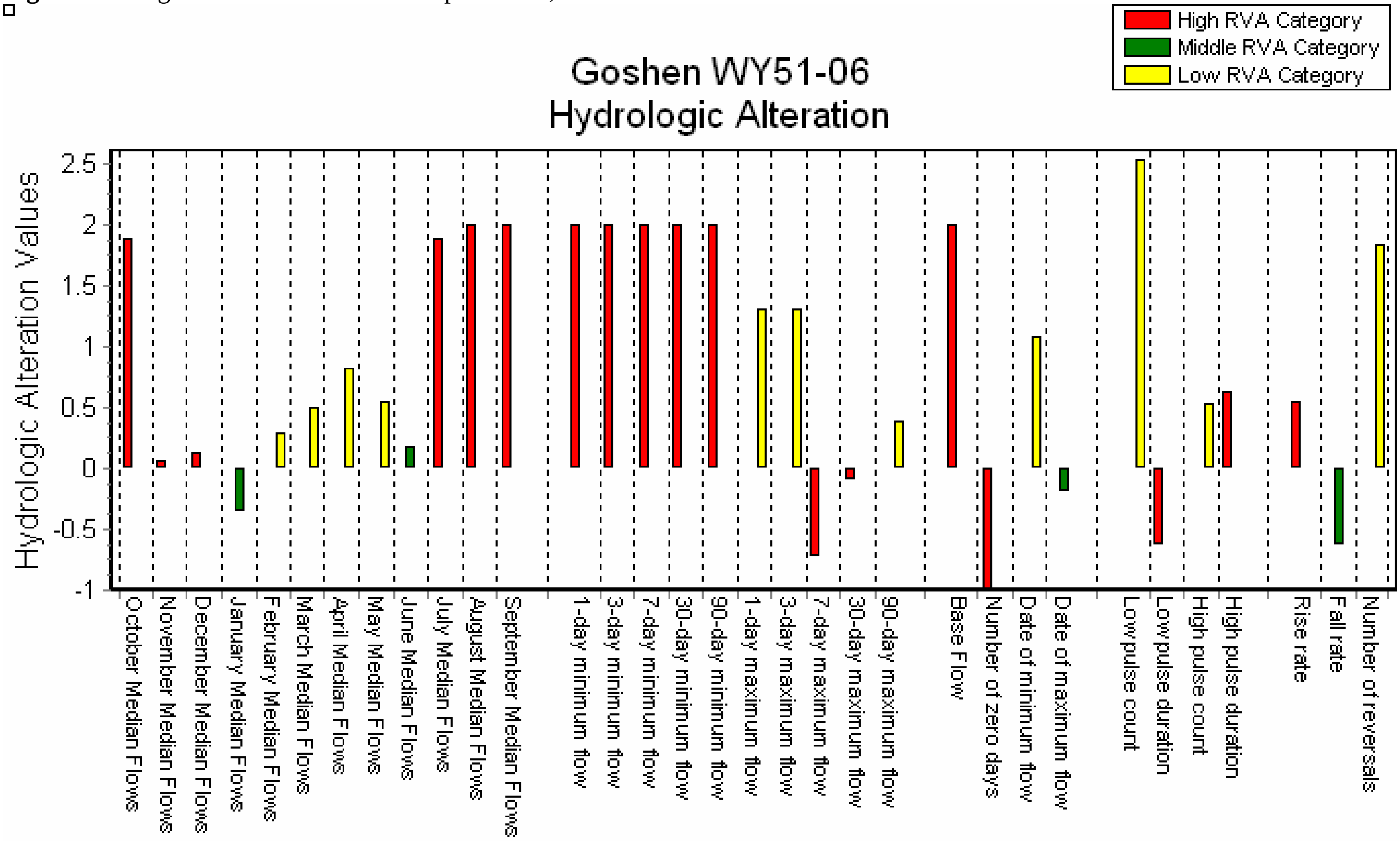


Figure 7. Seven-day minimum flows, Coast Fork Willamette River.

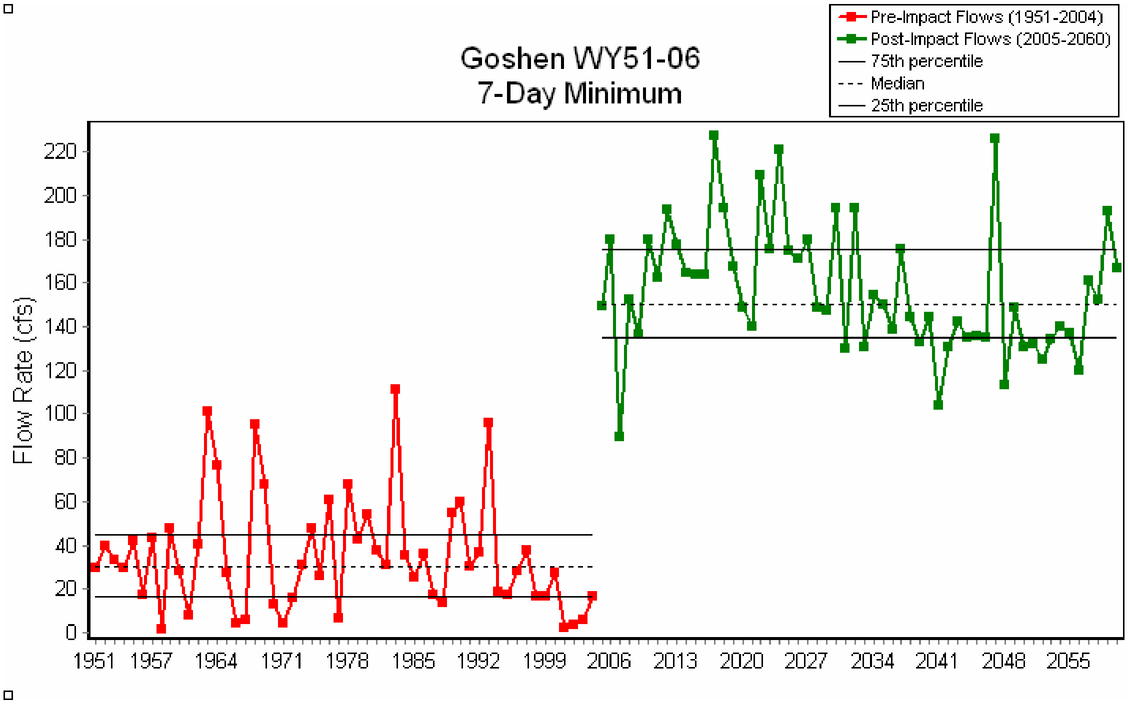


Figure 8. Monthly low flows for September, Coast Fork Willamette River.

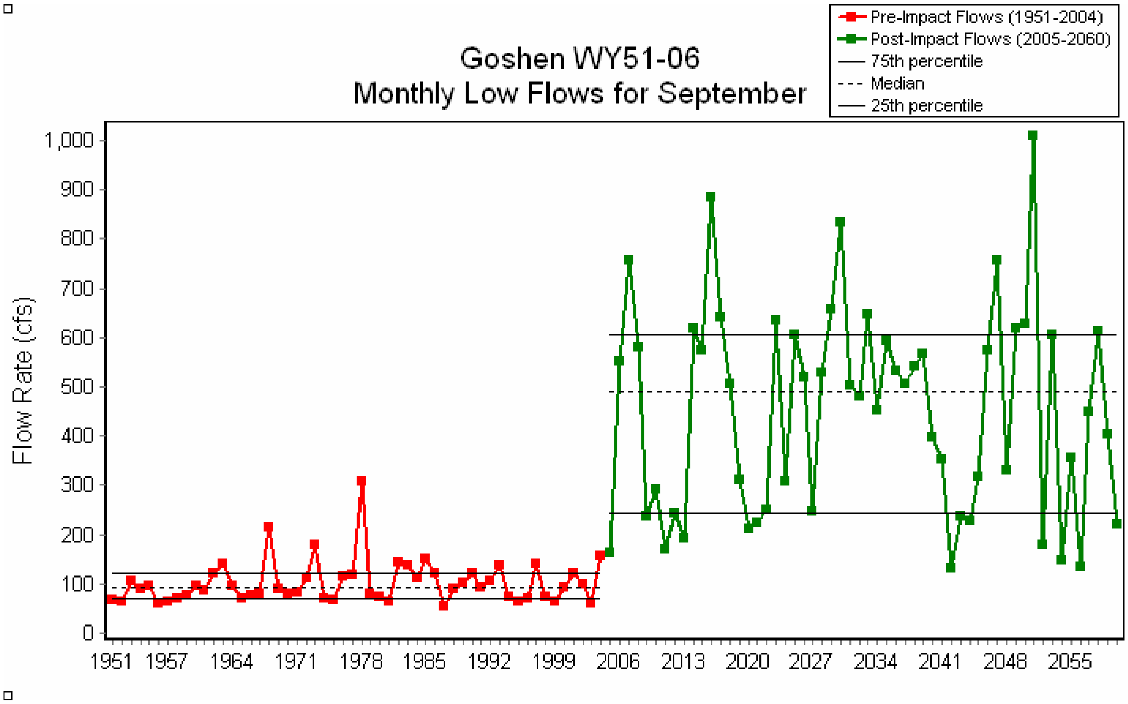


Figure 9. Magnitude of extreme low flow events, Coast Fork Willamette River.

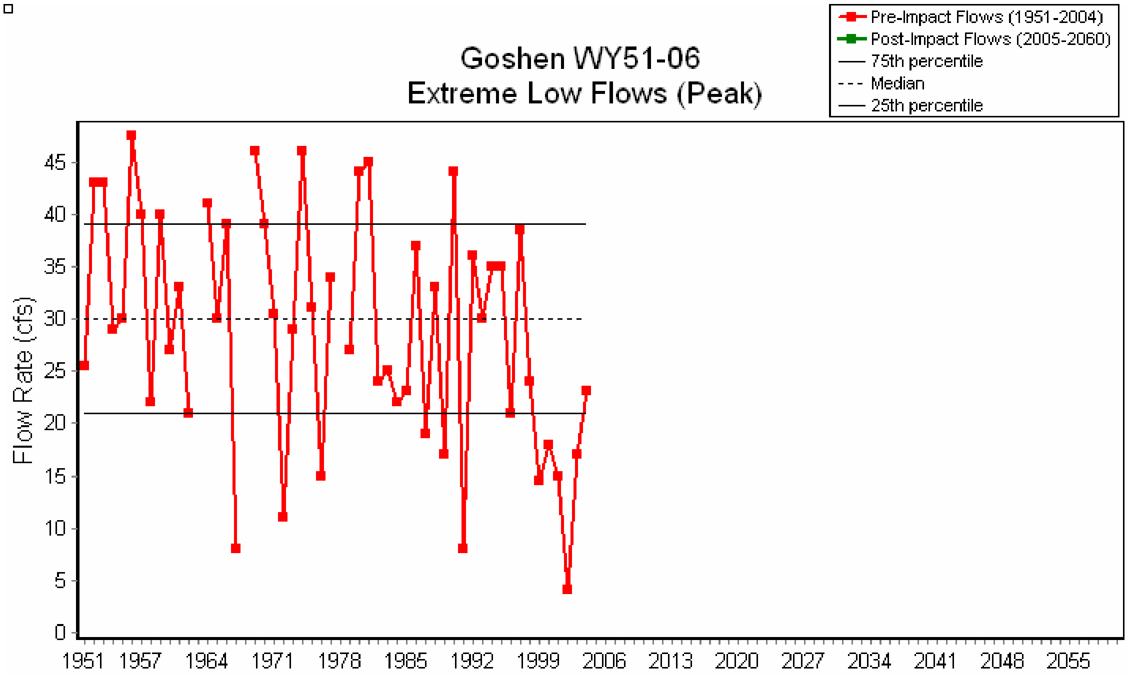


Figure 10. Environmental Flow Components for the Coast Fork Willamette River. Unregulated flows are to the left of the arrow and regulated flows are to the right of the arrow.

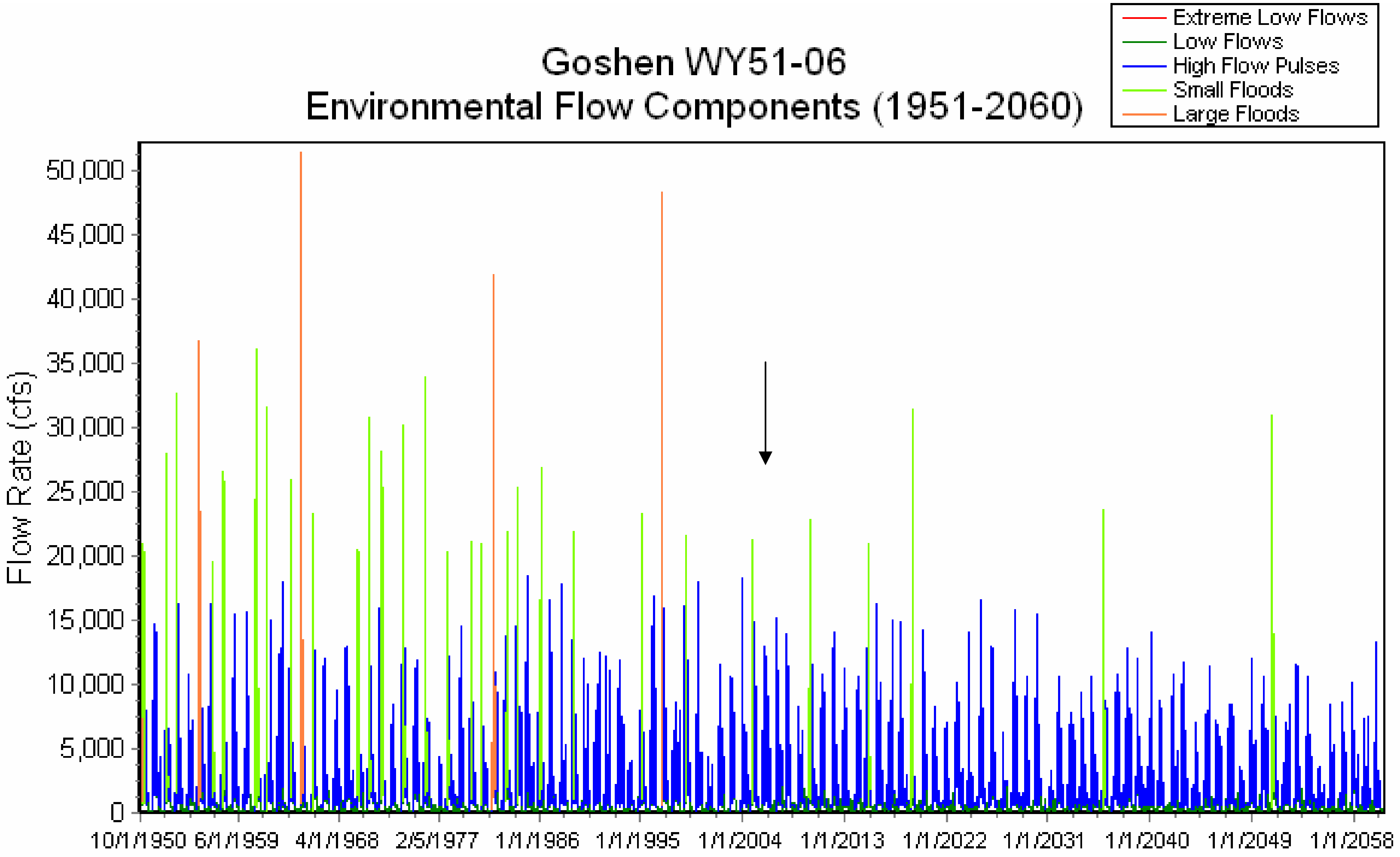


Figure 11. One-day maximum flows on the Coast Fork Willamette River.

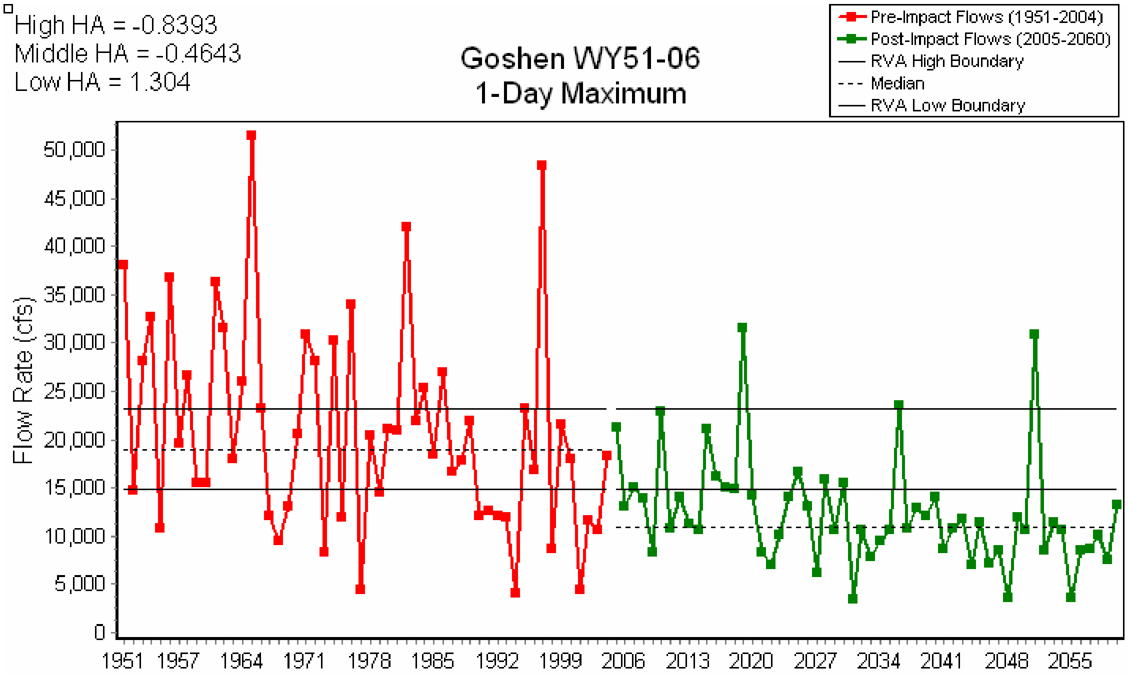


Figure 12. Thirty-day maximum flows, Coast Fork Willamette River.

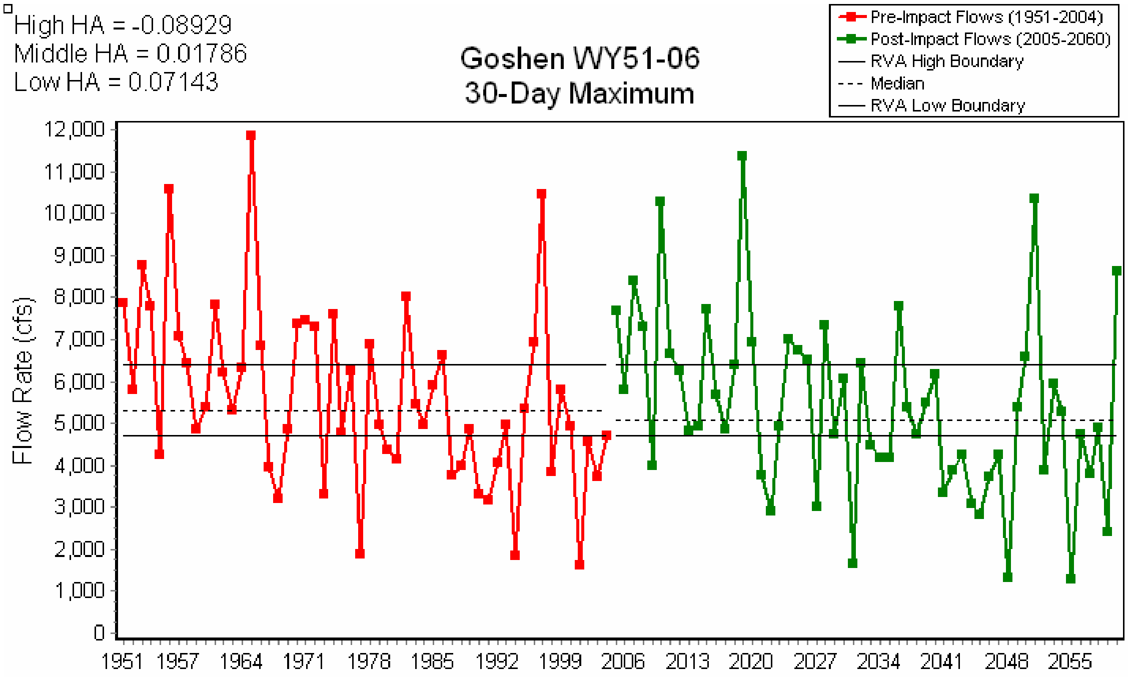


Figure 13. The magnitude of small flood events on the Coast Fork Willamette River.

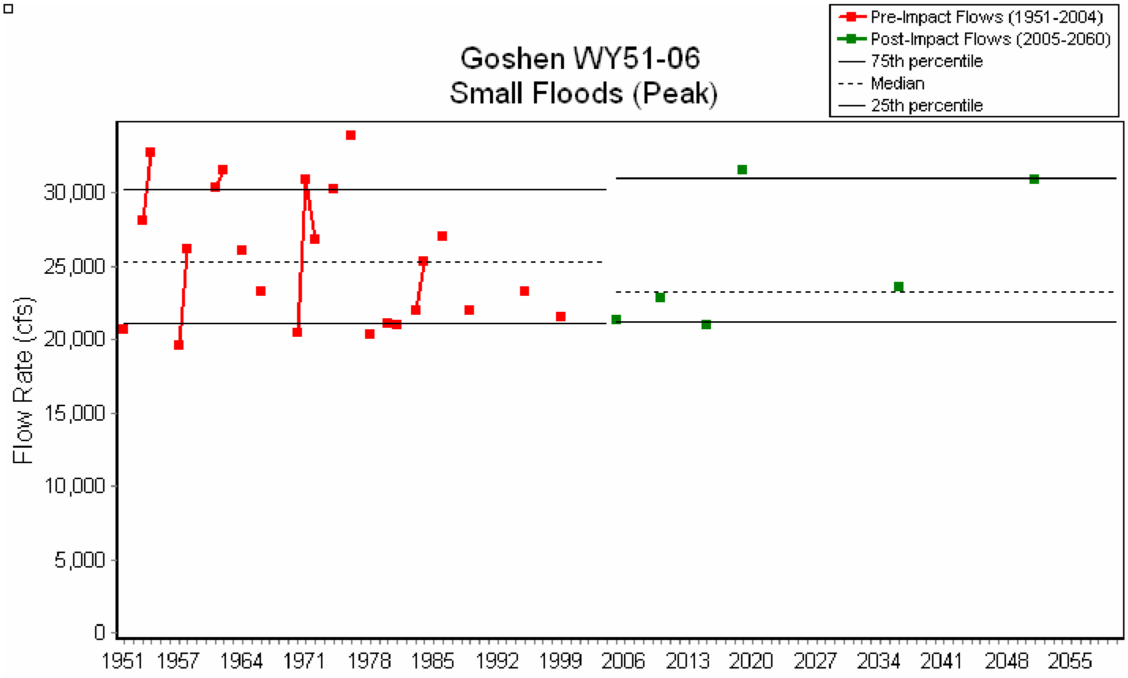


Figure 14. The duration of small flood events on the Coast Fork Willamette River.

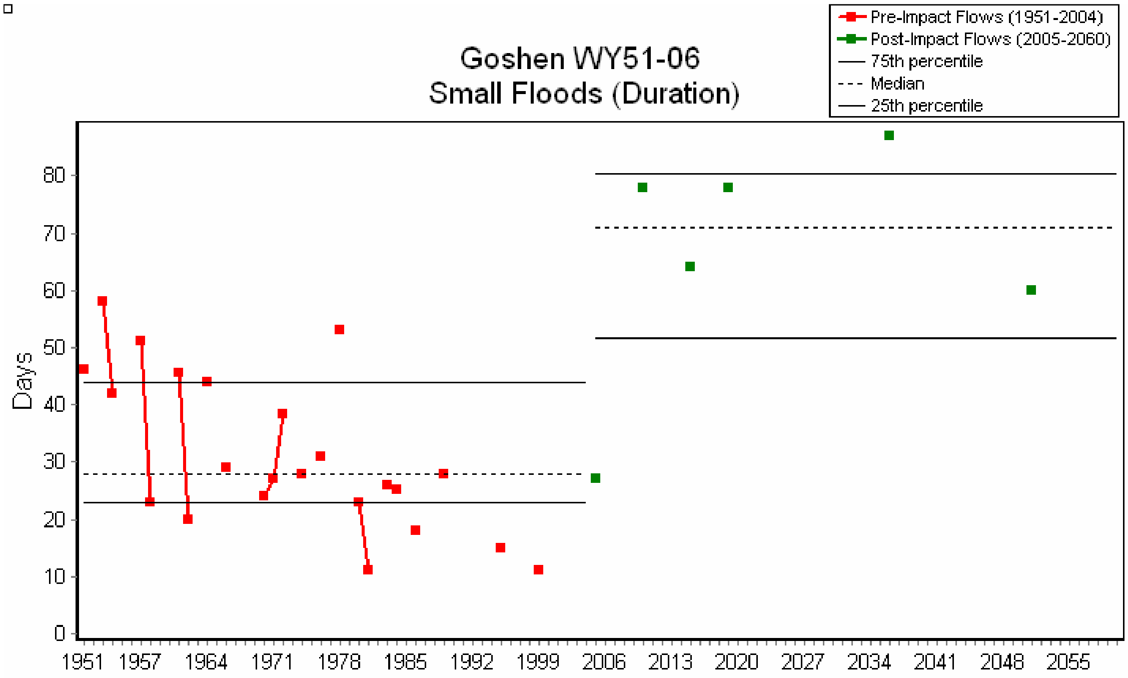


Figure 15. The peak of high flow pulses on the Coast Fork Willamette River.

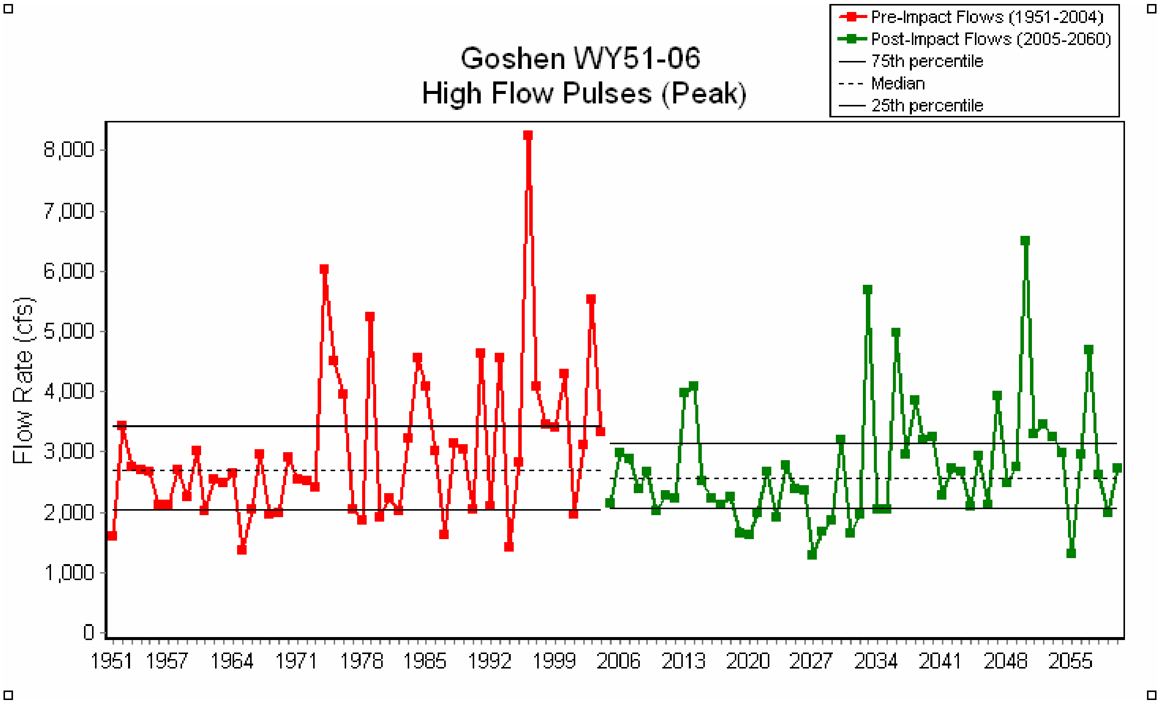
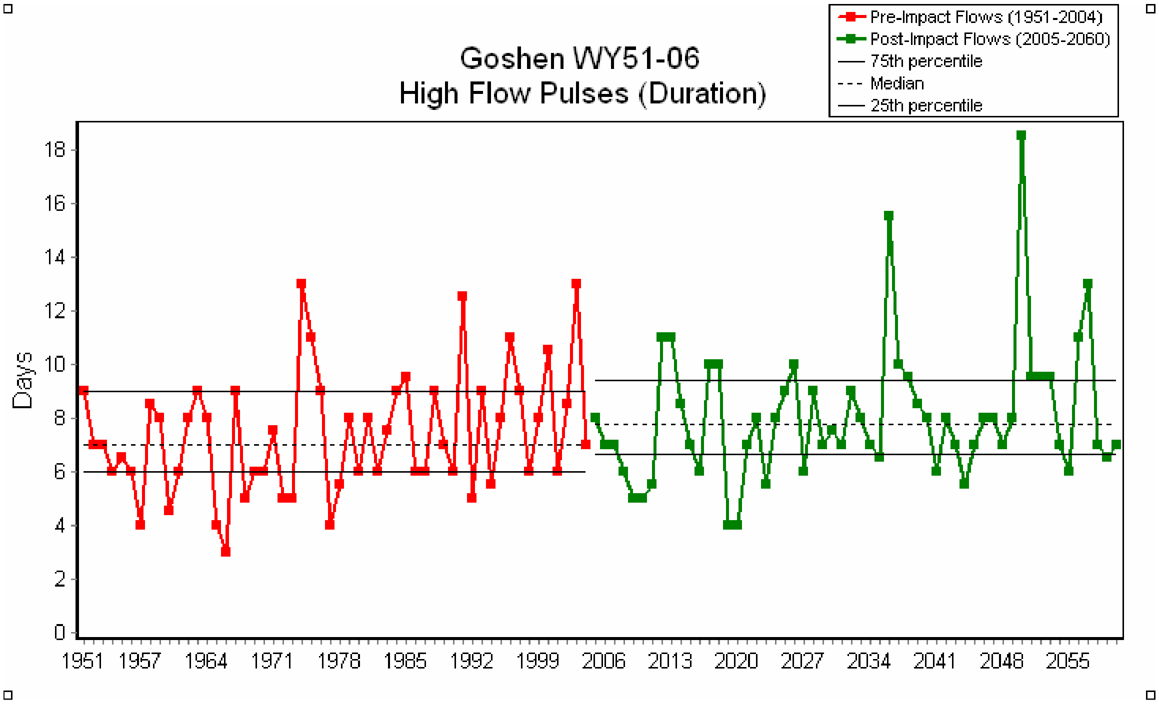


Figure 16. The duration of high flow pulses on the Coast Fork Willamette River.



APPENDIX 3

Preliminary IHA Analysis for the Willamette River at Harrisburg OR

Jeff Opperman (jopperman@tnc.org)
October 9, 2006

Background on IHA (please refer to report on Jasper for description of IHA)

Methods for Harrisburg

For this IHA analysis, unregulated flow data were provided by the Army Corps of Engineers. I acquired regulated flow data from the USGS website for gauge 14166000 (background information for this gauge is appended to the end of this report). Based on input from Bruce Duffe that the last Willamette storage project was completed in 1968, I began the analysis for both the unregulated and regulated data on 10/1/1968 (water year 1969). The unregulated flow data spanned from 10/01/1968 to 9/30/2004 while the regulated flow data spanned from 10/01/1968 to 9/30/2006.

A primary function of the IHA software is to compare to hydrological data sets and calculate a variety of statistics to assess the degree of hydrological alteration between them. The program is set up to process a single data set and the user is asked to input the year of the 'impact.' The simplest case is for a long hydrological record that has a single dam built at some point of time; the IHA then divides the data set into a 'pre-impact' period (before the year of dam completion) and 'post-impact' period. The Willamette data sets represent a different approach: comparing unregulated and regulated hydrological data from the same period of record. Within the IHA I defined the unregulated data as 'pre-impact' and the regulated data as 'post-impact.' However, because the IHA requires a single data set with a user-defined year of impact, I created 'dummy' years for the post-impact data (regulated data) with an impact date of 10/1/2004. Within the analysis you will see that the post-impact flows are represented by the water years 2005 to 2042. Keep in mind that theses post-impact years are the same years as the pre-impact data (with two extra years in post-impact) but for the purposes of the IHA analysis they've been labeled with future years.

In the results, I'll refer to 'RVA categories.' RVA stands for 'Range of Variability' and is based on the distribution of unregulated flows. The high RVA category is the upper third of the distribution of unregulated flows, the low RVA category is the lower third. Thus, when regulated flows have a positive value for the High RVA category and a negative value for the Low RVA category, it means that the distribution for regulated flows has shifted to higher magnitudes than the regulated data.

Results

While unregulated flows contain three large floods and numerous small floods, regulated flows show no large floods and few small floods (Figure 1). For maximum flows, the regulated (post-impact) flows have large negative Hydrological Alteration (HA) values in the high RVA category and high positive HA values for the low RVA category, indicating the regulated distribution of maximum flows has low magnitudes compared to the distribution of unregulated flows (Figure 2). Figure 2 also shows that regulated minimum flows are greatly elevated compared to unregulated flows and that summer and fall monthly regulated flows are elevated, and winter and spring regulated monthly flows are diminished, compared to unregulated flows.

These trends are illustrated in Figure 3 – 6. Figure 3 shows that monthly flows in December and January are very similar between the data sets. Unregulated monthly flows are then greater than regulated flows from February through May and regulated flows are greater than unregulated flows from July through November. Three-quarters of regulated monthly flows for April fall into the low RVA category (Figure 4). Every regulated September monthly flow falls into the high RVA category, and the median monthly regulated flow is approximately double the unregulated median (Figure 5). Monthly flows in January are very similar between the regulated and unregulated data sets (Figure 6).

The thirty-day minimum regulated flow is greatly elevated compared to the unregulated flow (Figure 7). Extreme low flows are an Environmental Flow Component (EFC) defined based on the unregulated flows and these types of flows no longer occur in the regulated data set (Figure 8)

Maximum flows have decreased in magnitude in the regulated data set. The median one-day maximum regulated flow (approximately 50,000 cfs) is somewhat lower than the unregulated median (70,000 cfs). No regulated maximum values fall into the high RVA category and approximately 75% fall into the low RVA category (Figure 9). The regulated seven day maximum flows are also diminished, although less dramatically as the one-day maximum flows (Figure 10).

Small floods, an EFC defined based on unregulated flow data, rarely occurs in the regulated data set and has lower magnitudes (Figure 11) but longer durations (Figure 12).

Regulated high-flow pulse magnitudes are slightly diminished (Figure 13), but have similar duration (Figure 14), and frequency (Figure 15) compared to unregulated high-flow pulses.

From USGS website:

Station operated in cooperation with the U.S. Army Corps of Engineers.
Note: Additional data is available from the National Weather Service.
STATION.-- 14166000 WILLAMETTE RIVER AT HARRISBURG, OR

LOCATION.--Lat 44° 16'14", long 123° 10' 21", in NW 1/4 NE 1/4 sec.16, T.15 S., R.4 W., Linn County, Hydrologic Unit 17090003, on right bank 75 ft north of intersection of First Street and Kesling Street in Harrisburg and at mile 161.0. *[Location map]*

DRAINAGE AREA.--3,420 mi^2, approximately.

PERIOD OF RECORD.--October 1944 to current year. Gage-height records collected at same site in 1927-28, 1931, 1934, are contained in reports of National Weather Service.

GAGE.--Water-stage recorder. Datum of gage is 288.39 ft above NGVD of 1929. Oct 1 to Nov. 14, 1944, nonrecording gage at bridge 1,110 ft upstream at different datum. Nov. 15, 1944, to Aug. 15, 1973, at site 1,100 ft upstream at datum 2.00 ft higher.

REMARKS.--Flow regulated by 8 reservoirs upstream from station. Many small diversions upstream from station for irrigation. Continuous water-quality records for the period June 1961 to September 1987 have been collected at this location.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 210,000 ft^3/s Dec. 29, 1945, gage height, 19.69 ft, from rating curve extended above 115,000 ft^3/s; minimum discharge, 1,990 ft^3/s Oct. 30, 1944.

EXTREMES OUTSIDE PERIOD OF RECORD.--Flood stage of 20.5 ft was reached in December 1861, and 20.1 ft in February 1890 (information from Corps of Engineers). Flood of Jan. 1, 1943, reached a stage of 19.1 ft from National Weather Service.

EXTREME FOR FEBRUARY 1996 FLOOD.--Maximum discharge, 76,100 ft^3/s, Feb. 8, gage height, 14.70 ft; minimum discharge, 4,530 ft^3/s July 11, 13.

Figure 1. Environmental flow components for the Willamette River at Harrisburg. Regulated flows begin in water year 2005 (noted by the arrow). To the left of the arrow are unregulated flows. Note that the unregulated and regulated flow data actually correspond to the same years, but for the purposes of IHA the regulated flows are considered 'post-impact' and are labeled with future years.

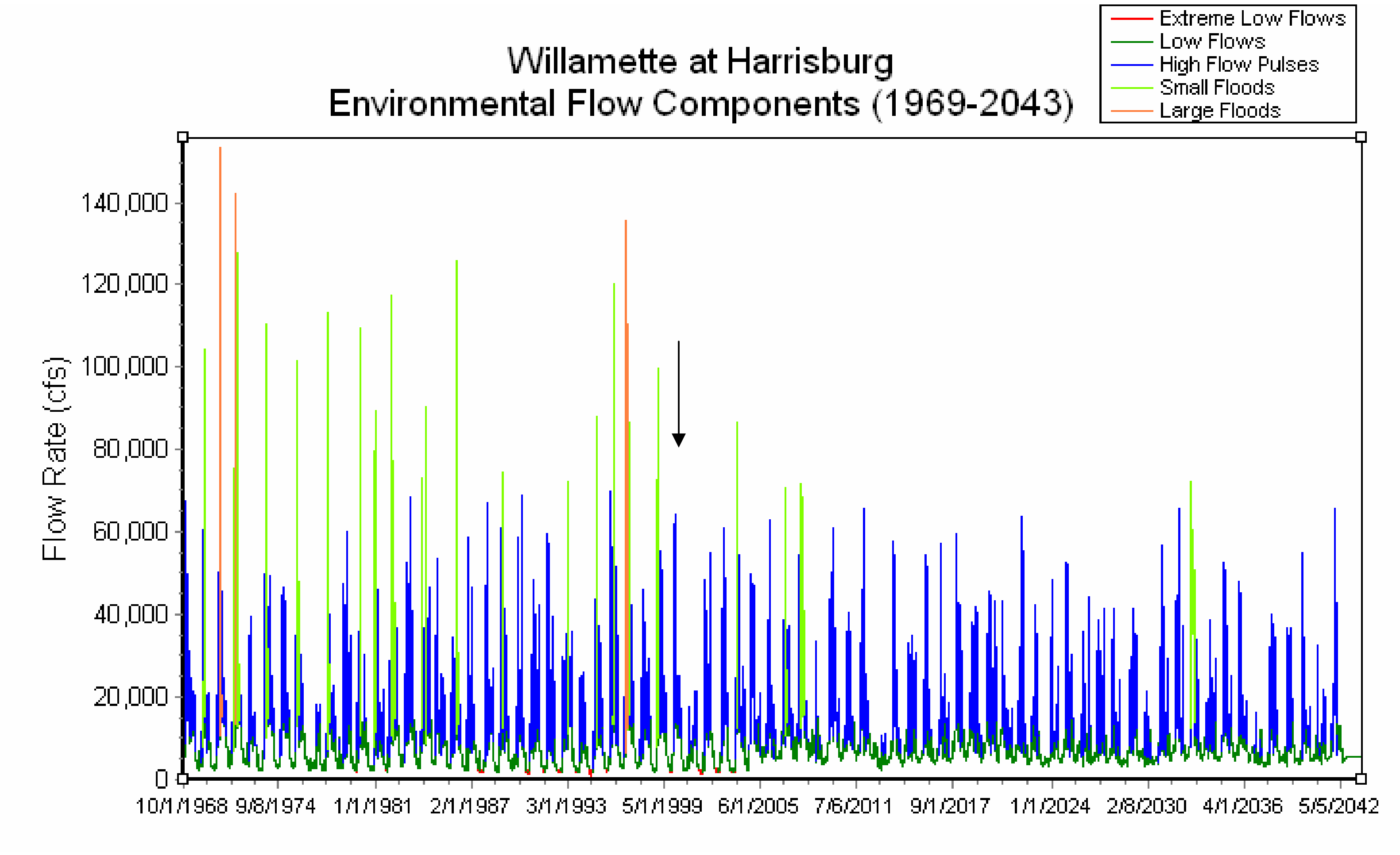


Figure 2. Hydrological alteration values for the Willamette River at Harrisburg.

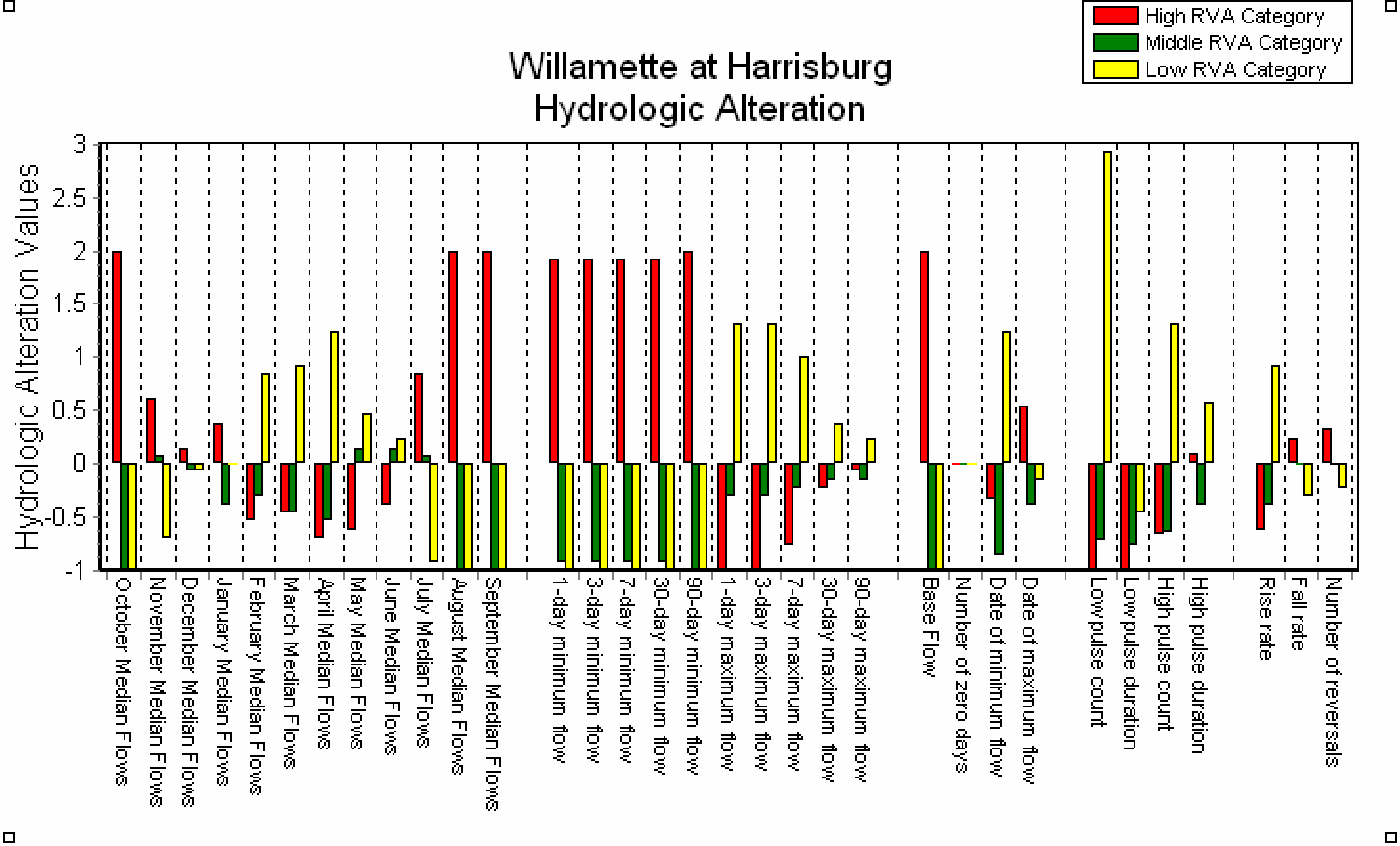


Figure 3. Monthly flow values for the Willamette River at Harrisburg. 'Pre-impact' flows (red) are unregulated data provided by the Army Corps, while 'post-impact' flows are regulated data provided by the USGS gauge at Harrisburg.

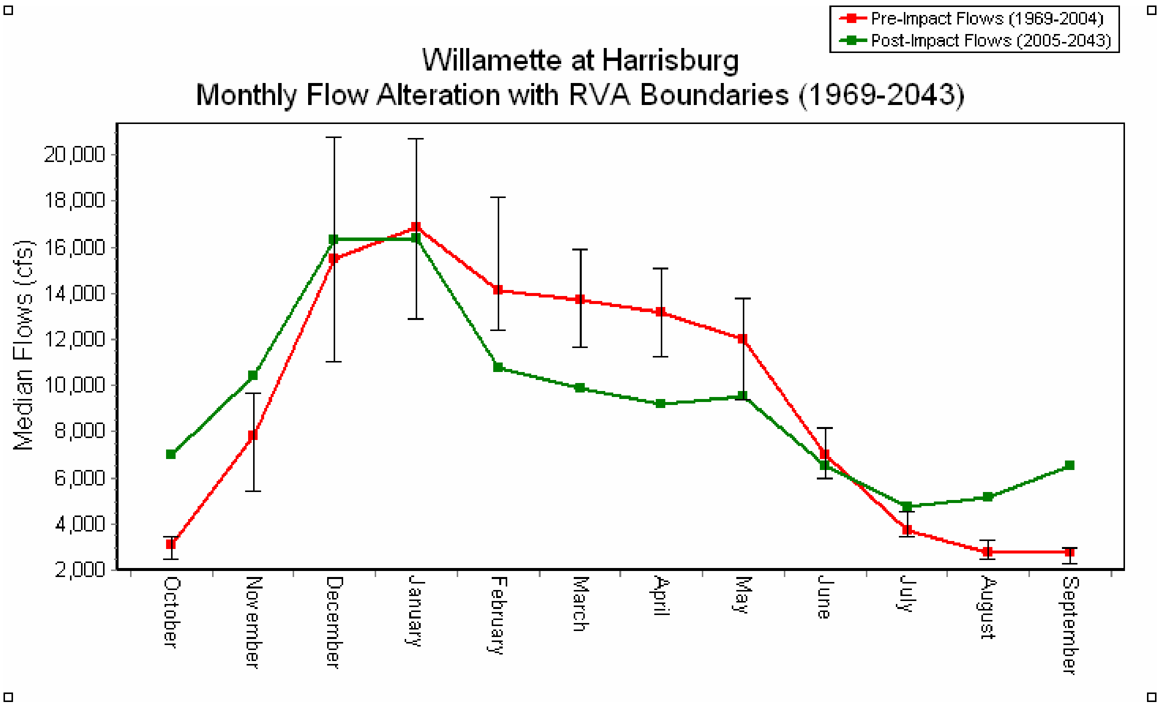


Figure 4. Monthly flows for April for the Willamette River at Harrisburg.

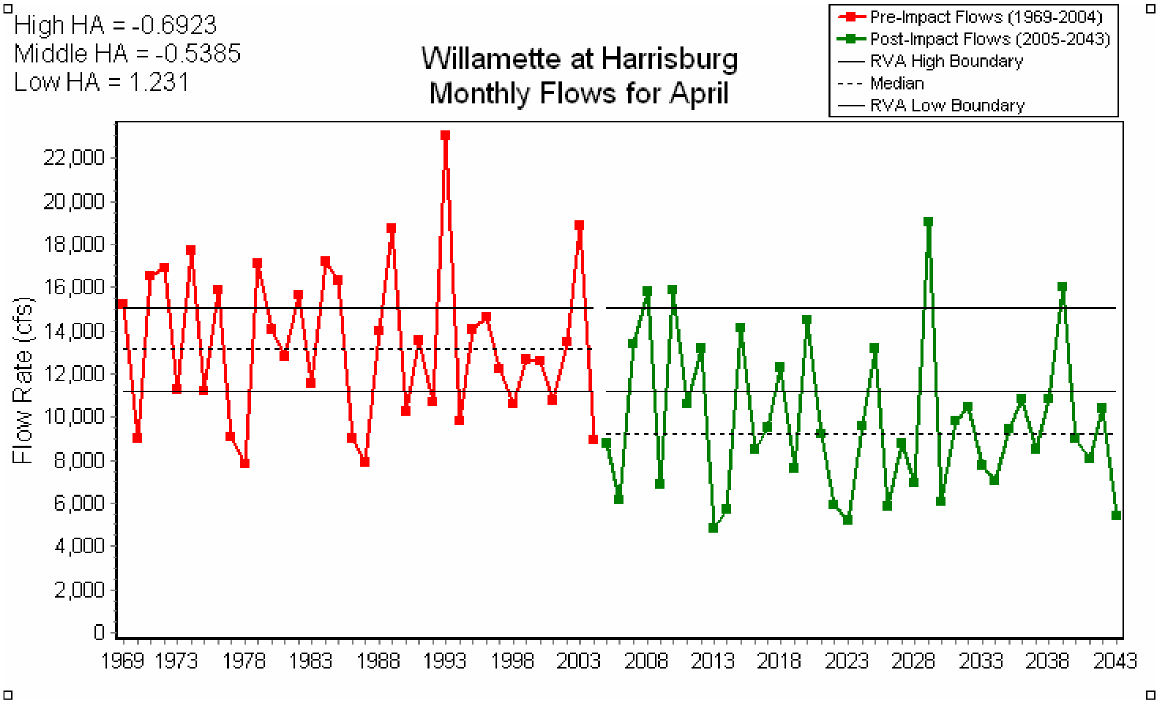


Figure 5. Monthly flows for September for the Willamette River at Harrisburg.

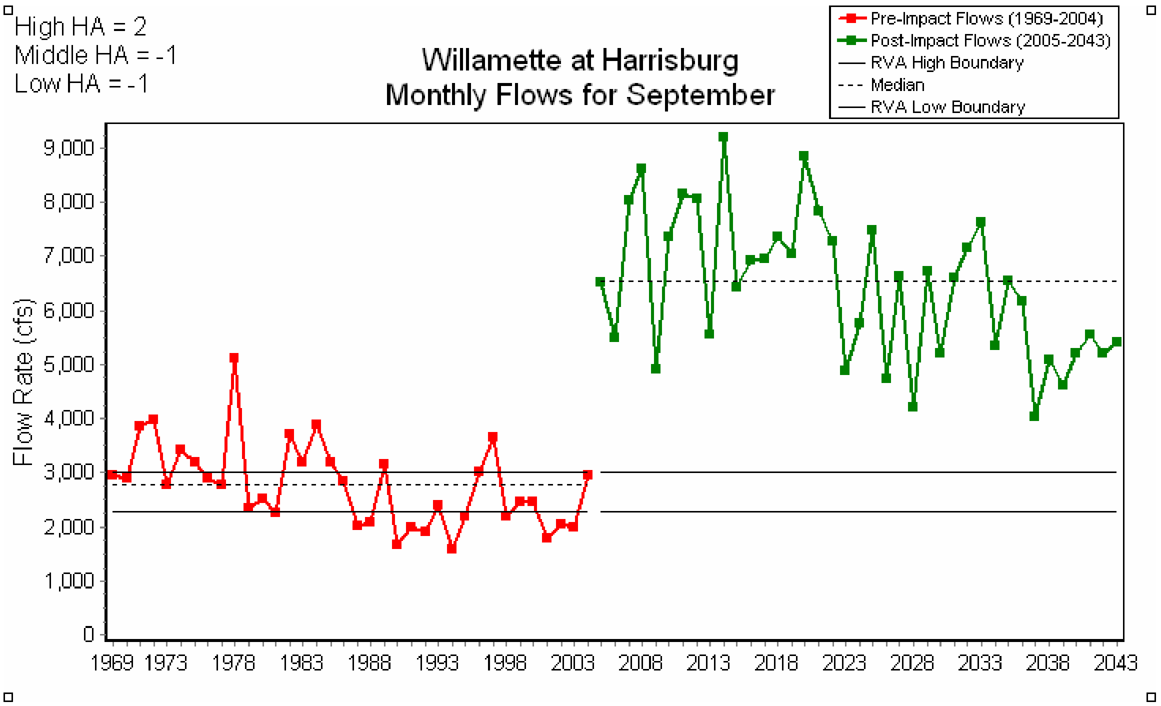


Figure 6. Monthly flows for January for the Willamette River at Harrisburg.

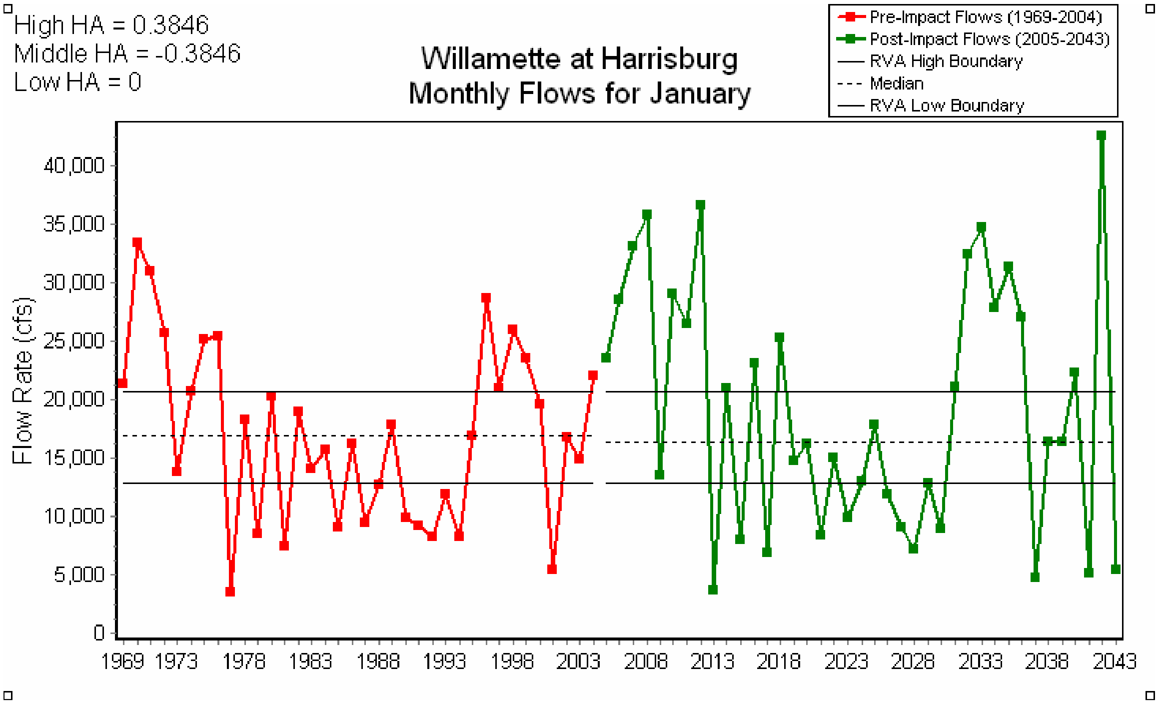


Figure 7. Thirty-day minimum flows for the Willamette River at Harrisburg.

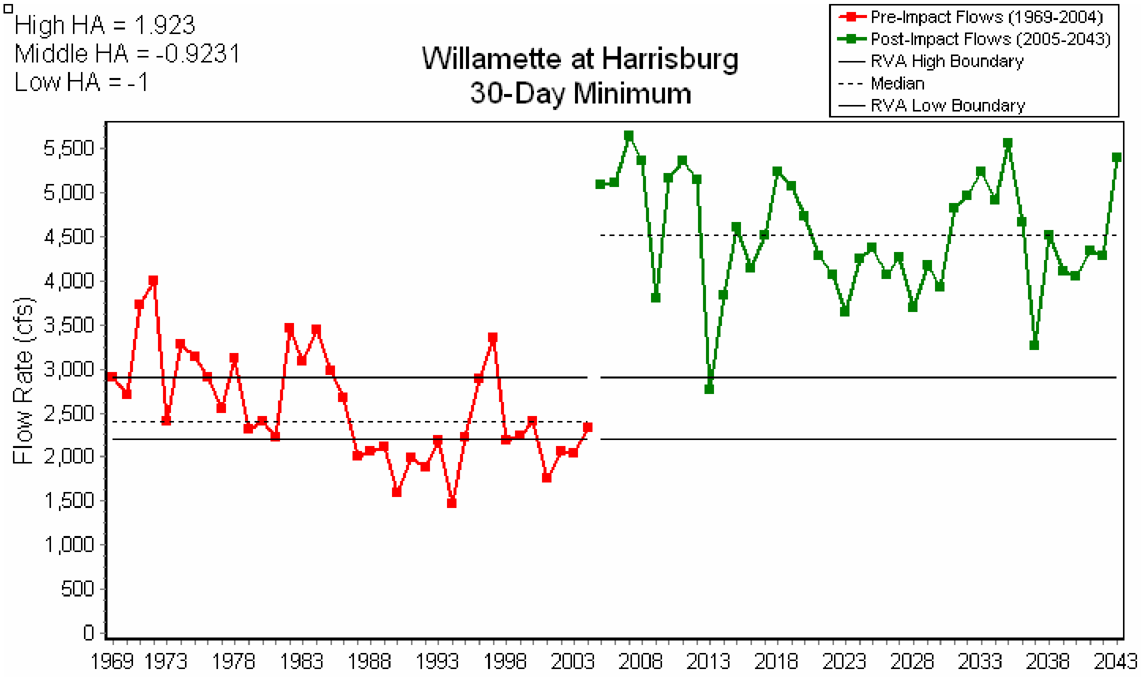


Figure 8. Extreme low flows for the Willamette River at Harrisburg.

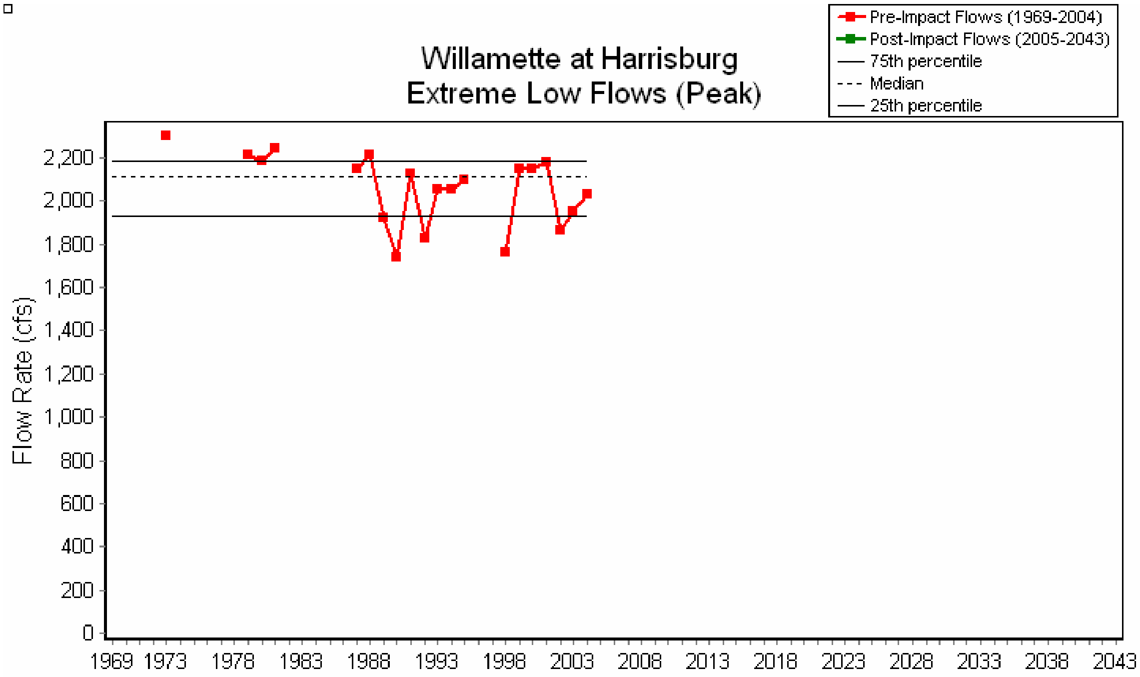


Figure 9. One-day maximum flows for the Willamette River at Harrisburg.

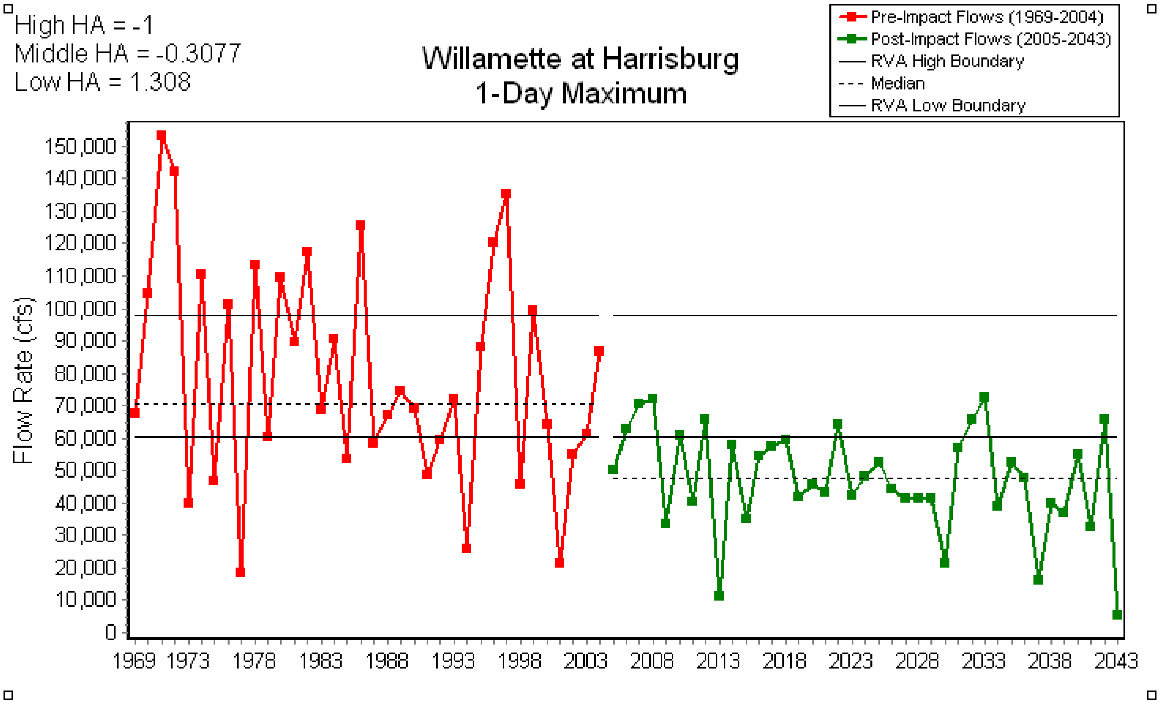


Figure 10. Seven-day maximum flows for the Willamette River at Harrisburg.

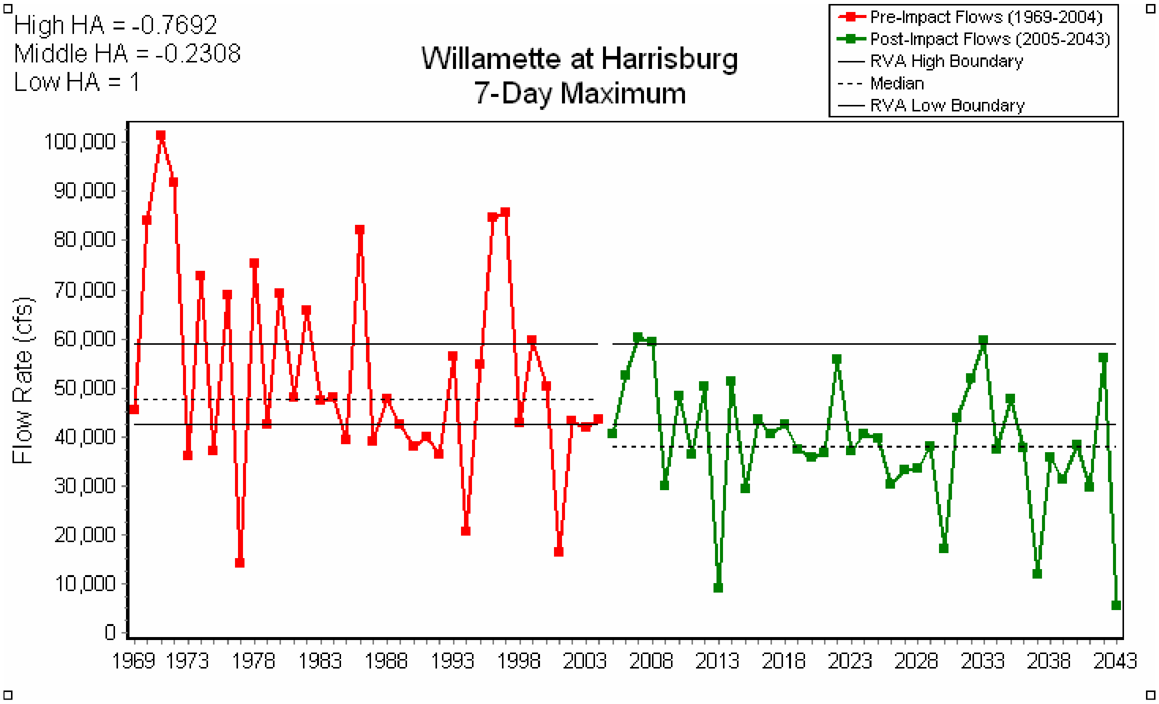


Figure 11. The magnitude of small floods, an Environmental Flow component defined based on the unregulated (pre-impact) data, for the Willamette River at Harrisburg.

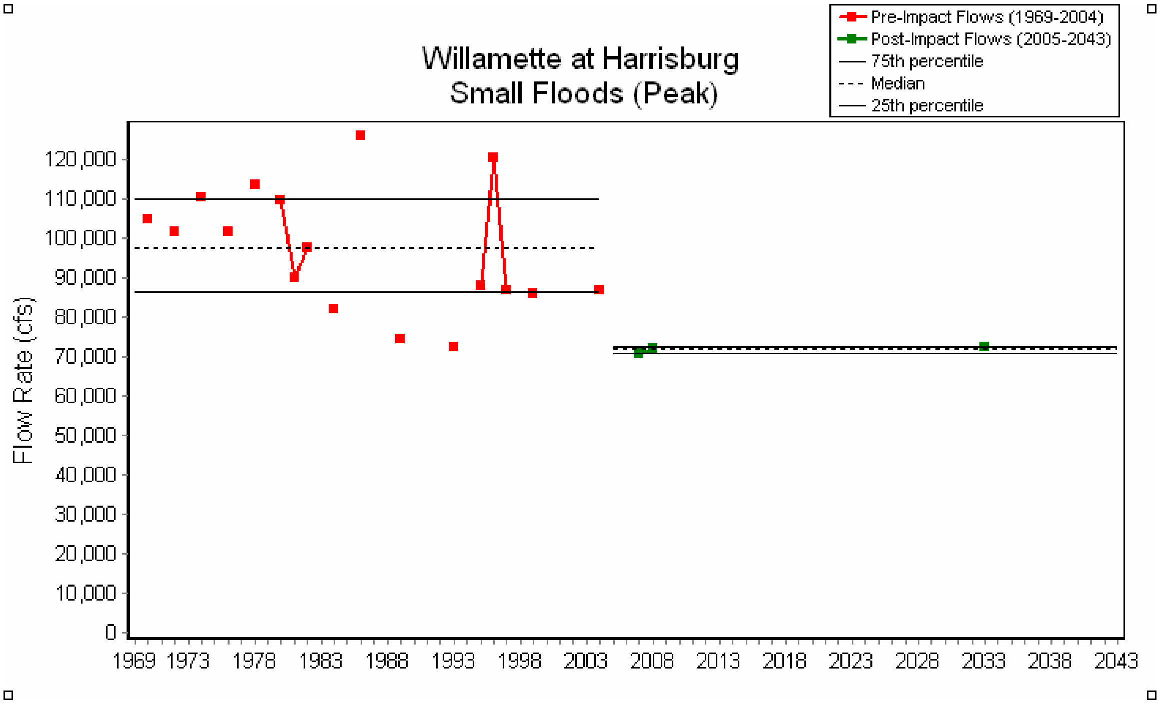


Figure 12. The duration of small floods for the Willamette River at Harrisburg.

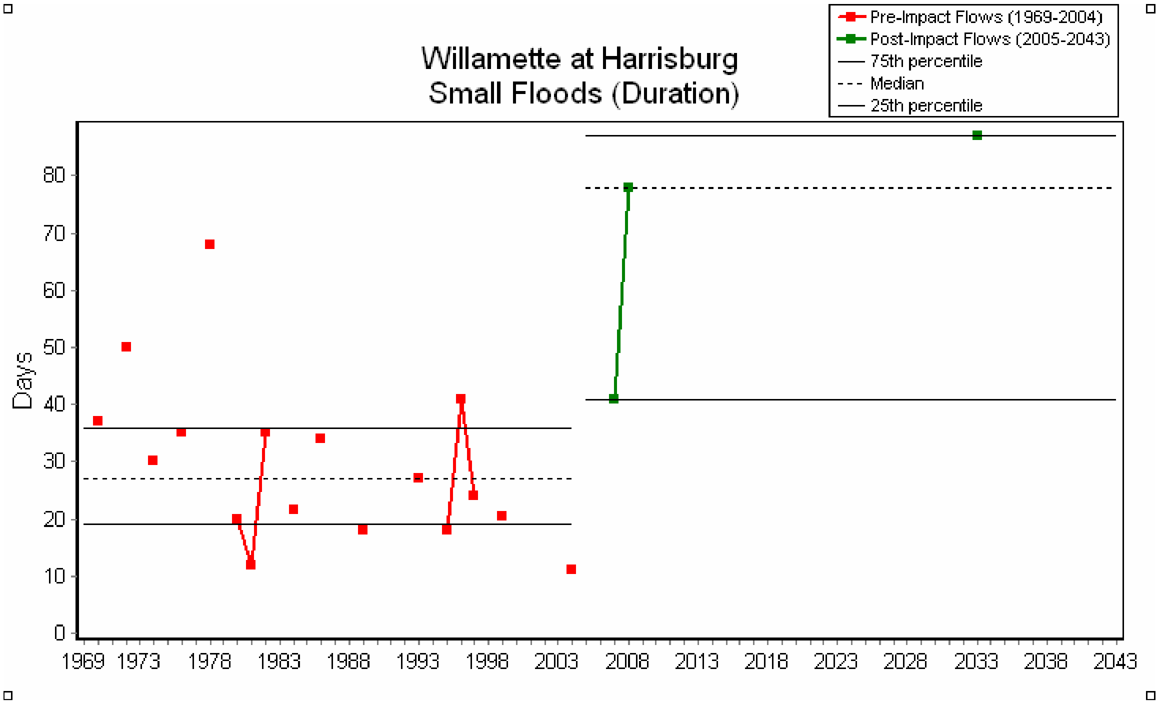


Figure 13. The magnitude of high-flow pulses for the Willamette River at Harrisburg.

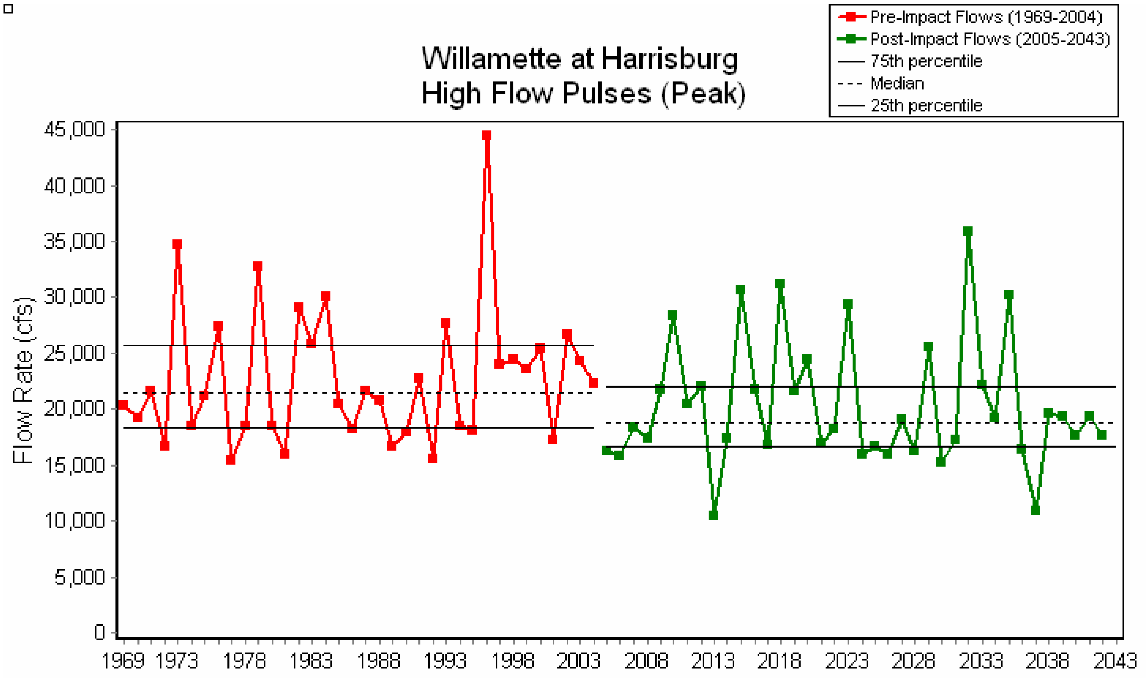


Figure 14. The duration of of high-flow pulses for the Willamette River at Harrisburg.

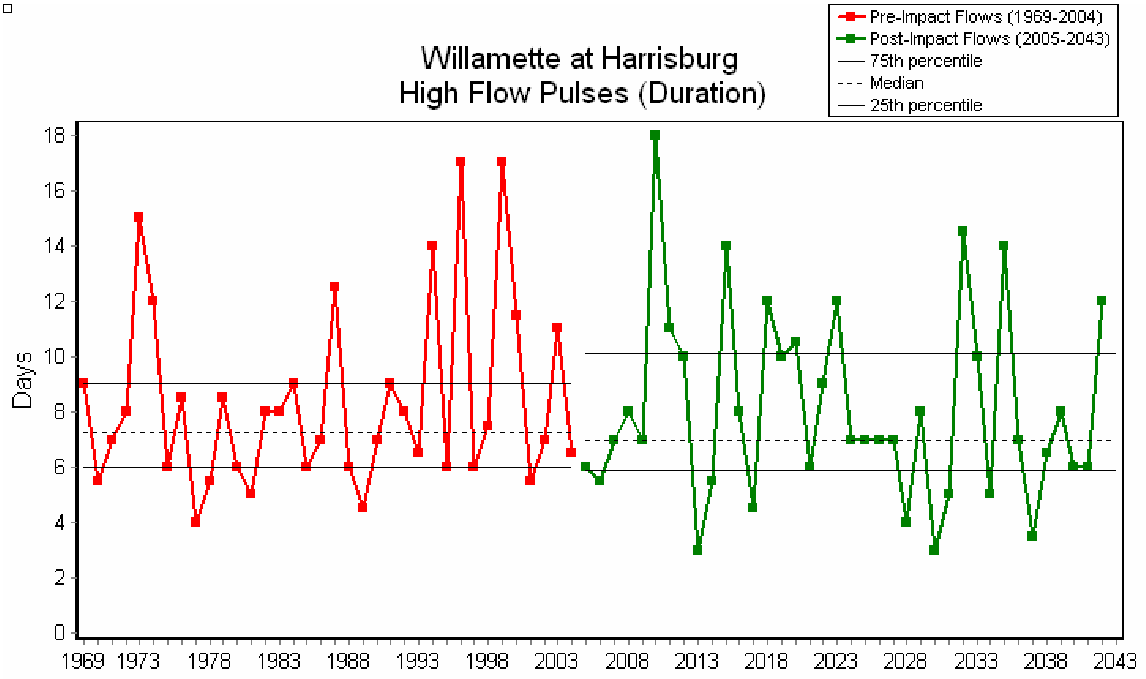


Figure 15. The frequency of high-flow pulses for the Willamette River at Harrisburg.