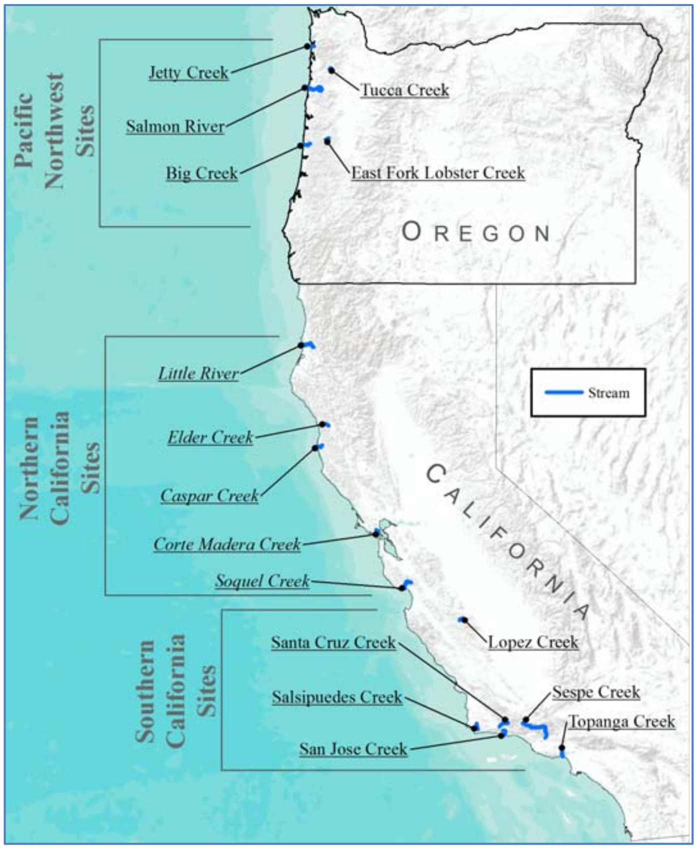
# COMPARING FISH PASSAGE OPPORTUNITY USING DIFFERENT FISH PASSAGE DESIGN FLOW CRITERIA IN THREE WEST COAST CLIMATE ZONES



Map by NOAA Fisheries West Coast Region, GIS Lab, Santa Rosa, CA.

**Prepared for:**

**National Marine Fisheries Service**
Santa Rosa, California

**Contract No:**

AB-133F-12-SE-2021

**Prepared by:**


**Margaret Lang, PhD, PE**
Humboldt State University
Arcata, California

**Michael Love, PE**
Michael Love & Associates, Inc.
Arcata, California


**August 2014**

# EXECUTIVE SUMMARY

## BACKGROUND

Key Points:

- Many instream structures and channel modifications result in partial or complete hydraulic barriers to anadromous fish passage.
- If passage is delayed or prohibited, anadromous fish populations may be significantly constrained or extirpated from a watershed.
- The overarching goal of this study is to generate information about differences in the time adult steelhead (*Oncorhynchus mykiss*) have to migrate upstream within different regional climates and relate it to the design of projects that affect fish passage opportunity; thus helping to achieve more "fish-friendly" stream structures and channel modifications along the West Coast of the United States.

**Fish Passage Opportunity and High and Low Fish Passage Delay:** Many inadequately designed instream structures and channel modifications (e.g. culverts, check dams, fish ladders, flood control channels, etc.) result in altered stream flows and hydraulic conditions that block or impede the passage of anadromous fish at some or all discharges within a stream. To remedy this problem, NOAA's National Marine Fisheries Service established design criteria that promote suitable passage conditions for anadromous fish at instream structures and within project reaches. A basic step in the design of a "fish-friendly" project is to establish hydraulic criteria known as the high and low fish passage design flows ($Q_{HFP}$ and $Q_{LFP}$). The intent of identifying $Q_{HFP}$ and $Q_{LFP}$ is to ensure that, when flows are between the $Q_{LFP}$ and $Q_{HFP}$, the hydraulic conditions generated within an instream structure or project reach are such that fish can freely migrate upstream and downstream to satisfy their biological requirements, i.e. - spawning, foraging, dispersing, and rearing in fresh water environments. It is further assumed that fish are unlikely to be present or need to migrate past the project reach at flows below $Q_{LFP}$ or above $Q_{HFP}$. Flows below $Q_{LFP}$ or above $Q_{HFP}$, at an instream structure or within a project reach, are allowed to be impassable or to cause passage delay due to lack of depth, high velocities, excessive turbulence, etc. The time period during which flows are less than the $Q_{LFP}$ is referred to as low flow passage delay and the time period during which discharges are higher than $Q_{HFP}$ is referred to as high flow passage delay. The passage opportunity (as defined in this report) refers to the total time within a migration season that flows are between $Q_{LFP}$ and $Q_{HFP}$. The $Q_{LFP}$ and $Q_{HFP}$ values adopted in an anadromous fish passage project should include a wide enough range of discharges that the project does not inadvertently delay fish passage to the extent spawning success is adversely affected. At the same time, adopting $Q_{HFP}$ and $Q_{LFP}$ criteria that provides passage over a wider range of flows than passage naturally occurs in a stream may only increase project complexity and cost without substantially improving fish access to spawning grounds.

## PURPOSE

Key Points:

- A paucity of information exists on how much time and opportunity anadromous fish have to migrate within the different climate conditions found along the West Coast of the United States.
- There are three objectives of this report:
    - Quantify how utilizing various federal and state $Q_{HFP}$ criteria affects adult steelhead (*Oncorhynchus mykiss*) migration opportunity within 16 small- to medium-sized watersheds along the West Coast of the United States.
    - Identify general trends in adult steelhead passage opportunity that may be related to the varying hydrologic conditions that exist between Oregon and Southern California.
    - Determine to what degree errors in estimating $Q_{HFP}$ can impact adult steelhead passage opportunities.

**Federal and State High and Low Fish Passage Design Flow Criteria:** Federal and state guidelines exist for identifying appropriate $Q_{LFP}$ and $Q_{HFP}$ values for anadromous salmonids and are typically stated in hydrologic terms as either a percentage of the 2-year flow event ($Q_{2\text{-year}}$) or as a flow exceedance percentage. However, a paucity of information exists regarding how these guidelines, when implemented in different hydrologic/climate zones, impact the total time that anadromous salmonids will have access to spawning grounds and the relative magnitude of the delays created by specific $Q_{LFP}$ and $Q_{HFP}$ criteria during wet, average and dry migration seasons. For species such as the steelhead (*Oncorhynchus mykiss*), which spawn in watersheds having a wide variety of hydrologic conditions, understanding how passage opportunity varies in different climatic regions is important to identify what might become excessive passage delay under certain conditions. Moreover, as $Q_{HFP}$ values must often be computed from regional flood frequency regression equations or flow duration curves (FDCs) derived from flow records of relatively short duration, it is unclear how much delay can be inadvertently introduced by errors in estimating the $Q_{HFP}$.

## STUDY METHODOLOGY

Key Points:

- Steelhead passage opportunity within 16 Pacific coast watersheds (divided into three regional climate zones) was studied.
- The amount of high fish passage delay and the total fish passage opportunity, created by adopting various federal and state high fish passage design flow criteria, in wet, average and dry years in each watershed was calculated.
- Moving spatially between the ‘Pacific Northwest’ and ‘Southern California’, several hydrologic parameters that differ and affect steelhead passage times were identified.
- How the year-to-year variation in steelhead passage time changes between the ‘Pacific Northwest’ and ‘Southern California’ was quantified.

- The amount of time fish may be delayed/denied fish passage due to errors in estimating high fish passage design discharges was investigated.

**Study Sites and Hydrologic Parameters:** Sixteen gaging stations/study sites, located along the West Coast of the United States, were selected for study. Each study site was located within a small- to medium-sized coastal watershed, had a mean daily discharge record spanning at least 19 years, had an unimpaired hydrograph during the fish migration period and currently, or historically, supported anadromous salmonids. These 16 study sites were divided into three different climate regions: the Pacific Northwest region; the Northern California region; and the Southern California region. The Pacific Northwest and Northern California regions contained five study sites each, while the Southern California region contained six study sites. Basic hydrologic parameters that may vary between regions and affect passage and delay times were identified and computed. These parameters included hydrograph 'flashiness', the variability in annual water yields, and whether conditions were 'Wet', 'Average' or 'Dry' during a migration season at a particular site. Flashiness was investigated by computing the rate flow increased and decreased on the rising and falling limbs of 20 individual storm hydrographs within each climate region. Additionally, the Richards-Baker flashiness index (Baker et al. 2004) was computed for each water year at each site two different ways: using all of the year's flow data; and using only the flow data occurring within the identified steelhead migration season.

Inter-annual water yield variability was assessed and compared across the three climate regions by normalizing each study site's annual water yield by the site's median annual water yield. The more a normalized yield deviates from a value of one, the more extreme the yield is relative to a site's median yield, thus reflecting how extreme a drought or wet year was. The sites' annual yields were used to classify each water year as either 'Wet', 'Average', or 'Dry'. Years with water yields in the lower 20$^{th}$ percentile for the site were classified as 'Dry' years. Years falling in the upper 20$^{th}$ percentile were classified as 'Wet' years, while the remaining 60 percent of the years were classified as 'Average'.

**Computation of Passage and Delay Times:** The amount of time that steelhead could pass and the amount of time that steelhead passage would be delayed under various $Q_{HFP}$ criteria were computed for each site. Specifically, the total passage time, total high flow delay time, and total low flow delay time that occurred between Nov 1 and May 15 (the assumed migration season for Southern California steelhead) were computed, at the 16 study sites, using the various federal and state high fish passage design criterion for each migration season for which a study site had a mean daily discharge record. The passage opportunity at each site, for each year, and under each design criterion was then expressed as a percentage of the total time within the assumed migration season (196 days) that discharges fell between the low and high flow design discharges. The high fish passage delay time within each migration season was also expressed as a percentage of the total passage time available within the migration season at each site, for each year, using each high fish passage design criterion. Box-and-whisker plots were then created to compare the variability that occurs in the total passage time and the high flow delay time that occurs within migration seasons at each study site using each of the high fish passage design discharge criterion. Box-and-whisker plots were also created for each study site showing the variability in passage and high flow delay time that occurred within 'Wet', 'Average', and 'Dry' years using various $Q_{HFP}$ criteria. The resulting suite of metrics and plots allow one to compare the passage opportunities and delay times between individual sites when a specific $Q_{HFP}$ is adopted. Regional trends in passage and high flow delay times were visually assessed by creating and comparing box-and-whisker plots that combine all the passage or high passage delay times for all of the study sites within each region using each of the $Q_{HFP}$ criteria. Such regional box-and-whisker plots were created using all of the years and for 'Wet', 'Average', and 'Dry' years to demonstrate how passage and high flow delay times varied amongst the regions for all years and during 'Wet', 'Average' and 'Dry' years.

**$Q_{LFP}$ and $Q_{HFP}$ Criteria Used:** The adult steelhead $Q_{HFP}$ criteria that were used in the above analyses included:

- the 1% annual exceedance ($Q_{1\%AnExc}$)
- the 1% exceedance for the steelhead migration season ($Q_{1\%SH\text{-}MP\text{-}EXC}$)
- the 5% exceedance for the steelhead migration season ($Q_{5\%SH\text{-}MP\text{-}EXC}$)
- 50% of the 2-year flow event calculated using annual peak flow records ($50\%Q_{2\text{-}Pk}$)
- 50% of the 2-year flow event calculated from regional regression equations ($50\%Q_{2\text{-}Em}$)
- Other criteria were used, on a limited basis, to briefly investigate adult coho and chinook passage times at specific sites, as well as juvenile steelhead passage times. The results of these analyses are not discussed in the executive summary, which like the report, focuses on adult steelhead passage, particularly in Southern California. Some of these results have been included in the report and appendices for interested readers.

The $Q_{LFP}$ criterion used at any given site was always the 50% annual exceedance ($Q_{50\%AnEX}$) or 3 cfs, whichever was greater. This is consistent with the $Q_{LFP}$ criterion used throughout coastal California and represents a low flow condition that often produces shallow depths in the natural channel that are assumed to impede adult steelhead movement.

**Sensitivity Analysis of Errors in $Q_{HFP}$ estimates:** How sensitive passage and high flow delay times are to errors in estimating $Q_{HFP}$ was analyzed. At selected sites within each climate region, flow duration curves (FDCs) were derived from the 5- 10-, 15- and 20-consecutive wettest and driest periods of the complete mean daily discharge record available at a site. The passage and high flow delay times that resulted from using $Q_{HFP}$ estimates derived from the shorter 5-, 10- 15- and 20- year FDCs were compared (via box-and-whisker plots) to the passage and high flow delay times obtained when the entire discharge record was used to develop the FDCs and estimate $Q_{HFP}$ values. The passage and high flow delay times that result from estimating $Q_{HFP}$ from the 2-year event obtained through regional flow frequency equations versus estimating the $Q_{HFP}$ from the 2-year flow event obtained from actual peak-discharge data were also compared via box-and-whisker plots.

## STUDY RESULTS

**Key Points:**

- Moving from the 'Pacific Northwest' to 'Southern California' there is a progressive pattern of less precipitation, fewer storm events, increased hydrograph flashiness, and increased inter-annual variability of water yields.
- Low instream flow delay increases from north to south, is typically the greatest in small streams, and was the largest factor affecting total fish passage opportunity within the 16 study watersheds.
- The total amount of time steelhead have to migrate upstream generally decreases as one moves from Oregon to Southern California with the smallest passage times being found in small Southern California watersheds. However, total fish passage opportunity between two streams within the same climate region can vary substantially.
- The 'regional' median fish passage opportunity in 'Southern California' during wet years (years having the most passage opportunity in Southern California) was similar to the 'regional' median fish passage opportunity in the 'Pacific Northwest' during dry years (years having the least passage opportunity in the Pacific Northwest).
- The inter-annual variability in both total passage opportunity and high fish passage delay time (as a percentage of the passage opportunity) generally increases as one moves from the Pacific Northwest to Southern California.
- Adopting higher fish passage design discharge reduces the annual variability in high fish passage delay within a watershed (particularly in Southern California).
- Passage opportunities in streams within Northern California generally exhibit characteristics that are between those found in the Pacific Northwest and Southern California.
- Inaccurate estimates of high fish passage design flows (due to a lack of stream gaging data and/or stream gaging data collected in dry years) may result in substantially increasing high fish passage delay times at fish passage projects.
- Further research is needed on how to accurately estimate high fish passage design discharges in ungaged basins, or in basins with little stream flow data.
- Additional research is needed to: (1) better define the relative importance of delay in wet, average, and dry years; (2) better identify when flow connectivity between the ocean and spawning grounds occurs (particularly in Southern California); and (3) better determine when and how fish actually migrate during high flow storm events.

**Trends in Total Fish Passage Opportunity:** Observations of the data suggest that there may be several general regional trends that affect the total time adult steelhead have passage within a stream as one moves north to south along the 16 study sites. These north-to-south trends include: 1) decreasing precipitation (Table 1); 2) decreasing number of storm events (Appendix B); 3) increasing storm hydrograph flashiness (Figure 11); and 4) increasing variability in inter-annual water yields (Figure 5). The net result of these trends (regardless of the $Q_{HFP}$ criteria adopted) shows that total passage times (as a percent of the assumed 196 day migration season) are typically the highest in the Pacific Northwest and decrease from north to south (Figures 29-31). The variability in the percentage of the time steelhead had to pass within a given migration season also tends to increase from north to south regardless of the $Q_{HFP}$ criteria adopted (Figures 29-31). Consequently, the passage times in Southern California generally have the largest variability from year to year, and the lowest median passage time of the three regions. Regardless of the region and the $Q_{HFP}$ criteria used, passage times were also generally the highest during the 'Wet' years and lowest in the 'Dry' years. However, the change in median passage time between 'Wet' and 'Dry' years for the Pacific Northwest region was typically substantially less than for Southern California (Figures 29-31). For example, using the 1% annual exceedance as the $Q_{HFP}$ criteria, the Pacific Northwest region had a median passage time of about 90% during 'Wet' years and about 65% during 'Dry' years. The corresponding 'Wet' and 'Dry' median passage times for the Southern California region were about 62% and 10%, respectively. The Northern California regional trends exhibited characteristics between those of the Pacific Northwest and Southern California.

The largest factor typically affecting total passage time within each migration season at each site was how often flows were less than the $Q_{LFP}$ criteria. Low flow delay increased substantially from north to south (Figures 17 – 20). Smaller watersheds (in all three regions) tended to have greater low flow delay than larger watersheds within the same region. Results show that, for smaller watersheds in Southern California, the percent of low flow delay, even within a Wet migration season, can exceed 50%, whereas in the Pacific Northwest smaller watersheds typically do not experience large amounts of low flow delay during Wet or Average water years.

Within a given climate region, median passage times and annual variability in passage time can vary from site to site regardless of the $Q_{HFP}$ criteria evaluated (Figures C-29 through C-33). For example, in Southern California, the median passage time for all migration seasons at San Jose Creek and Topanga Creek were approximately 10%, whereas the median passage time for all migration seasons at Lopez and Sespe creeks were approximately 70%. The differences in median passage times for these streams is likely due to the greater amounts of low flow delay being associated with smaller watersheds. San Jose Creek and Topanga Creek (which have the lower median passage times) have watershed areas of 5.5 and 18 square miles, respectively. Lopez and Sespe creeks (which have the higher median passage times) have watershed areas of 47 and 252 square miles, respectively. The variability of the migration passage times between sites within Southern California can also vary substantially. Using the 1% annual exceedance as the $Q_{HFP}$ criteria at San Jose Creek, 50% of the migration seasons provided passage approximately 5% to 18% of the time, whereas at Salsipuedes Creek 50% of the migration seasons provide passage approximately 15% to 63% of the time (Figure C-31).

**Differences in High Fish Passage Delay from the Various $Q_{HFP}$ Criteria:** When exceedance based $Q_{HFP}$ criteria are used, the average long-term high fish passage delay times are determined *a priori*. For $Q_{1\%AnExc}$, the average delay will be 3.65 days per year, while the average delays for the $Q_{1\%SH\text{-}MP\text{-}EXC}$, $Q_{5\%SH\text{-}MP\text{-}EXC}$, $Q_{10\%SH\text{-}MP\text{-}EXC}$ criteria will be 1.96, 9.8, and 19.6 days within the assumed 196 day steelhead migrations season. When the $50\%Q_{2\text{-}Pk}$ and $50\%Q_{2\text{-}Em}$ criteria are used, the long-term average number of high flow delay days that occur in a migration season, or year, is not known in advance and varies from site to site. Yet, it has historically been assumed that the average high flow delays associated with the $50\%Q_{2\text{-}Pk}$ and $50\%Q_{2\text{-}Em}$ criteria will be less than what the $Q_{1\%AnExc}$ criteria will yield. In this study, the annual exceedance values corresponding to the $50\%Q_{2\text{-}Pk}$ criteria ranged from 0.2% to 1.8% and were less than 1% for all sites in the Northern California and Southern California regions. Two of the annual exceedance values corresponding to the $50\%Q_{2\text{-}Pk}$ criteria were greater than 1% in the Pacific Northwest region. The annual exceedance values associated with the $50\%Q_{2\text{-}Em}$ criteria ranged from 0.2% to 3.9% with one annual exceedance value having a value greater than 1% in each climate region.

Regardless of the $Q_{HFP}$ criteria used, the total number of high flow delay days is greatest during Wet years and are the least during Dry years (Figures 23-25). The median percentage of time that high flow delay occurs within a migration season is also greatest in Wet years and least in Dry years for all regions. The variability in high flow delay among migration seasons, as well as the median percentage of time high flow delay occurs within Wet and Average migration seasons, increases from north to south. However, the median percentage of time high flow delay occurs during dry years tend to be higher in the Pacific Northwest and Northern California than in Southern California

Amongst the $Q_{HFP}$ criteria analyzed, the differences between the long-term average high flow delay, expressed as a steelhead migration season exceedance value, ranged from (0.3% to 10%). However, an important consideration in selecting an appropriate $Q_{HFP}$ is the importance of long-term average delay versus the year-to-year variability in delay provided by a specific criterion. The larger the high fish passage design discharge is, the more it tends to reduce the variability in the year to year high flow delay that occurs within a stream. For example, when using the $Q_{1\%AnExc}$ criteria, the percentage of time that high flow delay occurs within Average migration seasons within the Southern California region range from 0% to about 33% (Figure 27). However, when using the $50\%Q_{2\text{-}Pk}$ criteria (which always provided a larger high fish passage design discharge in Southern California), the percentage of time that high flow delay occurs within Average seasons in the Southern California region ranges from 0% to about 12%. Specifically, larger $Q_{HFP}$ values will tend to eliminate or substantially reduce delay that occurs within one or two larger storm events that in a particular year may provide much of the fish passage opportunity. Table B-16 demonstrates an example of where in an Average year flows exceeded $Q_{LFP}$ for only 13 days at Topanga Creek. Using the $Q_{1\%AnExc}$ criteria, 3 days of high flow delay would occur during this year. However, using the $50\%Q_{2\text{-}Pk}$ criteria, no high flow delay would occur and fish passage opportunity increases by 30%. A similar reduction in high fish passage delay occurs for Wet years in Southern California (Figure 28). Three out of 4 wet years have high fish passage delays of 8% or more when using the $Q_{1\%AnExc}$ criteria, whereas, on average, only 1 out of 4 wet years has a high fish passage delay of 8% or more, when using the higher $50\%Q_{2\text{-}Pk}$ criteria.

One potential concern with using $Q_{HFP}$ criteria based upon annual exceedance values in climate regions where much of the rainfall occurs within the steelhead migration season is that total number of high flow delay days occurring within the year are not likely to be equally distributed throughout the year, but are more likely to occur during the migration season. Thus, the percentage of time high flow delay actually occurs during the migration season is higher than the percent of time high flow delay occurs over the entire year. For example, on Sespe Creek the 2.5% annual exceedance value is equivalent to the 4.0% steelhead migration season exceedance value (Table 4). Consequently, when considering $Q_{HFP}$ criteria, it is important to determine whether it is more meaningful to base criteria on the percentage of time that high flow delay occurs within the migration season or over the entire year. Alternatively, it may be important to consider what percentage of time high flow delay is acceptable during Wet, Dry, and Average migration seasons as neither an annual exceedance value or a migration season exceedance value derived from all flow data is directly tailored for meeting any specific Wet, Dry or Average year passage goals.

**High Fish Passage Delay Due to Errors in $Q_{HFP}$ criteria estimates:** For $Q_{HFP}$ defined as exceedance values, the length of the data record used to create a flow duration curve as well as when the data was collected (wet, average, dry years) can influence the median passage and median high flow delay times as well as the variability in the high flow delay times. Short duration flow records collected within dry periods yield the lowest median passage times and the most high flow delay. Selecting a $Q_{HFP}$ using such flow duration records also increases the variability in the high flow delay times at a particular site. The degree to which median passage times were affected by using short duration flow data collected during dry periods increases from north to south (Figure 37). At Salsipuedes Creek (in Southern California), using a 5-year flow duration record derived from the 5 driest consecutive years on record resulted in severely underestimating the 1% annual exceedance flow and increasing the median delay time at the site by over 20%. At Tucca Creek (in the Pacific Northwest), the 1% annual exceedance flow estimated from the 5 driest consecutive years of data only reduced the median passage time by 1 to 2%. Results demonstrated that in Southern California, the 1% annual exceedance flow estimated from the 20 driest consecutive years were approximately 50% less than the 1% annual exceedance value, as defined by using the entire available data record (Figure 36).

The regional regression equations used in this study have standard errors that increase from 25.3-39% for Western Oregon to 47-134% in Southern California (Gotvald, 2012 and Cooper, 2005). For the 16 sites studied, the ratio of 50%$Q_{2\text{-}PK}$ to 50%$Q_{2\text{-}EM}$ ranged from 0.63 to 5.0 (Tables 3 and 4). As suggested by Gotvald (2012) and Cooper (2005), the errors in the 50%$Q_{2\text{-}EM}$ estimates increased from north to south. In southern California all of the 50%$Q_{2\text{-}EM}$ estimates were less than the 50%$Q_{2\text{-}PK}$ values. Despite these differences, when analyzed as a region, these two criteria do not result in substantially different total passage times (Figure 43). However, the two methods result in substantially different 75% quartile percent high flow delay times. For Southern California, the 75% quartile high flow delay increased by about 4% when using the regression equations versus the peak flow data to estimate high flow fish passage criteria (Figure 44). Thus, when compared to the 50%$Q_{2\text{-}PK}$ criteria, on average, 1 in four years at every site in Southern California would experience at least 4% more delay due to the underestimated 50$Q_{2\text{-}EM}$ values. The median percentage of high flow delay also increases approximately 2% when 50%$Q_{2\text{-}Em}$ values are used as the $Q_{HFP}$ criteria.

**Study Limitations and Future Study Needs:** The study results have several important limitations. First, the climate zones were selected for preliminary trend analyses purposes and do not coincide with any known demarcations of distinct climate zones along the West Coast. All of the trends in passage time and delay times are also based on visual inspection of the box-and-whisker plots, other graphs, and data shown in tables. Additional work is needed to determine if any clear demarcations in climate zones exist and whether any of the observed trends are statistically significant.

The fish passage opportunities in this report are all computed strictly based upon hydrologic criteria (e.g. whether or not flows fall between the chosen $Q_{LFP}$ and $Q_{HFP}$ values). Consequently, the reported fish passage opportunities may be under or overestimated due to unknown fish behavior and/or morphological conditions at a stream that are not accounted for in a purely hydrologic analysis. Some biological factors that may influence actual passage opportunities include: whether or not steelhead migrate at constant base flow conditions, migrate primarily on the rising and/or falling limbs of storm hydrographs, or require a 'migration initiating flow' (at a discharge substantially higher than the $Q_{LFP}$ discharge) before they begin to migrate. Some unaccounted for geomorphic conditions, particularly in Southern California, that could influence fish passage opportunities include: what flows are necessary to breach the estuaries and provide flow connectivity to the ocean; and naturally occurring features within streams that may limit the discharge range over which fish may migrate (e.g. excessive velocities and turbulence at higher discharges, or too shallow of a depth at critical riffles during lower flows). Further research is needed to better identify how such biological and geomorphic factors may influence total passage opportunities within the different climate regions.

Most fish passage projects occur at locations with short duration discharge records or within ungaged streams where exceedance and $Q_{2\text{-}PK}$ based criteria cannot be computed. Simultaneously, estimating $Q_{LFP}$ and $Q_{HFP}$ values at ungaged locations using 2-year regional regression equations is subject to large errors that may inadvertently create significant passage delay. Additional research needs to be conducted to better estimate $Q_{LFP}$ and $Q_{HFP}$ values at ungaged locations along with the amounts and types of data needed to provide $Q_{LFP}$ and $Q_{HFP}$ estimates accurate enough to meet fish passage goals.

# ACKNOWLEDGEMENTS

This work would not have been possible without the hard work and dedication of Humboldt State University Environmental Resources Engineering students Ryan Brown and Andres Benitez Opina who collected, processed and performed data analysis for the project study sites.

David Crowder, Rick Wantuck, and Steve Thomas from the National Marine Fisheries Service provided valuable feedback on all aspects of the project from site selection to review of the final document. The project also benefitted greatly from participation in review and comments by California Department of Fish and Wildlife Senior hydraulic Engineer, Marcin Whitman.

# Tables of Contents

# APPENDICES

# LIST OF TABLES

# List of Figures

# LIST OF VARIABLES AND ACRONYMS

| | |
|---|---|
| FDC | Flow Duration Curve |
| $Q_{HFP}$ | High Fish Passage Design Flow (cfs) |
| $Q_{LFP}$ | Low Fish Passage Design Flow (cfs) |
| $Q_{2\text{-year}}$ | 2-year return period flow |
| Pac NW | Pacific Northwest |
| Nor CA | Northern California |
| So CA | Southern California |
| $Q_{2\text{-year}}$ | 2-year return period flow |
| $Q_{2\text{-PK}}$ | 2-year return period flow calculated using the annual peak flow record for the site |
| $Q_{2\text{-EM}}$ | 2-year return period flow calculated using an empirical regional regression equation |
| WA | Watershed Area (square miles) |
| 50% Inst Peak Q2, 50%Q2-PK | 50% of the 2-year return period flow calculated using the annual peak flow record |
| 50% Empirical Q2, 50%Q2-Em | 50% of the 2-year return period flow calculated using a regional regression equation |
| 1% Annual, 1% AnExc | 1% annual exceedance flow |
| 1% SH Migration, 1% SH-MP_Exc | 1% exceedance flow for the steelhead migration period (November 1 – May 15) |
| 2% SH Migration | 2% exceedance flow for the steelhead migration period (November 1 – May 15) |
| 5% SH Migration | 5% exceedance flow for the steelhead migration period (November 1 – May 15) |
| 10% SH Migration | 10% exceedance flow for the steelhead migration period (November 1 – May 15) |

# 1 INTRODUCTION

## 1.1 BACKGROUND

Eliminating physical in-stream barriers to migrating Pacific salmon and steelhead is a key component in stock recovery plans developed by the National Marine Fisheries Service (NMFS) (NMFS 2012, NMFS 2013). NMFS and other fisheries resource agencies have developed design guidelines for providing fish passage at in-stream structures, such as at road-stream crossings and diversion dams (CDFG 2002, CDFG 2009, NMFS 2001, NMFS 2011, ODFW 2006, WDFW 2003). One of the commonly used fish passage design approaches involves creating hydraulic conditions that permit the target fish species and lifestage to freely move through the structure. Referred to as the hydraulic design approach, it utilizes hydraulic criteria to ensure passage of the target fish, such as minimum water depths and maximum water velocities.

Providing suitable hydraulic conditions for passage at all flows is usually impractical and unnecessary. For projects using the hydraulic design approach, fish passage design flows are established to define the range of flows for which passage criteria should be satisfied. The flow range is defined by a low fish passage design flow ($Q_{LFP}$) and high fish passage design flow ($Q_{HFP}$) for the target fish. The duration streamflow persists between $Q_{LFP}$ and $Q_{HFP}$ during the seasonal migration period is referred to as the *passage window*.

The fish passage flow range is intended to encompass nearly all the flows the target fish would be expected to use for upstream movement in the event that no artificial barriers existed in the stream or river. Even in unimpaired stream systems there are flows that fish will not attempt to move upstream due to physical and behavioral reasons, such as at low flows when depths throughout the channel are naturally too shallow and at high flows when excessive velocities, turbulence, or turbidity may persist. Although defining flows at which a target fish does not migrate is difficult, the fish passage flow range is not intended to include flows during which movement is unlikely.

Upstream fish movement can become delayed at a structure when streamflows are below $Q_{LP}$ or above $Q_{HP}$ and fish are attempting to move upstream. Lengthy delay in upstream movement for adult anadromous salmon or steelhead has the potential to prevent them from reaching spawning grounds, or cause the fish to spawn in lower reaches of the stream where their offspring may have reduced access to habitat and a reduced chance of survival (Kemp and O'Hanley 2010, Roni et al. 2008, Wofford et al. 2005). Excessive delay in upstream movement of juvenile salmonids is less time sensitive, but can affect their ability to redistribute and feed, thus affecting their growth rate and overall survival (Cederholm and Scarlett 1981, Nickelson et al. 1992, Kahler et al. 2001).

Selection of $Q_{LFP}$ and $Q_{HFP}$ strives to avoid delays in upstream movement that adversely affect the fish's life history and survivability of their offspring. However, increasing the passage window also affects project feasibility and cost. Therefore, ample consideration should also be given to whether the fish passage flow range includes flows that the target fish may not utilize for upstream movement and if the frequency and duration of delay to movement imposed by either $Q_{LFP}$ or $Q_{HFP}$ will adversely affect the fish.

## 1.2 STUDY NEED

Instream structures and channel modifications (e.g. culverts, check dams, fish ladders, flood control channels, etc.) can result in hydraulic conditions that block or impede the passage of anadromous fish at some or all discharges within a stream. To remedy this problem, NOAA's National Marine Fisheries Service (NMFS) establishes design criteria that promote suitable passage conditions for anadromous fish at instream structures and within project reaches. These criteria define high and low fish passage design flows ($Q_{HFP}$ and $Q_{LFP}$) and these values establish what is referred to as a "fish passage design window" or the total time during a migration period when streamflow is between $Q_{HFP}$ and $Q_{LFP}$. This study was initiated to evaluate west coast regional differences in the fish passage opportunities provided by different fish passage design windows/flow criteria. The current fish passage design flow criteria for California, which differs from criteria used in the Pacific Northwest, are defined by the National Marine Fisheries Service (NMFS 2001) and the California Department of Fish and Wildlife (CFDG 2002). They include design flow criteria for adult anadromous salmonids and juvenile salmonids, and are most frequently applied to smaller ungaged watersheds. The two agencies use the same definitions for design flows. Selection of the current design flow criteria was based primarily on hydrologic data and field observations of fish migration timing in north-coastal California streams (Lang, Love & Trush 2004).

Throughout coastal California watersheds, runoff is predominately generated from rainfall events rather than snowmelt or spring-flow hydrology. Adult steelhead generally use these runoff events to migrate to spawning grounds, as baseflow conditions often provide inadequate depth for migration or spawning. As such, the low and high passage design flow criteria and the duration, frequency, and magnitude of rainfall and resulting runoff events governs the passage window an adult steelhead may have to reach its spawning grounds within a given year.

Climatic differences between the northern and southern regions of California has generated concerns as to the impacts of high flow migration delay imposed on coastal central and southern California steelhead by current high passage design flow criteria. In general, the mean annual precipitation decreases moving from north to south, as does the frequency of rainfall and runoff events that adult steelhead may utilize to migrate inland. Annual and inter-annual variability in rainfall patterns also increases from north to south, which may further influence the opportunity adult steelhead have within a given year to migrate to their spawning grounds.

This study aims to investigate regional differences in the frequency and duration of provided passage windows and potential delay imposed by current passage design flow criteria for adult steelhead. For the purposes of this study, regions investigated were defined as Pacific Northwest (Oregon Coast), Northern California (Oregon Border to Monterey Bay), and Southern California (south of Monterey Bay to Orange County). These region definitions are used for presentation clarity only; climate differences along the US west coast do not vary within distinct regions but along gradients. Study results in this report are presented with sites arranged from northern-most to southern-most to identify whether a trend is observed. Evaluated passage design flow criteria include those currently used in California, Oregon, and Washington. Additional definitions of passage design flows were also evaluated.

To isolate the effects of regional differences in hydrology on migration, the analyses of passage conditions for adult steelhead presented in the main body of the report assumes the same migration period, November 1 through May 15, for all of the climate regions. Passage analysis for juvenile salmonids used the entire year. Passage analysis was also completed for adult coho and Chinook using shorter assumed migration periods (Oct 1 – Feb 28 and Sept 15 – Feb 15, respectively) and is presented in Appendix E.

## 1.3 Current Fish Passage Design Flow Criteria

Current state and federal criteria for calculating the high fish passage design flow ($Q_{HFP}$) and the low fish passage design flow ($Q_{LFP}$) for anadromous salmonids in coastal California, Oregon and Washington states are summarized below. Most methods rely on similar hydrologic analyses; typically daily exceedance flow methods derived from daily average flows, but vary as to the daily exceedance specified and the time periods used for determination (annual versus migration period data).

### *1.3.1 High Fish Passage Design Flow*

**California (NMFS 2001, CDFG 2002) -** The adult anadromous salmonid $Q_{HFP}$ is calculated as the 1% annual exceedance flow where site-specific or regional flow duration curves (FDCs) are available or can be constructed. If flow duration data are not available or inappropriate for a particular location, then 50% of the 2-year flood recurrence interval flow is used as the $Q_{HFP}$ criteria. A provision is also made to use hydraulic analysis of the stream active channel to determine flow needed to meet depth and velocity passage conditions. For upstream juvenile salmonid passage, $Q_{HFP}$ is the 10% annual exceedance flow.

**Oregon (ODFW 2006)** – The adult anadromous salmonid $Q_{HFP}$ is defined as the 5% exceedance flow during the migration season, with the migration season defined by the Oregon Department of Fish and Wildlife (ODFW). A juvenile salmonid $Q_{HFP}$ is not defined.

**Washington (Barnard et al. 2013)** – $Q_{HFP}$ is the 10% exceedance flow over the migration season for each target fish species and age class. The migration season generally varies for each target fish species and age class; thus, multiple 10% exceedance flows must be calculated at a particular project site and compared to determine the limiting $Q_{HFP}$ for passage and design.

**NMFS Northwest (NMFS 2011)** – For the region encompassing Oregon, Washington, and Idaho the adult anadromous salmonid $Q_{HFP}$ is defined as the 5% exceedance flow during the period of migration. A juvenile salmonid $Q_{HFP}$ is not defined.

### *1.3.2 Low Fish Passage Design Flow*

**California (NMFS 2001, CDFG 2002) -** Where FDCs are available or can be created, the adult anadromous salmonid $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs, whichever is greater. The 95% annual exceedance flow or 1 cfs, whichever is greater, should be used for juvenile salmonid $Q_{LFP}$.

**Oregon (ODFW 2006)** – The adult anadromous salmonid $Q_{LFP}$ is the 95% exceedance flow during the migration season as defined by the ODFW. A juvenile salmonid $Q_{LFP}$ is not defined.

**Washington (Barnard et al. 2013)** – The two-year, seven-day, low-flow or alternatively, meet fish passage criteria, primarily depth limitations, for all target fish species and age classes under zero flow conditions.

**NMFS Northwest (NMFS 2011)** – The adult salmonid $Q_{LFP}$ is the 95% exceedance flow during the migration season.

# 2 STUDY SITE SELECTION

To evaluate regional differences in hydrology and quantify the effects of these regional differences on the fish passage window and migration delay, five to six study sites were selected in each of three coastal climate regions (Southern/Central California, Northern California and the Pacific Northwest). Study sites consisted of streamflow gaging stations located on streams or rivers that currently or historically supported anadromous salmonid populations. To select the study sites an initial list of 32 potential sites was generated that included a summary of their location, data record length and data quality. From these 32 sites, and in collaboration with NMFS, 16 streamflow records for small-to-medium size watersheds in the three climate regions (Southern California – 6 sites; Northern California - 5 sites; and the Pacific Northwest - 5 sites) were selected for the study. The USGS Hydro-Climate Data Network (Slack and Landwehr 1992) was used as a resource for identifying the suitable streamflow gaging records. This USGS reference identifies gaging stations that meet record length and data quality criteria for climate analyses and that have minimal flow regulation. Eight of the 16 selected study sites are part of this USGS Hydro-Climate Data Network. Figure 1 shows the locations for the gage sites used for these analyses.

The site operational status, data record length and data availability are summarized in Table 1. All but one of the gage sites were operated by the USGS. The exception is the NF Caspar Creek gage, which was operated by the US Forest Service (USFS) Redwood Sciences Laboratory as part of their ongoing, long-term watershed studies in the Caspar Creek watershed (http://www.fs.fed.us/psw/ef/caspar_creek/).

*2. Study Site Selection*

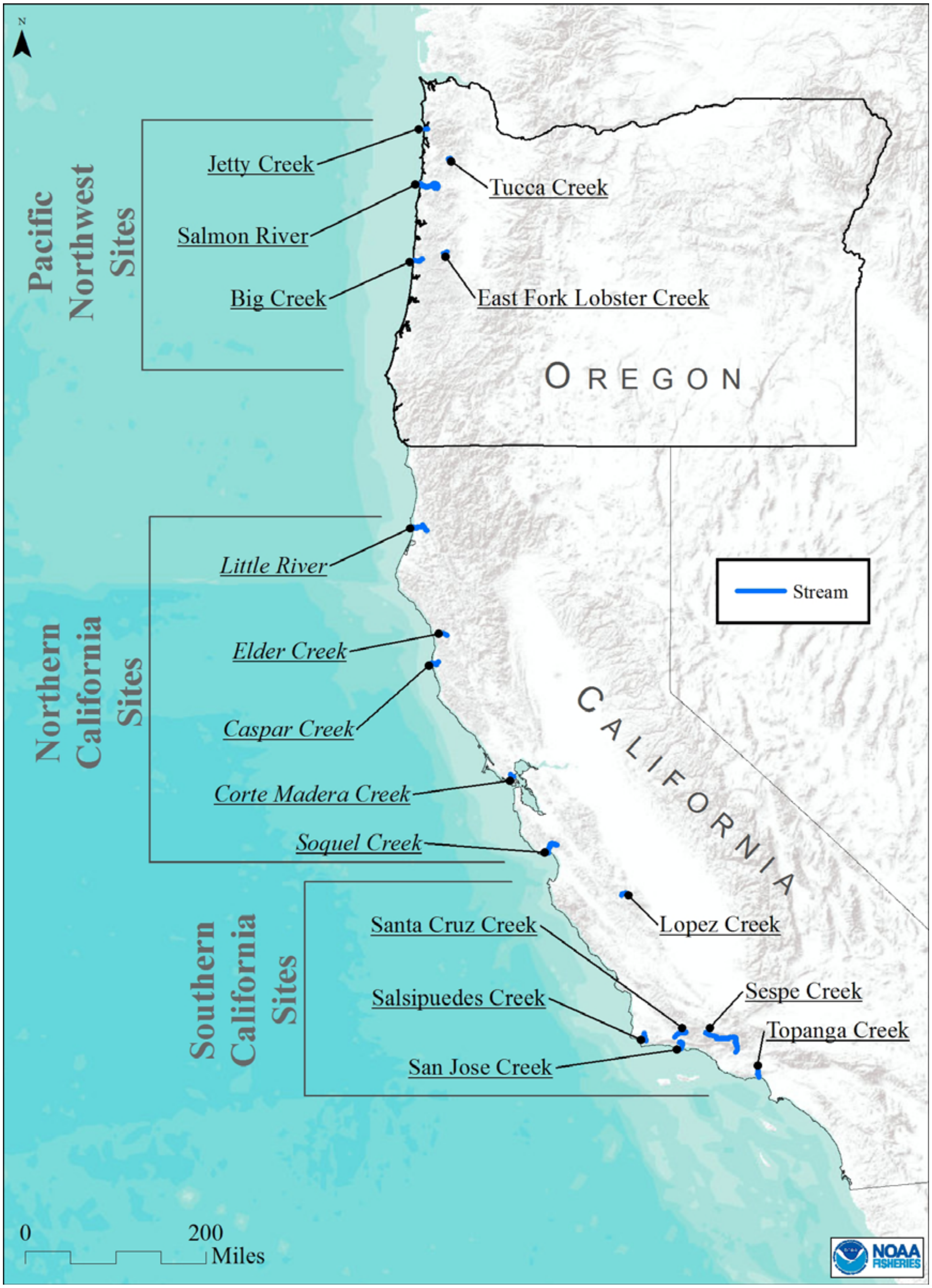



**Figure 1. Study site location map (prepared by NOAA Fisheries West Coast Region, GIS Lab, Santa Rosa, CA).**

*2. Study Site Selection*

**Table 1. Summary of the selected study sites' operational status, data records and data availability. Water years (WY) are defined as October 1 through September 30.**

| | | | | Annual Peak Flow | | | Mean Daily Flow | | | 15-minute Flow | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site Name | USGS Site Number | Drainage Area (sq. miles) | Mean Annual Precip (in) | Start Date | End Date | Years of Record | Start Date | End Date | Years of Record | Start Date | End Date | Years of Record |
| **Pacfici Northwest Region Sites** | | | | | | | | | | | | |
| Tucca Ck | 14303200 | 3.09 | Not Used[4] | WY 1984 | WY 2011 | 28 | 10/1/1983 | 9/13/2012 | 29 | 10/1/1986 | 9/30/2012 | 26 |
| EF Lobster Ck | 14306340 | 5.7 | | WY 1984 | WY 2011 | 28 | 10/1/1983 | 9/13/2012 | 29 | 10/1/1986 | 9/30/2012 | 26 |
| Big Ck[1] | 14306900 | 12.3 | | WY 1973 | WY 1991 | 19 | 10/1/1972 | WY 1991 | 19 | 10/1/1987 | 9/30/1991 | 4 |
| Salmon Riv[1] | 14303750 | 58.9 | | WY 1974 | WY 1995 | 21 | 10/1/1974 | 9/30/1995 | 21 | Not available | | |
| Jetty Ck[1] | 14301250 | 1.99 | | WY 1975 | WY 1995 | 20 | 10/1/1975 | 9/30/1995 | 20 | Not available | | |
| **Northern California Region Sites** | | | | | | | | | | | | |
| Little Riv | 11481200 | 40.5 | 67.6 | WY 1956 | WY 2011 | 56 | 10/1/1955 | 9/30/2012 | 57 | 10/1/1995 | 9/30/2007 | 12 |
| Elder Ck | 11475560 | 6.5 | 99.9 | WY 1965 | WY 2011 | 47 | 10/1/1967 | 9/30/2012 | 45 | 10/1/1988 | 9/30/2007 | 19 |
| NF Caspar Ck | USFS Site | 1.83 | 46.4 | WY 1964 | WY 2010 | 47 | 10/1/1963 | 9/30/2010 | 47 | 10/1/2004 | 9/30/2010 | 6 |
| Corte Madera Ck[2] | 11460000 | 18.1 | 42.3 | WY 1952 | WY 1997 | 43 | 10/1/1951 | 9/30/1993 | 42 | Not Available | | |
| Soquel Ck | 11160000 | 40.2 | 42.2 | WY 1951 | WY 2011 | 61 | 10/1/1951 | 9/30/2012 | 61 | 10/1/1988 | 9/30/2012 | 24 |
| **Central/Southern California Region Sites** | | | | | | | | | | | | |
| Lopez Ck | 11141280 | 20.9 | 28 | WY 1967 | WY 2010 | 44 | 10/1/1967 | 9/30/2012 | 45 | 10/1/1988 | 9/30/2012 | 24 |
| Salsipuedes Ck | 11132500 | 47.1 | 21 | WY 1941 | WY 2011 | 71 | 10/1/1941 | 9/30/2012 | 71 | 10/1/1988 | 9/30/2012 | 24 |
| San Jose Ck | 11120500 | 5.51 | 32.7 | WY 1941 | WY 2011 | 71 | 10/1/1941 | 9/30/2012 | 71 | 10/1/1988 | 9/30/2012 | 24 |
| Santa Cruz Ck | 11124500 | 74 | 25.5 | WY 1942 | WY 2011 | 70 | 10/1/1941 | 9/30/2012 | 71 | 10/1/1988 | 9/30/2012 | 24 |
| Sespe Ck[3] | 11113000 | 252 | 26.7 | WY 1933 | WY 2011 | 73 | 10/1/1927 | 9/30/2012 | 82 | 10/1/1992 | 9/30/2012 | 20 |
| Topanga Ck[1] | 11104000 | 18 | 23.4 | WY1931 | WY1979 | 49 | 10/1/1930 | 9/30/1979 | 49 | Not available | | |

[1] - Historic Gage Sites that are not currently operating

[2] - Gage stopped year round operation in 1993. Restarted Nov - May operation in 2009. Has a peak flow reported for 1997.

[3] - Gage has some data gaps. It initially operated in WY 1912 and 1913 then stopped, resuming in WY 1928. Water years 1986-1990 are also missing form both the daily average and peak flow data sets.

[4] - The mean annual precipitation was not determined for the Pacific Northwest region sites because it is not used in the USGS regression equations for this region. See Section 4.

# 3 Regional Differences in Hydrology

Differences in hydrology exist over the extent of anadromous salmonid habitat along the Pacific coast of the United States. The annual precipitation typically exhibits a north-to-south gradient with more northern watersheds generally receiving greater annual precipitation. This section evaluates the magnitude of these differences in regional hydrology by comparing hydrologic variability and watershed responses to precipitation. The trends and differences in hydrology and watershed responses between sites and regions are quantitatively compared but their effects on fish passage or other ecological influences were not evaluated for statistical significance.

## 3.1 Variation in Water Yield to Characterize Wet, Average and Dry Years

An important influence on the frequency and duration of fish passage windows is the number of storms creating and maintaining fish passage flows per year or migration period. One way to quantify flow availability in a given year is to use the annual water yield determined by converting the sum of the mean daily flow to an annual total volume. While this metric does not capture the effects of storm patterns or magnitudes, it provides a means for classifying years as Wet, Average or Dry based on annual water yield and evaluating variability among the Dry and Wet years.

For these analyses, Wet years are defined as those years in the upper 20 percentile of a site's annual average water yield, Average years comprise the middle 60 percent, and Dry years are the lower 20 percentile of annual water yields. Annual water yields were also normalized by the median annual water yield for each site's data record to allow direct comparison between sites.

To compare inter-annual variability in water yield between sites, the deviation from median annual water yield [(annual water yield – median annual water yield)/median annual water yield)] for each water year and site was plotted. The upper and lower 20 percentile, defining Wet and Dry water year classes, were also calculated for each site in terms of the deviation from median annual water yield and included as horizontal lines on the plots. Figure 2 through Figure 4 show the deviation from median annual water yield for a representative study site from each of the three climate regions. Similar figures for all of the study sites are included in Appendix A (Figures A-1 through A-16).

The upper and lower 20 percentiles of annual water yield defining Wet and Dry year classes for each site are shown as deviation from median annual water yield in Figure 5. The plot shows an increasing divergence from the median from north to south.

Appendix A also includes the non-normalized water yield plots for all study sites (Figure A-17 through Figure A-19). These plots more clearly show the frequency of water year types and inter-annual variability at each site. For the Pacific Northwest and Northern California sites, the longest period of consecutive Dry years occurred in the early 1990's, with four sites (Tucca Ck, EF Lobster Ck, Little Riv and Elder Ck) experiencing three consecutive Dry years. The data records for the Southern California sites are longer and most sites experienced four consecutive Dry years spanning water years 1948 to 1951.

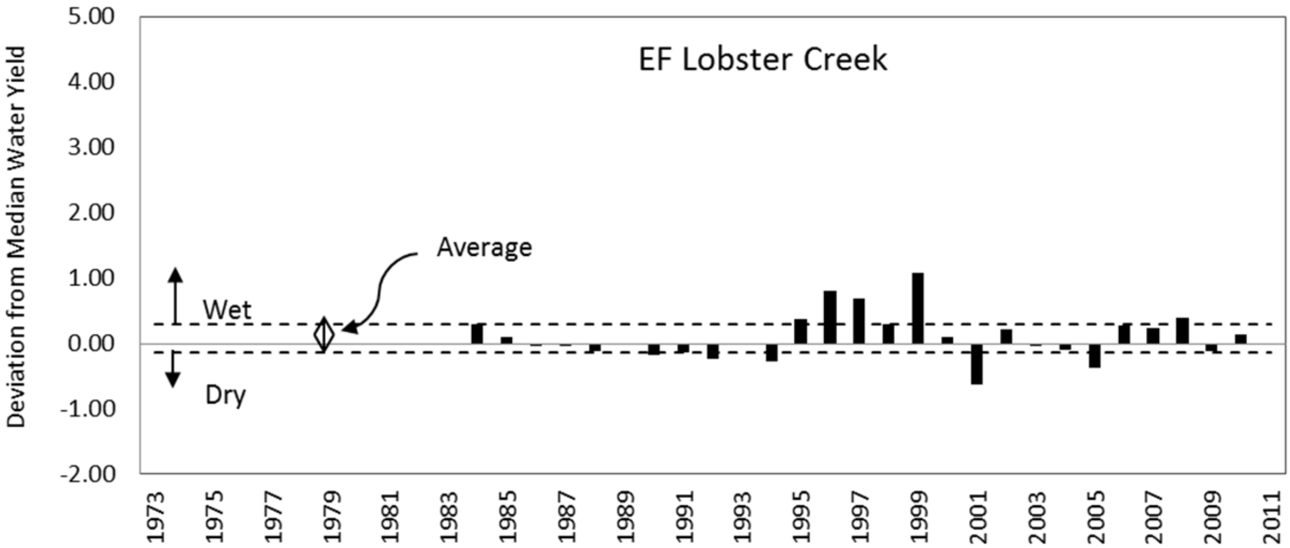



**Figure 2. Annual water yield expressed as the deviation from the median water yield for East Fork Lobster Creek (Pacific Northwest region). Wet years are the highest 20% of annual water yields and are indicated in these plots as those columns exceeding the upper dashed line. Dry years are the lowest 20% and are those years whose columns extend beyond the lower dashed line.**

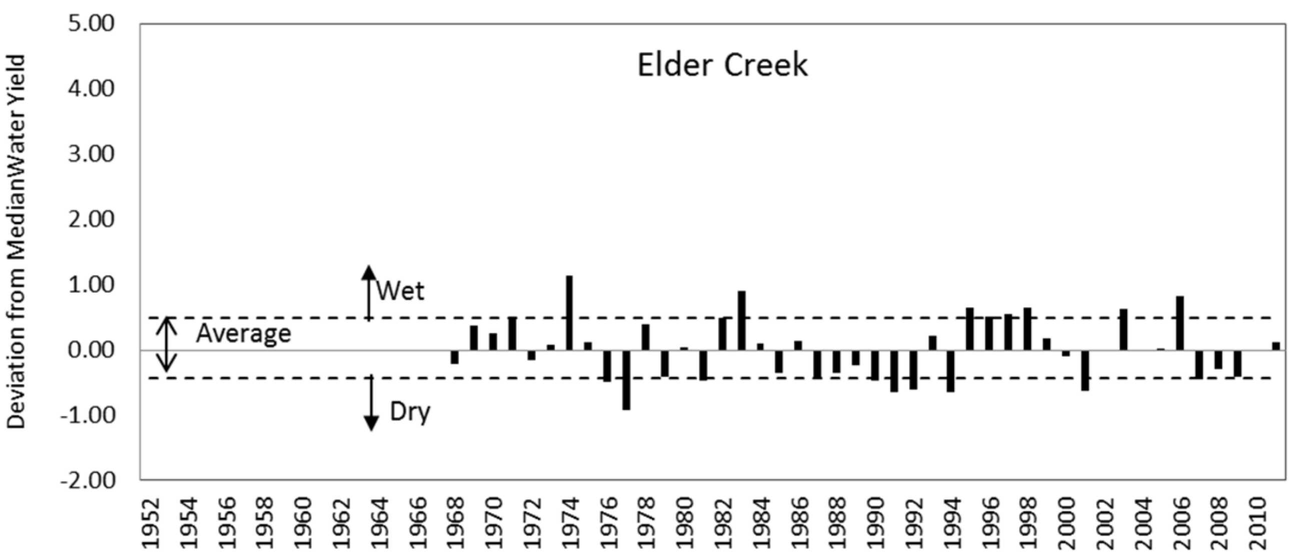



**Figure 3. Annual water yield expressed as the deviation from the median water yield for Elder Creek (Northern California region). Wet years are the highest 20% of annual water yields and are indicated in these plots as those columns exceeding the upper dashed line. Dry years are the lowest 20% and are those years whose columns extend beyond the lower dashed line.**

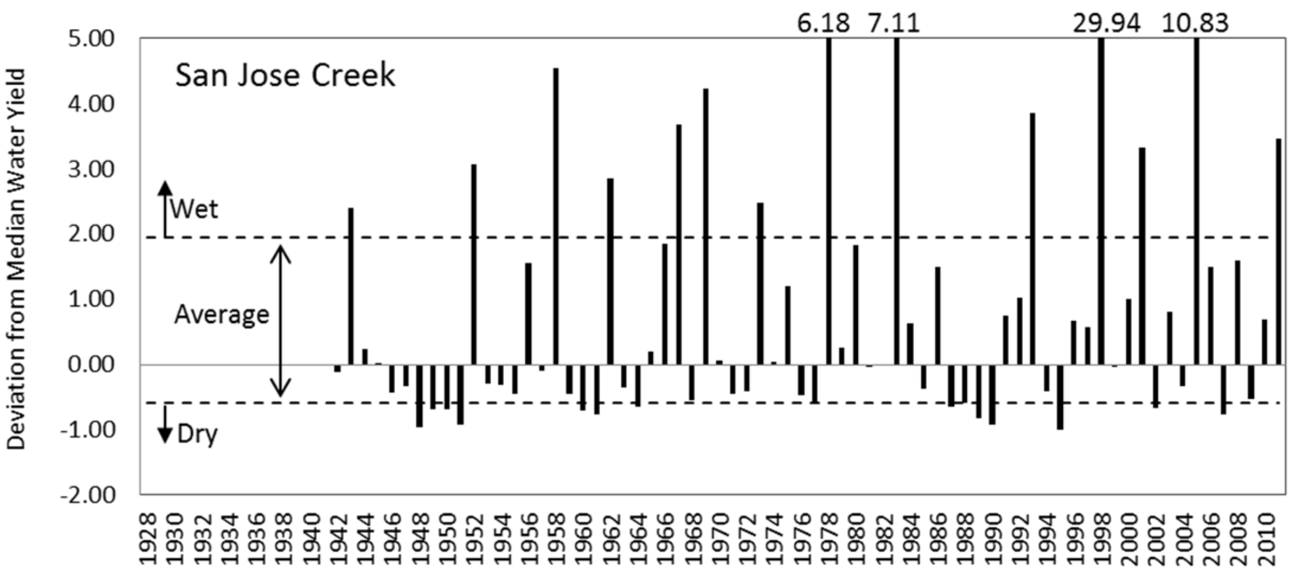



**Figure 4. Annual water yield expressed as the deviation from the median water yield for San Jose Creek (Southern California region). Wet years are the highest 20% of annual water yields and are indicated in these plots as those columns exceeding the upper dashed line. Dry years are the lowest 20% and are those years whose columns extend beyond the lower dashed line.**

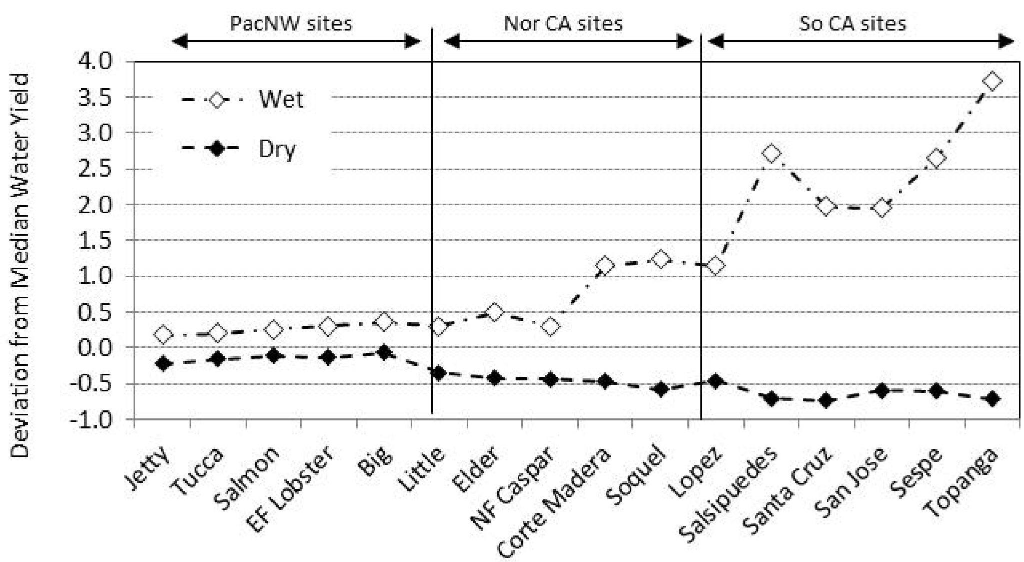



**Figure 5. Comparison of the upper 20th-percentile water yield (lower boundary of Wet year yields) and the lower 20th-percentile water yield (upper boundary of Dry year yields) expressed as the deviation from the median annual water yield. Sites are arranged from north to south moving left-to-right along the x-axis.**

## 3.2 Differences in Watershed Response to Storms

When fish passage conditions rely primarily on storm initiated flows, as is common in Pacific coastal watersheds, an individual watershed's hydrologic response to precipitation can determine the passage time available. If a watershed responds rapidly to precipitation, the flow hydrograph may rise and fall more quickly, possibly limiting passage opportunity during individual storms and providing a shorter passage window compared to a watershed with a slower response. This characteristic of storm hydrographs is often referred to as "flashiness" and depends on a number of watershed characteristics including drainage area, slopes, geology, land use, orientation and antecedent conditions. A watershed's ability to sustain base flows and the magnitude of these base flows is also a function of the watershed's groundwater storage and extraction rates. If the local water table elevation has decreased in response to groundwater extraction practices, streamflow may be affected as more water infiltrates to replenish groundwater storage (Barlow and Leake, 2012).

No single, widely adopted method for characterizing flashiness or the rate of change in flow exists. However, numerous researchers have proposed flashiness measures (Richter et al. 1996; Poff et al. 1997; Baker et al. 2004; and Shuster et al. 2008) and possible metrics to evaluate flashiness include:

- Rate of flow increase on the rising limb of a storm hydrograph
- Rate of flow decrease on the falling limb of a storm hydrograph
- The Richards-Baker (R-B) Index a measure of the day-to-day variation in flow (Baker et al. 2004).

The first three measures are used to evaluate individual storm hydrographs and were calculated for ten discrete hydrographs for two sites within each climate region, for a total of 60 hydrographs. The R-B index was calculated for all study sites using the mean daily flow records for each water year of record.

### *3.2.1 Storm Hydrograph Flashiness*

Evaluation of storm hydrograph flashiness was conducted using instantaneous streamflow records rather than mean daily flow. Two sites in each climate region were selected for the analysis. Selection was based in part on availability and quality of the instantaneous streamflow records and with consideration of the watershed location. The northern- and southern-most study sites with a quality data record were used for these analyses. Using the instantaneous streamflow records, ten discrete hydrographs were identified for each selected site. A discrete hydrograph was defined as a storm hydrograph that clearly rose from and returned to winter baseflow. Complex hydrographs generated from adjacent storms or with multiple peak flows were not included in these analyses. The rates of streamflow rise and fall were calculated as cfs per hour along an asymptote line from the peak flow to the first inflection point on the rising and falling hydrograph limbs (Figure 6), respectively. The asymptote slopes were calculated by visually selecting the peak and asymptote points for each hydrograph. The rates of rise and fall were then normalized by each storms' peak flow to allow comparison between sites and storm magnitudes. Figure 7 through Figure 9 present the maximum, median and minimum rates of rise and fall for the six sites.

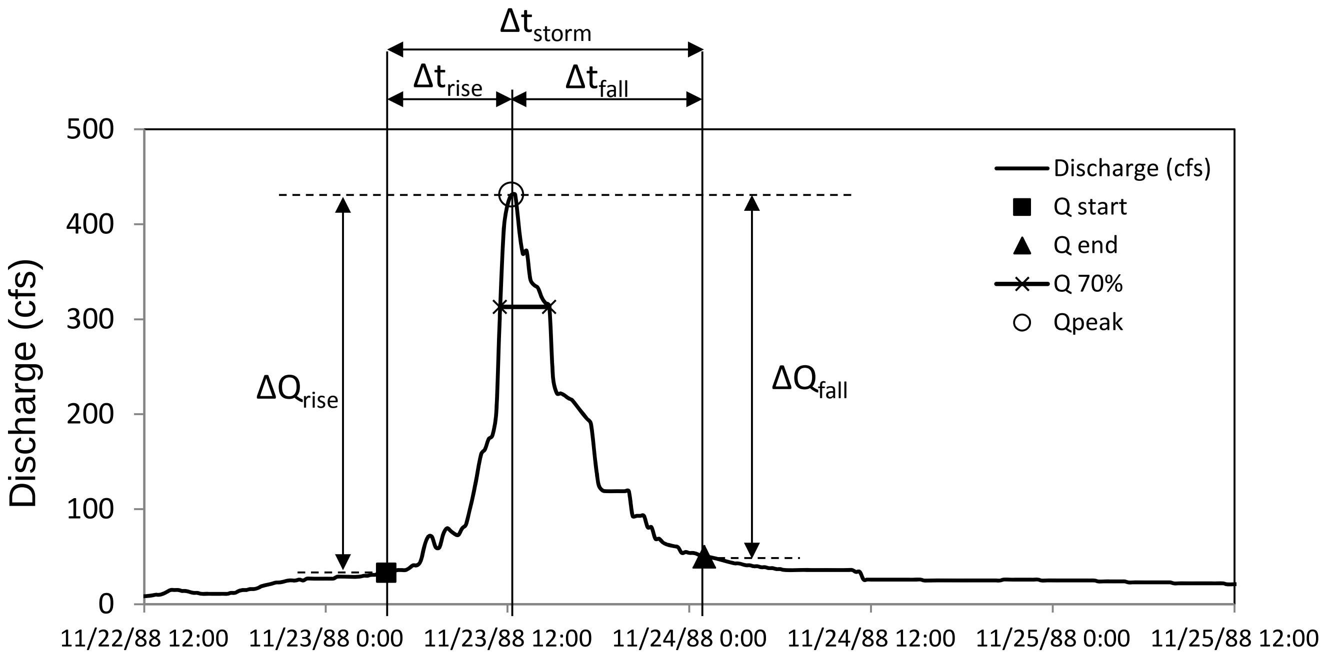



**Figure 6. Example storm hydrograph for analysis of rates of hydrograph rise and fall.**

In all climate regions and in almost all cases, the rate of hydrograph rise was at least twice the rate of hydrograph fall. This response is expected due to temporary storage and slower release of water from streambanks and near-channel groundwater inflows. A rising-to-falling limb rate ratio of 2:1 indicates that flows within the fish passage range (Q between $Q_{LFP}$ and $Q_{HFP}$) may persist twice as long for the falling limb of the hydrograph than for the rising limb.

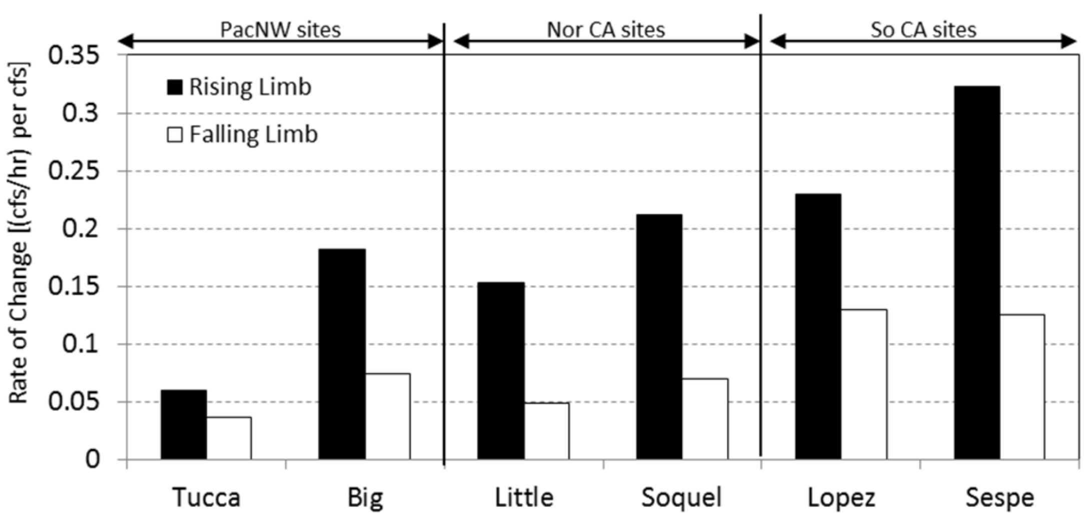



**Figure 7. Maximum rate of change for discrete hydrographs rising and falling limbs normalized by the peak flow of the event.**

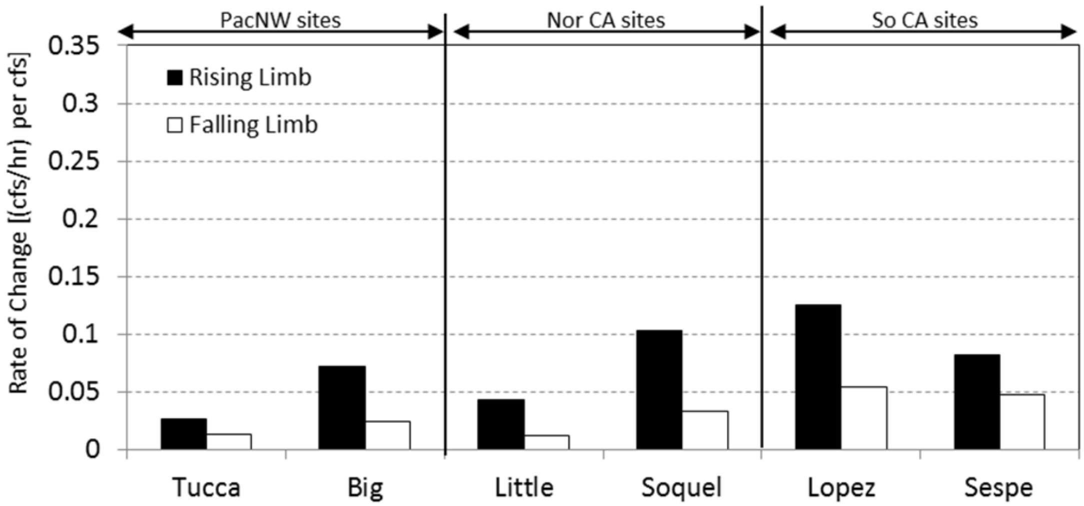



**Figure 8. Median rate of change for discrete hydrographs rising and falling limbs normalized by the peak flow of the event.**

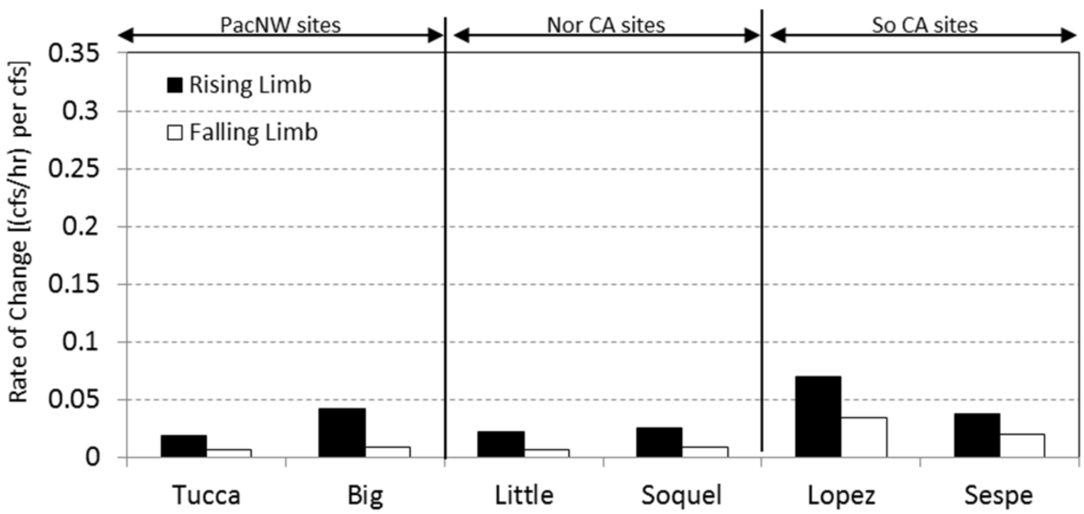



**Figure 9. Minimum rate of change for discrete hydrographs rising and falling limbs normalized by the peak flow of the event.**

### *3.2.2 Richards-Baker (R-B) Flashiness Index Analysis*

The R-B Index quantifies the day-to-day difference in mean daily discharge normalized by the sum of the mean daily discharge values throughout the water year (Baker et al. 2004). The R-B index evaluates the magnitude of fluctuations in mean daily discharge over the water year rather than for an individual hydrograph, thus is a good measure of day-to-day flow variation. The R-B index is calculated as:

$$R - B\ index = \frac{\sum_{i=1}^{n} |q_i - q_{i-1}|}{\sum_{i=1}^{n} q_i}$$

Where $q_i$ are the mean daily discharge values throughout the water year and n is the number of records in a water year.

To compare the study sites, the R-B index is calculated for each water year and inter-annual variability in the R-B index value is summarized for each site as box plots for the annual flow data (Figure 10) and for the period of November 1 through May 15, which is the assumed adult steelhead migration period as described in Section 4.1 (Figure 11). A higher R-B index value suggests that on an annual basis, the site's streamflow increases and decreases more rapidly and is more responsive to precipitation events. The Southern California sites clearly show a higher and larger variation in the R-B index. This regional difference is likely influenced by more discrete storms and lower frequency of precipitation events for the Southern California sites. The R-B index calculated over the different time periods, annual versus migration period, do not show significant differences because the migration period includes the time periods within which almost all storm flows occur.

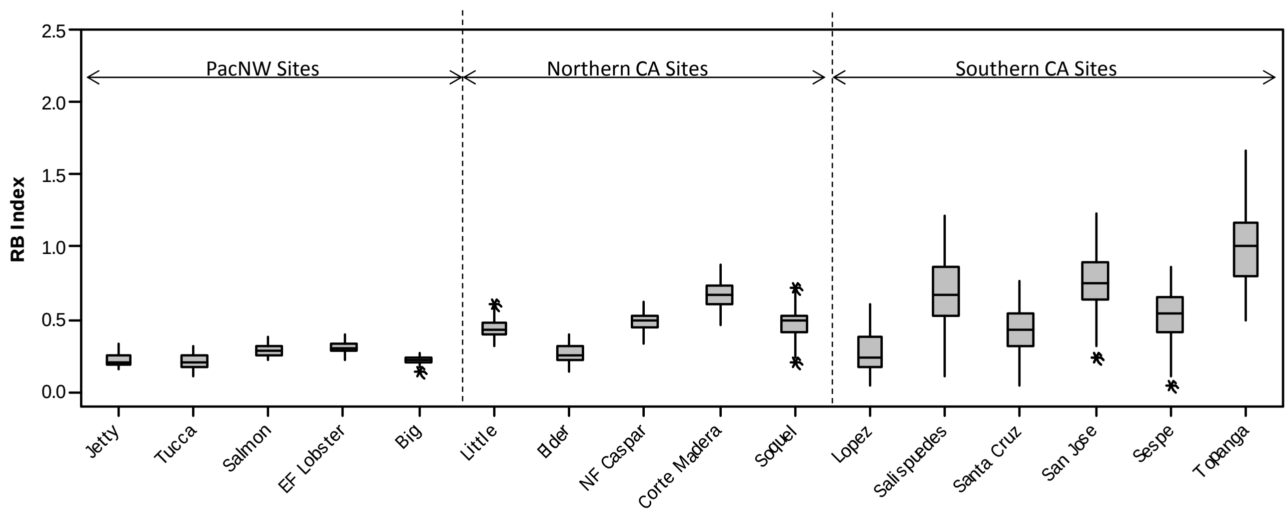



**Figure 10. Annual R-B index plot for sites in the three coastal climatic regions.**

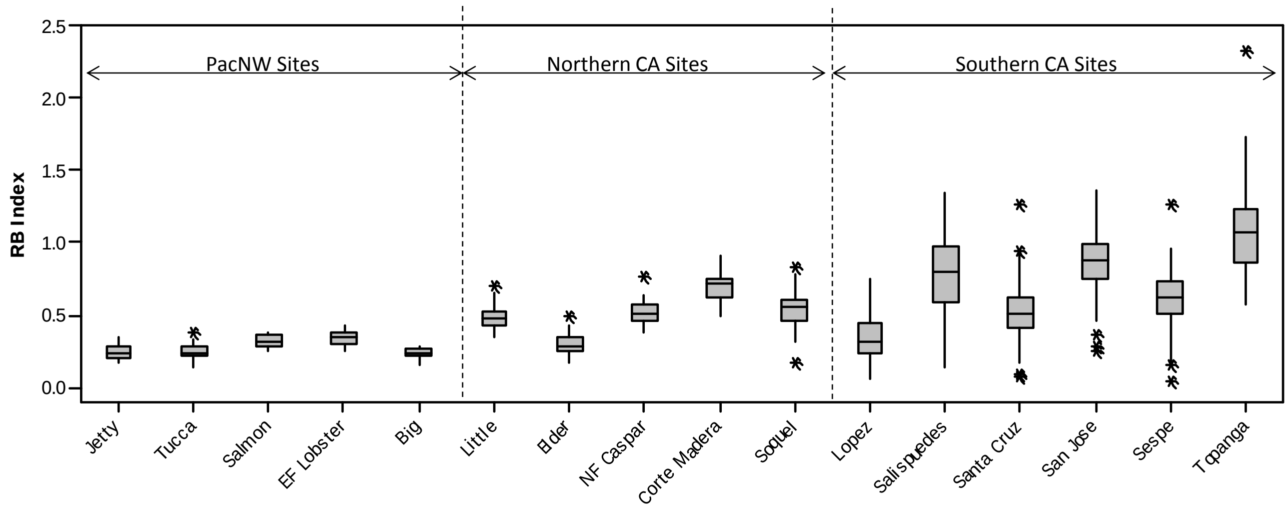



**Figure 11. Assumed migration period (Nov 1 – May 15) R-B index plot for sites in the three coastal climatic regions.**

## 3.3 Discussion

The southern California sites, with exception of Lopez Creek (which is the furthest north and has the shortest data record in this climate region), never experienced two consecutive Wet year classes, while the northern California and Pacific Northwest sites regularly experience two or more Wet years in a row. It is possible that consecutive Wet years experienced at the northern sites provide improved opportunities, in comparison to the southern sites, for adult steelhead to migrate and spawn and their off-spring to successfully out-migrate to the ocean. As such, in the Southern California sites it may be important to consider that the off-spring of adult steelhead spawning during a Wet year are likely to out-migrate during an Average or Dry water year, when water quality conditions and connectivity to the marine environment may be compromised.

Comparison of hydrographs for ten discrete storms showed that the Southern California study sites generally exhibit the largest rates of hydrograph rise and fall. Faster rising and falling rates indicate flashier watershed response to precipitation. The effect of a flashier watershed response on fish passage may be a shorter time meeting fish passage flow criteria during discrete storm events, as streamflow rises and falls more rapidly through the passage range (Q between $Q_{LFP}$ and $Q_{HFP}$).

The RB-Index also increased from north-to-south. This index captures variation in the day-to-day flow with higher values indicating greater variation. The higher RB-Index for the more southern study sites could indicate that they experience more isolated storms with less prolonged, steady flow. The migration period RB-Index values are higher than the annual values because they do not include the dry season when day-to-day variation in flow is expected to be small.

# 4 FISH PASSAGE DESIGN FLOWS

As summarized in Section 1.3, current fish passage design flow criteria vary along the Pacific coastal states and alternate criteria have been needed within California to address regional hydrologic differences. This section describes the methods typically used to define fish passage design flows and compares, for each site, the resulting design flows derived from the various criteria.

## 4.1 CALCULATION OF FISH PASSAGE FLOWS

Methods currently used to compute $Q_{LFP}$ and $Q_{HFP}$ in California, Oregon and Washington are either:

- Daily exceedance flow methods using flow duration curves (FDCs) constructed from daily average flow records, or
- Recurrence interval methods specifying a percent of a particular flow magnitude, typically the 2-year return period flow ($Q_{2\text{-year}}$) calculated using annual peak flows.

Daily exceedance flow-based criteria are more common because definitions based on daily exceedance directly ties the design flow to the percent of time the flow will exceed the criteria during the specified period (i.e. migration season). For example, defining $Q_{HFP}$ as the 1% annual exceedance flow means that, on average, flow will exceed $Q_{HFP}$ for 1% of the days within a year, or 3.6 days per year. Similarly, defining $Q_{HFP}$ as the 1% exceedance flow over a migration period that extends for 180 days means that, on average, flow will exceed $Q_{HFP}$ for 1% of the days within this migration period, or 1.8 days.

FDCs were calculated with an Excel spreadsheet by using Excel's percentile function to identify the flow magnitude corresponding to a particular daily exceedance. FDCs for annual exceedance flows used the entire data record for each study site and those developed for the migration periods used a data series truncated to include only those days within the assumed migration timing. The migration periods assumed for this study were suggested by NMFS staff in California for adult steelhead, coho and Chinook (Table 2). These assumed migration periods were selected as representative for the purposes of analysis and comparison between the climate regions, and are not intended to replace local knowledge or current regulatory guidelines.

**Table 2. Representative migration periods provided by NMFS for hydrologic comparison across the three climate regions.**

| Species/Lifestage | Migration Period |
|---|---|
| Adult Steelhead | November 1 – May 15 |
| Adult Coho | October 1 – February 28 |
| Adult Chinook | September 15 – February 15 |
| Juvenile Salmonids | Entire year |

Recurrence interval flows are typically calculated using the annual instantaneous peak flow record or using local or regional empirical equations to calculate the instantaneous peak flow for a specified recurrence interval. For this study, methods outlined in Bulletin 17B (USGS 1982) were used to calculate recurrence interval flows from instantaneous peak flow records for each study site. Regional equations developed by the USGS (Cooper 2005, Gotvald et al. 2012) were also used to calculate recurrence interval flows for each study site. Of note is that peak flow records from all but one of the study sites (NF Caspar Creek) were used in development of these regional equations

All of the Oregon sites used in these analyses were in coastal watersheds and the Oregon regression equations for western Oregon coastal streams, Region 1, are of the form (Cooper 2005):

$$Q_{Year} = K_1 * (Area)^a (I24 - 2)^b (MxJanT)^c (SoilC)^d (SoilP)^e$$

Where $Q_{Year}$ is the recurrence interval year of interest; *Area* is the contributing watershed area in square miles; *I24-2* is the 2-year, 24 hour precipitation intensity in inches; *MxJanT* is the mean maximum January temperature in Farenheit; *SoilC* is the soil storage capacity in inches; and *SoilP* is the soil permeability in inches per hour. $K_1$ , *a, b, c*, *d* and *e* are regression coefficients that vary with the recurrence interval of interest (Table 10 of Cooper, 2005). Equation parameter values for the $Q_{2\text{-year}}$ recurrence interval flows for Oregon were determined using the Oregon Department of Water Resources online peak discharge estimator (OWRD 2012).

The California regression equations (Gotvald et al. 2012) have recently been updated and are now based on streamflow data through 2006. The regression equations for all three coastal regions (North Coast, Central Coast and South Coast) have the form:

$$Q_{year} = K_2 * (Area)^y (Precip)^z$$

Where $Q_{year}$ is the recurrence interval year of interest, *Area* is the contributing watershed area in square miles, and *Precip* is the mean annual precipitation for the watershed in inches. $K_2$, *y* and *z* are regression coefficients that vary with the recurrence interval of interest (Table 5 of Gotvald et al. 2012). For this study, all of the study sites, except North Fork Caspar Creek, are USGS gaged streams whose data sets were used in deriving the California regional regression equations. Watershed areas are the contributing watershed area to the gage site and the mean annual precipitation for each site was taken from the Table 2 supplemental Excel spreadsheet accompanying Gotvald et al. (2012). For calculating recurrence interval flows for ungaged watersheds, the mean annual precipitation must be determined using GIS tools to determine the spatially averaged mean annual precipitation for the watershed of interest using the 800-meter resolution PRISM (Parameter-elevation Relationships on Independent Slopes Model) data (http://prism.nacse.org/).

## 4.2 Comparison of Fish Passage Design Flows Using Various Criteria

Comparing the fish passage design flows resulting from the various criteria at a study site and between sites reveals differences in regional hydrology and implications of these criteria for fish passage opportunities. This section provides a direct comparison between the high fish passage flow criteria.

Figure 12 compares the $Q_{HFP}$ criteria currently being used for adult salmon and steelhead in California (1% annual exceedance flow) and Oregon (5% migration period exceedance flow) for all study sites. The migration period used for this plot was the assumed steelhead migration period of November 1 through May 15. Also included in the plot are California's alternate criteria for $Q_{HFP}$, 50% of the 2-year recurrence interval flow. The $Q_{2\text{-year}}$ flows were calculated by the two different methods described above: direct analysis of the annual instantaneous peak flow record for each study site using USGS Bulletin 17B (USGS

1982) and using USGS regional regression equations (Gotvald et al. 2012). All flows have been scaled to the drainage area at the study site to facilitate comparisons between sites.

The plot reveals that the various definitions of $Q_{HFP}$ result in substantially different high passage flows. For 50% of the 2-year recurrence interval flow ($Q_{2\text{-year}}$), the empirical equations ($Q_{2\text{-EM}}$) generally under-predicted for the more southern study sites when compared to $Q_{2\text{-year}}$ calculated using the actual peak flow records for each study site ($Q_{2\text{-PK}}$). For the majority of the sites (12 of 16), use of the empirical equations rather than the annual peak flow record results in a lower $Q_{HFP}$. For the exceedance flow based $Q_{HFP}$ criteria, the 1% steelhead migration period exceedance flow was the highest, and was often close to the 50%$Q_{2\text{-EM}}$, followed by the 1% annual exceedance flow. The 5% and 10% migration period exceedance flows; used as the $Q_{HFP}$ criteria in Oregon and Washington, respectively; are significantly less than the other daily exceedance flow criteria, especially for the Southern California region sites. Comparing the scaled fish passage flow criteria between regions also reveals the regional differences. On a drainage area basis, the two northern regions have similar magnitude and variability in the $Q_{HFP}$. However, the Southern California study sites have a noticeably lower $Q_{HFP}$ than both Northern California and the Pacific Northwest. The most southern of the Northern California study sites, Soquel Creek, also shows decreasing magnitudes for $Q_{HFP}$, possibly showing that it is located in a transition between the two climatic regions.

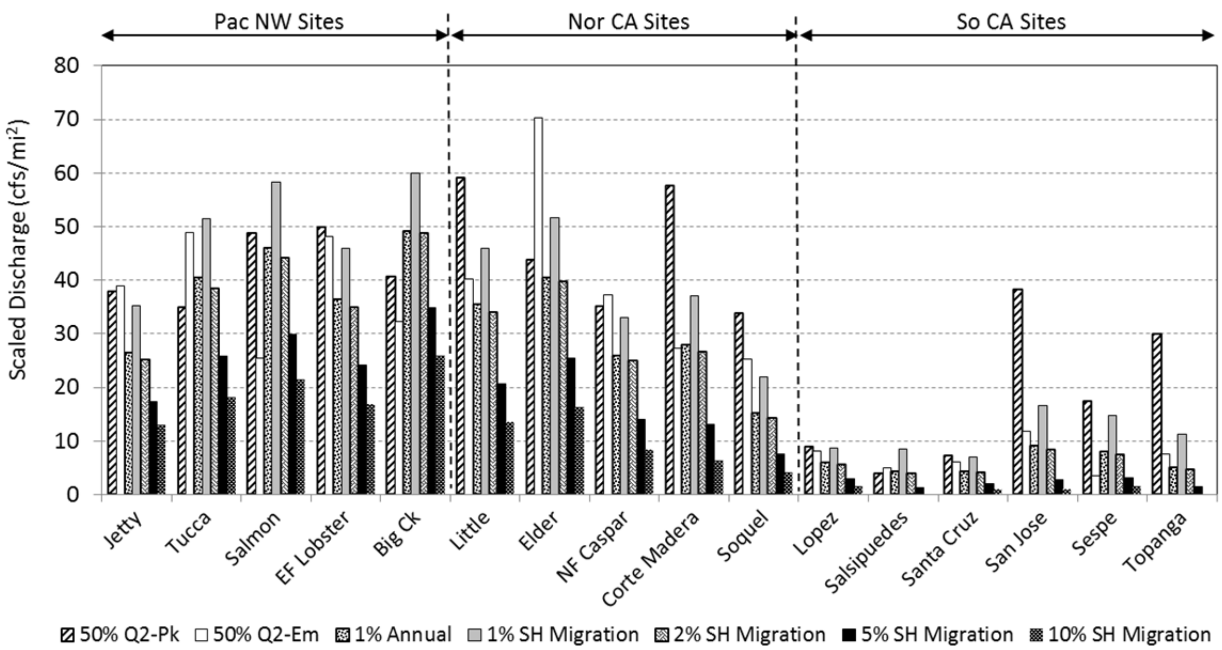



**Figure 12. Comparison of current high fish passage flow criteria for adult salmon and steelhead (50% of $Q_{2\text{-year}}$ determined from annual peak flow data and USGS regression equations, 1% annual exceedance flow, and the 1%, 2%, 5% and 10% migration period exceedance flows).**

Table 3 lists the return period of the flow associated with $50\%Q_{2\text{-}PK}$ and the equivalent daily exceedance of this flow for the annual and adult steelhead migration periods. Table 4 provides the same information for $50\%Q_{2\text{-}EM}$. The return periods were calculated using the peak flow record from the site with methods provided in USGS (1982). The daily exceedance was derived from the constructed FDCs (Appendix D). The $50\%Q_{2\text{-}PK}$ criteria results in a $Q_{HFP}$ with a return period between 1.01- and 1.48-years. The exceedance flow equivalent to $50\%Q_{2\text{-}PK}$ is generally less than the 1% annual exceedance flow and the 1% exceedance flow for the steelhead migration period, except for Tucca Creek, Salmon River, and Big Creek in the Pacific Northwest, and Elder Creek in Northern California. These exceptions explain some of the results displayed in Figure 12.

Table 3 suggests some regional differences regarding using $50\%Q_{2\text{-}PK}$ criteria for adult steelhead $Q_{HFP}$. The Southern California sites have a less frequent return period associated with $50\%Q_{2\text{-}PK}$ compared to the other regions. The average return period of $50\%Q_{2\text{-}PK}$ among the Southern California sites is 1.44-years, while the averages for the Pacific Northwest and Northern California sites are 1.13- and 1.18-years, respectively. In other terms, the annual exceedance flow equivalent to the $50\%Q_{2\text{-}PK}$ among the Pacific Northwest sites averages to be a 1.0% annual exceedance flow, while the Northern and Southern California sites annual exceedance flow equivalent average to be a 0.4% and 0.3% annual exceedance flow, respectively.

Similar to Table 3, Table 4 summarizes the return periods and annual exceedance flows equivalent to the $50\%Q_{2\text{-}EM}$. The average return period for the $50\%Q_{2\text{-}EM}$ flows were 1.19 years for the Southern and Northern California sites and 1.17 years for the Pacific Northwest sites. Annual exceedance flows equivalent to the $50\%Q_{2\text{-}EM}$ flows are 1.04% among the Southern California sites and 0.57% and 1.7% for the Pacific Northwest and Northern California sites, respectively. For almost all of the sites, the $50\%Q_{2\text{-}PK}$ flows were greater than the $50\%Q_{2\text{-}EM}$ flows and the lower return periods and higher annual exceedance flows reflect that difference.

Table 5 and Table 6 summarize the actual (unscaled) juvenile and adult steelhead passage flow criteria for all of the study sites. The adult passage analyses presented in the report use the 50% annual exceedance flow or 3 cfs whichever is greater for $Q_{LFP}$, and the juvenile passage analyses use the 95% annual exceedance flow or 1 cfs whichever is greater. For analysis of $Q_{HFP}$ the 1% annual and 1% steelhead migration period flows, and both versions of 50% of $Q_{2\text{-}year}$ ($50\%Q_{2\text{-}PK}$ and $50\%Q_{2\text{-}EMP}$) are presented throughout the report. Analysis of adult passage using a $Q_{HFP}$ equal to the 5% migration period exceedance flow is also included for most analyses but this criteria results in extremely low passage flows for the more southern study sites. The other alternatives for $Q_{HFP}$ are not presented because the 2% steelhead migration period exceedance flow is essentially equivalent to the 1% annual exceedance flow, and thus provides the same results for the passage window and passage delay. The 10% migration period exceedance flows is quite low, especially for the Southern California region sites, resulting in extremely short and impractical passage windows.

**Table 3. Equivalent return period and daily exceedance probability for the 50% of the 2-year return period flow calculated using the peak flow records from the site.**

| Region | Site | $50\%Q_{2\text{-}PK}$ (cfs) | Return Period of $50\%Q_{2\text{-}PK}$ (years) | Daily Exceedance of $50\%Q_{2\text{-}PK}$: Annual Period | Daily Exceedance of $50\%Q_{2\text{-}PK}$: Adult Steelhead Migration Period |
|---|---|---|---|---|---|
| Pacific Northwest | Jetty | 75 | 1.22 | 0.4% | 0.5% |
| | Tucca | 108 | 1.18 | 1.4% | 2.2% |
| | Salmon | 2,873 | 1.01 | 0.9% | 1.4% |
| | EF Lobster | 285 | 1.22 | 0.4% | 0.7% |
| | Big | 501 | 1.03 | 1.8% | 2.8% |
| Northern California | Little | 2,394 | 1.15 | 0.3% | 0.4% |
| | Elder | 285 | 1.22 | 0.8% | 1.3% |
| | NF Caspar | 64 | 1.10 | 0.5% | 0.8% |
| | Corte Madera | 1,045 | 1.17 | 0.2% | 0.3% |
| | Soquel | 1,361 | 1.25 | 0.2% | 0.3% |
| Southern California | Lopez | 186 | 1.47 | 0.5% | 0.8% |
| | Salsipuedes | 732 | 1.48 | 0.3% | 0.4% |
| | Santa Cruz | 541 | 1.42 | 0.5% | 0.8% |
| | San Jose | 211 | 1.37 | 0.2% | 0.3% |
| | Sespe | 4,392 | 1.44 | 0.4% | 0.7% |
| | Topanga | 540 | 1.46 | 0.2% | 0.3% |

**Table 4. Equivalent return period and daily exceedance probability for the 50% of the 2-year return period flow calculated using the regional empirical equations.**

| Region | Site | $50\%Q_{2\text{-}EM}$ (cfs) | Return Period of $50\%Q_{2\text{-}EM}$ (years) | Daily Exceedance of $50\%Q_{2\text{-}EM}$: Annual Period | Daily Exceedance of $50\%Q_{2\text{-}EM}$: Adult Steelhead Migration Period |
|---|---|---|---|---|---|
| Pacific Northwest | Jetty | 77.3 | 1.23 | 0.4% | 0.4% |
| | Tucca | 151 | 1.41 | 0.6% | 1.0% |
| | Salmon | 1,501 | < 1.0 | 3.9% | 6.2% |
| | EF Lobster | 275 | 1.20 | 0.5% | 0.7% |
| | Big | 399 | 1.01 | 3.2% | 5.1% |
| Northern California | Little | 1,625 | 1.05 | 0.7% | 1.2% |
| | Elder | 456 | 1.63 | 0.2% | 0.4% |
| | NF Caspar | 68.3 | 1.12 | 0.4% | 0.6% |
| | Corte Madera | 495 | 1.02 | 1.1% | 1.7% |
| | Soquel | 1,016 | 1.14 | 0.4% | 0.7% |
| Southern California | Lopez | 168 | 1.42 | 0.6% | 1.0% |
| | Salsipuedes | 237 | 1.15 | 0.9% | 1.4% |
| | Santa Cruz | 448 | 1.34 | 0.7% | 1.0% |
| | San Jose | 64.9 | 1.06 | 0.8% | 1.3% |
| | Sespe | 877 | 1.06 | 2.5% | 4.0% |
| | Topanga | 135 | 1.10 | 0.8% | 1.2% |

**Table 5. Summary of juvenile fish passage criteria for each study site.**

| | | Juvenile Low Flow[1] | Juvenile High Flow (cfs) | | |
|---|---|---|---|---|---|
| | Site Name | 95% Annual (cfs) | 10% Q2-Pk | 10% Q2-Em[2] | 10% Annual |
| Pacific NW sites | Jetty Ck | 1.2 | 15.1 | 15.5 | 20 |
| | Tucca Ck | 1.2 | 21.6 | 30.2 | 40 |
| | Salmon Riv | 32 | 574 | 300 | 910 |
| | EF Lobster Ck | 0.7 | 57 | 55 | 63 |
| | Big Cr | 6.3 | 100 | 79.8 | 230 |
| Northern CA sites | Little Riv | 4.5 | 479 | 325 | 358 |
| | Elder Ck | 0.7 | 56.8 | 91.2 | 67 |
| | NF Caspar Ck | 0.06 | 12.9 | 13.7 | 8.3 |
| | Corte Madera Ck | 0.01 | 209 | 99 | 52 |
| | Soquel Ck | 1 | 272 | 203 | 87 |
| Southern CA sites | Lopez Ck | 1.2 | 37 | 34 | 17 |
| | Salsipuedes Ck | 0.05 | 146 | 47.4 | 12 |
| | Santa Cruz Ck | 0.00 | 108 | 89.6 | 36 |
| | San Jose Ck | 0.00 | 42 | 13 | 2.3 |
| | Sespe Ck | 0.10 | 878 | 175 | 182 |
| | Topanga Ck | 0.00 | 108 | 27.0 | 3.6 |

[1] Passage analyses were conducted using the 95% annual exceedance flow or 1 cfs whichever was greater.

[2] The values for California were calculated using the updated CA regression equations (Gotvald et al. 2012) and those for Oregon using (Cooper 2005).

*4. Fish Passage Design Flows*

**Table 6. Summary of adult steelhead low and high passage flows based on various criteria for each study site.**

| | | Adult Low Flow[1] | Adult High Flow (cfs) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Site Name** | **50% Annual (cfs)** | **50% Q2-Pk** | **50% Q2-Em[2]** | **1% Annual** | **1% SH Mig Per[3]** | **2% SH Mig Per[3]** | **5% SH Mig Per[3]** | **10% SH Mig Per[3]** |
| Pacific NW sites | Jetty Ck | 6.5 | 75.7 | 77.3 | 52.6 | 70 | 50 | 34.6 | 26 |
| | Tucca Ck | 9.1 | 108 | 151 | 125 | 159 | 119 | 80 | 56 |
| | Salmon Riv | 213 | 2872 | 1501 | 2710 | 3430 | 2606 | 1760 | 1270 |
| | EF Lobster Ck | 9.5 | 285 | 275 | 208 | 262 | 199 | 138 | 96 |
| | Big Cr | 45 | 501 | 399 | 605 | 738 | 600 | 429 | 319 |
| Northern CA sites | Little Riv | 36 | 2394 | 1625 | 1440 | 1860 | 1380 | 854 | 547 |
| | Elder Ck | 5.5 | 284 | 456 | 263 | 336 | 258 | 166 | 106 |
| | NF Caspar Ck | 0.51 | 64.5 | 68.3 | 47.4 | 60.5 | 45.9 | 25.8 | 15.5 |
| | Corte Madera Ck | 1.9 | 1045 | 495 | 506 | 671 | 484 | 236 | 116 |
| | Soquel Ck | 7.9 | 1361 | 1016 | 610 | 879 | 576 | 304 | 168 |
| Southern CA sites | Lopez Ck | 3.8 | 186 | 168 | 125 | 182 | 118 | 61 | 33 |
| | Salsipuedes Ck | 1.5 | 732 | 237 | 200 | 398 | 183 | 64 | 12 |
| | Santa Cruz Ck | 1.5 | 542 | 448 | 320 | 511 | 300 | 150 | 75 |
| | San Jose Ck | 0.29 | 210 | 64.9 | 50 | 91 | 46 | 15 | 5.5 |
| | Sespe Ck | 12 | 4392 | 877 | 2031 | 3708 | 1899 | 783 | 385 |
| | Topanga Ck | 0.2 | 540 | 135 | 91.7 | 202 | 85.6 | 27 | 9.5 |

[1] Passage analyses were conducted using the 50% annual exceedance flow or 3 cfs whichever was greater.

[2] The values for California were calculated using the updated CA regression equations (Gotvald et al. 2012) and those for Oregon using (Cooper 2005).

[3] The migration period used for these percent exceedance flows is an assumed steelhead migration period of Nov 1 - May 15

# 5 Variation of Passage and Delay with Different Fish Passage Criteria

## 5.1 Methods

Fish passage windows, the time periods when flow is between $Q_{LFP}$ and $Q_{HFP}$, and passage delays due to flows lower than $Q_{LFP}$ or higher than $Q_{HFP}$ were determined for each study site using the mean daily flow record and all combinations of high and low fish passage criteria listed in Table 7 and Table 8 using a program developed for this purpose. All annual and migration period exceedance flows were calculated using the complete record of mean daily flow for the particular study site. For each combination of $Q_{LFP}$ and $Q_{HFP}$, the program determines whether the mean daily flow is above, below or between these values. Total time above, below and between $Q_{LFP}$ and $Q_{HFP}$ is computed for each water year. The program also outputs the number and length of each distinct time period above, below and between $Q_{LFP}$ and $Q_{HFP}$ per water year for the entire period of record.

Figure 13 illustrates the various passage and delay events using example Wet and Average year hydrographs. The individual storm fish passage windows and the high and low flow delay events are shown for $Q_{LFP}$ and $Q_{HFP}$ criteria defined as the 50 percent annual exceedance flow and 1-percent annual exceedance flow, respectively, at Lopez Creek.

**Table 7. Adult Fish Passage Criteria combinations analyzed**

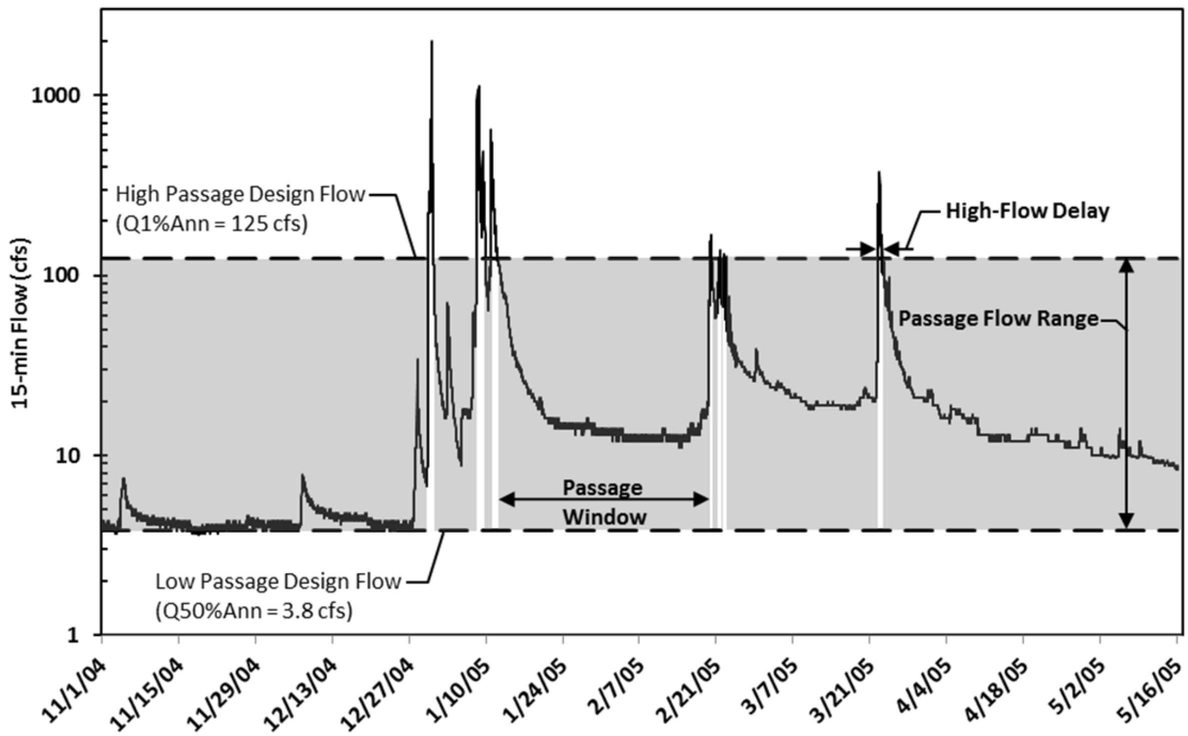
| $Q_{LFP}$ | $Q_{HFP}$ |
|---|---|
| 3 cfs or 50% annual exceedance flow, whichever value is greater [1] (Q3cfs & Q50%Ann) | 1% annual exceedance flow[1] (1%Annual) |
| | 50% $Q_{2\text{-}year}$; $Q_{2\text{-}year}$ determined from gage data[1] (50%Q2Pk) |
| | 50% $Q_{2\text{-}year}$; $Q_{2\text{-}year}$ determined using USGS regression equations (USGS, 2012)[1] (50%Q2Em) |
| | 1% migration period exceedance flow[3] (1%MigPer) |
| | 5% migration period exceedance flow[2] (5% MigPer) |

[1]NMFS Southwest Region, CDFG criteria
[2]Oregon Department of Fish and Wildlife criteria
[3]Hypothetical criteria, used for sensitivity analysis

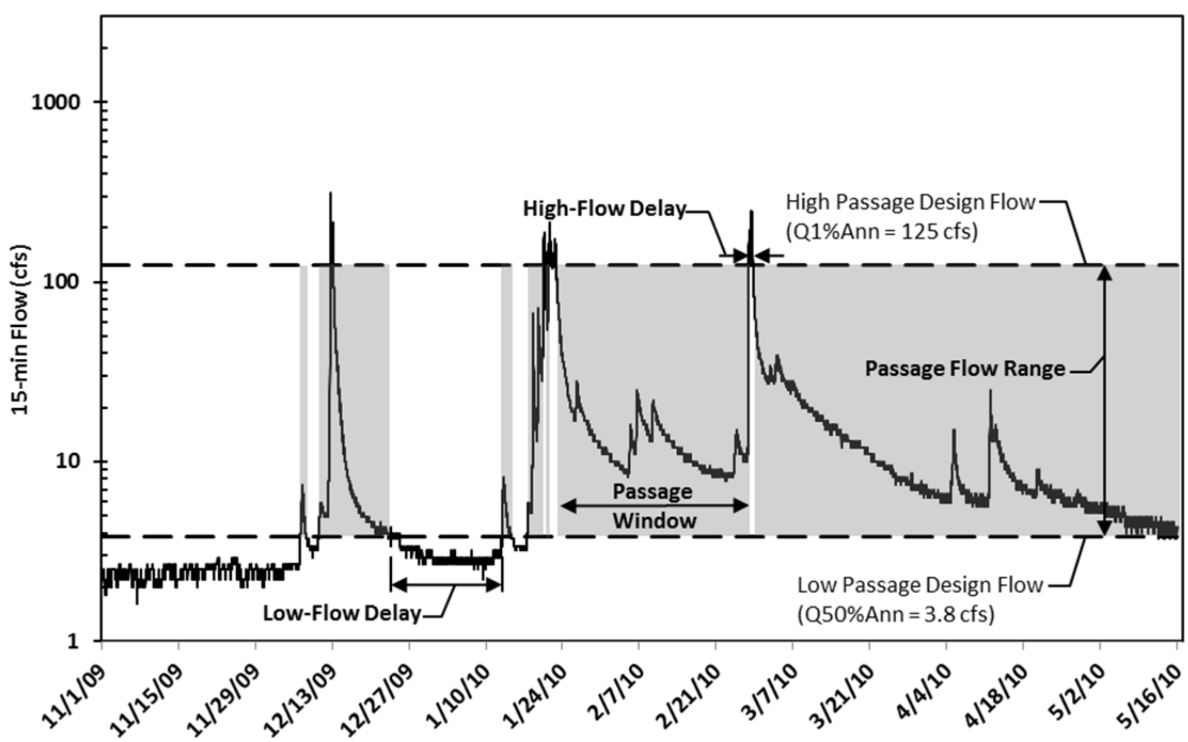
**Table 8. Juvenile Fish Passage Criteria combinations analyzed**

| $Q_{LFP}$ | $Q_{HFP}$ |
|---|---|
| 1 cfs or 95% annual exceedance flow whichever value is greater [1] (Q1cfs & Q95%Ann) | 10% annual exceedance flow[1] (Q10%Ann) |
| | 10% $Q_{2\text{-}year}$; $Q_{2\text{-}year}$ determined from gage data[1] (10%Q2Pk) |
| | 10% $Q_{2\text{-}year}$; $Q_{2\text{-}year}$ determined using USGS regression equations (USGS, 2012)[1] (10%Q2Em) |

[1]NMFS Southwest Region, CDFG criteria
[2]Oregon Department of Fish and Wildlife criteria
[3]Hypothetical criteria, used for sensitivity analysis




(a)




(b)

**Figure 13. Example of passage windows (gray) as defined using $Q_{HFP}$ =Q1%Ann and $Q_{LFP}$ = Q50%Ann for Lopez Creek during the steelhead migration season of (a) water year 2005 (classified as Wet) and (b) water year 2010 (classified as Average).**

Several different analyses were conducted to quantify the impacts of fish passage flow criteria on the annual and migration period passage windows and delay. Passage conditions were also compared across water year type classifications (Wet, Average and Dry) to focus on differences within inter-annual hydrologic variability across climatic regions. Section 5.2 presents detailed passage summaries for Wet, Average and Dry years by direct comparison of passage windows and high and low flow delays between sites and years at a given site. Section 5.3 presents composite analyses for all sites using the complete data records. The passage analysis presented in these sections evaluated a migration period from November 1 through May 15 which is assumed to represent adult steelhead migration period within these climate regions. Similar analyses of adult passage for migration periods representing adult coho and Chinook passage (Table 2) are provided in Appendix E. Assessment of juvenile passage criteria (Section 5.4) was conducted on an annual basis.

## 5.2 Comparison of Passage for Different Water Year Types

To compare the passage opportunities in different year types, water years were classified as "Wet", "Average" or "Dry" using the annual water yields calculated from the mean daily flows for each gaging record. Wet years are defined as those years in the upper 20 percentile of water yield, Average years are those in the middle 60 percentile, and Dry years are the lower 20 percentile of annual water yields.

### *5.2.1 Use of 15-Minute Versus Mean Daily Flow Data*

Two years bracketing the median in each year-type were selected for comparison. Three study sites (Lopez Ck, Salispuedes Ck and Sespe R) were selected to evaluate differences in the calculated passage window and delay associated with using the finer resolution 15-minute data sets compared to use of mean daily flow records. For these three sites, adjustments were made to the years analyzed to avoid years that had incomplete 15-minute flow records. The identification of the median water years in each water year type is included for Lopez Creek (Figure 14) as an example of the water year rankings and justification for the years selected for analysis.

Table 9 compares the passage characteristics of the six selected water years for Lopez Creek as determined using both the mean daily and 15-minute data for each year. These results are presented only to illustrate differences in the mean daily and 15-minute derived estimates of passage and low and high flow delay, and to demonstrate that both data records provide very similar predictions of total annual passage and delay times. The mean daily flow records for USGS gaging stations are available for a station's full period of record, more easily analyzed and manipulated. Most importantly, the mean daily flow data are verified before release. Thus, the mean daily flow records were used for all analyses except this analysis.

The comparison between passage predictions using the mean daily versus the 15-minute data also suggests that using the 15-minute data provides negligible improvement in accuracy for predicting annual passage windows and delay. Comparing the passage window and delay estimated using the different data records, the mean daily and 15-minute derived total passage window and delays agreed reasonably well for all years. For all $Q_{HFP}$ criteria analyzed, the mean daily high flow delay estimates were slightly greater than those determined from the 15-minute data for the Wet and Average years and slightly lower for the Dry years. This is primarily due to the differences in levels of precision (15 min versus mean daily data) provided by the two different data sets and the tendency of mean daily flows to overestimate duration because the value is an average rather than the median daily flow. During wetter years, the peak storm flows are generally higher than drier years; thus, the mean daily flow is more likely to exceed $Q_{HFP}$ resulting in an additional day of high flow delay predicted using the mean daily flow record, even if more than half of the day was below $Q_{HFP}$. In drier years, if storm flow peaks exceed $Q_{HFP}$, it is generally only for a few hours and the mean daily flow does not exceed $Q_{HFP;}$ thus, these few hours of high flow delay would not be detected using the mean daily flow record.

As expected, Table 9 shows the number of storms and their peak flow magnitudes on Lopez Creek are quite different in Wet versus Dry years. The passage windows, however, do not necessarily vary significantly between Wet and Dry years, with Dry year 1989 (the 14$^{th}$ percentile ranking in annual water yield for the Lopez Creek record) having a very similar total passage window to Wet year 1995 (the 88-percentile ranking in annual water yield). The Wet year 1995 has more days of high flow delay and the Dry year of 1989 has more days of low flow delay, resulting in similar total passage windows. The other Dry year, 2009 (the 4.6-percentile ranking in annual water yield), is quite different with only 17 days of passage predicted and all passage delay resulting from low-flow passage delay.

The complete set of tabular summaries for all study sites using the mean daily flow records is included in Appendix B (Tables B-1 through B-16). The results for Southern California region sites of Lopez Creek, Salisipuedes Creek and the Sespe Creek that compare the mean daily and 15-minute record-based analyses are also included in Appendix B (Tables B-17 through B-19).

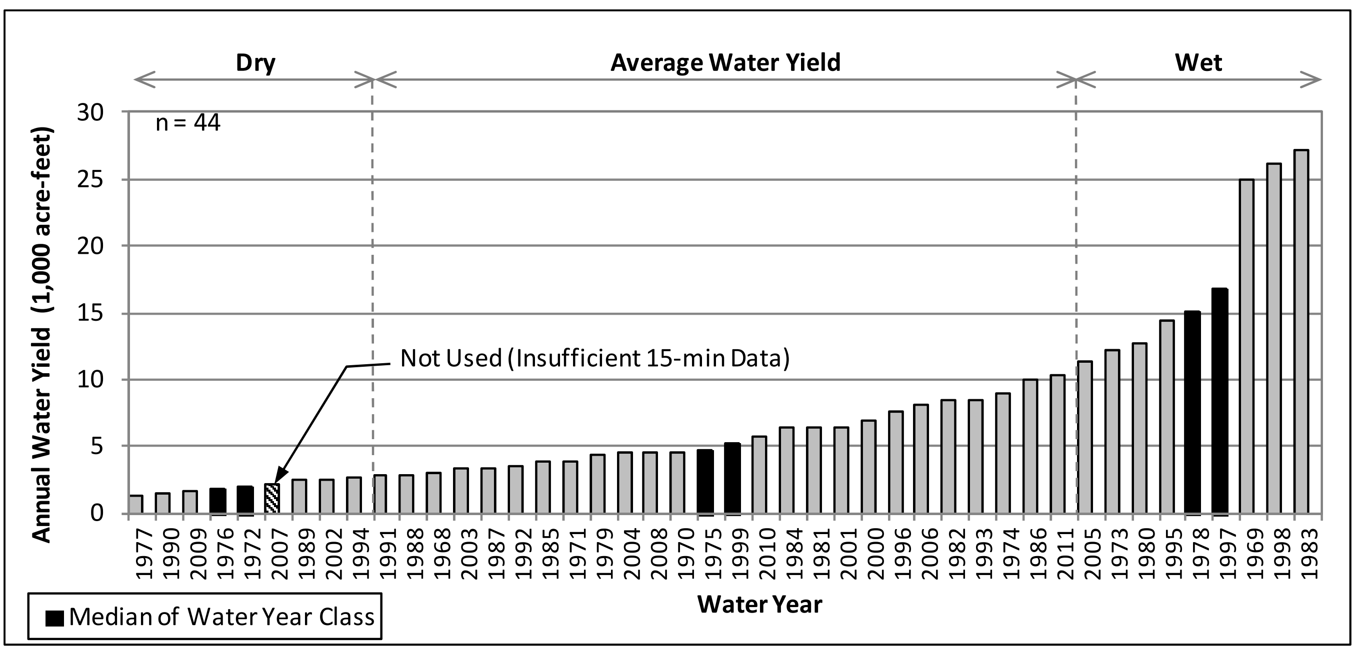



**Figure 14. Lopez Creek annual water yield rankings determined using mean daily flow. Water years used to compare passage conditions predicted using mean daily and 15-minute data are indicated.**

**Table 9. Lopez Creek comparison of fish passage using mean daily and 15-minute data for median Wet, Average and Dry years for the assumed steelhead migration period November 1 to May 15.**

| Water Year/Type | | 1995/Wet | | 2005/Wet | | 2001/Ave | | 2010/Ave | | 1989/Dry | | 2009/Dry | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank of 44 (Percentile) | | 6 (0.883) | | 9 (0.813) | | 18 (0.604) | | 21 (0.534) | | 38 (0.139) | | 42 (0.046) | |
| (Data Interval) | | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) |
| **Number of Storm Events[1]** | | 7 | | 4 | | 4 | | 4 | | 3 | | 2 | |
| Storm Qpeak (cfs) | Median | 130 | 242 | 265 | 754 | 68.5 | 81 | 107.5 | 234 | 13 | 18 | ---[2] | ---[2] |
| | Min | 19 | 52 | 91 | 169 | 24 | 49 | 15 | 25 | 9.7 | 13 | 6.8 | 16 |
| | Max | 594 | 2080 | 465 | 2020 | 450 | Missing | 148 | 313 | 40 | 163 | 9 | 22 |
| **Low Flow Delay (Days)** | | | | | | | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 3.8 cfs | Total | 63 | 61.9 | 0 | 0.4 | 54 | 47.0 | 59 | 60.9 | 76 | 80.6 | 179 | 181.6 |
| | Median Event | 63 | 9.00 | 0 | 0.01 | 4.5 | 0.01 | 10.5 | 0.03 | 14 | 10.20 | 28.5 | 0.02 |
| | Min Event | 63 | 7.34 | 0 | 0.01 | 1 | 0.01 | 2 | 0.01 | 1 | 0.01 | 1 | 0.01 |
| | Max Event | 63 | 28.11 | 0 | 0.05 | 28 | 17.50 | 36 | 36.20 | 20 | 19.20 | 70 | 43.00 |
| **High Flow Delay (Days)** | | | | | | | | | | | | | |
| $Q_{HFP}$=50%Q2-yr Peak = 186 cfs | Total | 4 | 3.67 | 4 | 3.54 | 1 | 0.22 | 0 | 0.57 | 0 | 0.00 | 0 | 0.00 |
| | Median Event | 1 | 0.11 | 1 | 0.66 | 1 | 0.00 | 0 | 0.19 | 0 | 0.00 | 0 | 0.00 |
| | Min Event | 1 | 0.00 | 1 | 0.00 | 1 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | Max Event | 2 | 1.81 | 2 | 2.21 | 1 | 0.11 | 0 | 0.21 | 0 | 0.00 | 0 | 0.00 |
| $Q_{HFP}$ = 1% MigPer = 182 cfs | Total | 4 | 3.69 | 4 | 3.61 | 1 | 0.25 | 0 | 0.68 | 0 | 0.00 | 0 | 0.00 |
| | Median Event | 1 | 0.11 | 1 | 0.66 | 1 | 0.00 | 0 | 0.22 | 0 | 0.00 | 0 | 0.00 |
| | Min Event | 1 | 0.00 | 1 | 0.00 | 1 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | Max Event | 2 | 1.83 | 2 | 2.25 | 1 | 0.14 | 0 | 0.24 | 0 | 0.00 | 0 | 0.00 |
| $Q_{HFP}$ = 1% Annual = 125 cfs | Total | 6 | 5.86 | 6 | 5.03 | 1 | 1.66 | 2 | 2.91 | 0 | 0.00 | 0 | 0.00 |
| | Median Event | 1 | 0.58 | 1 | 0.91 | 1 | 0.00 | 2 | 0.66 | 0 | 0.00 | 0 | 0.00 |
| | Min Event | 1 | 0.01 | 1 | 0.32 | 1 | 0.00 | 2 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | Max Event | 2 | 2.28 | 2 | 2.89 | 1 | 0.29 | 2 | 1.59 | 0 | 0.00 | 0 | 0.00 |
| **Passage Window (Days)** | | | | | | | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 3.8 cfs, $Q_{HFP}$ =50%Q2-yr Peak=186 cfs | Total | 129 | 115.40 | 192 | 192.1 | 141 | 138.7 | 137 | 132.1 | 120 | 121.2 | 17 | 14.4 |
| | Min Event | 6 | 0.01 | 6 | 0.01 | 4 | 0.01 | 2 | 0.01 | 2 | 0.01 | 2 | 0.01 |
| | Max Event | 57 | 38.6 | 68 | 69.7 | 70 | 50.9 | 76 | 74.1 | 113 | 105.8 | 6 | 3.2 |
| $Q_{LFP}$ = 50% Annual = 3.8 cfs, $Q_{HFP}$ = 1% MigPer = 182 cfs | Total | 129 | 115.38 | 192 | 192.0 | 141 | 138.7 | 137 | 134.4 | 120 | 121.2 | 17 | 14.3 |
| | Min Event | 7 | 0.01 | 1 | 0.01 | 1 | 0.01 | 1 | 0.01 | 1 | 0.01 | 1 | 0.01 |
| | Max Event | 58 | 38.6 | 124 | 69.7 | 71 | 51.0 | 119 | 77.4 | 114 | 138.4 | 7 | 12.2 |
| $Q_{LFP}$ = 50% Annual = 3.8 cfs, $Q_{HFP}$ = 1% Annual = 125 cfs | Total | 127 | 113.2 | 190 | 190.6 | 141 | 137.3 | 135 | 134.5 | 120 | 121.1 | 17 | 14.3 |
| | Min Event | 7 | 0.01 | 1 | 0.01 | 1 | 0.01 | 1 | 0.01 | 1 | 0.01 | 1 | 0.01 |
| | Max Event | 53 | 38.3 | 69 | 59.5 | 71 | 51.0 | 77 | 77.3 | 114 | 129.3 | 7 | 12.2 |

[1]- Storms are defined as discrete hydrographs with peak flow at least three times the base flow and intervals of 24 hours or greater between peak flows.

[2]- A median value is not reported when there are only two events during the year or migration period.

### *5.2.2 Low and High Flow Delay by Water Year Type and Region*

Figure 15 through Figure 20 summarize passage for the two median Wet, Average and Dry years for the northern and southern-most study sites in each climate region during the assumed adult steelhead migration period. The summary plots for all sites are included in Appendix B (Figures B-1 through B-16). Passage windows and reason for delay vary substantially between the climatic regions. The Southern California sites are dominated by low flow passage delays. Smaller watersheds in this region, such as San Jose and Topanga creeks, show very small total annual passage windows during Average and Dry years because flows persist below the $Q_{LFP}$ of 3 cfs for extended periods.

In all regions, adult steelhead passage delays due to low flows are greater than those due to high flows except for in the wettest years. For smaller watersheds a $Q_{LFP}$ of 3 cfs is typically used because the annual 50% exceedance flow is lower than alternative minimum flow of 3 cfs. As a result, in all regions the smaller watersheds have longer low flow passage delays in all year classes and the smallest watershed, NF Caspar Creek (Drainage Area = 1.83 sq. mi.) provides a good illustration of the effect of watershed size (Figure B-8). For the Pacific Northwest sites, the effect of watershed size on low-flow delay is not as great because even the smallest watersheds maintain flows greater than 3 cfs during the assumed adult steelhead migration period of November1 through May 15. Thus, all sites within this region exhibit similar duration of low-flow delay.

Plots Figure 15 through Figure 20 also show that even during Wet years, the total high flow delay is relatively small compared to the fish passage window. Figure 21 and Figure 22 show the number of days within the migration period where flow is below $Q_{LFP}$ for the Northern and Southern California region sites. The number of days with low flow delay increases dramatically for Dry years and is highest in the smaller watersheds (NF Caspar Ck in the Northern CA region, DA = 1.8 sq. mi. and San Jose Ck in the Southern CA region, DA = 5.5 sq. mi.). Because low flows persist during much of the selected migration period, the primary factor influencing the duration of the passage window is $Q_{LFP}$ rather than $Q_{HFP}$.

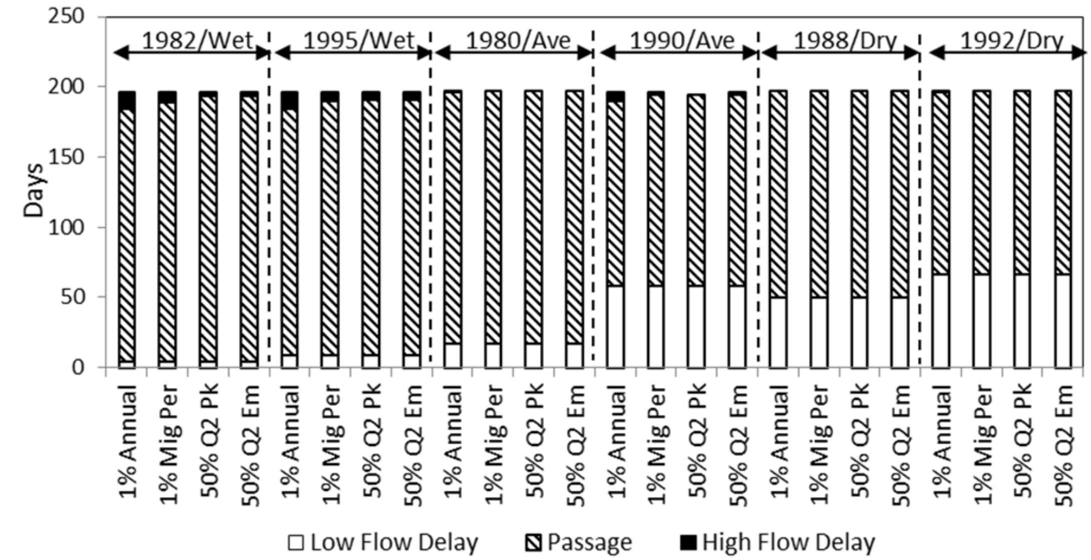



**Figure 15. Jetty Creek (the northern-most Pacific NW region site; WA = 1.99 sq. mi.) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

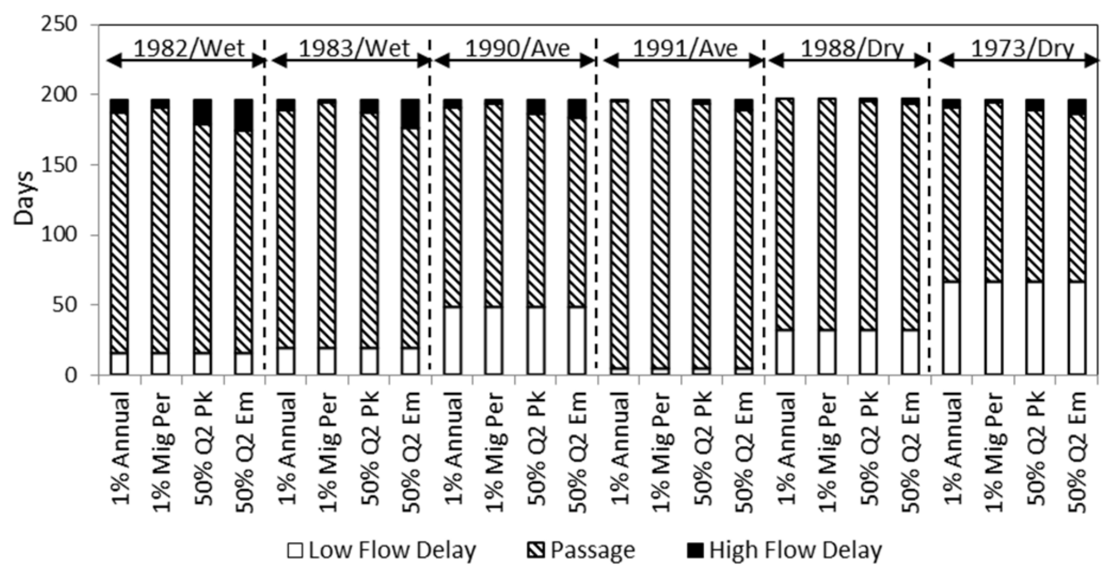



**Figure 16. Big Creek (the southern-most Pacific NW region site, WA = 12.3 sq. mi.) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

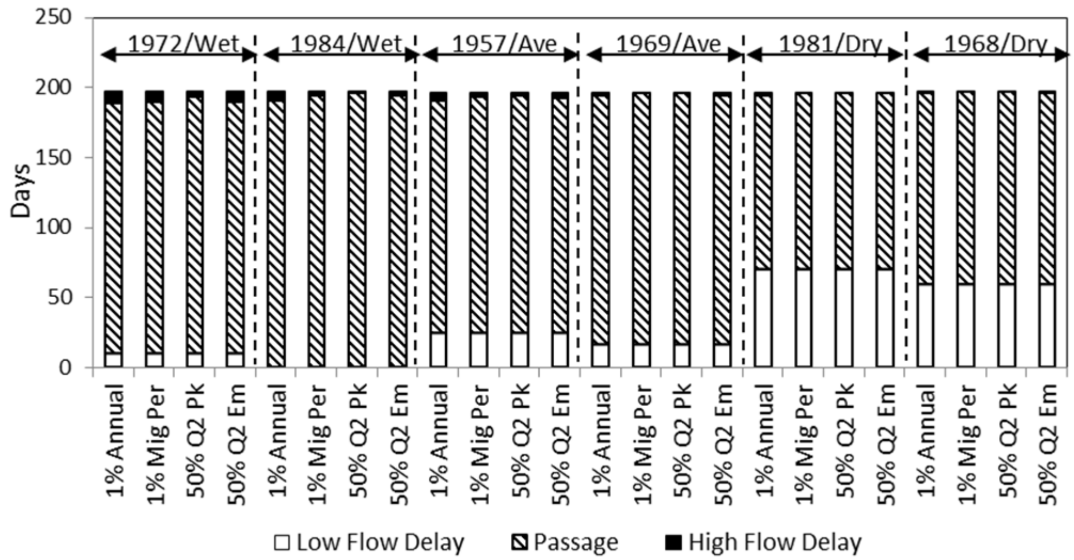



**Figure 17. Little River (the northern-most Northern California region site; WA = 40.5 sq. mi.) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

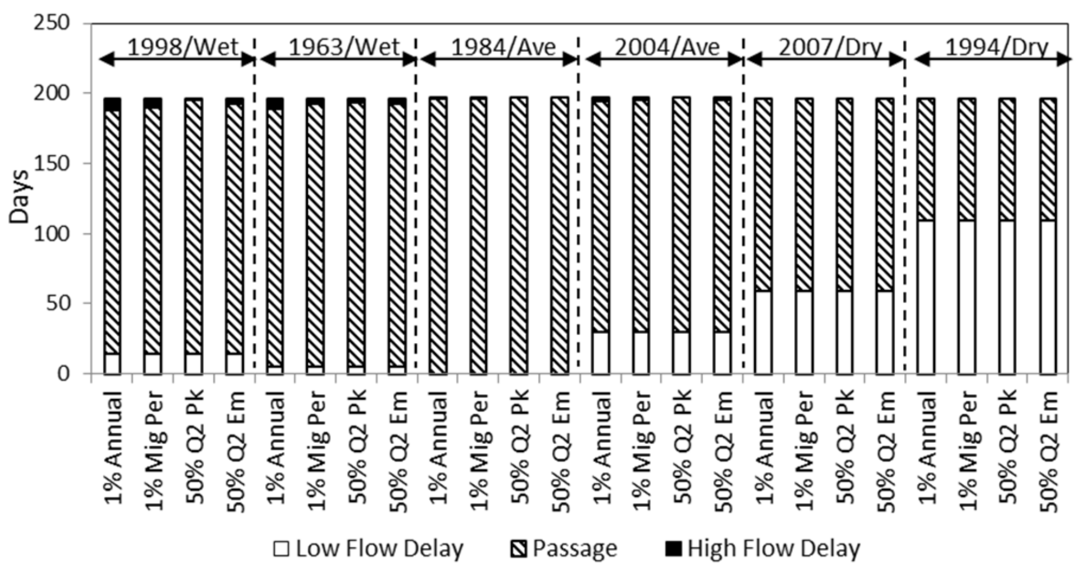



**Figure 18. Soquel Creek (the southern-most Northern California region site; WA = 40.2 sq. mi.) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

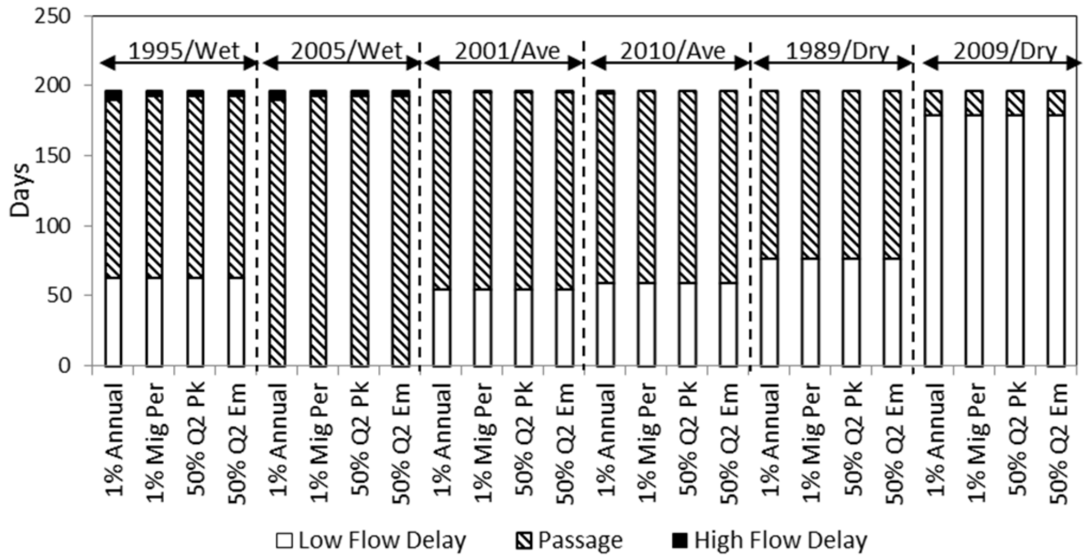



**Figure 19. Lopez Creek (the northern-most Southern California region site; WA = 20.9 sq. mi.) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

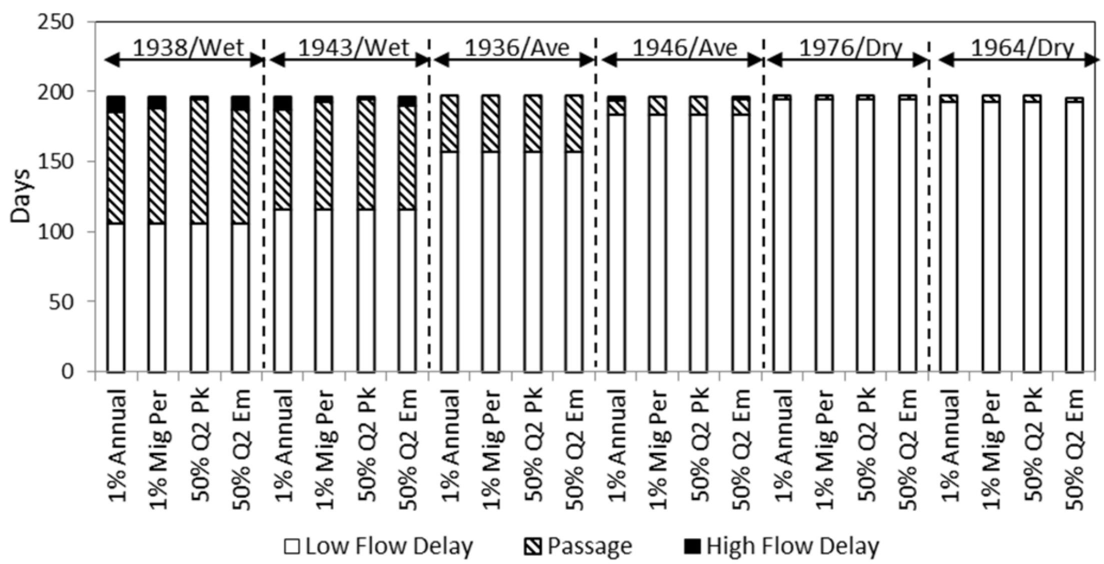



**Figure 20. Topanga Creek (the southern-most Southern California region site; WA = 18.0 sq. mi.) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

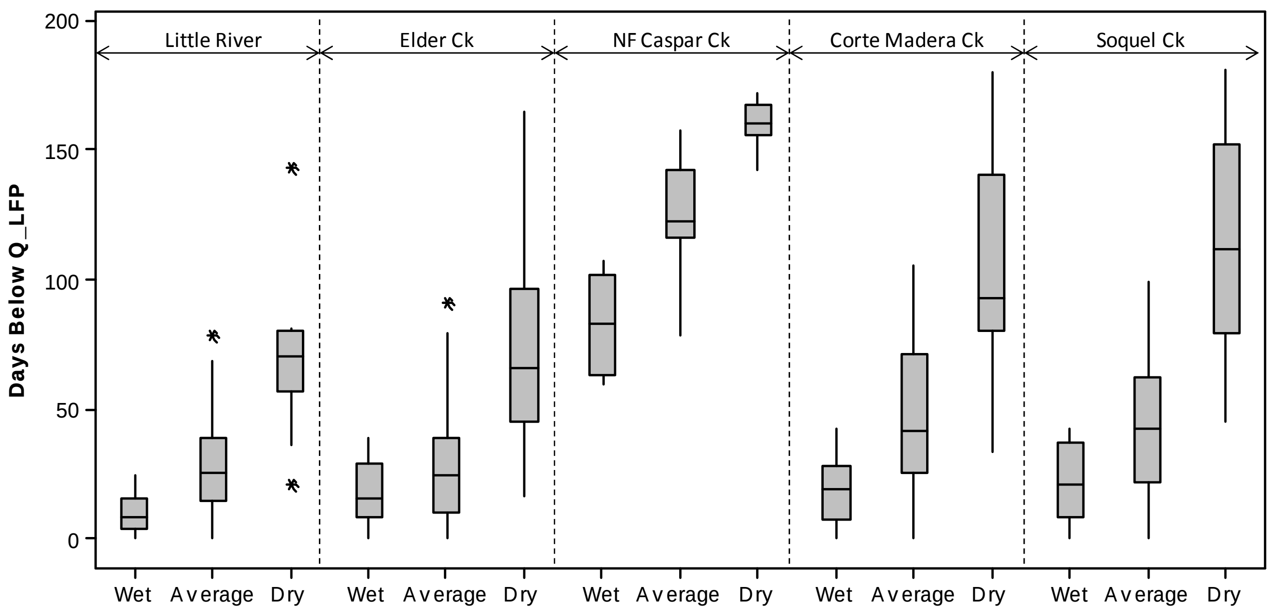



**Figure 21. Northern California site low flow delays (number of days per year flow below QLFP = 50% annual exceedance flow or 3 cfs whichever is greater) by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

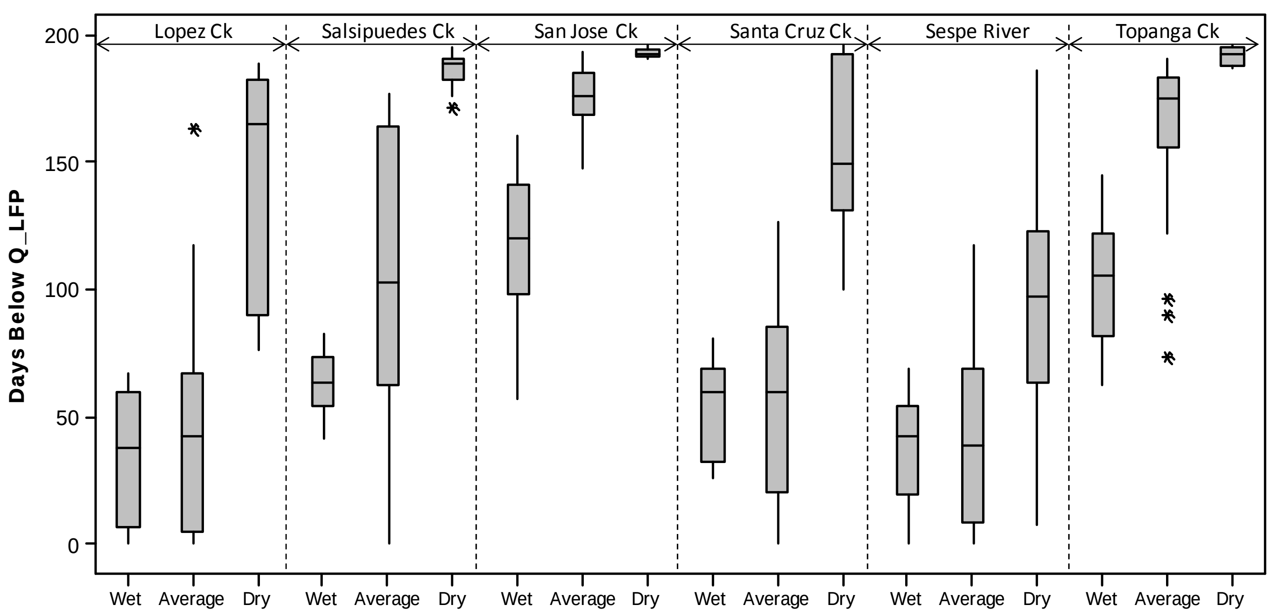



**Figure 22. Southern California site low flow delays (number of days per year flow below QLFP = 50% annual exceedance flow or 3 cfs whichever is greater) by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

## 5.3 Fish Passage Window and Delays for All Sites

As described above, a program was developed to calculate the passage and delay for each study site using the entire mean daily flow record and selected fish passage flow criteria. Section 5.2 described a subset of these analyses for the median Wet, Average and Dry water years at each site. This section presents the complete analysis of high-flow delay and available passage time within the assumed adult steelhead migration period by region and water year type (Wet, Average, Dry). These analyses consider only whether streamflow meets passage criteria or exceeds $Q_{HFP}$ and do not account for additional factors that may influence migration such as behavior or responses to changing flow conditions.

### *5.3.1 High Flow Delay*

The results for all sites grouped by region are summarized as box plots in Figure 23 through Figure 25 that show the days above $Q_{HFP}$ during the assumed migration period within a given year for the three different water yield classifications: Dry, Average and Wet. The box plots show the median (center line of the box), lower quartile (bottom line of the box), upper quartile (upper line of the box), whiskers that extend upward from the top of the box to the maximum data point within 1.5 times the quartile range and downward from the bottom of the box to the minimum data point within 1.5 times the quartile range. Outliers are plotted as asterisks and indicate values falling outside the whisker range.

Figure 23 shows that for all regions and $Q_{HFP}$ criteria, the median high flow delay during Dry years is zero days. High-flow delay during Dry years is essentially zero for all evaluated definitions of $Q_{HFP}$ for the Southern California sites. Northern California sites have essentially no high-flow delay during Dry years when $Q_{HFP}$ is defined as the 1% migration period exceedance value ($Q_{1\%SH\text{-}MP\text{-}EXC}$) or 50% of the $Q_{2\text{-}year}$ determined from the instantaneous peak flow records (50%$Q_{2\text{-}Pk}$). $Q_{HFP}$ defined as 50% of $Q_{2\text{-}PK}$, was generally the highest fish passage flow for the Northern and Southern California region study sites. $Q_{HFP}$ defined as 50% of the $Q_{2\text{-}year}$ determined from the regional empirical equations (50%$Q_{2\text{-}Em}$) resulted in more overall high flow delay in all regions when compared to using 50%$Q_{2\text{-}Pk.}$

During Dry years the Pacific Northwest sites experience the most high-flow delay compared to the other regions, as illustrated by the larger magnitudes of the upper quartile values. This observation primarily results from a larger difference in the 2-year recurrence interval flows predicted by the two methods for the Salmon River; 50%$Q_{2\text{-}Pk}$ is 2,872 cfs compared to a 50%$Q_{2\text{-}Em}$ of 1,500 cfs. This result is also influenced by less difference in the duration of high flows between Dry and Average year classes for the Pacific Northwest region sites compared to the sites in the other climate regions.

Median high flow delay during Average years is similar across all regions and all definitions of $Q_{HFP}$, at 1 to 3 days per year. The Southern California region sites have more delay noted as outliers. This is likely due to more variability in magnitude of high flow events in this region during Average years and a larger range in annual water yields being defined as Average (see Figure 4 and Figure 5). The number of outliers may also be influenced by the size of the data set, which is largest for the Southern California region.

For Wet years (Figure 25), median high flow delays increase to between 5 and 10 days per year. The Southern California region again has much greater variability which is consistent with the hydrologic variability noted in Section 3.1. The $Q_{HFP}$ criteria defined as 50%$Q_{2\text{-}Pk}$ results in the greatest magnitude $Q_{HFP}$ for Southern California region sites and; thus, results in the least high flow passage delay. The variability for $Q_{HFP}$ defined as 50%$Q_{2\text{-}Em}$ for the Pacific Northwest sites also shows high variability (greater box and whisker height), similar to the Southern California region sites. This variability results from the large difference between $Q_{2\text{-}Pk}$ and $Q_{2\text{-}Em}$ for two of the Pacific Northwest sites. For example, Salmon River 50%$Q_{2\text{-}Pk}$ is 2,872 cfs compared to a 50%$Q_{2\text{-}Em}$ of 1,500 cfs and Big Creek has 50%$Q_{2\text{-}Pk}$ of 501 cfs compared to a 50%$Q_{2\text{-}Em}$ of 399 cfs.

Appendix C contains additional analyses of these results including:

- presenting detailed comparison of high flow delay by study site for different $Q_{HFP}$ criteria,
- plots showing high flow delay by study site, region and water year type,
- composite plots of high flow delay in Wet, Average and Dry years by region, and
- plots of low flow delay by site and water year type for the Northern and Southern California region sites.

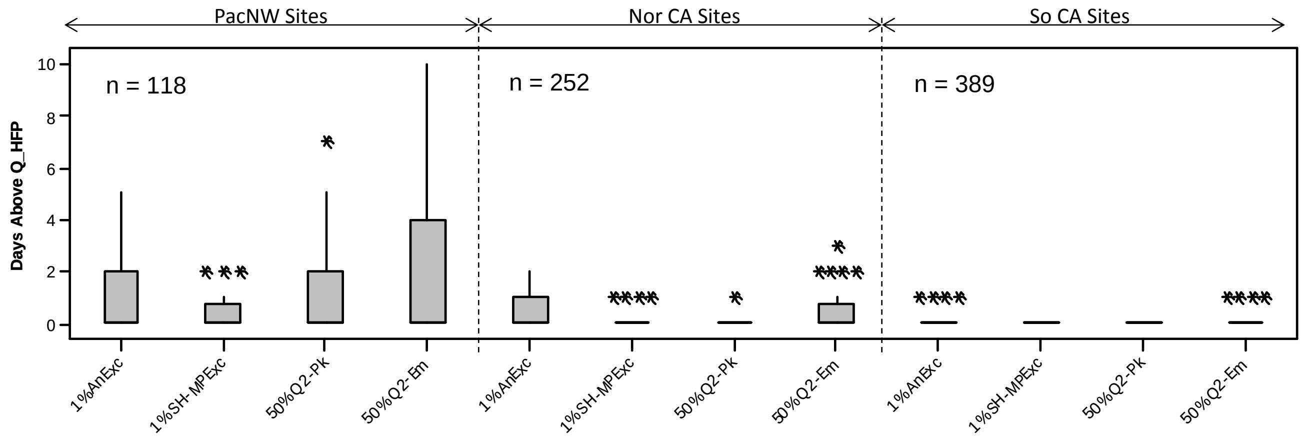



**Figure 23. High flow passage delay during Dry years for different $Q_{HFP}$ criteria. For all $Q_{HFP}$ criteria and regions, the median high flow delay during Dry years is zero days. The total years of record for all sites in each region is indicated by n.**

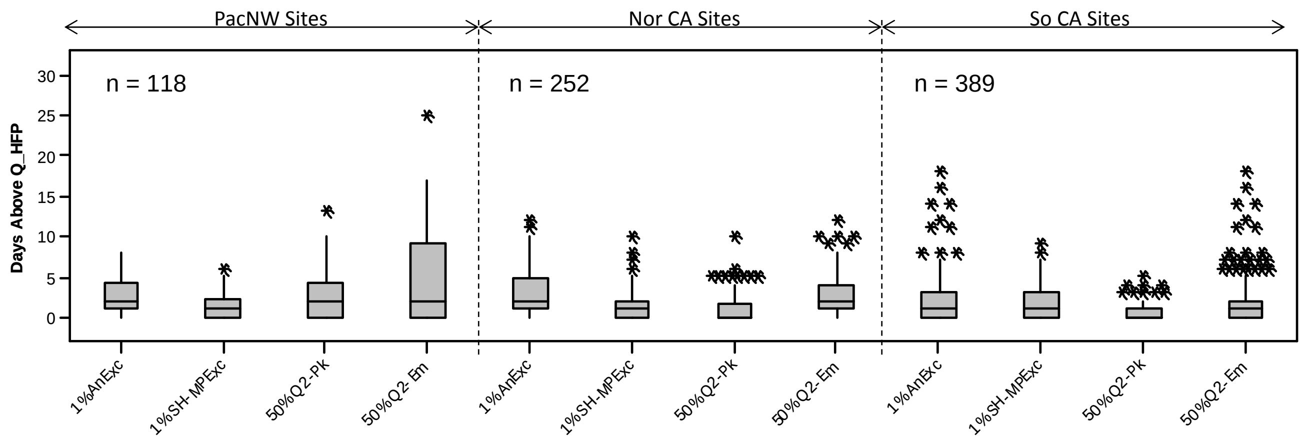



**Figure 24. High flow passage delay during Average years for different $Q_{HFP}$ criteria. The total years of record for all sites in each region is indicated by n.**

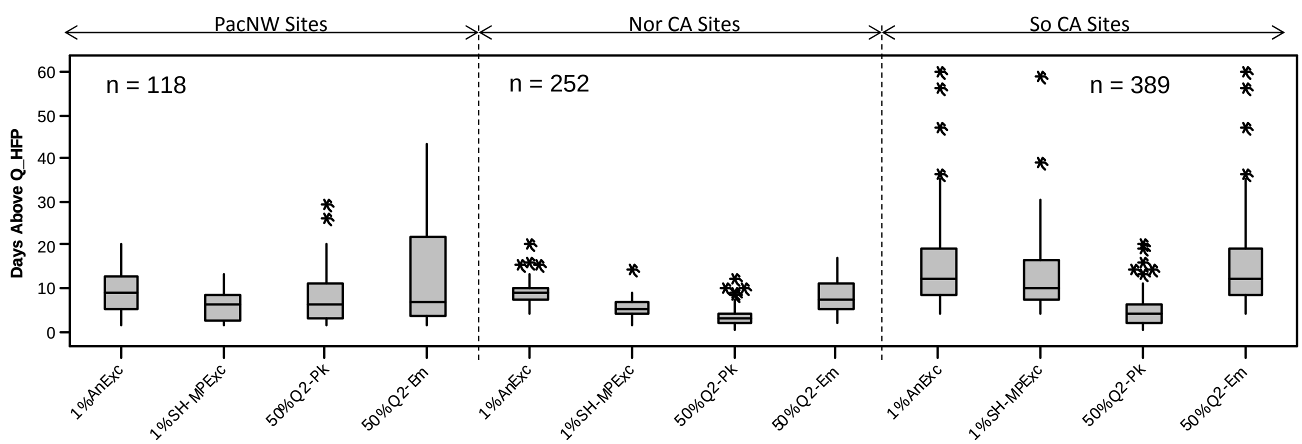



**Figure 25. High flow passage delay during Wet years for different $Q_{HFP}$ criteria. The total years of record for all sites in each region is indicated by n.**

### 5.3.2 *Percent Passage Analysis*

The analysis of high flow delay above isolates the effect of specific $Q_{HFP}$ criteria on the number of days high flow may impede passage. The overall impact of high flow delay should also be evaluated in terms of the annual duration of high flow delay relative to the annual passage. For example, if the total passage window is 150 days and high flow delay is 5 days total, the percent of delay due to high flow is low. However, in some years the available passage window may be reduced by low flows and any high flow delay could be substantial when compared to the short passage window available to the fish. . Figure 26 through Figure 28 summarize the percent of high flow delay compared to the passage time during a Nov. 1 through May 15 migration period. This percentage is calculated for each water year as:

$$100\% \times \frac{\#\ of\ days\ exceeding\ Q_{HFP}}{\#\ of\ days\ meeting\ passage\ criteria\ (Q_{LFP} \leq Q \leq Q_{HFP})}$$

The percent of high flow delay may exceed 100% if the number of days of high flow delay exceeds the number of days meeting the passage criteria within a given water year. The plots presented here are truncated to 50% on the y-axis to better show the median percent values. Several sites in the Southern California region have water years with percent of high flow outliers greater than 100%. These large percent values occur in drier years because the drier years have few days of passage due to flows being consistently lower than $Q_{LFP}$; thus, one or two events exceeding $Q_{HFP}$ results in the number of days where flow exceeds $Q_{HFP}$ equaling or exceeding the number of days of passage. The individual site results for the Southern California region are included in Appendix C (Figures C-23 through C-33) to show the variation in percent of high flow delay between sites. The smaller watersheds generally experience much higher percent of high flow delay because their available passage time in a given year is often limited by prolonged periods of flows less than $Q_{LFP}$.

Another metric is to evaluate the percent of passage time provided during the migration period. . Figure 29 through Figure 31 summarizes the percent of passage time during a Nov.1 to May 15 migration period calculated as:

$$100\% \times \frac{\#\ of\ days\ meeting\ passage\ criteria\ (Q_{LFP} \leq Q \leq Q_{HFP})}{migration\ period\ (196\ day)}$$

Dry and Average years show little difference in the median percent passage for the different $Q_{HFP}$ criteria and percent passage time decreases from the northern to the southern-most regions. As expected, the $Q_{HFP}$ criteria shows more influence on percent of passage time in Wet years because more days have flow exceeding $Q_{HFP}$. Higher magnitude $Q_{HFP}$ criteria result in larger percent passage times. The median percent of passage time remains essentially constant for all $Q_{HFP}$ criteria for Dry and Average years because the high flow delay is minimal. The impacts of various $Q_{HFP}$ are apparent in the Wet years (Figure 31) because there is greater high flow delay with the lower magnitude of $Q_{HFP}$ (5% SH-MPExc) having the least passage time. For the composite of the Southern California sites, a $Q_{HFP}$ criteria of the 1% exceedance flow during a Nov. 1 to May 15 migration period had a median passage percent of 65%, compared to a $Q_{HFP}$ criteria equal to the 5% migration period exceedance flow which provided a median passage percent of 57%.

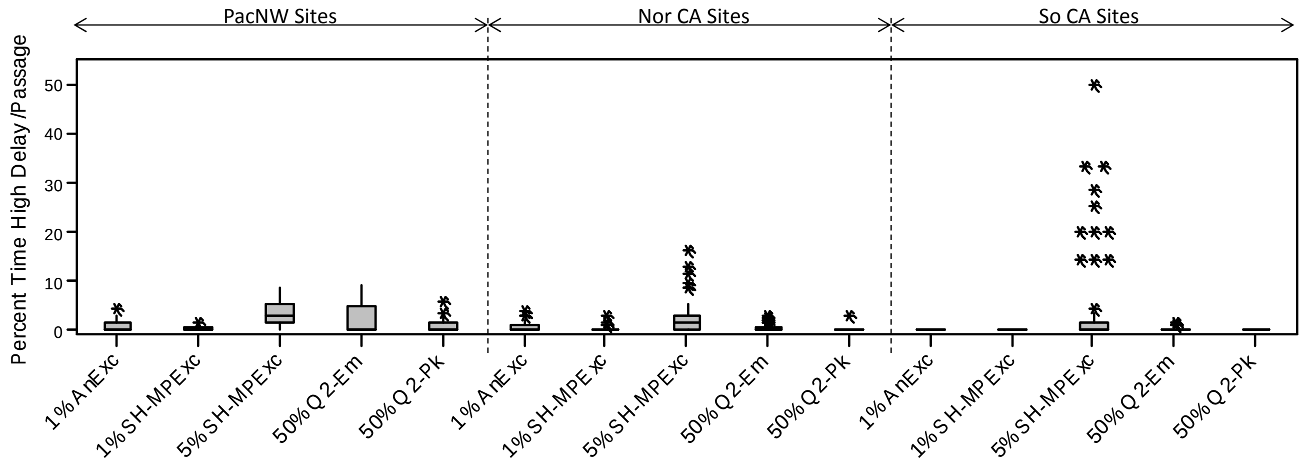



**Figure 26. Percent time of high passage delay relative to passage time during Dry years for different $Q_{HFP}$ criteria.**

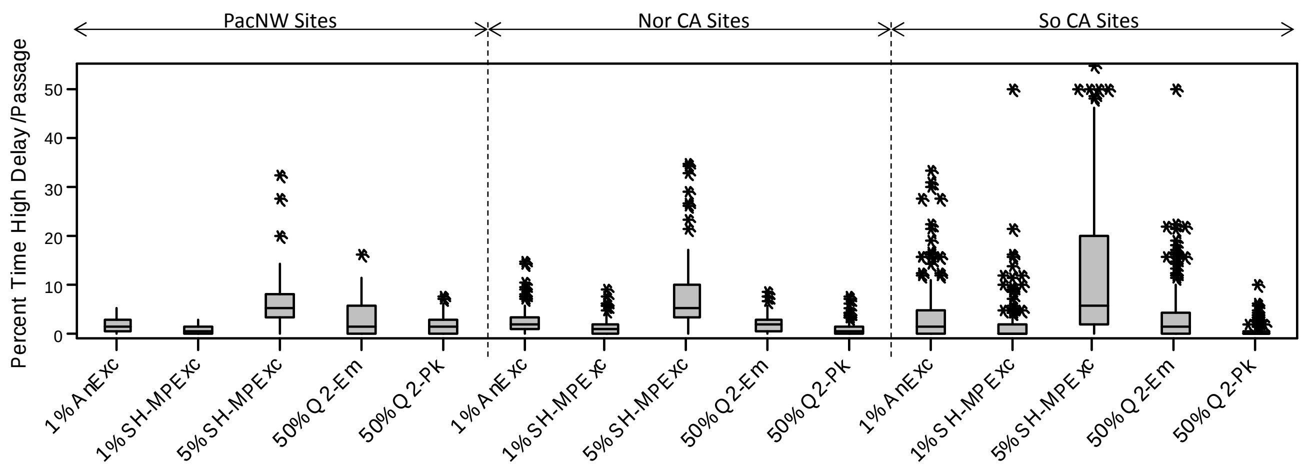



**Figure 27. Percent time of high passage delay relative to passage time during Average years for different $Q_{HFP}$ criteria.**

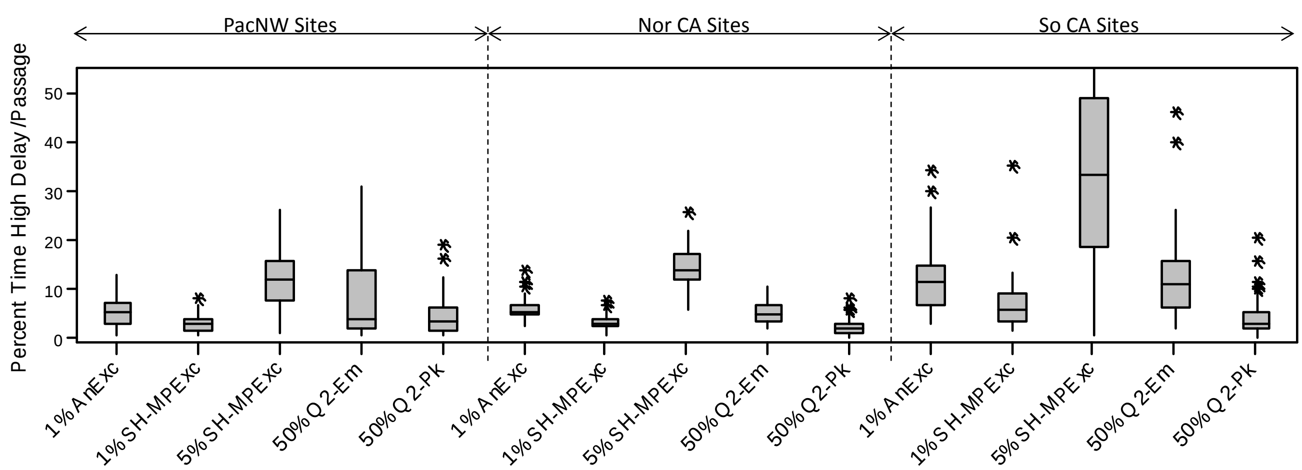



**Figure 28. Percent time of high passage delay relative to passage time during Wet years for different $Q_{HFP}$ criteria.**

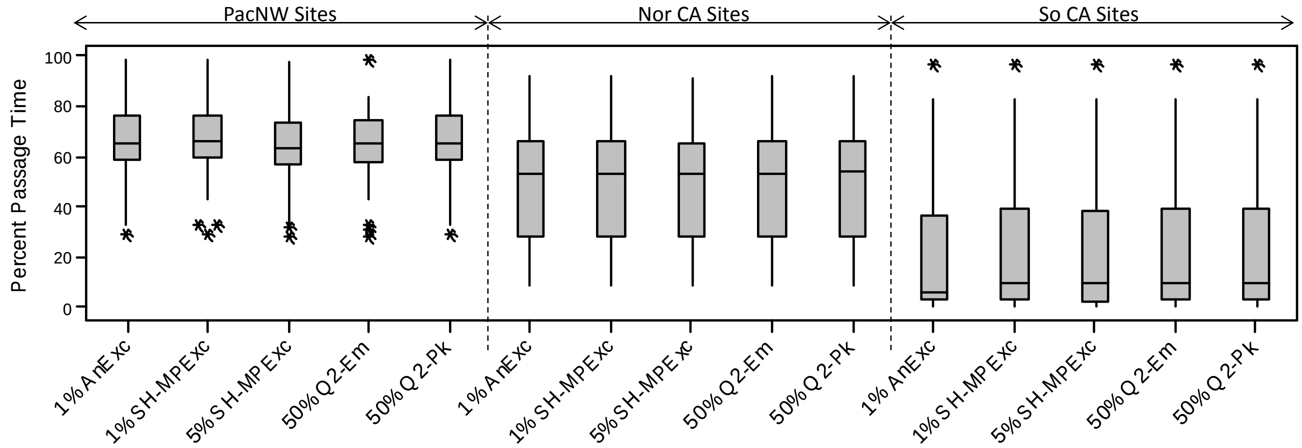



**Figure 29. Percent passage time during Dry years for different $Q_{HFP}$ criteria.**

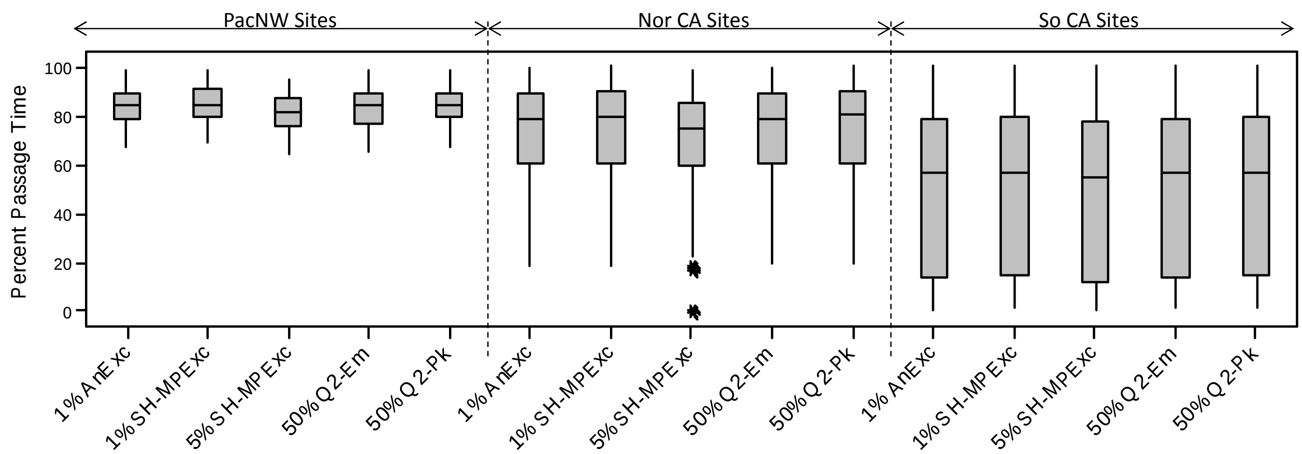



**Figure 30. Percent passage time during Average years for different $Q_{HFP}$ criteria.**

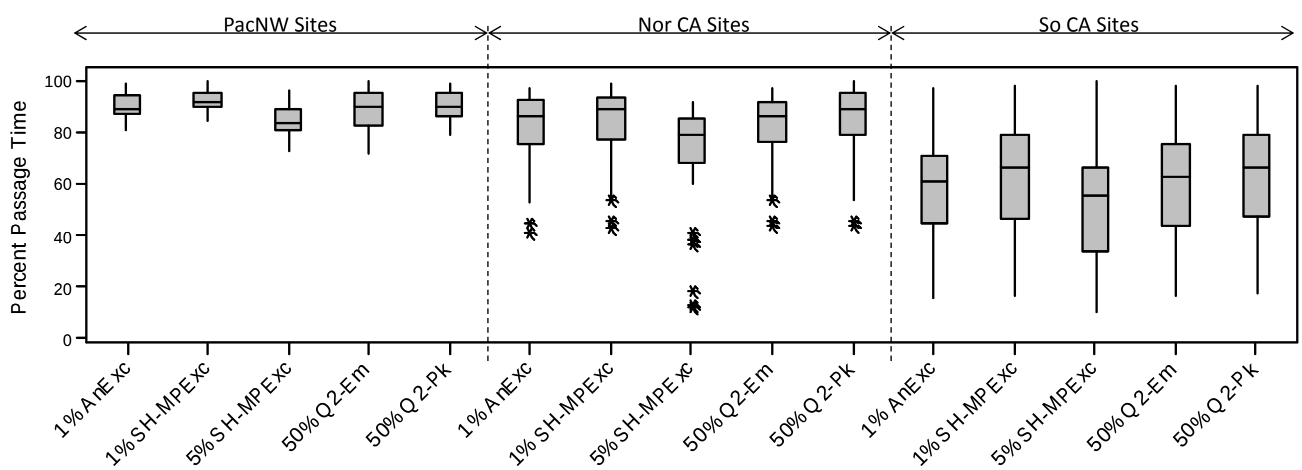



**Figure 31. Percent passage time during Wet years for different $Q_{HFP}$ criteria.**

## 5.4 JUVENILE PASSAGE CRITERIA ANALYSIS

Figure 32 and Figure 33 summarize high flow passage delay and percent passage time for juvenile salmonids using the California criteria for $Q_{LFP}$ and $Q_{HFP}$. Analysis of juvenile passage was evaluated on an annual basis for all sites and regions. These plots provide a composite of results for all water year types, Wet, Average and Dry. The $Q_{HFP}$ criteria used for a particular estimate of high flow delay or passage time are indicated on each plot. The $Q_{LFP}$ criteria for all analyses were the 95% annual exceedance flow or 1 cfs whichever was greater (Table 5).

The visual trends are similar to those seen for the adult passage analysis for the migration period with some notable exceptions. First, the 10% annual exceedance flow for almost all study sites in the Southern California region is much lower than the 10%$Q_{2\text{-year}}$ flows. This difference causes a lower percent passage median and high variability in percent of high passage delay associated with using the 10% annual exceedance flow for the Southern California sites. The effect is even more pronounced in the small watersheds in this region because they have lower values of the 10% annual exceedance flow and because $Q_{LFP}$ defaults to 1 cfs which leads to a small range of fish passage flows (see Appendix C juvenile result plots by site). Second, the impact of the anomalous $Q_{2\text{-Year}}$ regression equation estimates for the Salmon River site in the Pacific Northwest region creates high variability in percent high passage delay for this region.

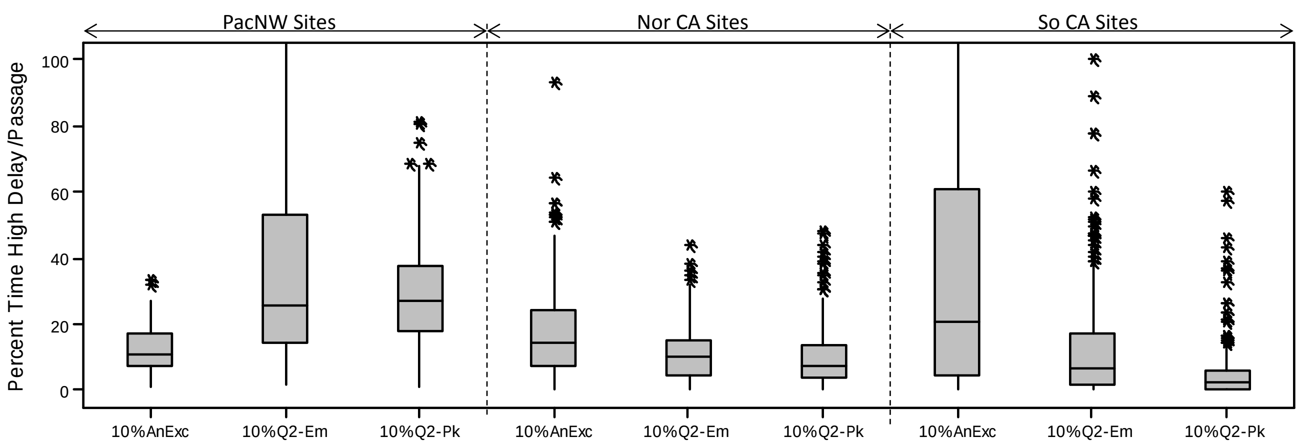



**Figure 32. Percent time of high flow delay for juvenile salmonid relative to passage time during a year for all three $Q_{HFP}$ criteria evaluated.**

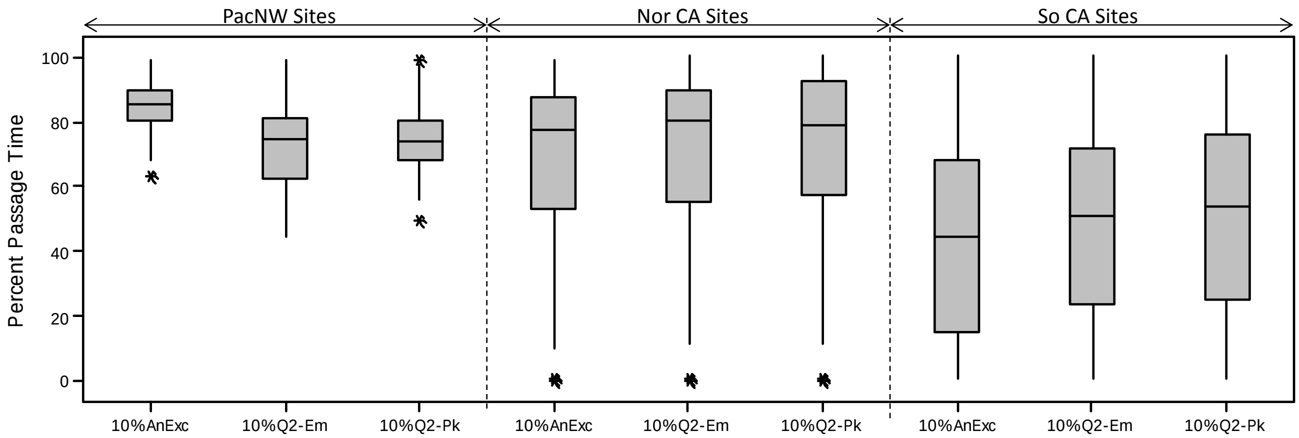



**Figure 33. Percent passage time for juvenile passage over the entire year for all three $Q_{HFP}$ criteria evaluated.**

## 5.5 Discussion

Total time that passage conditions are met (flows between $Q_{LFP}$ and $Q_{HFP}$) is clearly influenced by selection of the design flow criteria. $Q_{LFP}$ are criteria intended to represent geomorphic limitations to movement within the natural channel, so lowering this flow below the naturally passable flow in the channel will not increase the amount of passage opportunity for the fish. $Q_{HFP}$ criteria can be selected to increase the total passage time available on an annual or migration period basis but their influence is limited to improving passage during the often short duration of storm flows. As such, a large increase in the magnitude of $Q_{HFP}$ may only result in an incremental increase in the total available passage window.

Passage opportunity and high flow delays in all regions varied for Wet, Average and Dry years. Wet years in all regions experience more high flow delay due to the greater number and magnitude of storms experienced during Wet years. However, the percent of these high flow delays relative to the total passage time during the migration period was highest for the Southern California region sites because the total number of days within the passage flow range is lower.

Passage in Average and Dry years is influenced more by low flow passage delays and this influence increases for sites located further south and for smaller watersheds in all of the climate regions. This result suggests that meeting low flow design criteria can be critical to maximizing passage opportunities. In addition, because low flow passage is a strong function of channel morphology, it may be necessary to adopt site specific low flow passage criteria to avoid setting $Q_{LFP}$ below the flows that are naturally passable in the channel.

The passage analysis presented here used the complete records of mean daily flow for each of the study sites with a comparison to the 15-minute data for some sites to evaluate predictions resulting from the different data time periods. The 15-minute data captures the peak flows occurring during storm hydrographs.  As such, this data could possibly provide more accurate estimates of high flow delay compared to using mean daily flow data. Comparing the estimates of total high flow delay for a given year predicted using the two different data sets showed that, in general, the mean daily flow data predicted slightly longer high flow delays because the smallest delay time possible is one day. Many high flow delay periods are shorter than this as the hydrograph rises above then drops below $Q_{HFP}$ over a few hours rather than days. This likely becomes more significant smaller the watershed size. Thus, using the mean daily flow record provides a conservative estimate of high flow delay for a given $Q_{HFP}$ value. The total passage time during the migration period was essentially equal for both flow data sets. Given the verified data quality and ease of analysis, using the mean daily flow records are recommended.

# 6 EFFECTS OF DATA QUANTITY AND QUALITY ON FISH PASSAGE FLOW CRITERIA

Determining fish passage flow criteria, whether defined as exceedance values, percent of recurrence interval flows or other methods, relies on streamflow data. Thus, the quality and quantity of data used in the criteria calculations may strongly influence the criterion value. As an example, a flow duration curve determined from a short data record may not capture enough of the year-to-year variation to provide an acceptable estimate of the higher daily exceedance flows commonly used to define $Q_{HFP}$. This section evaluates the influence of data quantity on calculation of fish passage design flows determined using both the daily exceedance- and recurrence interval-based methods, and attempts to quantify the influence of uncertainty in calculating the fish passage criteria on passage opportunities and delay.

### *6.1.1 DAILY EXCEEDANCE FLOW METHODS*

Fish passage flow criteria defined by exceedance flows determined for either the annual or migration period record require developing flow duration curves (FDCs). As described in Section 4.1, annual and migration period FDCs were derived from mean daily flows and calculated using the complete data record for all study sites. To assess the sensitivity on exceedance flow estimates to the length of available data record, FDCs calculated using the complete mean daily flow record at all study sites were compared to FDCs calculated from truncated data sets derived from the 5-, 10-, 15-, and 20-consecutive wettest and driest years in a site's data record. These truncated data sets represent data sets that might result from a site with a short data record collected during a prolonged wet or dry climate period. These analyses were completed for at least two sites in each climate region using the study sites with the longest data records.

The wettest and driest consecutive year periods were identified by summing the annual water yields for each time period of interest (5-, 10-, 15- or 20-years) within the data record then identifying the maximum and minimum values for each study site. The 1% annual exceedance flow, the current California adult anadromous salmonid high passage flow criteria, was then determined for each of the shorter record FDCs and compared to the 1% exceedance flow determined from the study site's entire record.

Figure 34 and Figure 35 compares the FDCs derived for these different record lengths for Salsipuedes Creek using the annual mean daily flow record. FDC comparison plots for the other sites analyzed are included in Appendix D. Figure 34 shows the entire FDC and Figure 35 focuses on the 0 to 20% exceedance values representing the higher flows. As expected, the FDCs derived from the wettest and driest consecutive five-year periods predicted the highest and lowest daily exceedance flows, respectively. The 1-percent annual exceedance flow determined using the five consecutive wettest years (Water Years 1995-1999) and five consecutive driest years (Water Years 1947-1951) was 540 cfs and 16 cfs, respectively, while the 1 percent annual exceedance flow using the entire date record was 200 cfs. The FDCs derived using longer data records also differed from that calculated using the entire record, but the difference from the value for the entire data record decreases as record length increases.

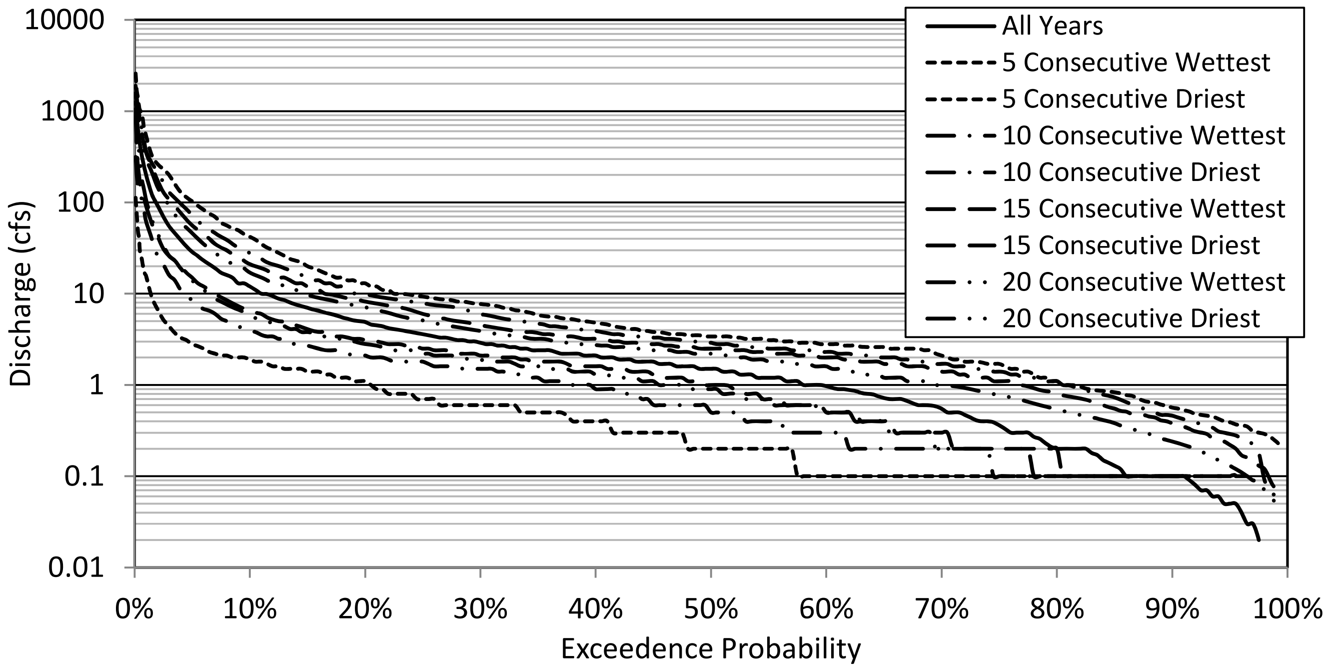



**Figure 34. Salsipuedes Creek (71 year record length) flow duration curves calculated using the mean daily flows for the entire record and shorter record lengths sampling preferentially Wet or Dry year types. (Similar plots for the other sites for which this sensitivity analysis was conducted are located in Appendix D).**

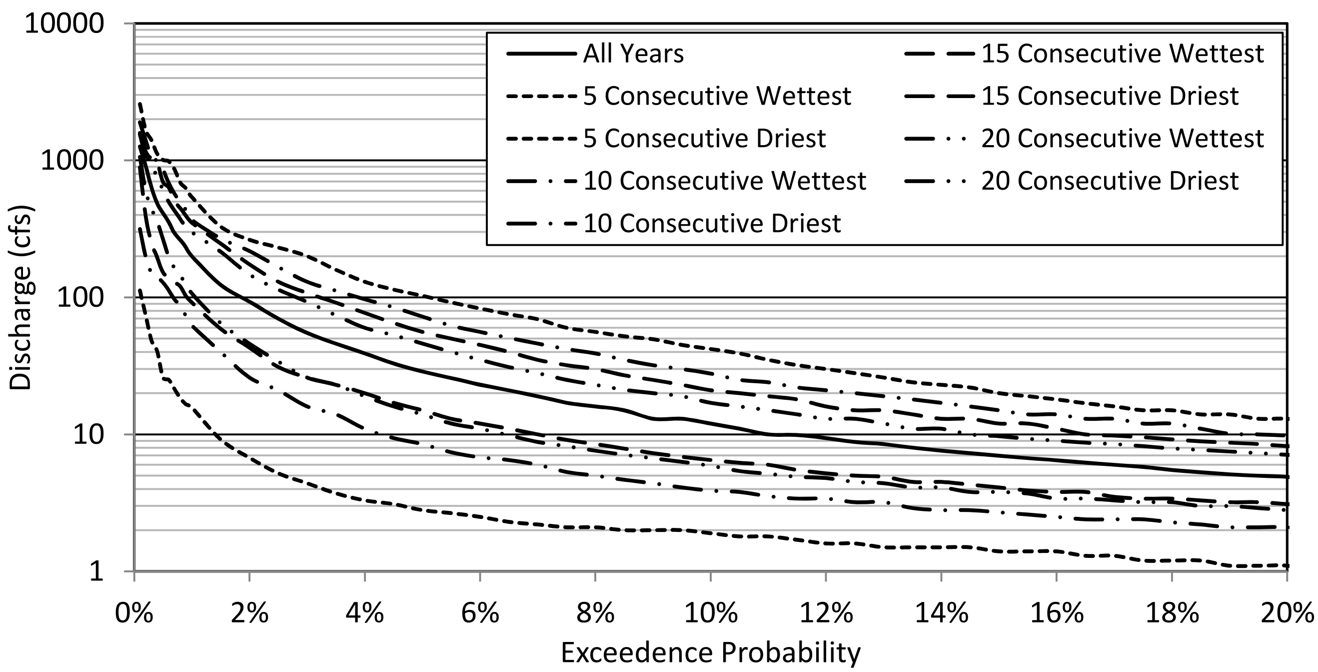



**Figure 35. Salsipuedes Creek (71 year record length) flow duration curves calculated using the mean daily flows for the entire record and shorter record lengths sampling preferentially Wet or Dry year types. (Same plot as Figure 34 but emphasizing the higher flows).**

Figure 36 compares the variation in magnitude of the 1% annual exceedance flow determined for the varying record lengths of wettest and driest consecutive periods for all sites analyzed. The 1-percent annual exceedance flows derived from each shortened data record at a site were normalized by the 1-percent annual exceedance flow calculated using the entire data record. Figure 36 shows that both the 15- and 20-year record lengths provide good estimates of the 1-percent annual exceedance flow for the Pacific Northwest and Northern California sites as indicated by normalized values at or near 1.0. The Southern California sites are not as consistent and even the longer record lengths sampled over wetter and drier periods for these sites varied by 50 to 200% from the 1% annual exceedance flow calculated using the entire data record.

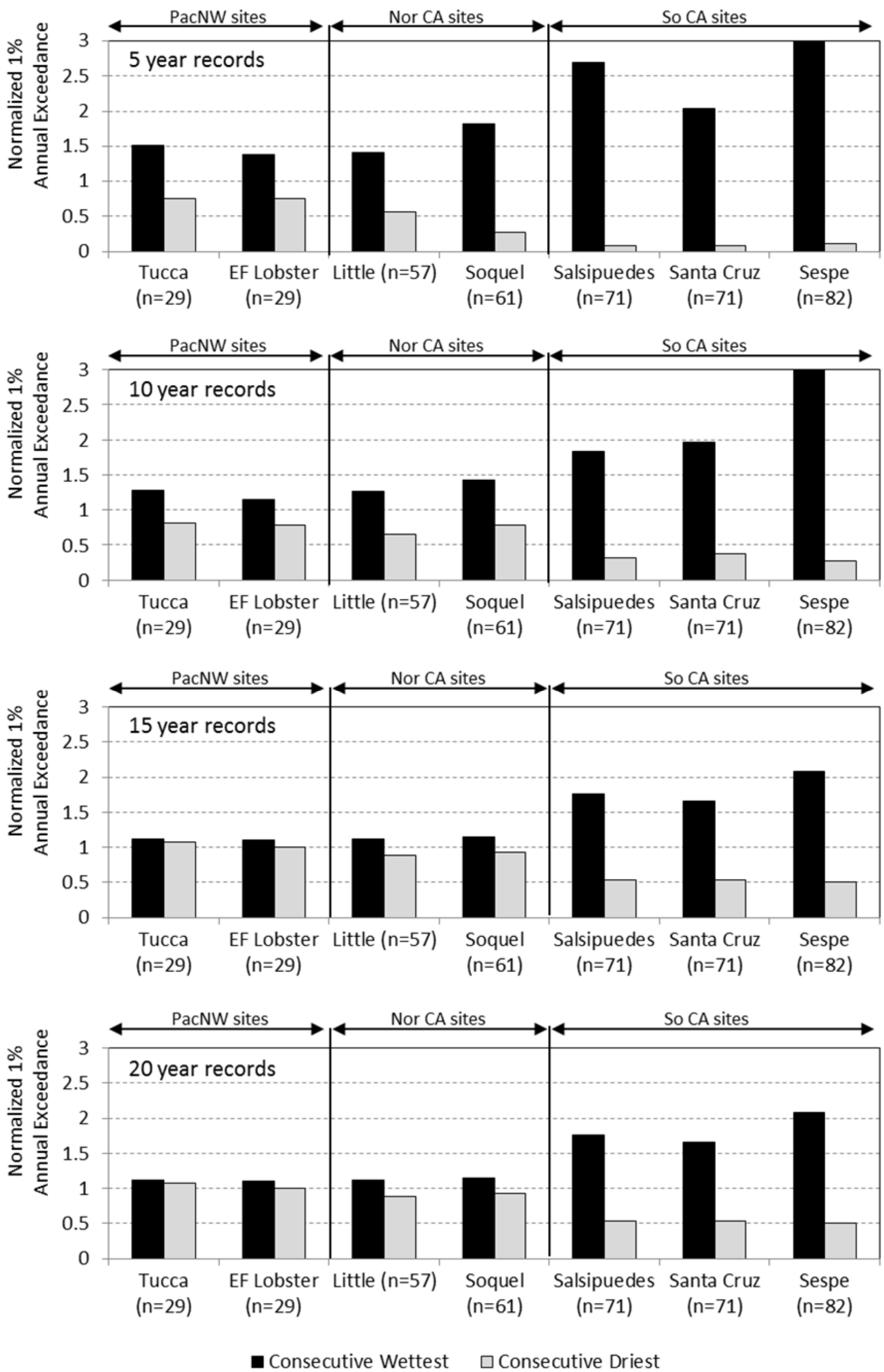



**Figure 36. Normalized 1% annual exceedance flows for shortened data records sampling wetter and drier climate periods within a site's data record. Values were normalized by the 1% annual exceedance flow calculated using the entire data record for each site A value of one indicates that the value predicted using the shortened data record was equal to that determined using the entire data record.**

While variation in the $Q_{HFP}$ value associated with varying data records is important to understand, of greater interest is the impact this variation might have on passage opportunity or high flow delay. Figure 37 shows the change in median percent passage time (see Section 5.3.2) for $Q_{HFP}$ criteria derived from the eight analyzed record lengths compared to the median percent passage time predicted using the 1% annual exceedance flow derived from the entire data record. For all sites, a 1% annual exceedance value determined from a shorter data record collected during a drier period results in the largest difference in predicted percent passage time. This result occurs because the 1% annual exceedance flow determined from short, drier records is lower than $Q_{HFP}$ values determined from longer records. The lower $Q_{HFP}$ value decreases the available passage window. All analyses used $Q_{LFP}$ equal to the 50% annual exceedance flow or 3 cfs whichever was greater (Table 6).

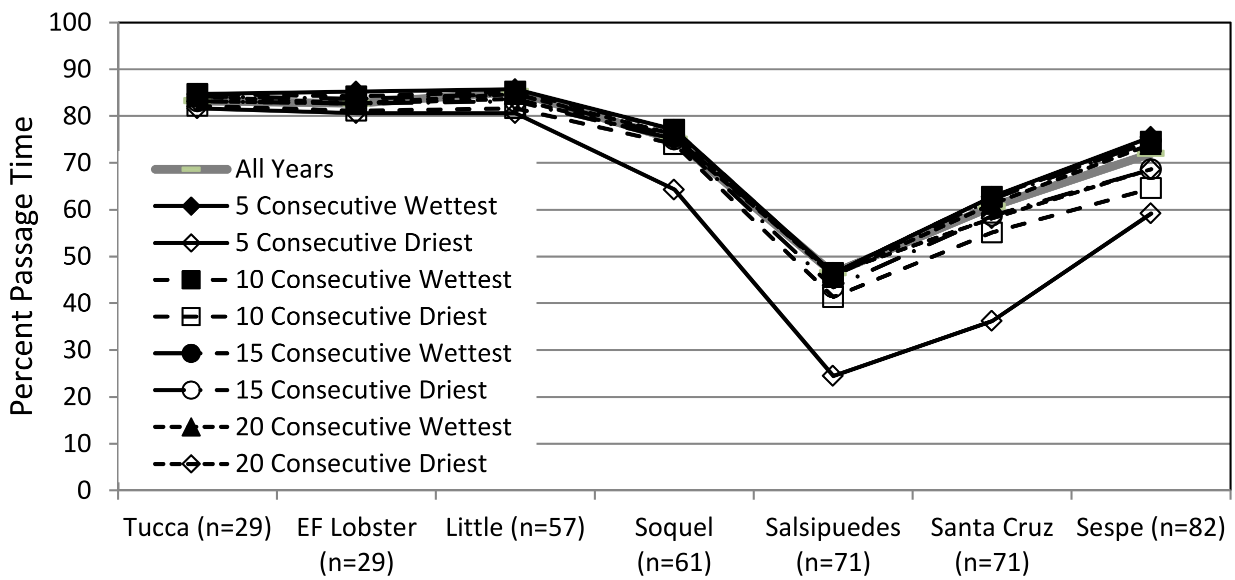



**Figure 37. Comparison of median percent passage time predicted using the 1% annual exceedance flows determined from the entire record and truncated mean daily flow records as the $Q_{HFP}$ criteria.**

The influence of $Q_{HFP}$ values on the median percent of high passage delay compared to the percent passage time calculated in the same manner as described in Section 5.3.1 is shown in Figure 38. Similar to the percent passage time results (Figure 37), the largest differences occur for $Q_{HFP}$ determined from a 5-year record length collected during a prolonged dry period. These results reflect the influence of the magnitude of $Q_{HFP}$ on the predicted passage time and high flow delay because the smaller $Q_{HFP}$ values predicted from dry period data are more commonly exceeded.

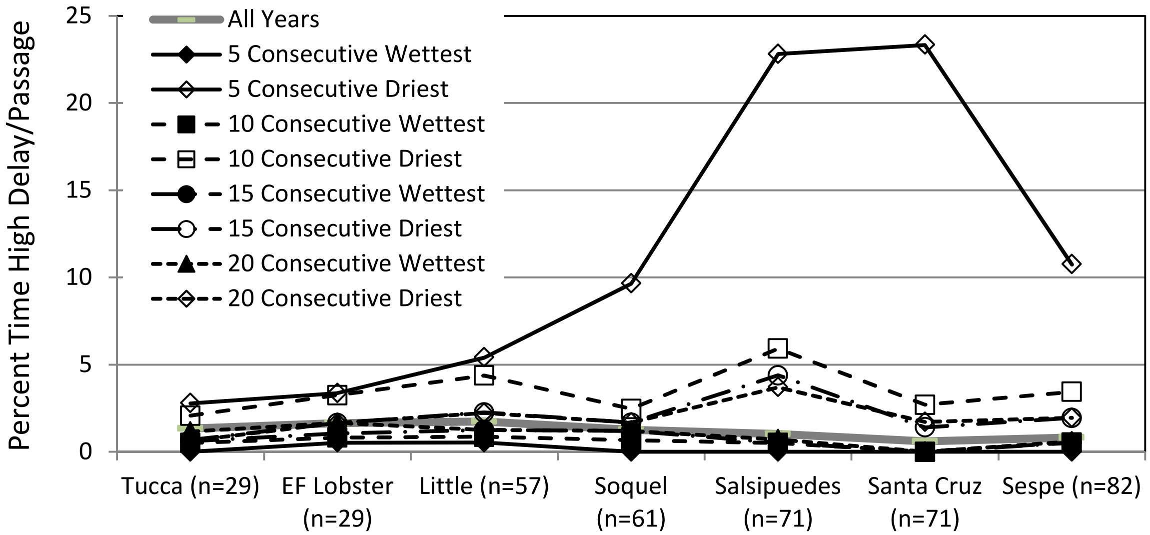



**Figure 38. Comparison of median percent of high passage delay predicted using the 1% annual exceedance flows determined from the entire record and truncated mean daily flow records as the $Q_{HFP}$ criteria.**

Figure 39 shows a more detailed analysis of variation in predicted percent passage time for Salsipuedes Creek. The box plots summarize the percent passage time for all 71 years in the data record using the 1-percent annual exceedance flows from the entire record and each truncated record. A median percent passage time during the assumed steelhead migration period of 46% for Salsipuedes Creek is predicted using the entire data records 1-percent annual exceedance flow. The 15- and 20-year records from the wettest periods of these record lengths are essentially identical to the predictions using the entire record derived 1% annual exceedance flow as $Q_{HFP}$. The 15- and 20-year dry record length predictions remain different in both the median and upper quartile for the 15-year record and just in the upper quartile for the 20-year record. This result is observed because the wetter years include the high flows that represent the low percent exceedance range but these values are missing from the drier years' records. The lower quartile is minimally influenced by whether a record period is wetter or drier because the lower quartile represents passage during Dry years where high flow delays are minimal or non-existent. Similar figures for the other sites analyzed are included in Appendix D.

Figure 40 shows the percent time of high flow delay compared to percent passage time for Salsipuedes Creek and the same variations in $Q_{HFP}$ criteria as Figure 39. Similar to Figure 39, the predictions approach those using the entire data record derived 1% annual exceedance flow for record lengths of 15- and 20-years collected during wetter climate periods, but the predicted median percent of high flow delay is higher than the median for the entire record compared to records from prolonged dry periods. For the 15-year dry period $Q_{HFP}$, the median is 4.4% compared to 1% for the entire record and the 20-year dry period has a median of 3.7%.

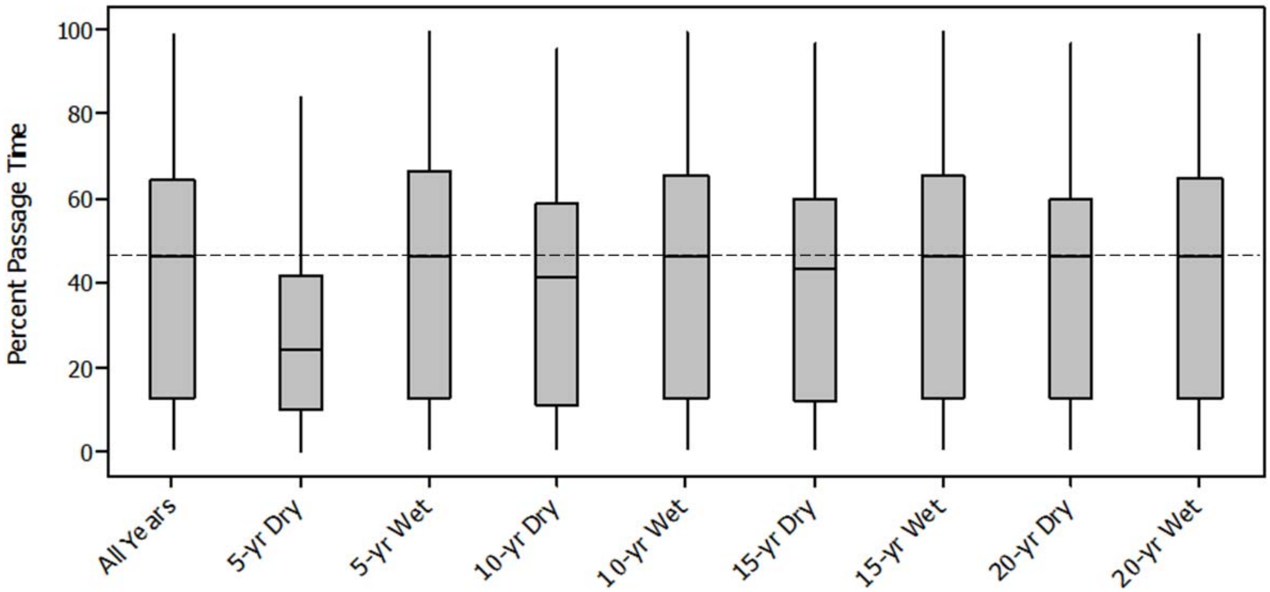



**Figure 39. Box plots summarizing percent passage time in all years of the data record for Salsipuedes Creek predicted using the 1% annual exceedance values predicted from various data record lengths as $Q_{HFP}$. The low fish passage flow for all analyses is 3 cfs. The dashed line indicates the median percent passage time using the 1% annual exceedance flow calculated from the entire data record as $Q_{HFP}$.**

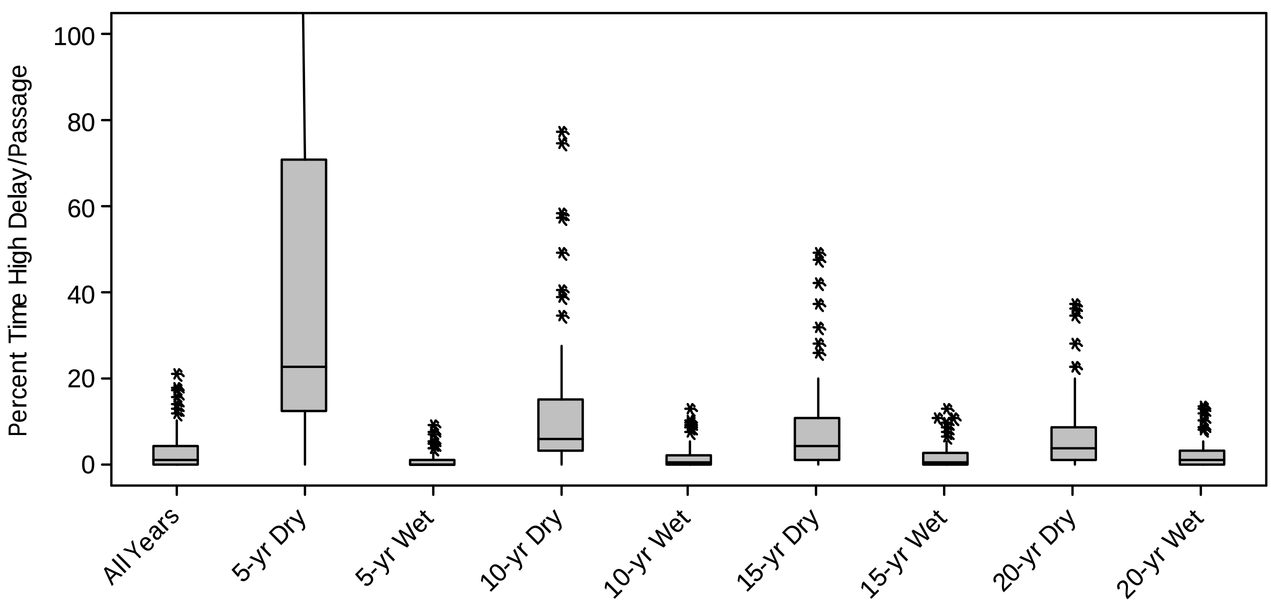



**Figure 40. Box plots summarizing percent time of high passage delay relative to passage time in all years of the data record for Salsipuedes Creek predicted using the 1% annual exceedance values predicted from various data record lengths as $Q_{HFP}$. The low fish passage flow for all analyses is 3 cfs.**

### *6.1.2 Recurrence-Interval Based Methods*

At some locations in California, an alternate $Q_{HFP}$ criteria for adult anadromous salmonids defined as 50% of the 2-year recurrence interval flow has been used because flow duration curves are not available or result in inappropriate $Q_{HFP}$ criteria. The magnitude of various recurrence interval flows (e.g. $Q_{2\text{-year}}$, $Q_{10\text{-year}}$, etc.) for a location of interest can be estimated in several ways:

- Using the instantaneous annual peak flow record for a site – if it exists
- Generating an instantaneous annual peak flow record for a site from adjacent gaged watersheds
- Calculating the recurrence interval flows using empirically derived USGS regional regression equations

If the data are available and a site's data record is long enough to meet data quality standards described in Bulletin 17B (USGS 1982), determining $Q_{2\text{-year}}$ from the data record is preferred. Generating a synthetic record of instantaneous annual peak flows requires evidence that the gaged watershed (or watersheds) peak flows are representative of and highly correlated with the watershed of interest. In general, this method would only be appropriate when the watershed of interest has some flow data but the data record length is insufficient to meet data quality standards and needs to be extended by correlation to a nearby gage. The final method, estimation using USGS regression equations, can be applied at all sites but the regression equation estimates may have significant uncertainty.

Figure 42 and Figure 41 compare $Q_{2\text{-year}}$ flows determined directly from the instantaneous annual peak flows and estimated using the most current USGS regression equations for the Oregon (Cooper 2005) and California (Gotvald et al. 2012) study sites, respectively. These regression equations were presented in Section 4.1. For all but one of the Oregon study sites (Salmon River), the regression equation estimates of $Q_{2\text{-year}}$ were similar to the $Q_{2\text{-year}}$ values calculated using the annual instantaneous peak flow data.

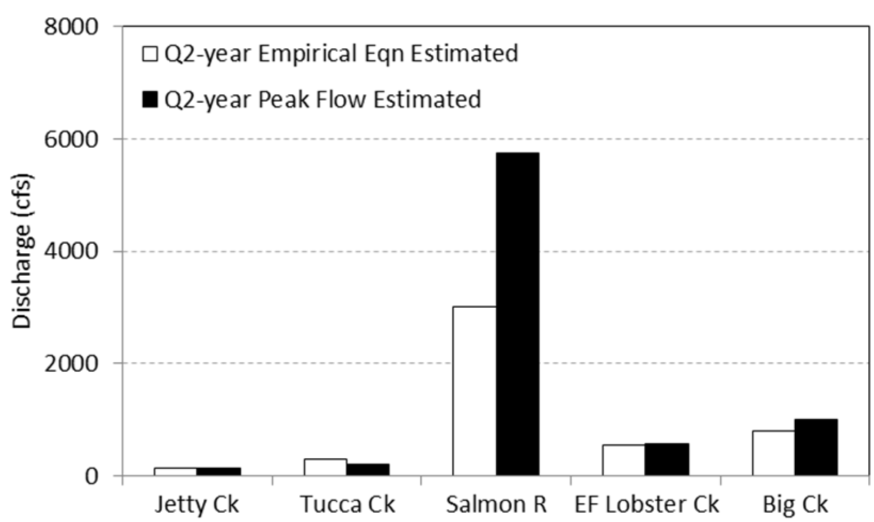



**Figure 41. Comparison of $Q_{2\text{-year}}$ magnitudes estimated using the instantaneous annual peak flow data records and the USGS Western Oregon regional regression equations (Cooper 2005).**

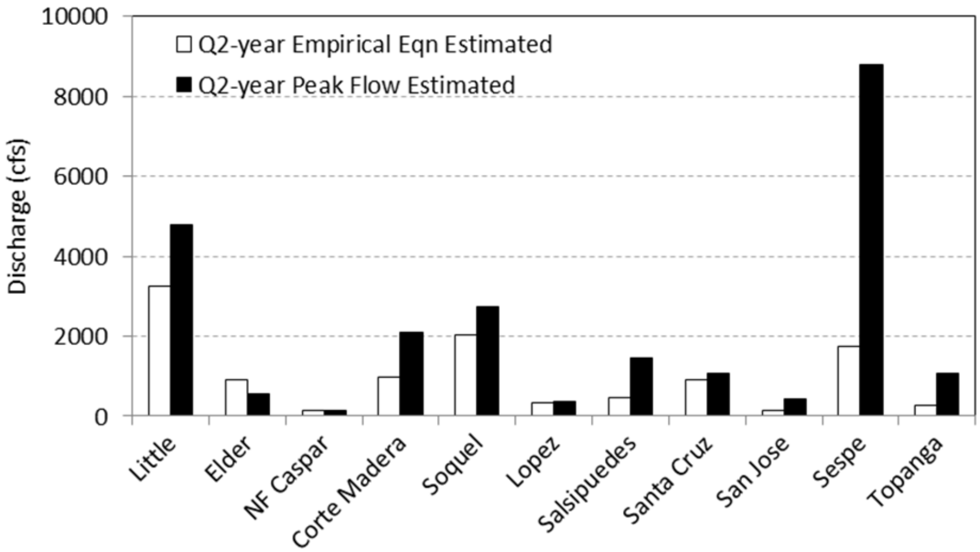



**Figure 42. Comparison of $Q_{2\text{-year}}$ magnitudes estimated using the instantaneous annual peak flow data records and the USGS California regional regression equations (Gotvald et al. 2012).**

For eight of the 11 California sites, the regression equation $Q_{2\text{-year}}$ value is less than that calculated from the site data and for the Sespe Creek, the regression estimate is more than four times lower. The USGS recommends that the regression equation estimated recurrence intervals be corrected using nearby gaged watershed data and the correction procedure is described in the technical report (Gotvald et al. 2012). These corrections were not made for the study sites to show the maximum possible differences in $Q_{2\text{-year}}$ magnitudes. The California regression equations are also largely dependent on the basin average mean annual precipitation (MAP) and many watersheds have high topographic relief which creates highly variable point-to-point precipitation. The MAP values used for these regression equation $Q_{2\text{-year}}$ values were the same values used by the USGS for these gage sites in their development of the regional regression equations. For ungaged sites, watershed averaged MAPs need to be determined using GIS analysis of the 800-meter resolution PRISM data (http://prism.nacse.org/).

With respect to the use of either the regression equation or instantaneous peak data for calculating the 50% of Q2-year values, the resulting differences on passage and delay predictions are summarized regionally in Figure 43 and Figure 44. Even for large differences between the two $Q_{2\text{-year}}$ values for the Southern California sites, the percent passage times predicted are similar. However, the median percent of high flow delay is greater for $Q_{HFP}$ defined using the regression equation values, 1.5% compared to a median of 0% for 50% of $Q_{2\text{-year}}$ from the peak flow data. This difference reflects the fact that the regression equation estimate of $Q_{2\text{-year}}$ was often much lower than the peak flow-derived value; thus, $Q_{HFP}$ equal to 50% $Q_{2\text{-Em}}$ would be exceeded more frequently because of its lower magnitude.

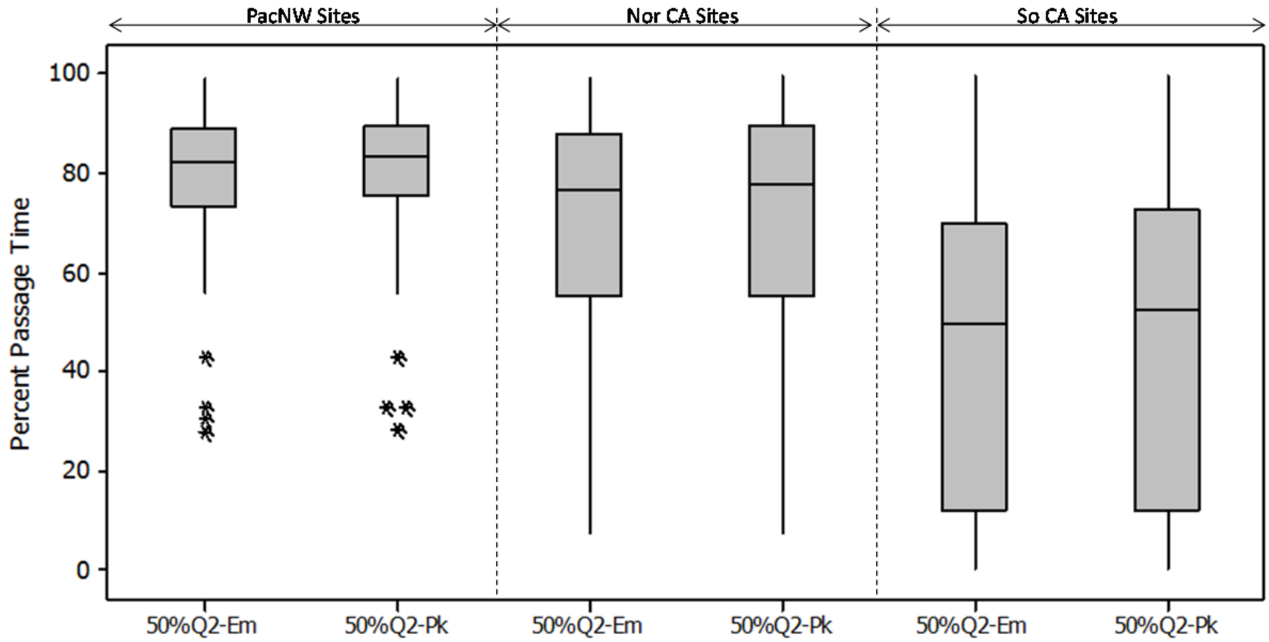



**Figure 43. Box plots summarizing percent passage time in all years of the data record for all sites within each climate region using 50% of $Q_{2\text{-year}}$ from USGS regression equations and each site's annual instantaneous peak flow data as $Q_{HFP}$. The low fish passage flow for all analyses was either the 50% annual exceedance value or 3 cfs whichever was greater.**

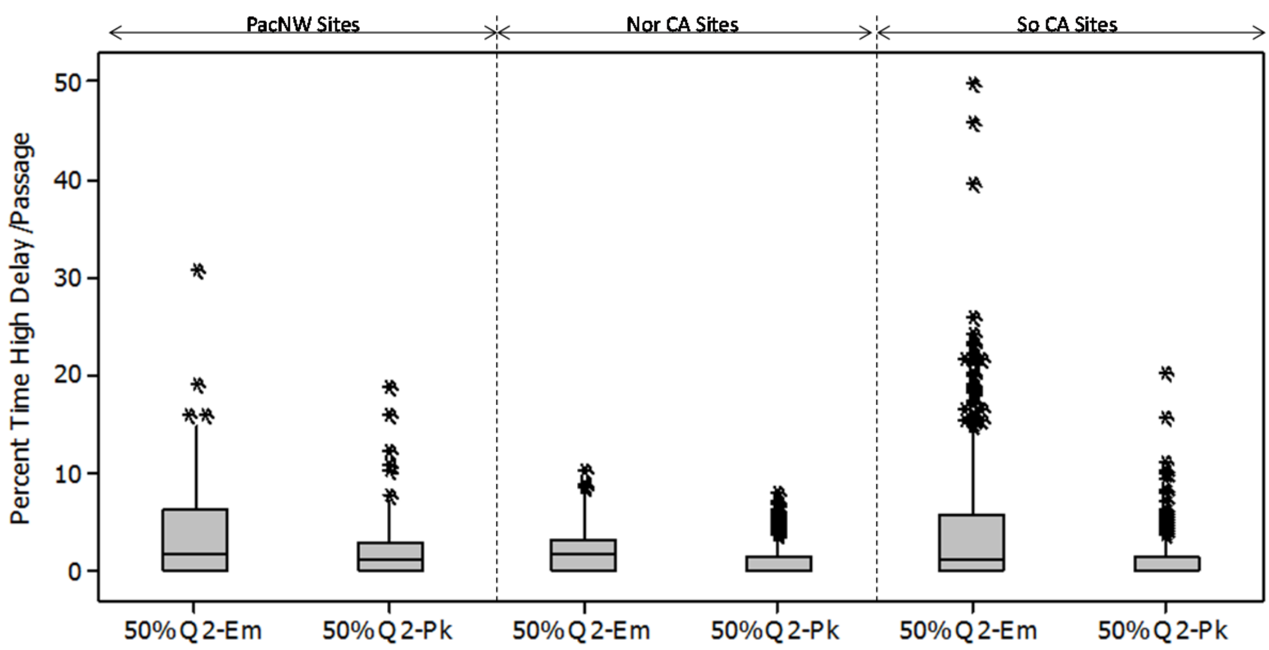



**Figure 44. Box plots summarizing percent time of high passage delay relative to passage time in all years of the data record for all sites within each climate region using 50% of $Q_{2\text{-year}}$ from USGS regression equations and each site's annual instantaneous peak flow data as $Q_{HFP}$. The low fish passage flow for all analyses was either the 50% annual exceedance value or 3 cfs whichever was greater.**

## 6.2 DISCUSSION

Analysis of data quality and quantity effects reveals several notable results.

- Streamflow record lengths of at least 15 years, and preferably longer, are recommended for deriving annual or migration period flow duration curves. These record lengths are needed to sample enough years to reasonably predict the low percent exceedance, higher flow values that define $Q_{HFP}$.

- Streamflow records collected during prolonged dry periods, even with 15- or 20-year record lengths, may not include the high flows needed to provide good estimates of low percent exceedance values used to define $Q_{HFP}$. Shorter streamflow records could be compared to longer, nearby gaging records to evaluate whether these records were collected during periods of wetter or drier conditions by evaluating the cumulative annual water yields for the record length of interest.

- USGS empirical regression equation estimates of recurrence interval flows may have high error and should be compared to nearby gaged streams when possible and adjusted using procedures described in the USGS manuals (Gotvald et al. 2012; Cooper 2005).

- The error in prediction of percent passage and high flow delay resulting from uncertainty in estimating and defining $Q_{HFP}$ is highest when the $Q_{HFP}$ magnitude is lower than expected. This occurs because a lower value for $Q_{HFP}$ creates more high flow delay; thus, decreasing the passage window.

# 7 Discussion/Synthesis

Many factors influence successful fish passage through natural channels and engineered structures. This project was limited to analysis of the hydrologic influence on fish passage by comparing actual flow to possible low ($Q_{LFP}$) and high ($Q_{HFP}$) fish passage design flow criteria, and thus did not address:

- Flows needed to breach a closed estuary for access to/from the ocean
- Flow needed to provide sufficient depth in the natural channel to support fish movement
- Fish behavior that may dictate passage timing under particular conditions such as migrating under light versus dark conditions or on the rising versus falling limb of a storm hydrograph
- Fish behavior associated with movement triggered by flow or velocity thresholds, or changes in atmospheric conditions

This study investigated regional differences in the frequency and duration of passage windows (flows between $Q_{LFP}$ and $Q_{HFP}$) and potential delay imposed by current passage design flow criteria. To evaluate passage, variability in regional hydrology was quantified and the effects of this variability on the fish passage window and migration delay was analyzed. Five to six study sites were selected in each of three coastal climate regions (Southern/Central California, Northern California and the Pacific Northwest), and these study sites consisted of streamflow gaging stations located on streams or rivers that currently or historically supported anadromous salmonid populations.

## 7.1 Hydrologic Differences Between Regions

Evaluation of annual water yield for each study site revealed that the Southern California sites have dramatically increased year-to-year variability compared to the Northern California and Pacific Northwest sites. The results suggest that Wet years in Southern California region produce substantially more runoff than Average and Dry years, while most of the sites in the two northern regions showed substantially less variability in water yield between Wet and Dry years (Figure 5).

The Southern California sites, with exception of Lopez Creek (which is the furthest north and has the shortest data record in this climate region), never experienced two consecutive Wet years, while the Northern California and Pacific Northwest sites regularly experience two or more Wet years in a row. It is possible that consecutive Wet years experienced at the northern sites provide improved opportunities, in comparison to the southern sites, for adult steelhead to migrate and spawn and their off-spring to successfully out-migrate to the ocean. As such, when considering potential steelhead recovery sites in Southern California, it may be important to consider that the off-spring of adult steelhead spawning during a Wet year are likely to out-migrate during an Average or Dry water year, when water quality conditions and connectivity to the marine environment are more likely to be compromised.

Comparison of hydrographs for ten discrete storms showed that the Southern California study sites generally exhibit the largest rates of hydrograph rise and fall. Faster rising and falling rates indicate flashier watershed response to precipitation. The effect of a flashier response on fish passage may be a shorter passage window during discrete storm events, as streamflow rises and falls more rapidly through the passage range (Q between $Q_{LFP}$ and $Q_{HFP}$).

The RB-Index calculated for both the annual and migration period flow records at all study sites also increased from north-to-south. This index captures variation in the day-to-day flow with higher values indicating greater variation. The higher RB-Index for the more southern study sites could indicate that they experience more isolated storms with less prolonged, steady flow. The migration period RB-Index values are higher than the annual values because they do not include the dry season when day-to-day variation in flow is expected to be small.

The observed regional difference in hydrology suggest that providing adult steelhead passage during both Dry and Wet years may require a wider range in fish passage flows than needed in the two northern regions. The observed inter-annual variability around the long-term median water yield at each Southern California study site suggest fish passage design flow criteria based on averages or medians should be evaluated to ensure that the passage windows provided during different hydrologic year classes are biologically sufficient.

## 7.2 Fish Passage Flow Criteria

### *7.2.1 $Q_{HFP}$ Based on $Q_{2\text{-}YEAR}$ Versus Daily Exceedance*

Comparing values of the various $Q_{HFP}$ definitions for each study site reveals substantial differences. $Q_{HFP}$ values based on daily exceedance resulted in predictable relationships between flow magnitudes from low to high exceedance values at a site and when comparing between sites. However, definitions of $Q_{HFP}$ based on $Q_{2\text{-year}}$ provided less predictable results than those based on daily exceedance. These differences occur because return period of a peak flow event is not related to the frequency of daily average flows during the year or migration period. For the sites analyzed in this study, exceedance values for 50%$Q_{2\text{-year}}$ using the site's peak flow record ranged from 0.4% – 1.8%, 0.2% – 0.8%, and 0.2%-0.5%, in the Pacific Northwest, Northern California, and Southern California regions, respectively (Table 3). Exceedance values for 50%$Q_{2\text{-year}}$ showed a slightly larger range when using the empirical equation to calculate $Q_{2\text{-year}}$ (Table 4). It is worth noting that 50%$Q_2$-year was initially proposed as a high fish passage design discharge that would be conservative (i.e. meet or exceed the 1% annual exceedance criteria) so the criteria is meeting this intent.

The magnitude of $Q_{HFP}$ for 50% of $Q_{2\text{-year}}$ relative to the daily exceedance definitions of $Q_{HFP}$ varied between sites within a region and between regions. As an example, for the Pacific Northwest Tucca Creek and Big Creek sites (Table 3), the 1% exceedance flows for both the annual and steelhead migration period are greater than 50% of $Q_{2\text{-PK}}$, while for the other Pacific Northwest sites 50% of $Q_{2\text{-PK}}$ is greater than all the evaluated daily exceedance definitions of $Q_{HFP}$. Another example of the variability associated with 50% of $Q_{2\text{-year}}$ criteria compared to other definitions of $Q_{HFP}$ is found in the Southern California region. For the San Jose Creek and Topanga Creek sites (Figure 12), the 50% of $Q_{2\text{-PK}}$ flows are two to three times greater than flows calculated using definitions of $Q_{HFP}$ based on daily exceedance, while 50% of $Q_{2\text{-PK}}$ within the region's other four study sites is relatively close to the various daily exceedance-based definitions of $Q_{HFP}$.

Use of $Q_{2\text{-year}}$ calculated from the empirically derived regional regression equations ($Q_{2\text{-EM}}$) may include substantial error when compared to calculation of the 2-year return period flow using the annual peak flow record for the site ($Q_{2\text{-PK}}$). Gotvald (2012) and Cooper (2005) report standard errors associated with predicted flows using the empirical equations of 25.3-39% for Western Oregon, 43-59% for California's North Coast Region, 66-162% for California's Central Coast Region and 47-134% for California's South Coast Region. Since most project sites are on ungaged streams, use of empirical equations will likely be widespread if the 2-year return period flow is used to define $Q_{HFP}$. In some cases, the error associated with using the empirical equations can result in $Q_{2\text{-}EM}$ being half of $Q_{2\text{-}PK}$. In the case of Corte Madera Creek, 50% of $Q_{2\text{-}EM}$ was even less than the 1% annual exceedance flow.

Constructed regional flow duration curves have been used to determine fish passage flows in ungaged streams rather than use of the empirical equations for calculating $Q_{2\text{-}year}$. However, the error associated with extrapolating daily exceedance flows for application to ungaged streams is untested, and could be as high as the error associated with use of the empirical equations for estimating the 2-year peak flow. This should be investigated in future studies.

### 7.2.2 *BANKFULL FLOW AND $Q_{2\text{-}PK}$*

The bankfull flow is commonly associated with full mobilization of the streambed in gravel/cobble bedded channels (Dunne and Leopold, 1978), and as such, some have conjectured that salmonids may cease upstream movement during these conditions. In humid climates, such as the Pacific Northwest and northern coastal California, the bankfull flow has been routinely found to have a return period ranging between 1.2- and 1.8-years (Leopold et al., 1995; Dunne and Leopold, 1978; Harman and Jennings, 1999). The results of this study found that 50% of $Q_{2\text{-}PK}$ produces a flow with a return period averaging 1.15-years among the Pacific Northwest and Northern California Sites. These results would suggest that using 50% of $Q_{2\text{-}PK}$ in the two northern regions leads to a $Q_{HFP}$ with a return period that has a return period that is commonly associated with a bankfull flow.

However, in more arid climates, such as the Southern California region, the bankfull flow has been found to occur less frequently. A study of eight streams in the Los Angeles Basin and Santa Monica Mountains found the return period associated with a bankfull discharge ranging from 2.1- and 6.7-years, with a median return period of 2.5-years (Coleman et al. 2005). For the Southern California sites, this study found that 50%$Q_{2\text{-}PK}$ produces a flow with a return period averaging 1.44-years, which may be less than a bankfull, or channel forming flow in these streams.

### 7.2.3 *INFLUENCE OF MIGRATION PERIOD ON DAILY EXCEEDANCE FLOW*

For this study, the adult steelhead migration period was defined by NMFS staff for the purpose of consistent comparisons between regions to encompass the wide range of migration timing experienced throughout coastal California watersheds. The variation in migration periods is influenced in part by the inter-annual variability in timing of storm events and associated migration opportunities. The result is a fairly lengthy migration period of November 1 through May 15. When defining $Q_{HFP}$ based on a migration period, such as the 1% exceedance flow for the migration period, the assumed migration period directly influences the magnitude of $Q_{HFP}$. Generally, using a longer migration period results in a lower $Q_{HFP}$ because it encompasses longer dry periods. Even though a steelhead in Southern California may migrate upstream in November if conditions permit, during most years the flow would likely be too low. Therefore, including November in the calculation of the 1% exceedance flow for the migration period produces a lower $Q_{HFP}$ than if it was not included. To avoid including drier periods in calculation of $Q_{HFP}$, which can unintentionally reduce the resulting design flow, it may be best to focus on using only the wettest period. For example, in western Washington State, a common means of calculating $Q_{HFP}$ is to use the wettest month during the anticipated migration period, which is typically January in that region (WDFW, 2013).

## 7.3 Effect of Fish Passage Flow Criteria on Passage

Total time that passage conditions, flows between $Q_{LFP}$ and $Q_{HFP}$, are met is clearly influenced by selection of these design flow criteria. The $Q_{LFP}$ criteria are intended to represent geomorphic limitations to movement within the natural channel. The alternative low flow criteria of 3 cfs for adult anadromous salmonids was originally selected based on critical riffle measurements in a number of alluvial streams and rivers in northern coastal California (Lang, Love & Trush 2004). However, there can be substantial variation in low flow depths verses streamflow in natural channels. Therefore, site specific field studies of the low flow geomorphic controls in a stream may be necessary to identify a $Q_{LFP}$ that maximizes the passage window at low flows. This would likely be required on a project-by-project basis.

$Q_{HFP}$ criteria can be selected to improve the total passage on an annual or migration period basis but their influence is limited to improving passage during the often short duration of storm flows. The magnitude and frequency of storm flows varies between water year types (Wet, Average or Dry) influencing the passage opportunity and high flow delay. Passage opportunity and high flow delays in all regions varied for Wet, Average and Dry years. Wet years in all regions experience more high flow delay due to the greater number and magnitude of storms experienced during Wet years. However, the percent of these high flow delays compared to the available passage time during the migration period was highest for the Southern California region sites because the total number of days meeting passage flows is lower.

Passage in Average and Dry years is influenced more by low flow passage delays and this influence also increases for sites located further south and for smaller watersheds in all of the climate regions. Thus, meeting low flow design criteria can be critical to maximizing passage opportunities. In addition, because low flow passage is a strong function of channel morphology, it may be necessary to adopt site specific low flow passage criteria.

The passage analysis presented here used the complete records of mean daily flow for each of the study sites with a comparison to the 15-minute data for some sites to compare calculated passage windows and passage delay resulting from the different data time periods. The 15-minute data captures the true peak flows occurring during storm hydrographs, which could possibly provide more accurate estimates of high flow delay compared to the mean daily flow. Comparing the estimates of high flow delay for the same year predicted using the two different data sets showed that, in general, the mean daily flow data predicted slightly longer high flow delays because the smallest delay time possible is one day. Many high flow delay periods are shorter than this as the hydrograph rises above then drops below $Q_{HFP}$ over a time period of a few hours rather than one day. Thus, using the mean daily flow record provides a conservative estimate of high flow delay for a given $Q_{HFP}$ value. Differences between flow data sets in the total passage time during the migration period were negligible. Given the verified data quality and ease of analysis for calculations based on the mean daily flow records, using the mean daily flow data to calculate exceedance flows is recommended.

## 7.4 Effect of Streamflow Data Quality and Quantity

Calculation of fish passage flow criteria defined by exceedance flows determined for either the annual or migration period record require developing flow duration curves (FDCs) from the stream flow record at a site or a regional flow duration curve derived from nearby gage records. The duration of these records and the water year types included in the record can influence the magnitude of the predicted exceedance flows. Analysis of data quality and quantity effects on flow duration curves and exceedance flows suggests:

- Streamflow record lengths of at least 15 years, and preferably longer, are recommended for deriving annual or migration period flow duration curves. These record lengths are needed to sample enough years to reasonably predict the low percent exceedance, higher flow values, that define $Q_{HFP}$.

- Streamflow records collected during prolonged dry periods, even with 15- or 20-year record lengths, may not include the high flows needed to provide good estimates of low percent exceedance values. Shorter streamflow records could be compared to longer, nearby gaging records to evaluate whether these records were collected during periods of wetter or drier conditions by evaluating the cumulative annual water yields for the record length of interest.

- USGS regression equation estimates of recurrence interval flows may have high error and should be compared to nearby gaged streams when possible and adjusted using procedures described in the USGS manuals (Gotvald et al. 2012; Cooper 2005).

- The error in prediction of percent passage and high flow delay resulting from uncertainty in estimating $Q_{HFP}$ is highest when the $Q_{HFP}$ magnitude is underestimated. This occurs because a lower value for $Q_{HFP}$ creates more high flow delay; thus, shrinking the passage window. $Q_{HFP}$ is underestimated compared to exceedance flows calculated from a long flow record when exceedance flows for $Q_{HFP}$ are calculated using a short flow record collected during a drier climate period.

## 7.5 Additional Considerations

As noted above, this study was limited to analysis of hydrology to determine frequency and duration of flows assumed suitable for fish passage. In previous studies to identify appropriate fish passage flows (Lang et al. 2004), observation of fish migration and behavior were invaluable to matching $Q_{HFP}$ criteria to fish needs. Recommendations for future work to further inform and refine selection of fish passage design flows include:

- Observing local fish movement and migration behavior

  These observations may be needed to optimize passage opportunity and minimize delay within specific watersheds. Incorporating channel geomorphological knowledge and considerations may also better define low flow passage criteria and minimize low flow delay.

- Evaluate the effects of water quality and unique hydraulic conditions

  Many watersheds pose additional water quality or hydraulic conditions that limit migration timing. Identifying natural upper flow limits for migration due to factors (e.g. turbidity, velocities, turbulence, etc.) at a particular location or channel condition might better match $Q_{HFP}$ criteria to fish migration needs of the watershed.

Even when regional or watershed specific fish passage flow criteria are not warranted, estimation of fish passage flow criteria for ungaged streams is problematic. Simpler methods, such as using a percent of a recurrence interval flow estimated using a regional regression equation, can have high error and the methods for using and correcting estimates from these equations should be highly specified and verified. Alternatively, regional flow duration curves could be developed and used for $Q_{HFP}$ estimation in ungaged streams. Regardless of the method used to estimate $Q_{HFP}$, streamflow data quantity and quality will influence design flow estimations and the longest record data sets possible should be used for flow criteria development.

# 8 REFERENCES

Baker, D.B., R.P. Richards, T.T. Loftus, and J.W. Kramer. 2004. A New Flashiness Index: Characteristics and Applications to Midwestern Rivers and Streams. Journal of the American Water Resources Association, April, 2004, pp. 503-522.

Barlow, P.M., and Leake, S.A., 2012. Streamflow depletion by wells—Understanding and managing the effects of groundwater pumping on streamflow: U.S. Geological Survey Circular 1376, 84 p. (Also available at http://pubs.usgs.gov/circ/1376/)

Barnard, R. J., J. Johnson, P. Brooks, K. M. Bates, B. Heiner, J. P. Klavas, D.C. Ponder, P.D. Smith, and P. D. Powers. 2013. Water Crossings Design Guidelines, Washington Department of Fish and Wildlife (WDFW), Olympia, Washington.

California Department of Fish and Game (CDFG). 2002. Culvert Criteria for Fish Passage, CDFG, May 2002.

California Department of Fish and Game (CDFG). 2009. California Salmonid Stream Habitat Restoration Manual: Part XII: Fish Passage Design and Implementation, California Department of Fish and Game, April, 2009.

Cederholm, C.J. and W.J. Scarlett. 1981. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981, p. 98-110. In E.L. Brannon and E.O. Salo, editors. Proceedings of the Salmon and Trout Migratory Behavior Symposium. School of Fisheries, University of Washington, Seattle, WA.

Coleman, D., C. MacRae and E. D. Stein. 2005. Effect of Increases in Peak Flows and Imperviousness on the Morphology of Southern California Streams. A report from the Stormwater Monitoring Coalition. Southern California Coastal Water Research Project. Technical Report #450.

Cooper, R.M., 2005, Estimation of peak discharges for rural, unregulated streams in Western Oregon: U.S. Geological Survey Scientific Investigations Report 2005–5116, 134 p.

Dunne, T. and L. B. Leopold. 1978. *Water in Environmental Planning*. W.H. Freeman and Company, New York.

Gotvald, A.J., Barth, N.A., Veilleux, A.G., and Parrett, Charles, 2012, Methods for determining magnitude and frequency of floods in California, based on data through water year 2006: U.S. Geological Survey Scientific Investigations Report 2012–5113, 38 p., 1 pl., available online only at http://pubs.usgs.gov/sir/2012/5113/.

Harman, W. A. and G. D. Jennings. 1999. Application of the Rosgen Stream Classification System to North Carolina. River Course Fact Sheet # 2. AG-590-2. NC CES, Raleigh, NC.

Kahler, T.H., P. Roni, and T. P. Quinn. 2001. Summer movement and growth of juvenile anadromous salmonids in small western Washington Streams. Can. J. Fish. Aquat. Sci. V 58, p. 1947-1956.

Kemp, P. S. and J. R. O'Hanley. 2010. Procedures for evaluating and prioritising the removal of fish passage barriers: a synthesis. Fisheries Management and Ecology, 17, 297–322.

Lang, M., M. Love and W. Trush. 2004. Improving Stream Crossings for Fish Passage. Final Report for National Marine Fisheries Service Contract No. 50ABNF800082

Leopold, Luna B.; Wolman, M. Gordon; and Miller, John P. (1995). *Fluvial Processes in Geomorphology*. Dover Publications.

Nickelson, T.E., J.D. Rogers, S.L. Johnson, and M.F. Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Can. J. Aquat. Sci. 49: 783-789.

NMFS, 2001. Guidelines for Salmonid Passage at Stream Crossings, NMFS, Sept 2001.

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

NMFS, 2012. Final Southern California Steelhead Recovery Plan, Southwest Region, Protected Resources Division, Long Beach, California. Jan 2012.

NMFS, 2013. South-Central California Steelhead Recovery Plan, West Coast Region, Long Beach, California. December 2013.

Oregon Department of Fish and Wildlife (ODFW). 2006. Oregon Administrative Rules. Division 412: Fish Passage. http://www.dfw.state.or.us/OARS/412.pdf. More general information at: http://www.dfw.state.or.us/fish/passage.

Oregon Water Resources Department (OWRD). 2012. Online peak discharge estimator. http://www.oregon.gov/owrd/pages/sw/peak_flow.aspx

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg, 1997. The Natural Flow Regime: A Paradigm for River Conservation and Restoration. BioScience 47:769-784.

Richter, B.D., J.V. Baumgartner, and J. Powell. 1996. A Method for Assessment of Hydrologic Alteration Within Ecosystems. Conservation Biology 10:1163-1174.

Roni P., Hanson K. & Beechie T. (2008) Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. North American Journal of Fisheries Management 28, 856–890.

Shuster, W.D., Y. Zhang, A.H. Roy, F.B. Daniel, and M. Troyer. 2008. Characterizing Storm Hydrograph Rise and Fall Dynamics with Stream Stage Data. Journal of the American Water Resources Association, December 2008, pp. 1431-1440.

Slack, J.R. and J.M. Landwehr. 1992. USGS Hydro-Climatic Data Network: A U.S. Geological Survey streamflow data set for the United States for the study of climate variations, 1874-1988. USGS Open-File Report 92-129. http://pubs.usgs.gov/of/1992/ofr92-129/.

Washington Department of Fish and Wildlife (WDFW). 2003. Design of road culverts for fish passage. http://wdfw.wa.gov/conservation/habitat/fish_passage/

Wofford J.E.B., Gresswell R.E. & Banks M.A. (2005) Influence of barriers to movement on within-watershed genetic variation of coastal cutthroat trout. Ecological Applications 15, 628–637.

US Forest Service. Caspar Creek Experimental Watershed. http://www.fs.fed.us/psw/ef/caspar_creek/. Accessed November 2012.

US Geological Survey (USGS). 1982. Guidelines for determining flood flow frequency, Bulletin 17-B of the Hydrology Subcommittee: Reston, Virginia, U.S. Geological Survey, Office of Water Data Coordination, 183 p. Available from the National Technical Information Service, Springfield VA 22161 as report no. PB 86 157 278 or from FEMA on the World-Wide Web at http://www.fema.gov/mit/tsd/dl_flow.html

# APPENDIX A – FREQUENCY OF WET, AVERAGE AND DRY WATER YEARS

Appendix A supplements material presented in Section 3.1 and contains plots comparing the frequency and magnitude of wet, average and dry years for each of the projects study sites. The water year classifications (Wet, Average and Dry) are defined using the annual water yield calculated from the site's mean daily flow record as:

- Wet years - those years in the upper 20 percentile of a site's annual average water yield,
- Average years - those in the middle 60 percentile, and
- Dry years – those years in the lower 20 percentile of annual water yields.
-

Figure A- 1 through Figure A- 16 show the annual water yield expressed as the deviation from the median water yield.

$$\frac{Annual\ Yield\ for\ Year\ i - Median\ Annual\ Yield\ for\ Site\ Record}{Median\ Annual\ Yield\ for\ Site\ Record}$$

Wet years are the highest 20% of annual water yields and are indicated in these plots as those columns exceeding the upper dashed line. Dry years are the lowest 20% and are those years whose columns extend beyond the lower dashed line.. The figures are presented from north-to-south with the northern-most site in the Pacific Northwest Region first (Figure A- 1 - Jetty Creek) to the southern-most site in the southern California region (Figure A- 16 - Topanga Creek). These plots were created to allow direct comparison between sites and highlight the increase in water yield variability observed in the more southern site data records. The variability in annual water yields at a site is emphasized by the range in the deviation from the median for each year of a site's data record. For example, Jetty Creek has low variability with a range in deviation from the meidan water yield of -0.29 to 0.56 and Topanga Creek shows high variability with a range from -0.96 to 19.38. The range increases consistently from north-to-south.

Figure A- 17 through Figure A- 19 show the actual annual water yields for each of the sites. These plots more clearly show the actual variation in water yield magnitude from year-to-year and patterns of sequential wet, average and dry years.

## List of Figures

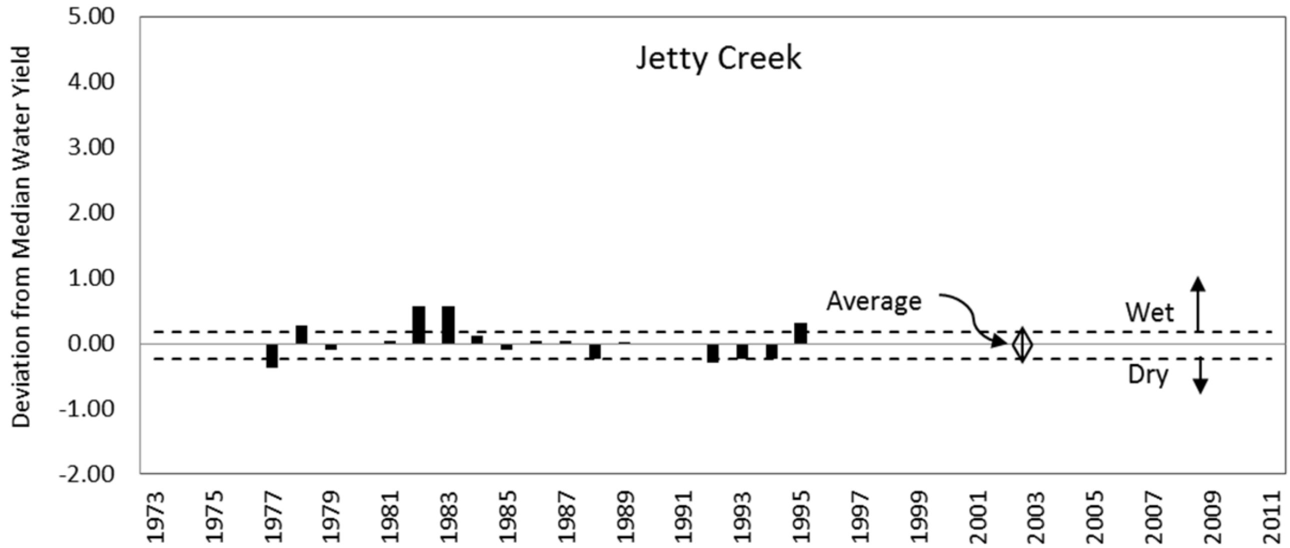



**Figure A- 1. Annual water yield expressed as the deviation from the median water yield for Jetty Creek.**

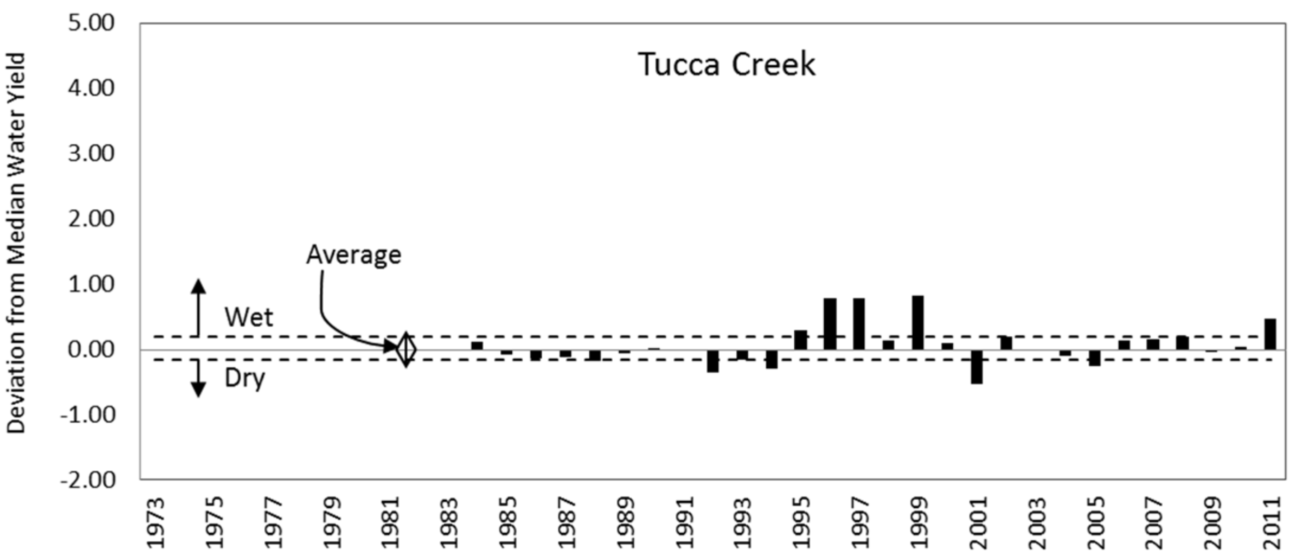



**Figure A- 2. Annual water yield expressed as the deviation from the median water yield for Tucca Creek.**

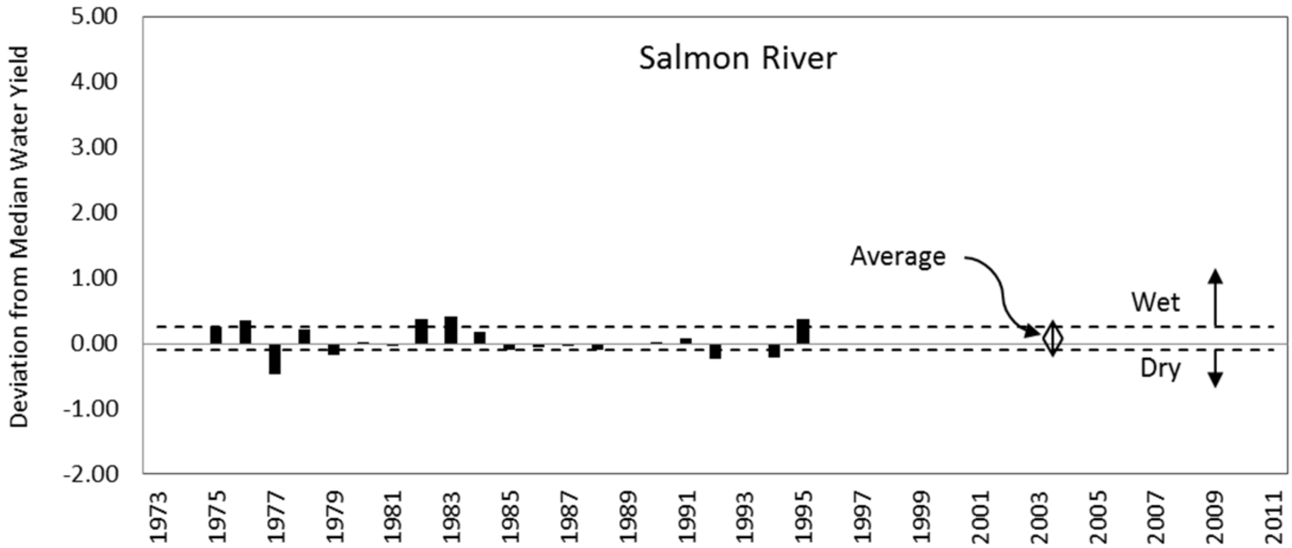



**Figure A- 3. Annual water yield expressed as the deviation from the median water yield for Salmon River.**

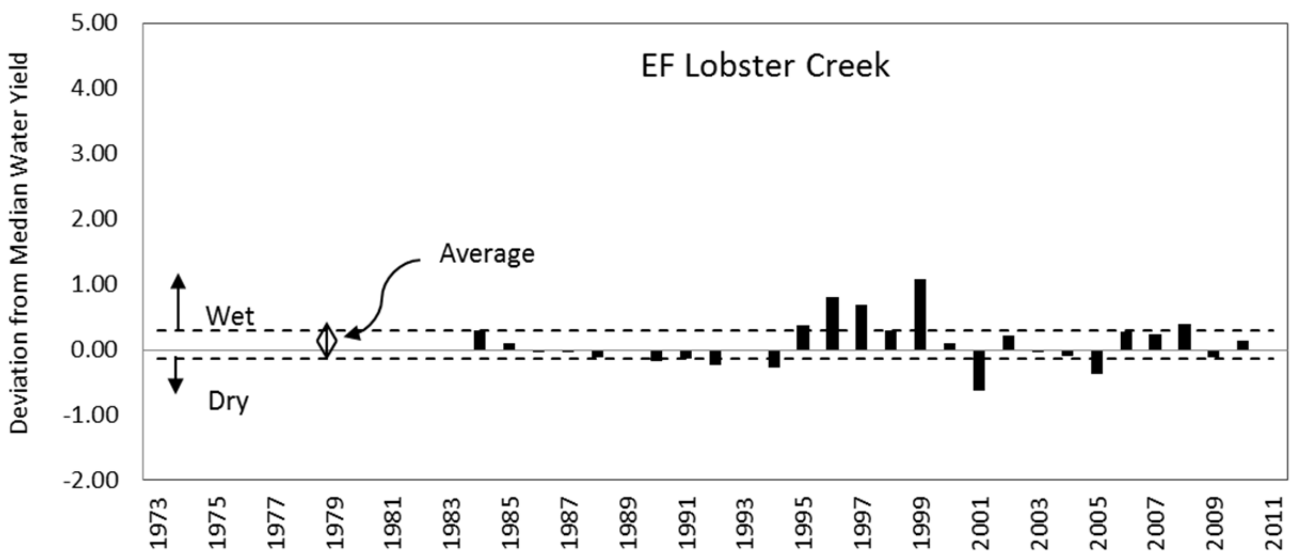



**Figure A- 4. Annual water yield expressed as the deviation from the median water yield for East Fork Lobster Creek.**

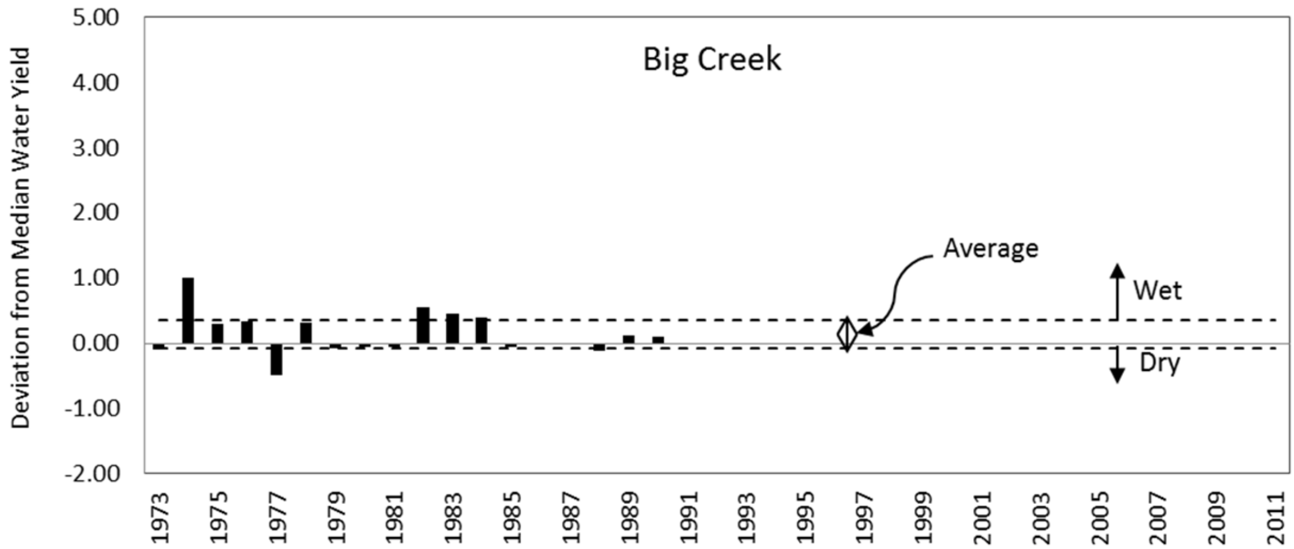



**Figure A- 5. Annual water yield expressed as the deviation from the median water yield for Big Creek.**

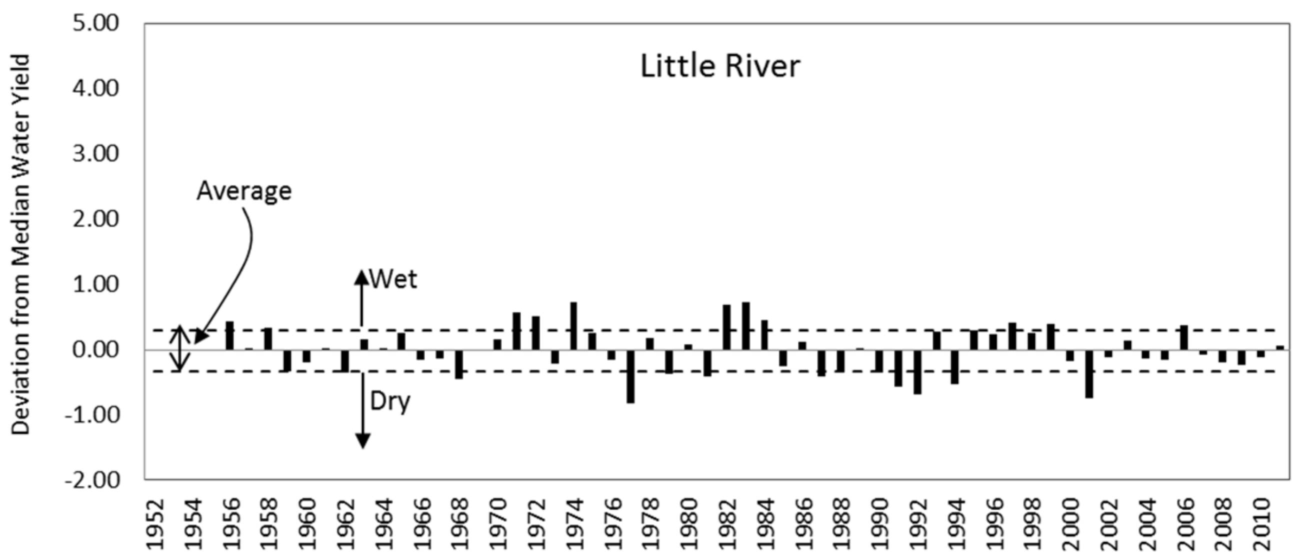



**Figure A- 6. Annual water yield expressed as the deviation from the median water yield for Little River.**

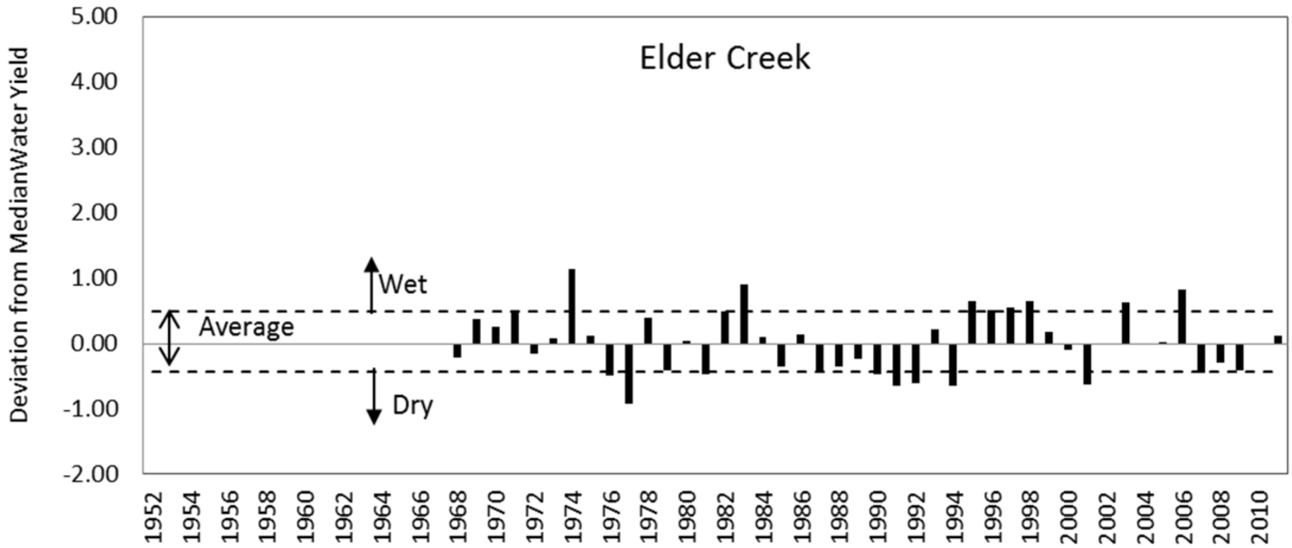



**Figure A- 7. Annual water yield expressed as the deviation from the median water yield for Elder Creek.**

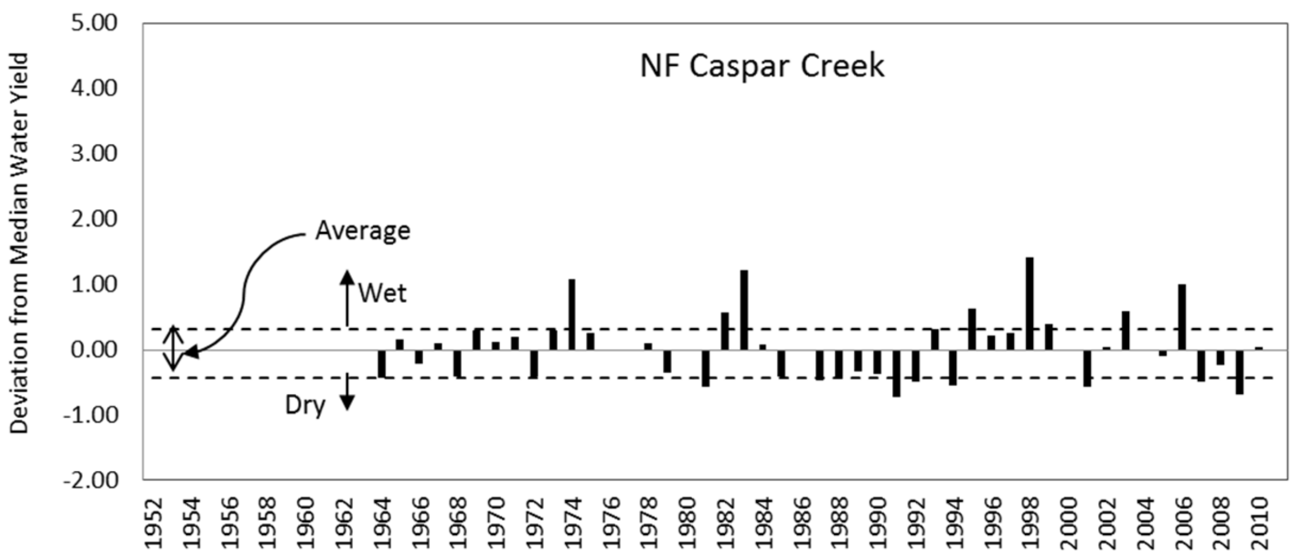



**Figure A- 8. Annual water yield expressed as the deviation from the median water yield for North Fork Caspar Creek.**

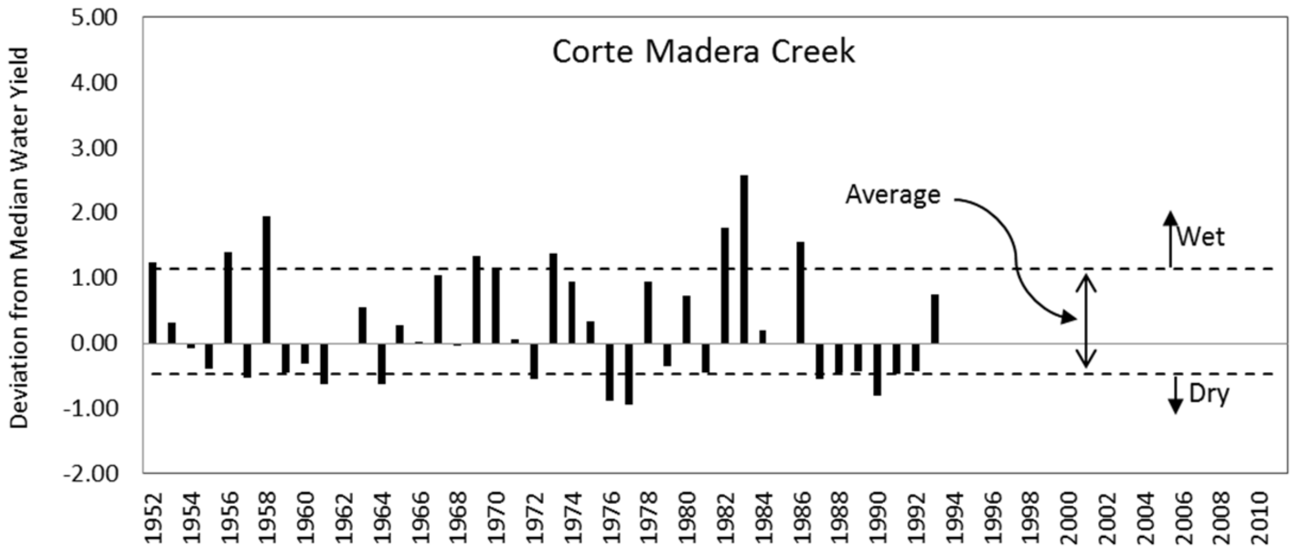



**Figure A- 9. Annual water yield expressed as the deviation from the median water yield for Corte Madera.**

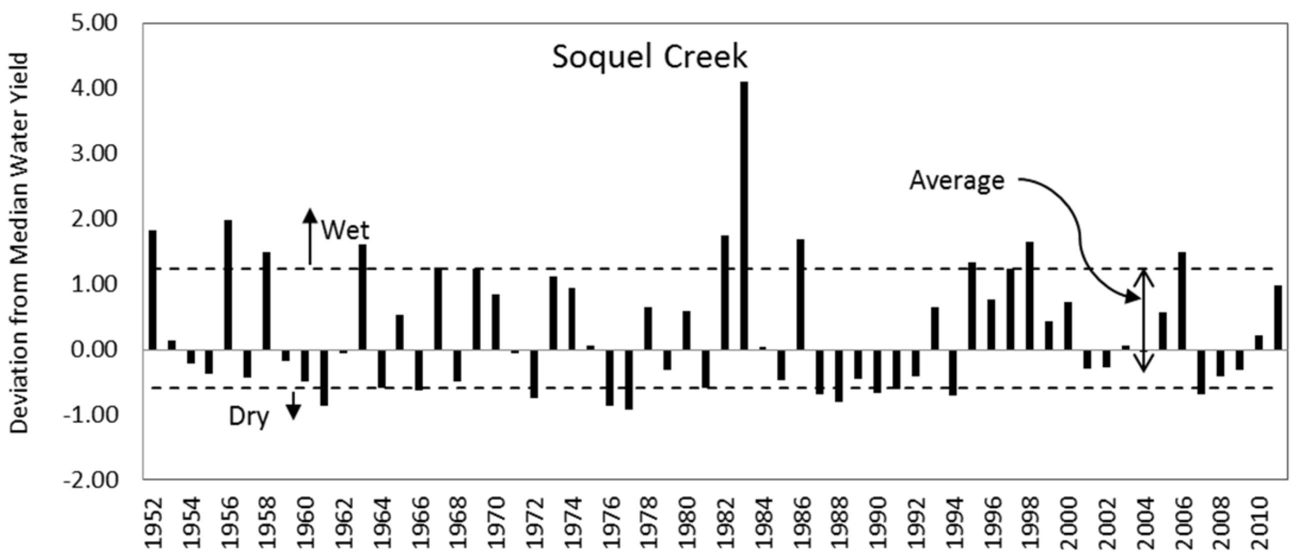



**Figure A- 10. Annual water yield expressed as the deviation from the median water yield for Soquel Creek.**

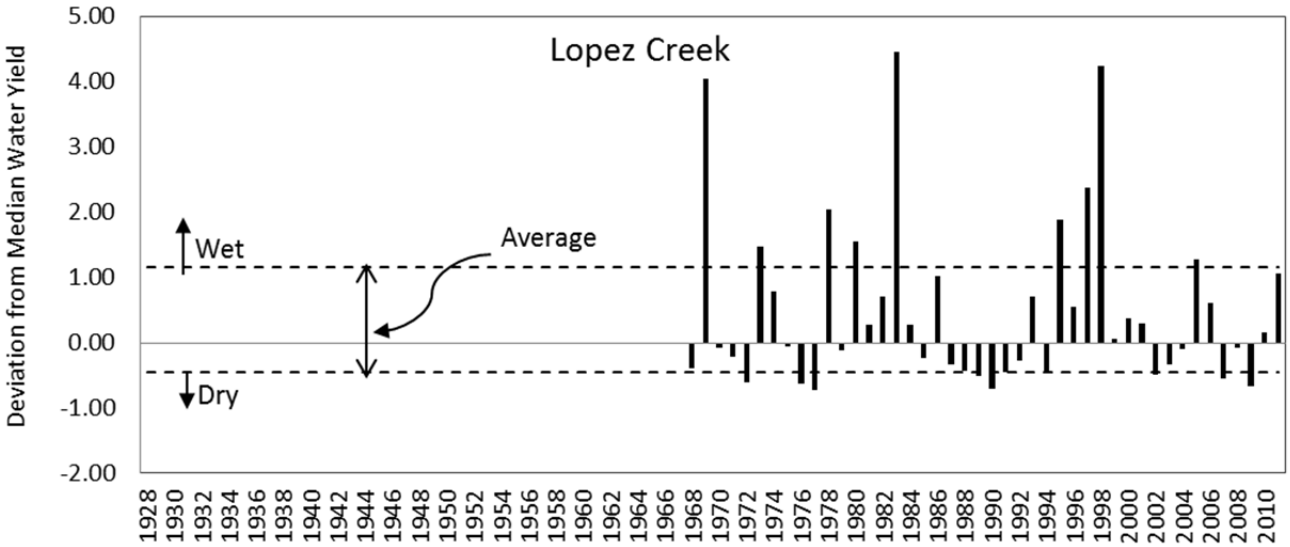



**Figure A- 11. Annual water yield expressed as the deviation from the median water yield for Lopez Creek.**

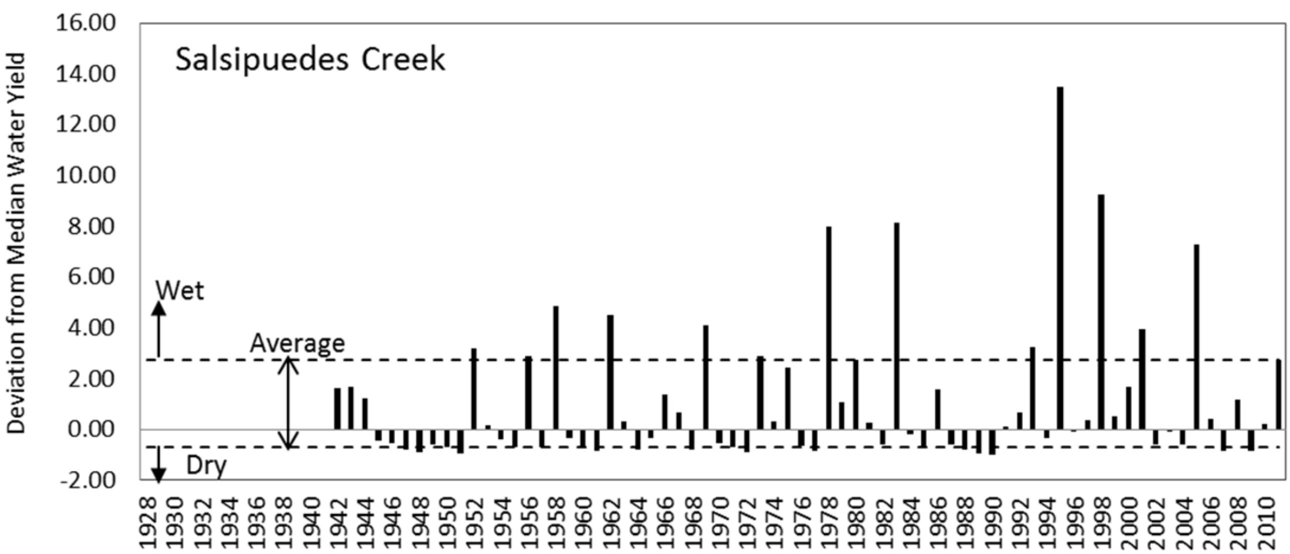



**Figure A- 12. Annual water yield expressed as the deviation from the median water yield for Salsipuedes.**

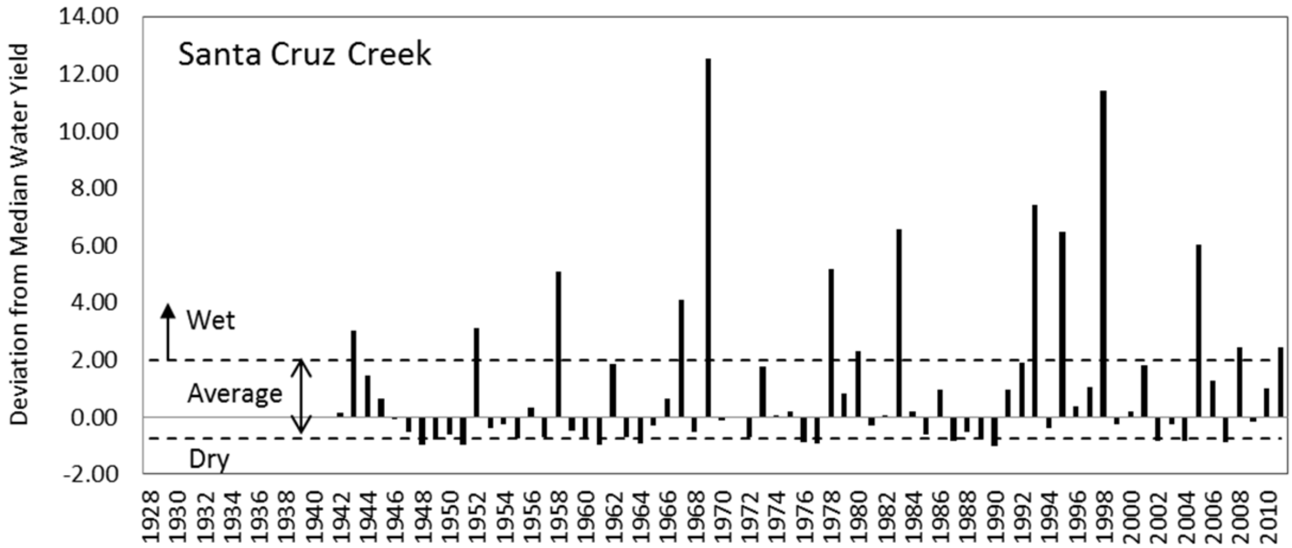



**Figure A- 13. Annual water yield expressed as the deviation from the median water yield for Santa Cruz Creek.**

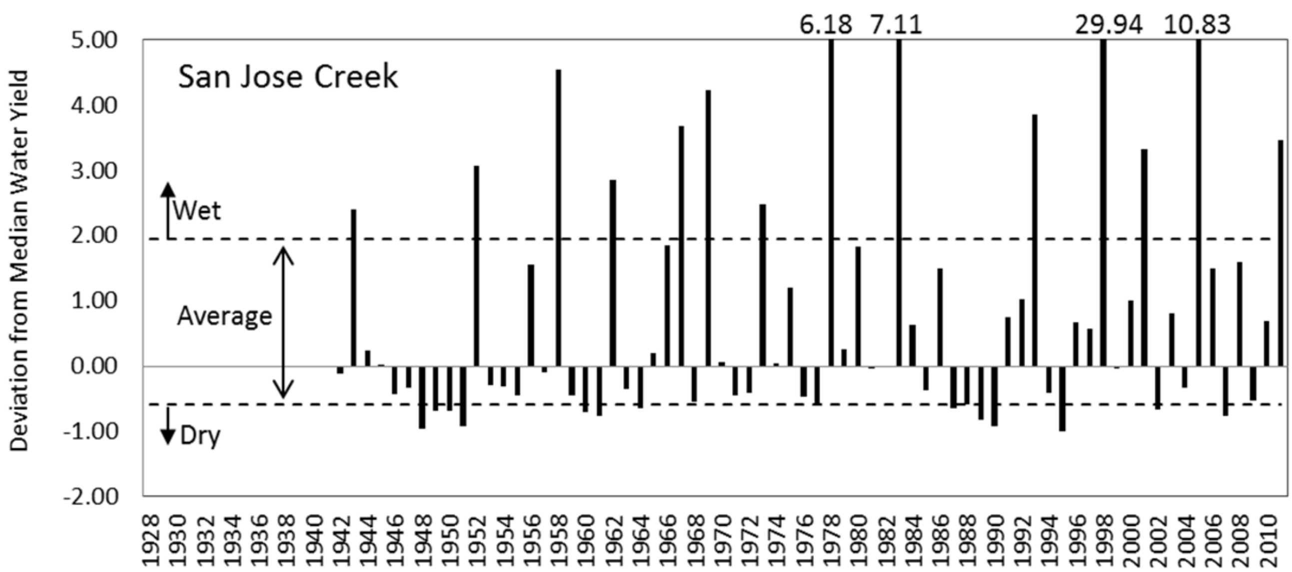



**Figure A- 14. Annual water yield expressed as the deviation from the median water yield for San Jose Creek.**

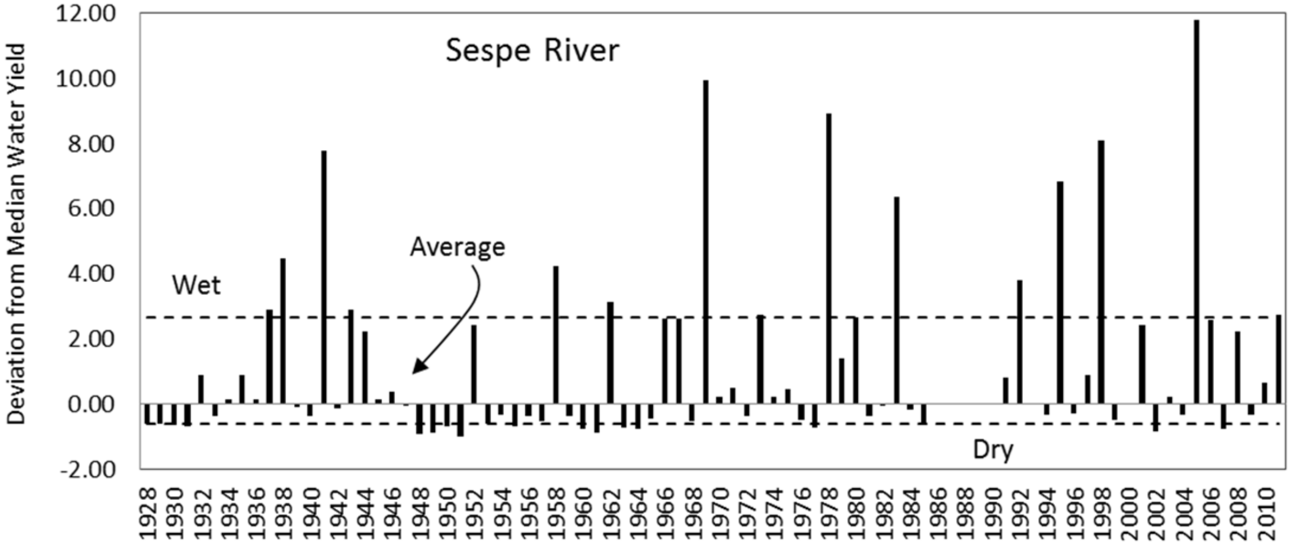



**Figure A- 15. Annual water yield expressed as the deviation from the median water yield for Sespe River.**

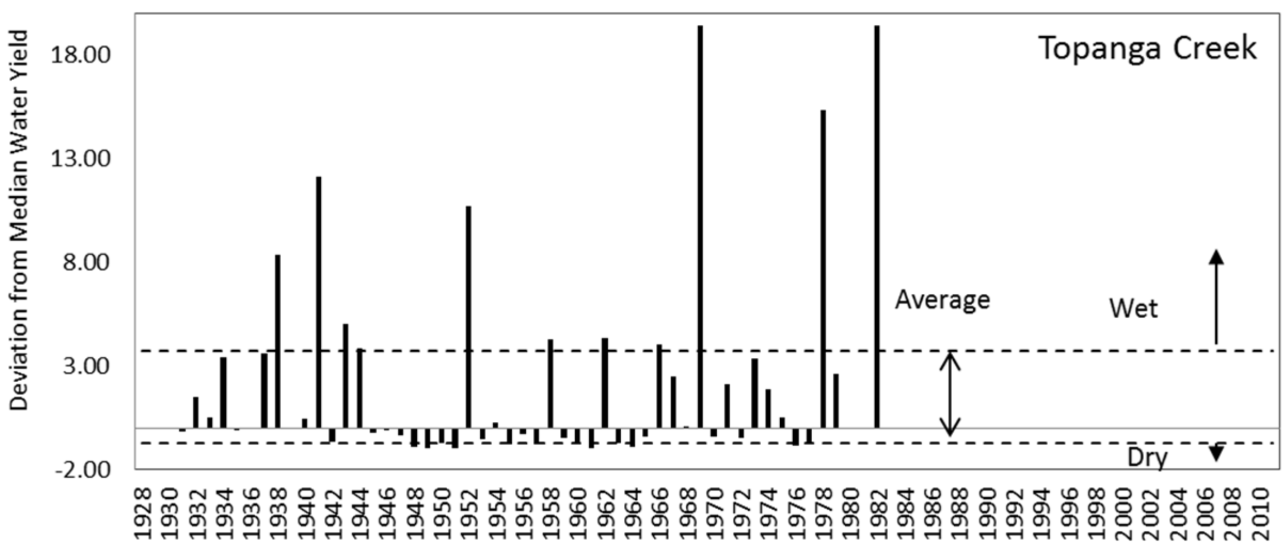



**Figure A- 16. Annual water yield expressed as the deviation from the median water yield for Topanga Creek.**

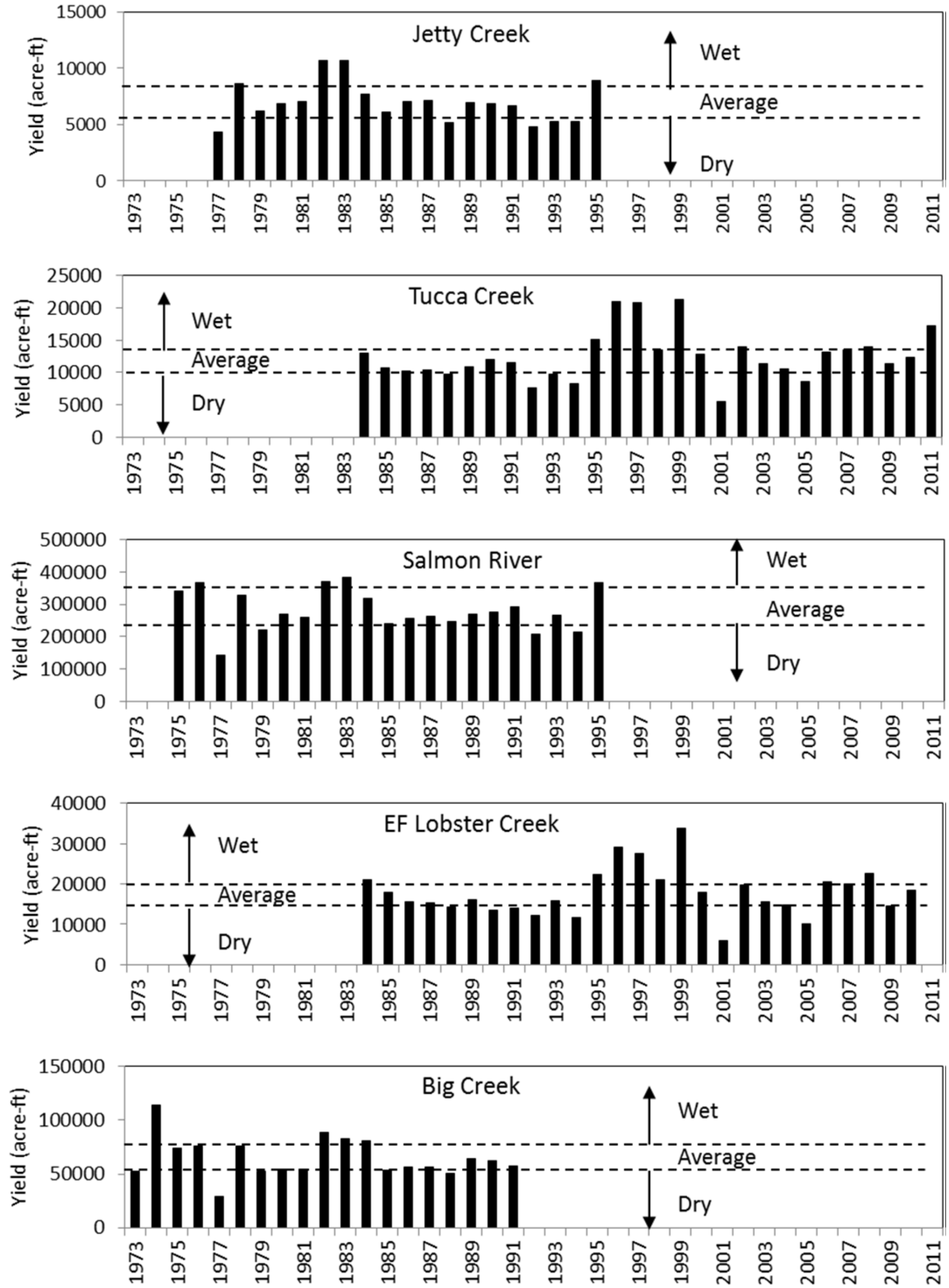



**Figure A- 17. Water year type comparisons for the Pacific Northwest sites. Water year types were determined using the annual water yield calculated from the mean daily flow data. Wet years are the highest 20% of annual water yields, dry years are the lowest 20%.**

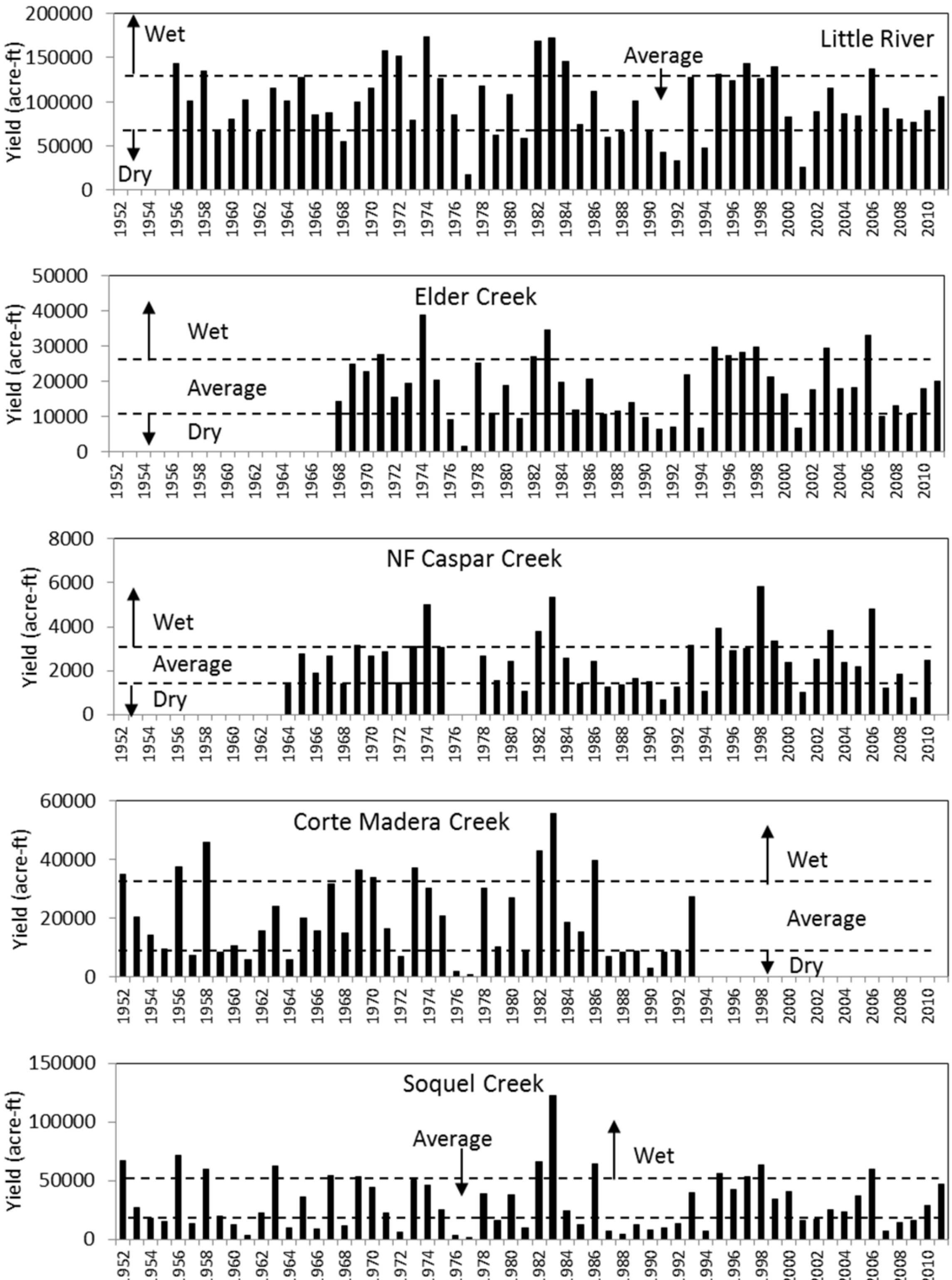



**Figure A- 18. Water year type comparisons for the Northern California sites. Water year types were determined using the annual water yield calculated from the mean daily flow data. Wet years are the highest 20% of annual water yields, dry years are the lowest 20%.**

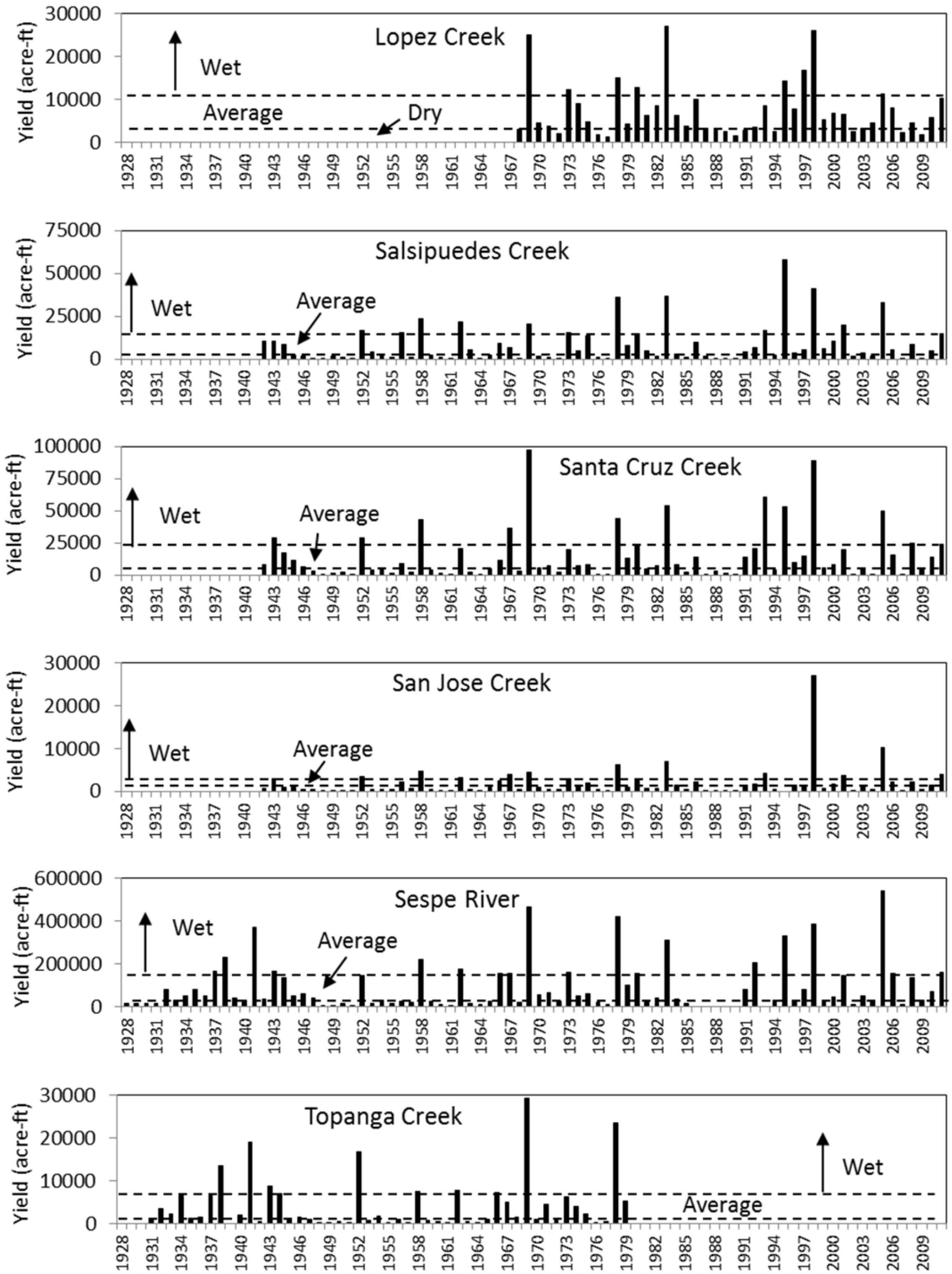



**Figure A- 19. Water year type comparisons for the Southern California sites. Water year types were determined using the annual water yield calculated from the mean daily flow data. Wet years are the highest 20% of annual water yields, dry years are the lowest 20%.**

# APPENDIX B - PASSAGE SUMMARIES FOR MEDIAN WET, AVERAGE AND DRY YEARS

Appendix B supplements material presented in Section 5.1 and contains tabular summaries comparing the passage opportunities at each study site for the different water year type classifications “Wet”, “Average” or “Dry.” The water year type classifications are the same as those used throughout this document and are defined using the annual water yield calculated from the site’s mean daily flow record as:

- Wet years - those years in the upper 20 percentile of a site’s annual average water yield,
- Average years - those in the middle 60 percentile, and
- Dry years – those years in the lower 20 percentile of annual water yields.

For analysis of passage within each water type classification, two years bracketing the median in each year-type classification were selected for comparison. Results for a total of six years --two Wet, two Average and two Dry years-- is presented for each study site. The mean daily flow record for the comparison years is used for the results presented in Table B- 1 through Table B- 16.

For three study sites (Lopez Ck, Salispuedes Ck and Sespe R), the passage window and delays were determined using both the mean daily and 15-minute flow data records. For these three sites, adjustments were made to the years analyzed to include years that had complete mean daily and 15-minute records. Comparison of the mean daily and 15-minute derived results are included in Table B- 17 through Table B- 19.

## List of Tables

**Table B- 1. Jetty Creek storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1982/Wet | 1995/Wet | 1980/Ave | 1990/Ave | 1988/Dry | 1992/Dry |
|---|---|---|---|---|---|---|---|
| Rank of 19 (Percentile) | | 2 (0.944) | 3 (0.888) | 10 (0.500) | 11 (0.444) | 17 (0.111) | 18 (0.055) |
| (Data Sample Period) | | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) |
| **Number of Storm Events** | | 10 | 9 | 11 | 8 | 9 | 10 |
| Storm Qpeak (cfs) | Median | 72 | 70 | 27 | 38 | 23 | 20 |
| | Min | 26 | 17 | 13 | 15 | 8.2 | 12 |
| | Max | 303 | 136 | 53 | 154 | 42 | 55 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 6.5 cfs | Total | 4 | 9 | 17 | 58 | 50 | 66 |
| | Median Event | 4 | ---** | 4 | 9 | 6 | 4 |
| | Min Event | 4 | 4 | 1 | 1 | 1 | 1 |
| | Max Event | 4 | 5 | 12 | 22 | 13 | 34 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr Peak = 75 cfs | Total | 3 | 5 | 0 | 2 | 0 | 0 |
| | Median Event | ---** | 1 | 0 | 2 | 0 | 0 |
| | Min Event | 1 | 1 | 0 | 2 | 0 | 0 |
| | Max Event | 2 | 2 | 0 | 2 | 0 | 0 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 77.3 cfs | Total | 3 | 5 | 0 | 2 | 0 | 0 |
| | Median Event | ---** | 1 | 0 | 2 | 0 | 0 |
| | Min Event | 1 | 1 | 0 | 2 | 0 | 0 |
| | Max Event | 2 | 2 | 0 | 2 | 0 | 0 |
| QHFP = 1% MigPer = 70 cfs | Total | 7 | 6 | 0 | 2 | 0 | 0 |
| | Median Event | 2 | 1 | 0 | 2 | 0 | 0 |
| | Min Event | 1 | 1 | 0 | 2 | 0 | 0 |
| | Max Event | 3 | 3 | 0 | 2 | 0 | 0 |
| $Q_{HFP}$ = 1% Annual = 53 cfs | Total | 12 | 12 | 1 | 6 | 0 | 1 |
| | Median Event | 3 | 2 | 1 | 2 | 0 | 1 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 1 |
| | Max Event | 8 | 3 | 1 | 3 | 0 | 1 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 6.5 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 75 cfs | Total | 189 | 182 | 180 | 136 | 147 | 131 |
| | Min Event | 26 | 1 | 4 | 5 | 1 | 1 |
| | Max Event | 83 | 75 | 164 | 80 | 70 | 44 |
| $Q_{LFP}$ = 50% Annual = 6.5 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 77.3 cfs | Total | 189 | 182 | 180 | 136 | 147 | 131 |
| | Min Event | 26 | 1 | 4 | 5 | 1 | 1 |
| | Max Event | 83 | 75 | 164 | 80 | 70 | 44 |
| $Q_{LFP}$ = 50% Annual = 6.5 cfs<br>$Q_{HFP}$ = 1% MigPer = 70 cfs | Total | 185 | 181 | 180 | 136 | 147 | 131 |
| | Min Event | 1 | 1 | 4 | 5 | 1 | 1 |
| | Max Event | 83 | 75 | 164 | 80 | 70 | 44 |
| $Q_{LFP}$ = 50% Annual = 6.5 cfs<br>$Q_{HFP}$ = 1% Annual = 53 cfs | Total | 180 | 175 | 179 | 132 | 147 | 130 |
| | Min Event | 6 | 1 | 4 | 2 | 1 | 1 |
| | Max Event | 79 | 74 | 138 | 48 | 70 | 44 |

**- A median value is not reported when there are only two events during the year or migration period.

**Table B- 2. Tucca Creek storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1997/Wet | 2011/Wet | 1990/Ave | 1991/Ave | 2005/Dry | 1994/Dry |
|---|---|---|---|---|---|---|---|
| Rank of 28 (Percentile) | | 3 (0.925) | 4 (0/888) | 14 (0.518) | 15 (0.481) | 25 (0.111) | 26 (0.074) |
| (Data Sample Period) | | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) |
| **Number of Storm Events** | | 9 | 15 | 9 | 11 | 6 | 6 |
| Storm Qpeak (cfs) | Median | 114 | 66 | 61 | 46 | 48 | 57 |
| | Min | 39 | 34 | 21 | 14 | 20 | 28 |
| | Max | 296 | 198 | 218 | 160 | 85 | 181 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 9.1 cfs | Total | 5 | 0 | 58 | 30 | 60 | 81 |
| | Median Event | 2 | 0 | 6.5 | 3 | 9.5 | 21.5 |
| | Min Event | 1 | 0 | 2 | 1 | 4 | 9 |
| | Max Event | 2 | 0 | 23 | 8 | 37 | 29 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr Peak = 108 cfs | Total | 19 | 2 | 7 | 4 | 0 | 2 |
| | Median Event | 3 | 2 | 2 | 1 | 0 | 2 |
| | Min Event | 1 | 2 | 1 | 1 | 0 | 2 |
| | Max Event | 5 | 2 | 4 | 1 | 0 | 2 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 151 cfs | Total | 8 | 1 | 3 | 1 | 0 | 1 |
| | Median Event | 3 | 1 | ---** | 1 | 0 | 1 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 1 |
| | Max Event | 4 | 1 | 2 | 1 | 0 | 1 |
| $Q_{HFP}$ = 1% MigPer = 159 cfs | Total | 7 | 1 | 3 | 1 | 0 | 1 |
| | Median Event | 2 | 1 | ---** | 1 | 0 | 1 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 1 |
| | Max Event | 4 | 1 | 2 | 1 | 0 | 1 |
| $Q_{HFP}$ = 1% Annual = 125 cfs | Total | 13 | 2 | 7 | 3 | 0 | 2 |
| | Median Event | 3 | 2 | 2 | 1 | 0 | 2 |
| | Min Event | 2 | 2 | 1 | 1 | 0 | 2 |
| | Max Event | 5 | 2 | 4 | 1 | 0 | 2 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 9.1 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 108 cfs | Total | 172 | 194 | 131 | 162 | 136 | 113 |
| | Min Event | 1 | 76 | 3 | 2 | 1 | 9 |
| | Max Event | 65 | 118 | 49 | 52 | 84 | 56 |
| $Q_{LFP}$ = 50% Annual = 9.1 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 151 cfs | Total | 183 | 195 | 135 | 165 | 136 | 114 |
| | Min Event | 1 | 76 | 5 | 2 | 1 | 9 |
| | Max Event | 95 | 119 | 49 | 52 | 84 | 57 |
| $Q_{LFP}$ = 50% Annual = 9.1 cfs<br>$Q_{HFP}$ = 1% MigPer = 159 cfs | Total | 184 | 195 | 135 | 165 | 136 | 114 |
| | Min Event | 2 | 76 | 5 | 2 | 1 | 9 |
| | Max Event | 95 | 118 | 49 | 52 | 84 | 57 |
| $Q_{LFP}$ = 50% Annual = 9.1 cfs<br>$Q_{HFP}$ = 1% Annual = 125 cfs | Total | 178 | 194 | 131 | 163 | 136 | 113 |
| | Min Event | 1 | 76 | 3 | 2 | 1 | 9 |
| | Max Event | 94 | 118 | 49 | 52 | 84 | 56 |

** - A median value is not reported when there are only two events during the year or migration period.

**Table B- 3. East Fork Lobster Creek storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1997/Wet | 2008/Wet | 1989/Ave | 1993/Ave | 1992/Dry | 1994/Dry |
|---|---|---|---|---|---|---|---|
| Rank of 27 (Percentile) | | 3 (0.923) | 4 (0.884) | 14 (0.500) | 15 (0.461) | 24 (0.115) | 25 (0.076) |
| (Data Sample Period) | | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) |
| **Number of Storm Events** | | 12 | 12 | 15 | 18 | 14 | 8 |
| Storm Qpeak (cfs) | Median | 145 | 146 | 66 | 66 | 74.5 | 62.5 |
| | Min | 66 | 46 | 13 | 16 | 11 | 19 |
| | Max | 600 | 425 | 233 | 204 | 232 | 198 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 9.5 cfs | Total | 21 | 19 | 29 | 13 | 46 | 57 |
| | Median Event | 4 | ---** | 4 | 3 | 8 | 3 |
| | Min Event | 1 | 4 | 2 | 1 | 2 | 1 |
| | Max Event | 12 | 15 | 19 | 6 | 22 | 30 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr Peak = 285 cfs | Total | 5 | 2 | 0 | 0 | 0 | 0 |
| | Median Event | 1 | 2 | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 2 | 0 | 0 | 0 | 0 |
| | Max Event | 2 | 2 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 275 cfs | Total | 6 | 2 | 0 | 0 | 0 | 0 |
| | Median Event | 1 | 2 | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 2 | 0 | 0 | 0 | 0 |
| | Max Event | 2 | 2 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 1% MigPer = 262 cfs | Total | 8 | 2 | 0 | 0 | 0 | 0 |
| | Median Event | 1 | 2 | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 2 | 0 | 0 | 0 | 0 |
| | Max Event | 5 | 2 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 1% Annual = 202 cfs | Total | 13 | 5 | 1 | 0 | 1 | 0 |
| | Median Event | 2 | 2 | 1 | 0 | 1 | 0 |
| | Min Event | 1 | 1 | 1 | 0 | 1 | 0 |
| | Max Event | 5 | 2 | 1 | 0 | 1 | 0 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 9.5 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 285 cfs | Total | 170 | 176 | 167 | 183 | 151 | 139 |
| | Min Event | 1 | 4 | 3 | 2 | 1 | 2 |
| | Max Event | 95 | 163 | 122 | 91 | 122 | 116 |
| $Q_{LFP}$ = 50% Annual = 9.5 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 275 cfs | Total | 169 | 176 | 167 | 183 | 151 | 139 |
| | Min Event | 1 | 4 | 3 | 2 | 1 | 2 |
| | Max Event | 65 | 163 | 122 | 91 | 122 | 116 |
| $Q_{LFP}$ = 50% Annual = 9.5 cfs<br>$Q_{HFP}$ = 1% MigPer = 262 cfs | Total | 167 | 176 | 167 | 183 | 151 | 139 |
| | Min Event | 2 | 4 | 3 | 2 | 1 | 2 |
| | Max Event | 65 | 163 | 122 | 91 | 122 | 116 |
| $Q_{LFP}$ = 50% Annual = 9.5 cfs<br>$Q_{HFP}$ = 1% Annual = 202 cfs | Total | 162 | 173 | 166 | 183 | 150 | 139 |
| | Min Event | 1 | 4 | 3 | 2 | 1 | 2 |
| | Max Event | 37 | 125 | 100 | 91 | 95 | 116 |

**- A median value is not reported when there are only two events during the year or migration period.

**Table B- 4. Salmon River storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1982/Wet | 1995/Wet | 1989/Ave | 1993/Ave | 1994/Dry | 1992/Dry |
|---|---|---|---|---|---|---|---|
| Rank of 21 (Percentile) | | 2 (0.950) | 3 (0.900) | 11 (0.500) | 12 (0.450) | 19 (0.100) | 20 (0.050) |
| (Data Sample Period) | | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) |
| **Number of Storm Events** | | 18 | 20 | 13 | 17 | 10 | 15 |
| Storm Qpeak (cfs) | Median | 2115 | 1380 | 1860 | 1050 | 1340 | 1010 |
| | Min | 729 | 319 | 486 | 550 | 271 | 224 |
| | Max | 5420 | 4140 | 2690 | 2660 | 5160 | 2640 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 213 cfs | Total | 15 | 4 | 37 | 24 | 73 | 47 |
| | Median Event | ---** | 1 | 3.5 | 3 | 12 | 7 |
| | Min Event | 5 | 1 | 1 | 1 | 7 | 2 |
| | Max Event | 10 | 2 | 29 | 17 | 29 | 22 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr Peak = 2872 cfs | Total | 9 | 7 | 0 | 0 | 2 | 0 |
| | Median Event | 1 | 1 | 0 | 0 | 2 | 0 |
| | Min Event | 1 | 1 | 0 | 0 | 2 | 0 |
| | Max Event | 2 | 1 | 0 | 0 | 2 | 0 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 1501 cfs | Total | 25 | 25 | 16 | 7 | 10 | 9 |
| | Median Event | 2.5 | 3 | 2 | 1 | 2.5 | 1 |
| | Min Event | 1 | 1 | 1 | 1 | 1 | 1 |
| | Max Event | 9 | 6 | 4 | 2 | 4 | 4 |
| $Q_{HFP}$ = 1% MigPer = 3430 cfs | Total | 5 | 5 | 0 | 0 | 1 | 0 |
| | Median Event | 1 | 1 | 0 | 0 | 1 | 0 |
| | Min Event | 1 | 1 | 0 | 0 | 1 | 0 |
| | Max Event | 2 | 1 | 0 | 0 | 1 | 0 |
| $Q_{HFP}$ = 1% Annual = 2710 cfs | Total | 9 | 8 | 0 | 0 | 2 | 0 |
| | Median Event | 1 | 1 | 0 | 0 | 2 | 0 |
| | Min Event | 1 | 1 | 0 | 0 | 2 | 0 |
| | Max Event | 2 | 2 | 0 | 0 | 2 | 0 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 213 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 2872 cfs | Total | 172 | 185 | 159 | 172 | 121 | 150 |
| | Min Event | 1 | 1 | 44 | 5 | 1 | 1 |
| | Max Event | 74 | 34 | 60 | 75 | 55 | 112 |
| $Q_{LFP}$ = 50% Annual = 213 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 1501 cfs | Total | 156 | 167 | 143 | 165 | 113 | 141 |
| | Min Event | 2 | 1 | 1 | 1 | 1 | 1 |
| | Max Event | 49 | 31 | 34 | 53 | 54 | 51 |
| $Q_{LFP}$ = 50% Annual = 213 cfs<br>$Q_{HFP}$ = 1% MigPer = 3430 cfs | Total | 176 | 187 | 159 | 172 | 122 | 150 |
| | Min Event | 5 | 2 | 44 | 5 | 1 | 1 |
| | Max Event | 74 | 53 | 60 | 75 | 56 | 112 |
| $Q_{LFP}$ = 50% Annual = 213 cfs<br>$Q_{HFP}$ = 1% Annual = 2710 cfs | Total | 172 | 184 | 159 | 172 | 121 | 150 |
| | Min Event | 1 | 1 | 44 | 5 | 1 | 1 |
| | Max Event | 74 | 34 | 60 | 75 | 55 | 112 |

** - A median value is not reported when there are only two events during the year or migration period.

**Table B- 5. Big storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1982/Wet | 1983/Wet | 1990/Ave | 1991/Ave | 1988/Dry | 1973/Dry |
|---|---|---|---|---|---|---|---|
| Rank of 19 (Percentile) | | 2 (0.944) | 3 (0.888) | 9 (0.555) | 10 (0.500) | 17 (0.111) | 18 (0.055) |
| (Data Sample Period) | | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) |
| **Number of Storm Events** | | 12 | 10 | 8 | 10 | 13 | 11 |
| Storm Qpeak (cfs) | Median | 386 | 489 | 402 | 297 | 125 | 105 |
| | Min | 161 | 68 | 96 | 102 | 95 | 50 |
| | Max | 1000 | 848 | 769 | 626 | 602 | 953 |
| **3** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 45 cfs | Total | 15 | 19 | 48 | 4 | 32 | 66 |
| | Median Event | 2 | 2.5 | 8 | 4 | 13 | 7 |
| | Min Event | 1 | 1 | 3 | 4 | 4 | 2 |
| | Max Event | 12 | 13 | 22 | 4 | 16 | 14 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yrPeak = 501 cfs | Total | 17 | 9 | 10 | 3 | 2 | 7 |
| | Median Event | 3 | 2 | 4 | ---** | ---** | 2 |
| | Min Event | 1 | 2 | 2 | 1 | 1 | 1 |
| | Max Event | 8 | 5 | 4 | 2 | 1 | 4 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 398 cfs | Total | 22 | 20 | 13 | 7 | 4 | 10 |
| | Median Event | 2.5 | 2 | 3 | 1 | ---** | 2 |
| | Min Event | 1 | 1 | 2 | 1 | 1 | 2 |
| | Max Event | 9 | 6 | 5 | 5 | 3 | 6 |
| $Q_{HFP}$ = 1% MigPer = 738 cfs | Total | 5 | 2 | 3 | 0 | 0 | 2 |
| | Median Event | 1 | ---** | 1 | 0 | 0 | 2 |
| | Min Event | 1 | 1 | 1 | 0 | 0 | 2 |
| | Max Event | 2 | 1 | 1 | 0 | 0 | 2 |
| $Q_{HFP}$ = 1% Annual = 605 cfs | Total | 9 | 7 | 5 | 1 | 0 | 5 |
| | Median Event | 2 | 1 | 2 | 1 | 0 | ---** |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 1 |
| | Max Event | 3 | 5 | 2 | 1 | 0 | 4 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 45 cfs; $Q_{HFP}$ = 50% Q2-yr Peak = 501 cfs | Total | 164 | 168 | 138 | 189 | 163 | 123 |
| | Min Event | 1 | 1 | 5 | 10 | 2 | 1 |
| | Max Event | 69 | 103 | 47 | 108 | 95 | 48 |
| $Q_{LFP}$ = 50% Annual = 45 cfs; $Q_{HFP}$ = 50% Q2-yr Emp = 398 cfs | Total | 159 | 157 | 135 | 185 | 161 | 120 |
| | Min Event | 1 | 1 | 5 | 10 | 2 | 1 |
| | Max Event | 68 | 39 | 47 | 79 | 98 | 48 |
| $Q_{LFP}$ = 50% Annual = 45 cfs; $Q_{HFP}$ = 1% MigPer = 738 cfs | Total | 176 | 175 | 145 | 192 | 165 | 128 |
| | Min Event | 1 | 1 | 5 | 10 | 2 | 1 |
| | Max Event | 70 | 104 | 48 | 182 | 145 | 48 |
| $Q_{LFP}$ = 50% Annual = 45 cfs; $Q_{HFP}$ = 1% Annual = 605 cfs | Total | 172 | 170 | 143 | 191 | 165 | 125 |
| | Min Event | 1 | 1 | 5 | 10 | 2 | 1 |
| | Max Event | 69 | 103 | 48 | 109 | 145 | 48 |

**- A median value is not reported when there are only two events during the year or migration period.

**Table B- 6. Little River storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type<br>Rank of 56 (Percentile)<br>(Data Sample Period) | | 1972/Wet<br>5 (0.927)<br>(Daily) | 1984/Wet<br>6 (0.909)<br>(Daily) | 1957/Ave<br>28 (0.509)<br>(Daily) | 1969/Ave<br>29 (0.490)<br>(Daily) | 1981/Dry<br>50 (0.109)<br>(Daily) | 1968/Dry<br>51 (0.090)<br>(Daily) |
|---|---|---|---|---|---|---|---|
| **Number of Storm Events** | | 12 | 20 | 15 | 23 | 13 | 10 |
| Storm Qpeak (cfs) | Median | 833 | 727 | 520 | 470 | 456 | 445 |
| | Min | 238 | 111 | 71 | 79 | 64 | 75 |
| | Max | 7740 | 2950 | 2650 | 1820 | 1500 | 1730 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 36 cfs | Total | 10 | 0 | 24 | 16 | 70 | 59 |
| | Median Event | ---** | 0 | ---** | 5 | 12.5 | 13 |
| | Min Event | 2 | 0 | 9 | 1 | 1 | 1 |
| | Max Event | 8 | 0 | 15 | 10 | 22 | 26 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr Peak = 2364 cfs | Total | 4 | 1 | 2 | 0 | 0 | 0 |
| | Median Event | ---** | 1 | 2 | 0 | 0 | 0 |
| | Min Event | 2 | 1 | 2 | 0 | 0 | 0 |
| | Max Event | 2 | 1 | 2 | 0 | 0 | 0 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 1625 cfs | Total | 7 | 3 | 4 | 2 | 0 | 1 |
| | Median Event | 2 | ---** | 1 | 2 | 0 | 1 |
| | Min Event | 2 | 1 | 1 | 2 | 0 | 1 |
| | Max Event | 3 | 2 | 2 | 2 | 0 | 1 |
| $Q_{HFP}$ = 1% MigPer = 1860 cfs | Total | 7 | 3 | 3 | 0 | 0 | 0 |
| | Median Event | 2 | 1 | ---** | 0 | 0 | 0 |
| | Min Event | 2 | 1 | 1 | 0 | 0 | 0 |
| | Max Event | 3 | 1 | 2 | 0 | 0 | 0 |
| $Q_{HFP}$ = 1% Annual = 1440 cfs | Total | 8 | 6 | 5 | 2 | 2 | 1 |
| | Median Event | 2 | 2 | 1 | 2 | ---** | 1 |
| | Min Event | 1 | 1 | 1 | 2 | 1 | 1 |
| | Max Event | 3 | 3 | 2 | 2 | 1 | 1 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 36 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 2364 cfs | Total | 183 | 196 | 170 | 180 | 126 | 138 |
| | Min Event | 13 | 43 | 3 | 1 | 1 | 2 |
| | Max Event | 73 | 153 | 96 | 179 | 97 | 100 |
| $Q_{LFP}$ = 50% Annual = 36 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 1625 cfs | Total | 180 | 194 | 168 | 178 | 126 | 137 |
| | Min Event | 11 | 2 | 3 | 1 | 1 | 2 |
| | Max Event | 73 | 153 | 76 | 112 | 97 | 92 |
| $Q_{LFP}$ = 50% Annual = 36 cfs<br>$Q_{HFP}$ = 1% MigPer = 1860 cfs | Total | 180 | 194 | 169 | 180 | 126 | 138 |
| | Min Event | 11 | 2 | 3 | 1 | 1 | 2 |
| | Max Event | 73 | 153 | 89 | 179 | 97 | 100 |
| $Q_{LFP}$ = 50% Annual = 36 cfs<br>$Q_{HFP}$ = 1% Annual = 1440 cfs | Total | 179 | 191 | 167 | 178 | 124 | 137 |
| | Min Event | 2 | 1 | 1 | 1 | 1 | 2 |
| | Max Event | 73 | 152 | 74 | 112 | 96 | 92 |

** - A median value is not reported when there are only two events during the year or migration period.

**Table B- 7. Elder Creek storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1995/Wet | 2003/Wet | 2005/Ave | 2010/Ave | 1976/Dry | 1992/Dry |
|---|---|---|---|---|---|---|---|
| Rank of 44 (Percentile) | | 5 (0.906) | 6 (0.883) | 22 (0.511) | 23 (0.488) | 39 (0.116) | 40 (0.093) |
| (Data Sample Period) | | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) |
| **Number of Storm Events** | | 11 | 12 | 13 | 14 | 8 | 10 |
| Storm Qpeak (cfs) | Median | 209 | 210 | 72 | 90 | 35 | 27 |
| | Min | 10 | 24 | 39 | 8.9 | 16 | 6.4 |
| | Max | 789 | 647 | 292 | 300 | 278 | 125 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 5.5 cfs | Total | 22 | 35 | 35 | 37 | 16 | 63 |
| | Median Event | 4 | ---** | 35 | ---** | ---** | 8 |
| | Min Event | 1 | 6 | 35 | 18 | 4 | 2 |
| | Max Event | 7 | 29 | 35 | 19 | 12 | 29 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr Peak = 285 cfs | Total | 10 | 12 | 1 | 2 | 0 | 0 |
| | Median Event | 2.5 | 2.5 | 1 | 2 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 2 | 0 | 0 |
| | Max Event | 4 | 6 | 1 | 2 | 0 | 0 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 456 cfs | Total | 4 | 4 | 0 | 0 | 0 | 0 |
| | Median Event | 1 | 1 | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 1 | 0 | 0 | 0 | 0 |
| | Max Event | 2 | 1 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 1% MigPer = 336 cfs | Total | 7 | 9 | 0 | 0 | 0 | 0 |
| | Median Event | 1.5 | 2 | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 1 | 0 | 0 | 0 | 0 |
| | Max Event | 3 | 3 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 1% Annual = 263 cfs | Total | 11 | 15 | 1 | 2 | 1 | 0 |
| | Median Event | 2 | 2 | 1 | 2 | 1 | 0 |
| | Min Event | 1 | 1 | 1 | 2 | 1 | 0 |
| | Max Event | 8 | 6 | 1 | 2 | 1 | 0 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 5.5 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 285 cfs | Total | 164 | 149 | 160 | 157 | 181 | 134 |
| | Min Event | 1 | 1 | 2 | 4 | 2 | 2 |
| | Max Event | 61 | 117 | 158 | 109 | 92 | 109 |
| $Q_{LFP}$ = 50% Annual = 5.5 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 456 cfs | Total | 170 | 157 | 161 | 159 | 181 | 134 |
| | Min Event | 1 | 1 | --- | 4 | 2 | 2 |
| | Max Event | 62 | 135 | 161 | 155 | 92 | 109 |
| $Q_{LFP}$ = 50% Annual = 5.5 cfs<br>$Q_{HFP}$ = 1% MigPer = 336 cfs | Total | 167 | 152 | 161 | 159 | 181 | 134 |
| | Min Event | 1 | 1 | --- | 4 | 2 | 2 |
| | Max Event | 62 | 118 | 161 | 155 | 92 | 109 |
| $Q_{LFP}$ = 50% Annual = 5.5 cfs<br>$Q_{HFP}$ = 1% Annual = 263 cfs | Total | 163 | 146 | 160 | 157 | 180 | 134 |
| | Min Event | 1 | 1 | 2 | 4 | 2 | 2 |
| | Max Event | 61 | 104 | 158 | 109 | 87 | 109 |

**- A median value is not reported when there are only two events during the year or migration period.

**Table B- 8. NF Caspar Creek storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1995/Wet | 2003/Wet | 1986/Ave | 1980/Ave | 1994/Dry | 1981/Dry |
|---|---|---|---|---|---|---|---|
| Rank of 45 (Percentile) | | 5 (0.909) | 6 (0.886) | 23 (0.500) | 24 (0.477) | 41 (0.090) | 42 (0.068) |
| (Data Sample Period) | | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) |
| **Number of Storm Events** | | 12 | 11 | 7 | 13 | 7 | 8 |
| Storm Qpeak (cfs) | Median | 28 | 37 | 29.5 | 15 | 5.7 | 12.6 |
| | Min | 3.2 | 4.1 | 3.5 | 4.8 | 3.4 | 3.4 |
| | Max | 133 | 123 | 124 | 98 | 50 | 44 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 3 cfs | Total | 107 | 79 | 137 | 117 | 162 | 156 |
| | Median Event | 7.5 | 3 | 8 | 6 | 13 | 11.5 |
| | Min Event | 1 | 1 | 2 | 1 | 1 | 1 |
| | Max Event | 43 | 42 | 54 | 25 | 56 | 48 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr Peak = 64 cfs | Total | 4 | 4 | 1 | 1 | 0 | 0 |
| | Median Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Max Event | 1 | 2 | 1 | 1 | 0 | 0 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 68.3 cfs | Total | 4 | 2 | 1 | 1 | 0 | 0 |
| | Median Event | 1 | ---** | 1 | 1 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Max Event | 1 | 1 | 1 | 1 | 0 | 0 |
| $Q_{HFP}$ = 1% MigPer = 60 cfs | Total | 5 | 4 | 1 | 1 | 0 | 0 |
| | Median Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Max Event | 2 | 2 | 1 | 1 | 0 | 0 |
| $Q_{HFP}$ = 1% Annual = 47 cfs | Total | 9 | 8 | 4 | 1 | 1 | 0 |
| | Median Event | 2 | 1 | 4 | 1 | 1 | 0 |
| | Min Event | 1 | 1 | 4 | 1 | 1 | 0 |
| | Max Event | 3 | 2 | 4 | 1 | 1 | 0 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 64 cfs | Total | 85 | 113 | 58 | 79 | 34 | 40 |
| | Min Event | 1 | 3 | 1 | 1 | 1 | 1 |
| | Max Event | 26 | 20 | 16 | 24 | 11 | 12 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 68.3 cfs | Total | 85 | 115 | 58 | 79 | 34 | 40 |
| | Min Event | 1 | 3 | 1 | 1 | 1 | 1 |
| | Max Event | 26 | 31 | 16 | 24 | 11 | 12 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 1% MigPer = 60 cfs | Total | 84 | 113 | 58 | 79 | 34 | 40 |
| | Min Event | 1 | 3 | 1 | 1 | 1 | 1 |
| | Max Event | 25 | 20 | 16 | 24 | 11 | 12 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 1% Annual = 47 cfs | Total | 80 | 109 | 55 | 79 | 33 | 40 |
| | Min Event | 1 | 1 | 1 | 1 | 1 | 1 |
| | Max Event | 25 | 20 | 16 | 24 | 10 | 12 |

** - A median value is not reported when there are only two events during the year or migration period.

**Table B- 9. Corte Madera Creek storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type<br>Rank of 42 (Percentile)<br>(Data Sample Period) | | 1986/Wet<br>4 (0.926)<br>(Daily) | 1956/Wet<br>5 (0.902)<br>(Daily) | 1966/Ave<br>21 (0.512)<br>(Daily) | 1962/Ave<br>20 (0.487)<br>(Daily) | 1987/Dry<br>37 (0.121)<br>(Daily) | 1964/Dry<br>38 (0.077)<br>(Daily) |
|---|---|---|---|---|---|---|---|
| **Number of Storm Events** | | 10 | 11 | 9 | 9 | 9 | 13 |
| Storm Qpeak (cfs) | Median | 376 | 552 | 73 | 154 | 63 | 19 |
| | Min | 53 | 29 | 11 | 15 | 8.9 | 5.1 |
| | Max | 2950 | 2360 | 1510 | 1400 | 776 | 310 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 3 cfs | Total | 42 | 35 | 26 | 55 | 91 | 33 |
| | Median Event | 7 | 3 | 5 | 10.5 | 6 | 3.5 |
| | Min Event | 1 | 1 | 1 | 3 | 1 | 3 |
| | Max Event | 13 | 12 | 11 | 31 | 33 | 6 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr Peak = 1045 cfs | Total | 4 | 4 | 1 | 1 | 0 | 0 |
| | Median Event | ---** | 1 | 1 | 1 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Max Event | 3 | 2 | 1 | 1 | 0 | 0 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 495 cfs | Total | 9 | 8 | 3 | 3 | 1 | 0 |
| | Median Event | 1 | 1 | ---** | ---** | 1 | 0 |
| | Min Event | 1 | 1 | 1 | 1 | 1 | 0 |
| | Max Event | 6 | 3 | 2 | 2 | 1 | 0 |
| $Q_{HFP}$ = 1% MigPer = 671 cfs | Total | 7 | 4 | 2 | 2 | 1 | 0 |
| | Median Event | 1 | 1 | 2 | 2 | 1 | 0 |
| | Min Event | 1 | 1 | 2 | 2 | 1 | 0 |
| | Max Event | 4 | 2 | 2 | 2 | 1 | 0 |
| $Q_{HFP}$ = 1% Annual = 506 cfs | Total | 9 | 7 | 3 | 3 | 1 | 0 |
| | Median Event | 1 | 1 | ---** | ---** | 1 | 0 |
| | Min Event | 1 | 1 | 1 | 1 | 1 | 0 |
| | Max Event | 6 | 2 | 2 | 2 | 1 | 0 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 1045 cfs | Total | 150 | 158 | 169 | 140 | 105 | 164 |
| | Min Event | 1 | 1 | 1 | 2 | 1 | 1 |
| | Max Event | 78 | 155 | 114 | 91 | 87 | 100 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 495 cfs | Total | 145 | 154 | 167 | 138 | 104 | 164 |
| | Min Event | 1 | 1 | 1 | 2 | 1 | 1 |
| | Max Event | 53 | 60 | 84 | 90 | 64 | 100 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 1% MigPer = 671 cfs | Total | 147 | 158 | 168 | 139 | 104 | 164 |
| | Min Event | 1 | 1 | 1 | 2 | 1 | 1 |
| | Max Event | 58 | 60 | 114 | 90 | 64 | 100 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 1% Annual = 506 cfs | Total | 145 | 155 | 167 | 138 | 104 | 164 |
| | Min Event | 1 | 1 | 1 | 2 | 1 | 1 |
| | Max Event | 83 | 60 | 84 | 90 | 64 | 100 |

**- A median value is not reported when there are only two events during the year or migration period.

**Table B- 10. Soquel Creek storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1998/Wet | 1963/Wet | 1984/Ave | 2004/Ave | 2007/Dry | 1994/Dry |
|---|---|---|---|---|---|---|---|
| Rank of 60 (Percentile) | | 6 (0.915) | 7 (0.898) | 30 (0.508) | 31 (0.491) | 54 (0.101) | 55 (0.084) |
| (Data Sample Period) | | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) |
| **Number of Storm Events** | | 19 | 11 | 10 | 13 | 6 | 10 |
| Storm Qpeak (cfs) | Median | 449 | 476 | 203 | 59 | 36 | 37 |
| | Min | 49 | 126 | 66 | 13 | 23 | 21 |
| | Max | 1840 | 4150 | 929 | 1320 | 187 | 322 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 7.9 cfs | Total | 14 | 5 | 0 | 30 | 59 | 109 |
| | Median Event | ---** | 5 | 0 | 7 | 6 | 6 |
| | Min Event | 2 | 5 | 0 | 3 | 1 | 1 |
| | Max Event | 12 | 5 | 0 | 20 | 11 | 35 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr Peak = 1361 cfs | Total | 1 | 3 | 0 | 0 | 0 | 0 |
| | Median Event | 1 | 3 | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 3 | 0 | 0 | 0 | 0 |
| | Max Event | 1 | 3 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 1016 cfs | Total | 4 | 4 | 0 | 2 | 0 | 0 |
| | Median Event | 1 | ---** | 0 | ---** | 0 | 0 |
| | Min Event | 1 | 1 | 0 | 1 | 0 | 0 |
| | Max Event | 2 | 3 | 0 | 1 | 0 | 0 |
| $Q_{HFP}$ = 1% MigPer = 879 cfs | Total | 6 | 4 | 1 | 2 | 0 | 0 |
| | Median Event | 1.5 | ---** | 1 | ---** | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Max Event | 2 | 3 | 1 | 1 | 0 | 0 |
| $Q_{HFP}$ = 1% Annual = 610 cfs | Total | 8 | 7 | 1 | 3 | 0 | 0 |
| | Median Event | 2 | 2.5 | 1 | 1 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Max Event | 3 | 3 | 1 | 1 | 0 | 0 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 7.9 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 1361 cfs | Total | 181 | 188 | 197 | 167 | 137 | 87 |
| | Min Event | 1 | 37 | 197 | 3 | 1 | 2 |
| | Max Event | 167 | 103 | 197 | 164 | 81 | 31 |
| $Q_{LFP}$ = 50% Annual = 7.9 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 1016 cfs | Total | 178 | 187 | 197 | 165 | 137 | 87 |
| | Min Event | 3 | 31 | 197 | 2 | 1 | 2 |
| | Max Event | 97 | 71 | 197 | 132 | 81 | 31 |
| $Q_{LFP}$ = 50% Annual = 7.9 cfs<br>$Q_{HFP}$ = 1% MigPer = 879 cfs | Total | 176 | 187 | 196 | 165 | 137 | 87 |
| | Min Event | 2 | 31 | 54 | 2 | 1 | 2 |
| | Max Event | 83 | 71 | 142 | 132 | 81 | 31 |
| $Q_{LFP}$ = 50% Annual = 7.9 cfs<br>$Q_{HFP}$ = 1% Annual = 610 cfs | Total | 174 | 184 | 196 | 164 | 137 | 87 |
| | Min Event | 2 | 6 | 54 | 2 | 1 | 2 |
| | Max Event | 83 | 48 | 142 | 77 | 81 | 31 |

** - A median value is not reported when there are only two events during the year or migration period.

**Table B- 11. Lopez Creek storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1995/Wet | 2005/Wet | 2001/Ave | 2010/Ave | 1989/Dry | 2009/Dry |
|---|---|---|---|---|---|---|---|
| Rank of 44 (Percentile) | | 6 (0.883) | 9 (0.813) | 18 (0.604) | 21 (0.534) | 38 (0.139) | 42 (0.046) |
| (Data Interval) | | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) |
| **Number of Storm Events** | | 7 | 4 | 4 | 4 | 3 | 2 |
| Storm Qpeak (cfs) | Median | 130 | 265 | 68.5 | 107.5 | 13 | ---** |
| | Min | 19 | 91 | 24 | 15 | 9.7 | 6.8 |
| | Max | 594 | 465 | 450 | 148 | 40 | 9 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 3.8 cfs | Total | 63 | 0 | 54 | 59 | 76 | 179 |
| | Median Event | 63 | 0 | 4.5 | 10.5 | 14 | 28.5 |
| | Min Event | 63 | 0 | 1 | 2 | 1 | 1 |
| | Max Event | 63 | 0 | 28 | 36 | 20 | 70 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr Peak = 186 cfs | Total | 4 | 4 | 1 | 0 | 0 | 0 |
| | Median Event | 1 | 1 | 1 | 0 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 0 | 0 | 0 |
| | Max Event | 2 | 2 | 1 | 0 | 0 | 0 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 168 cfs | Total | 4 | 4 | 1 | 0 | 0 | 0 |
| | Median Event | 1 | 1 | 1 | 0 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 0 | 0 | 0 |
| | Max Event | 2 | 2 | 1 | 0 | 0 | 0 |
| $Q_{HFP}$ = 1% MigPer = 182 cfs | Total | 4 | 4 | 1 | 0 | 0 | 0 |
| | Median Event | 1 | 1 | 1 | 0 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 0 | 0 | 0 |
| | Max Event | 2 | 2 | 1 | 0 | 0 | 0 |
| $Q_{HFP}$ = 1% Annual = 125 cfs | Total | 6 | 6 | 1 | 2 | 0 | 0 |
| | Median Event | 1 | 1 | 1 | 2 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 2 | 0 | 0 |
| | Max Event | 2 | 2 | 1 | 2 | 0 | 0 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 3.8 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 186 cfs | Total | 129 | 192 | 141 | 137 | 120 | 17 |
| | Min Event | 6 | 6 | 4 | 2 | 2 | 2 |
| | Max Event | 57 | 68 | 70 | 76 | 113 | 6 |
| $Q_{LFP}$ = 50% Annual = 3.8 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 168 cfs | Total | 129 | 192 | 141 | 137 | 120 | 17 |
| | Min Event | 7 | 1 | 1 | 2 | 1 | 1 |
| | Max Event | 58 | 68 | 71 | 76 | 114 | 7 |
| $Q_{LFP}$ = 50% Annual = 3.8 cfs<br>$Q_{HFP}$ = 1% MigPer = 182 cfs | Total | 129 | 192 | 141 | 137 | 120 | 17 |
| | Min Event | 7 | 1 | 1 | 1 | 1 | 1 |
| | Max Event | 58 | 124 | 71 | 119 | 114 | 7 |
| $Q_{LFP}$ = 50% Annual = 3.8 cfs<br>$Q_{HFP}$ = 1% Annual = 125 cfs | Total | 127 | 190 | 141 | 135 | 120 | 17 |
| | Min Event | 7 | 1 | 1 | 1 | 1 | 1 |
| | Max Event | 53 | 69 | 71 | 77 | 114 | 7 |

** - A median value is not reported when there are only two events during the year or migration period.

**Table B- 12. Salsipuedes Creek storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 2005/Wet | 2001/Wet | 1997/Ave | 2003/Ave | 2007/Dry | 2009/Dry |
|---|---|---|---|---|---|---|---|
| Rank of 70 (Percentile) | | 5 (0.942) | 9 (0.884) | 29 (0.594) | 36 (0.492) | 62 (0.115) | 64 (0.086) |
| (Data Interval) | | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) |
| **Number of Storm Events** | | 7 | 6 | 5 | 7 | 4 | 1 |
| Storm Qpeak (cfs) | Median | 664 | 201.5 | 159 | 80 | 4.25 | 67 |
| | Min | 142 | 94 | 50 | 17 | 3.5 | 67 |
| | Max | 1600 | 1990 | 256 | 503 | 7.2 | 67 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 3 cfs | Total | 56 | 69 | 62 | 136 | 188 | 190 |
| | Median Event | 56 | ---** | 13 | 7 | 39 | 85 |
| | Min Event | 56 | 1 | 1 | 2 | 10 | 8 |
| | Max Event | 56 | 68 | 20 | 37 | 81 | 97 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr Peak = 732 cfs | Total | 7 | 3 | 0 | 0 | 0 | 0 |
| | Median Event | 1 | 3 | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 3 | 0 | 0 | 0 | 0 |
| | Max Event | 4 | 3 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 237 cfs | Total | 15 | 6 | 2 | 1 | 0 | 0 |
| | Median Event | 1 | ---** | ---** | 1 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Max Event | 6 | 5 | 1 | 1 | 0 | 0 |
| $Q_{HFP}$ = 1% MigPer = 399 cfs | Total | 12 | 5 | 0 | 1 | 0 | 0 |
| | Median Event | 1 | ---** | 0 | 1 | 0 | 0 |
| | Min Event | 1 | 1 | 0 | 1 | 0 | 0 |
| | Max Event | 5 | 4 | 0 | 1 | 0 | 0 |
| $Q_{HFP}$ = 1% Annual = 200 cfs | Total | 16 | 8 | 3 | 1 | 0 | 0 |
| | Median Event | 1 | 1 | ---** | 1 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Max Event | 6 | 6 | 2 | 1 | 0 | 0 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 732 cfs | Total | 133 | 124 | 134 | 60 | 8 | 6 |
| | Min Event | 2 | 1 | 2 | 1 | 1 | 2 |
| | Max Event | 82 | 70 | 114 | 15 | 4 | 4 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 237 cfs | Total | 125 | 121 | 132 | 59 | 8 | 6 |
| | Min Event | 1 | 1 | 1 | 1 | 1 | 2 |
| | Max Event | 54 | 68 | 79 | 14 | 4 | 4 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 1% MigPer = 399 cfs | Total | 128 | 122 | 134 | 59 | 8 | 6 |
| | Min Event | 1 | 1 | 2 | 1 | 1 | 2 |
| | Max Event | 54 | 69 | 114 | 14 | 4 | 4 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 1% Annual = 200 cfs | Total | 124 | 119 | 131 | 59 | 8 | 6 |
| | Min Event | 1 | 1 | 1 | 1 | 1 | 2 |
| | Max Event | 54 | 67 | 78 | 14 | 4 | 4 |

**- A median value is not reported when there are only two events during the year or migration period.

**Table B- 13. Santa Cruz Creek storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1978/Wet | 1958/Wet | 1974/Ave | 1971/Ave | 2007/Dry | 1976/Dry |
|---|---|---|---|---|---|---|---|
| Rank of 70 (Percentile) | | 7 (0.913) | 8 (0.898) | 35 (0.507) | 36 (0.492) | 63 (0.101) | 64 (0.086) |
| (Data Sample Period) | | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) |
| **Number of Storm Events** | | 8 | 12 | 8 | 9 | 8 | 4 |
| Storm Qpeak (cfs) | Median | 202 | 398 | 70 | 56 | 5 | 10.5 |
| | Min | 67 | 126 | 12 | 13 | 4 | 4.5 |
| | Max | 2290 | 1680 | 359 | 378 | 6.5 | 100 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 3 cfs | Total | 66 | 80 | 48 | 35 | 132 | 139 |
| | Median Event | 7 | ---** | 17 | ---** | 22 | 28 |
| | Min Event | 2 | 35 | 12 | 7 | 2 | 12 |
| | Max Event | 57 | 45 | 19 | 28 | 47 | 99 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr Peak = 541 cfs | Total | 6 | 9 | 0 | 0 | 0 | 0 |
| | Median Event | ---** | 1 | 0 | 0 | 0 | 0 |
| | Min Event | 2 | 1 | 0 | 0 | 0 | 0 |
| | Max Event | 4 | 6 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 448 cfs | Total | 9 | 11 | 0 | 0 | 0 | 0 |
| | Median Event | ---** | 1 | 0 | 0 | 0 | 0 |
| | Min Event | 4 | 1 | 0 | 0 | 0 | 0 |
| | Max Event | 5 | 9 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 1% MigPer = 511 cfs | Total | 6 | 10 | 0 | 0 | 0 | 0 |
| | Median Event | ---** | 1 | 0 | 0 | 0 | 0 |
| | Min Event | 2 | 1 | 0 | 0 | 0 | 0 |
| | Max Event | 4 | 8 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 1% Annual = 319.5 cfs | Total | 10 | 17 | 1 | 1 | 0 | 0 |
| | Median Event | ---** | 2 | 1 | 1 | 0 | 0 |
| | Min Event | 5 | 1 | 1 | 1 | 0 | 0 |
| | Max Event | 5 | 11 | 1 | 1 | 0 | 0 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 541 cfs | Total | 124 | 107 | 148 | 161 | 64 | 58 |
| | Min Event | 2 | 1 | 1 | 10 | 1 | 10 |
| | Max Event | 71 | 45 | 140 | 151 | 57 | 48 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 448 cfs | Total | 121 | 105 | 148 | 161 | 64 | 58 |
| | Min Event | 2 | 5 | 1 | 10 | 1 | 10 |
| | Max Event | 69 | 45 | 140 | 151 | 57 | 48 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 1% MigPer = 511 cfs | Total | 124 | 106 | 148 | 161 | 64 | 58 |
| | Min Event | 2 | 5 | 1 | 10 | 1 | 10 |
| | Max Event | 71 | 45 | 140 | 151 | 57 | 48 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 1% Annual = 319.5 cfs | Total | 120 | 99 | 147 | 160 | 64 | 58 |
| | Min Event | 2 | 5 | 1 | 9 | 1 | 10 |
| | Max Event | 68 | 34 | 128 | 151 | 57 | 48 |

** - A median value is not reported when there are only two events during the year or migration period.

**Table B- 14. San Jose Creek storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1993/Wet | 1967/Wet | 1974/Ave | 1945/Ave | 1950/Dry | 1960/Dry |
|---|---|---|---|---|---|---|---|
| Rank of 69 (Percentile) | | 7 (0.911) | 8 (0.897) | 34 (0.514) | 35 (0.50) | 62 (0.102) | 63 (0.088) |
| (Data Sample Period) | | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) |
| **Number of Storm Events** | | 12 | 11 | 6 | 5 | 4 | 3 |
| Storm Qpeak (cfs) | Median | 67 | 27 | 13.5 | 12 | 13.5 | 11 |
| | Min | 4.5 | 16 | 6.8 | 7.5 | 5 | 8.5 |
| | Max | 182 | 390 | 103 | 145 | 42 | 16 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 3 cfs | Total | 116 | 116 | 176 | 185 | 191 | 192 |
| | Median Event | 13 | 17 | 16 | 24 | 27 | 46.5 |
| | Min Event | 3 | 6 | 3 | 2 | 9 | 17 |
| | Max Event | 36 | 40 | 43 | 80 | 97 | 84 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr Peak = 211 cfs | Total | 0 | 2 | 0 | 0 | 0 | 0 |
| | Median Event | 0 | ---** | 0 | 0 | 0 | 0 |
| | Min Event | 0 | 1 | 0 | 0 | 0 | 0 |
| | Max Event | 0 | 1 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 65 cfs | Total | 8 | 7 | 1 | 2 | 0 | 0 |
| | Median Event | 1 | 2 | 1 | ---** | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Max Event | 2 | 2 | 1 | 1 | 0 | 0 |
| $Q_{HFP}$ = 1% MigPer = 91 cfs | Total | 3 | 4 | 1 | 1 | 0 | 0 |
| | Median Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Max Event | 1 | 2 | 1 | 1 | 0 | 0 |
| $Q_{HFP}$ = 1% Annual = 50 cfs | Total | 10 | 8 | 1 | 2 | 0 | 0 |
| | Median Event | 1 | 2 | 1 | 2 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 2 | 0 | 0 |
| | Max Event | 2 | 3 | 1 | 2 | 0 | 0 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 211 cfs | Total | 80 | 78 | 20 | 11 | 5 | 5 |
| | Min Event | 1 | 2 | 1 | 1 | 1 | 1 |
| | Max Event | 33 | 36 | 9 | 5 | 2 | 2 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 65 cfs | Total | 72 | 73 | 19 | 9 | 5 | 5 |
| | Min Event | 1 | 1 | 1 | 1 | 1 | 1 |
| | Max Event | 17 | 36 | 5 | 3 | 2 | 2 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 1% MigPer = 91 cfs | Total | 77 | 76 | 19 | 10 | 5 | 5 |
| | Min Event | 1 | 1 | 1 | 1 | 1 | 1 |
| | Max Event | 18 | 36 | 5 | 3 | 2 | 2 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 1% Annual = 50 cfs | Total | 70 | 72 | 19 | 9 | 5 | 5 |
| | Min Event | 1 | 1 | 1 | 1 | 1 | 1 |
| | Max Event | 17 | 36 | 5 | 3 | 2 | 2 |

**- A median value is not reported when there are only two events during the year or migration period.

**Table B- 15. Sespe River storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1938/Wet | 1958/Wet | 2000/Ave | 1947/Ave | 1977/Dry | 2007/Dry |
|---|---|---|---|---|---|---|---|
| Rank of 78 (Percentile) | | 8 (0.909) | 9 (0.896) | 39 (0.506) | 40 (0.493) | 70 (0.103) | 71 (0.090) |
| (Data Sample Period) | | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) |
| **Number of Storm Events** | | 7 | 10 | 5 | 5 | 6 | 6 |
| Storm Qpeak (cfs) | Median | 4320 | 3720 | 1120 | 1130 | 112 | 36 |
| | Min | 109 | 476 | 174 | 62 | 32 | 29 |
| | Max | 14800 | 11700 | 2410 | 3730 | 753 | 248 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 12 cfs | Total | 39 | 43 | 84 | 34 | 123 | 7 |
| | Median Event | 39 | ---** | 6 | 11 | 20 | 7 |
| | Min Event | 39 | 9 | 1 | 7 | 5 | 7 |
| | Max Event | 39 | 34 | 77 | 16 | 60 | 7 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr = 4392 cfs | Total | 4 | 3 | 0 | 0 | 0 | 0 |
| | Median Event | 1 | 1 | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 1 | 0 | 0 | 0 | 0 |
| | Max Event | 2 | 1 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 877 cfs | Total | 28 | 29 | 5 | 6 | 0 | 0 |
| | Median Event | 3.5 | 4 | 1 | 1 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Max Event | 20 | 13 | 2 | 3 | 0 | 0 |
| $Q_{HFP}$ = 1% MigPer = 3708 cfs | Total | 7 | 6 | 0 | 1 | 0 | 0 |
| | Median Event | 1 | 1 | 0 | 1 | 0 | 0 |
| | Min Event | 1 | 1 | 0 | 1 | 0 | 0 |
| | Max Event | 4 | 1 | 0 | 1 | 0 | 0 |
| $Q_{HFP}$ = 1% Annual = 2031 cfs | Total | 15 | 16 | 1 | 1 | 0 | 0 |
| | Median Event | 2 | 2 | 1 | 1 | 0 | 0 |
| | Min Event | 1 | 1 | 1 | 1 | 0 | 0 |
| | Max Event | 8 | 8 | 1 | 1 | 0 | 0 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 12 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 4392 cfs | Total | 153 | 150 | 113 | 162 | 73 | 189 |
| | Min Event | 8 | 1 | 2 | 3 | 1 | 189 |
| | Max Event | 64 | 55 | 84 | 159 | 42 | 189 |
| $Q_{LFP}$ = 50% Annual = 12 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 877 cfs | Total | 129 | 124 | 108 | 156 | 73 | 189 |
| | Min Event | 1 | 1 | 1 | 1 | 1 | 189 |
| | Max Event | 57 | 47 | 39 | 113 | 42 | 189 |
| $Q_{LFP}$ = 50% Annual = 12 cfs<br>$Q_{HFP}$ = 1% MigPer = 3708 cfs | Total | 150 | 147 | 113 | 161 | 73 | 189 |
| | Min Event | 7 | 1 | 2 | 3 | 1 | 189 |
| | Max Event | 64 | 51 | 97 | 115 | 42 | 189 |
| $Q_{LFP}$ = 50% Annual = 12 cfs<br>$Q_{HFP}$ = 1% Annual = 2031 cfs | Total | 142 | 137 | 112 | 161 | 73 | 189 |
| | Min Event | 1 | 1 | 2 | 3 | 1 | 189 |
| | Max Event | 62 | 47 | 84 | 115 | 42 | 189 |

** - A median value is not reported when there are only two events during the year or migration period.

**Table B- 16. Topanga Creek storm characteristics and passage summary for median Wet, Dry and Average years determined using the mean daily flow record. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1938/Wet | 1943/Wet | 1936/Ave | 1946/Ave | 1976/Dry | 1964/Dry |
|---|---|---|---|---|---|---|---|
| Rank of 48 (Percentile) | | 5 (0.914) | 6 (0.893) | 24 (0.510) | 25 (0.489) | 43 (0.106) | 44 (0.085) |
| (Data Sample Period) | | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) | (Daily) |
| **Number of Storm Events** | | 6 | 6 | 6 | 5 | 2 | 4 |
| Storm Qpeak (cfs) | Median | 441 | 107.5 | 27.5 | 27 | ---** | 9.8 |
| | Min | 135 | 15 | 6.5 | 4.7 | 3.2 | 6.9 |
| | Max | 2670 | 1110 | 77 | 182 | 24 | 17 |
| **Low Flow Delay (Days)** | | | | | | | |
| $Q_{LFP}$ = 3 cfs | Total | 106 | 116 | 157 | 183 | 194 | 192 |
| | Median Event | 6 | 32 | 28 | 37 | 75 | 44 |
| | Min Event | 1 | 3 | 9 | 8 | 19 | 9 |
| | Max Event | 51 | 81 | 92 | 50 | 100 | 61 |
| **High Flow Delay (Days)** | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr = 540 cfs | Total | 2 | 2 | 0 | 0 | 0 | 0 |
| | Median Event | ---** | 2 | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 2 | 0 | 0 | 0 | 0 |
| | Max Event | 1 | 2 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 50% Q2-yr Emp = 135 cfs | Total | 9 | 6 | 0 | 2 | 0 | 0 |
| | Median Event | 2 | 1.5 | 0 | 2 | 0 | 0 |
| | Min Event | 1 | 1 | 0 | 2 | 0 | 0 |
| | Max Event | 4 | 2 | 0 | 2 | 0 | 0 |
| $Q_{HFP}$ = 1% MigPer = 202 cfs | Total | 8 | 4 | 0 | 0 | 0 | 0 |
| | Median Event | 3 | ---** | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 2 | 0 | 0 | 0 | 0 |
| | Max Event | 4 | 2 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 1% Annual = 92 cfs | Total | 11 | 9 | 0 | 3 | 0 | 0 |
| | Median Event | 2 | 3 | 0 | ---** | 0 | 0 |
| | Min Event | 1 | 3 | 0 | 1 | 0 | 0 |
| | Max Event | 5 | 3 | 0 | 2 | 0 | 0 |
| **Passage Window (Days)** | | | | | | | |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 50% Q2-yr = 540 cfs | Total | 88 | 78 | 40 | 13 | 3 | 5 |
| | Min Event | 1 | 1 | 2 | 1 | 1 | 1 |
| | Max Event | 51 | 52 | 32 | 5 | 2 | 2 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 50% Q2-yr Emp = 135 cfs | Total | 81 | 74 | 40 | 11 | 3 | 3 |
| | Min Event | 1 | 1 | 2 | 1 | 1 | 1 |
| | Max Event | 40 | 40 | 32 | 5 | 2 | 2 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 1% MigPer =202 cfs | Total | 82 | 76 | 40 | 13 | 3 | 5 |
| | Min Event | 1 | 1 | 2 | 1 | 1 | 1 |
| | Max Event | 40 | 40 | 32 | 5 | 2 | 2 |
| $Q_{LFP}$ = 3 cfs<br>$Q_{HFP}$ = 1% Annual = 92 cfs | Total | 79 | 71 | 40 | 10 | 3 | 5 |
| | Min Event | 1 | 1 | 2 | 1 | 1 | 1 |
| | Max Event | 40 | 39 | 32 | 3 | 2 | 2 |

** - A median value is not reported when there are only two events during the year or migration period.

**Table B- 17. Lopez Creek storm characteristics and passage summary for median Wet, Dry and Average years determined comparing results using the mean daily and 15-minute flow records. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1995/Wet | | 2005/Wet | | 2001/Ave | | 2010/Ave | | 1989/Dry | | 2009/Dry | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank of 44 (Percentile) | | 6 (0.883) | | 9 (0.813) | | 18 (0.604) | | 21 (0.534) | | 38 (0.139) | | 42 (0.046) | |
| (Data Interval) | | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) |
| **Number of Storm Events** | | 7 | | 4 | | 4 | | 4 | | 3 | | 2 | |
| Storm Qpeak (cfs) | Median | 130 | 242 | 265 | 754 | 68.5 | 81 | 107.5 | 234 | 13 | 18 | ---** | ---** |
| | Min | 19 | 52 | 91 | 169 | 24 | 49 | 15 | 25 | 9.7 | 13 | 6.8 | 16 |
| | Max | 594 | 2080 | 465 | 2020 | 450 | Missing | 148 | 313 | 40 | 163 | 9 | 22 |
| **Low Flow Delay (Days)** | | | | | | | | | | | | | |
| QLFP = 50% Annual = 3.8 cfs | Total | 63 | 61.9 | 0 | 0.4 | 54 | 47.0 | 59 | 60.9 | 76 | 80.6 | 179 | 181.6 |
| | Median Event | 63 | 9.00 | 0 | 0.01 | 4.5 | 0.01 | 10.5 | 0.03 | 14 | 10.20 | 28.5 | 0.02 |
| | Min Event | 63 | 7.34 | 0 | 0.01 | 1 | 0.01 | 2 | 0.01 | 1 | 0.01 | 1 | 0.01 |
| | Max Event | 63 | 28.11 | 0 | 0.05 | 28 | 17.50 | 36 | 36.20 | 20 | 19.20 | 70 | 43.00 |
| **High Flow Delay (Days)** | | | | | | | | | | | | | |
| QHFP = 50% Q2-yr = 186 cfs | Total | 4 | 3.67 | 4 | 3.54 | 1 | 0.22 | 0 | 0.57 | 0 | 0.00 | 0 | 0.00 |
| | Median Event | 1 | 0.11 | 1 | 0.66 | 1 | 0.00 | 0 | 0.19 | 0 | 0.00 | 0 | 0.00 |
| | Min Event | 1 | 0.00 | 1 | 0.00 | 1 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | Max Event | 2 | 1.81 | 2 | 2.21 | 1 | 0.11 | 0 | 0.21 | 0 | 0.00 | 0 | 0.00 |
| QHFP = 1% MigPer = 182 cfs | Total | 4 | 3.69 | 4 | 3.61 | 1 | 0.25 | 0 | 0.68 | 0 | 0.00 | 0 | 0.00 |
| | Median Event | 1 | 0.11 | 1 | 0.66 | 1 | 0.00 | 0 | 0.22 | 0 | 0.00 | 0 | 0.00 |
| | Min Event | 1 | 0.00 | 1 | 0.00 | 1 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | Max Event | 2 | 1.83 | 2 | 2.25 | 1 | 0.14 | 0 | 0.24 | 0 | 0.00 | 0 | 0.00 |
| QHFP = 1% Annual = 125 cfs | Total | 6 | 5.86 | 6 | 5.03 | 1 | 1.66 | 2 | 2.91 | 0 | 0.00 | 0 | 0.00 |
| | Median Event | 1 | 0.58 | 1 | 0.91 | 1 | 0.00 | 2 | 0.66 | 0 | 0.00 | 0 | 0.00 |
| | Min Event | 1 | 0.01 | 1 | 0.32 | 1 | 0.00 | 2 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | Max Event | 2 | 2.28 | 2 | 2.89 | 1 | 0.29 | 2 | 1.59 | 0 | 0.00 | 0 | 0.00 |
| **Passage Window (Days)** | | | | | | | | | | | | | |
| QLFP = 50% Annual = 3.8 cfs<br>QHFP = 50% Q2-yr = 186 cfs | Total | 129 | 115.40 | 192 | 192.1 | 141 | 138.7 | 137 | 132.1 | 120 | 121.2 | 17 | 14.4 |
| | Min Event | 6 | 0.01 | 6 | 0.01 | 4 | 0.01 | 2 | 0.01 | 2 | 0.01 | 2 | 0.01 |
| | Max Event | 57 | 38.6 | 68 | 69.7 | 70 | 50.9 | 76 | 74.1 | 113 | 105.8 | 6 | 3.2 |
| QLFP = 50% Annual = 3.8 cfs<br>QHFP = 1% MigPer = 182 cfs | Total | 129 | 115.38 | 192 | 192.0 | 141 | 138.7 | 137 | 134.4 | 120 | 121.2 | 17 | 14.3 |
| | Min Event | 7 | 0.01 | 1 | 0.01 | 1 | 0.01 | 1 | 0.01 | 1 | 0.01 | 1 | 0.01 |
| | Max Event | 58 | 38.6 | 124 | 69.7 | 71 | 51.0 | 119 | 77.4 | 114 | 138.4 | 7 | 12.2 |
| QLFP = 50% Annual = 3.8 cfs<br>QHFP = 1% Annual = 125 cfs | Total | 127 | 113.2 | 190 | 190.6 | 141 | 137.3 | 135 | 134.5 | 120 | 121.1 | 17 | 14.3 |
| | Min Event | 7 | 0.01 | 1 | 0.01 | 1 | 0.01 | 1 | 0.01 | 1 | 0.01 | 1 | 0.01 |
| | Max Event | 53 | 38.3 | 69 | 59.5 | 71 | 51.0 | 77 | 77.3 | 114 | 129.3 | 7 | 12.2 |

**- A median value is not reported when there are only two events during the year or migration period.

**Table B- 18. Salsipuedes Creek storm characteristics and passage summary for median Wet, Dry and Average years determined comparing results using the mean daily and 15-minute flow records. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 2005/Wet | | 2001/Wet | | 1997/Ave | | 2003/Ave | | 2007/Dry | | 2009/Dry | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank of 70 (Percentile) | | 5 (0.942) | | 9 (0.884) | | 29 (0.594) | | 36 (0.492) | | 62 (0.115) | | 64 (0.086) | |
| (Data Interval) | | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) |
| **Number of Storm Events** | | 7 | | 6 | | 5 | | 7 | | 4 | | 1 | |
| Storm Qpeak (cfs) | Median | 664 | 2440 | 201.5 | 851 | 159 | 733 | 80 | 267 | 4.25 | 8.2 | 67 | 306 |
| | Min | 142 | 460 | 94 | 267 | 50 | 180 | 17 | 32 | 3.5 | 5.3 | 67 | 306 |
| | Max | 1600 | 3690 | 1990 | 5790 | 256 | 1250 | 503 | 1430 | 7.2 | 12 | 67 | 306 |
| **Low Flow Delay (Days)** | | | | | | | | | | | | | |
| QLFP = 3 cfs | Total | 56 | 55.8 | 69 | 69.5 | 62 | 60.6 | 136 | 136.4 | 188 | 189.7 | 190 | 190.6 |
| | Median Event | 56 | 27.90 | ---** | 34.70 | 13 | 0.45 | 7 | 1.15 | 39 | 10.70 | 85 | 0.05 |
| | Min Event | 56 | 18.90 | 1 | 1.16 | 1 | 0.01 | 2 | 0.01 | 10 | 0.01 | 8 | 0.01 |
| | Max Event | 56 | 36.90 | 68 | 68.30 | 20 | 20.60 | 37 | 36.10 | 81 | 81.10 | 97 | 72.30 |
| **High Flow Delay (Days)** | | | | | | | | | | | | | |
| QHFP = 50% Q2-yr = 732 cfs | Total | 7 | 5.84 | 3 | 2.42 | 0 | 0.23 | 0 | 0.45 | 0 | 0 | 0 | 0 |
| | Median Event | 1 | 0.40 | 3 | 0.06 | 0 | 0.01 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 0.00 | 3 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| | Max Event | 4 | 2.94 | 3 | 2.21 | 0 | 0.03 | 0 | 0.34 | 0 | 0 | 0 | 0 |
| QHFP = 1% MigPer = 399 cfs | Total | 12 | 8.98 | 5 | 4.18 | 0 | 0.72 | 1 | 0.67 | 0 | 0 | 0 | 0 |
| | Median Event | 1 | 0.51 | ---** | 0.17 | 0 | 0.19 | 1 | 0.00 | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 0.03 | 1 | 0.00 | 0 | 0.00 | 1 | 0.00 | 0 | 0 | 0 | 0 |
| | Max Event | 5 | 4.03 | 4 | 3.17 | 0 | 0.21 | 1 | 0.41 | 0 | 0 | 0 | 0 |
| QHFP = 1% Annual = 200 cfs | Total | 16 | 14.17 | 8 | 7.65 | 3 | 1.80 | 1 | 1.18 | 0 | 0 | 0 | 0.08 |
| | Median Event | 1 | 0.83 | 1 | 0.34 | ---** | 0.29 | 1 | 0.08 | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 0.40 | 1 | 0.19 | 1 | 0.00 | 1 | 0.00 | 0 | 0 | 0 | 0 |
| | Max Event | 6 | 5.30 | 6 | 5.52 | 2 | 0.84 | 1 | 0.55 | 0 | 0 | 0 | 0 |
| **Passage Window (Days)** | | | | | | | | | | | | | |
| QLFP = 3 cfs<br>QHFP = 50% Q2-yr = 732 cfs | Total | 133 | 134.4 | 124 | 124.10 | 134 | 135.1 | 60 | 59.2 | 8 | 6.3 | 6 | 5.4 |
| | Min Event | 2 | 0.01 | 1 | 1.01 | 2 | 0.03 | 1 | 0.01 | 1 | 0.02 | 2 | 0.01 |
| | Max Event | 82 | 54.2 | 70 | 70.2 | 114 | 76.2 | 15 | 14.0 | 4 | 1.5 | 4 | 3.4 |
| QLFP = 3 cfs<br>QHFP = 1% MigPer = 399 cfs | Total | 128 | 131.2 | 122 | 122.30 | 134 | 134.6 | 59 | 58.9 | 8 | 6.3 | 6 | 5.4 |
| | Min Event | 1 | 0.01 | 1 | 0.17 | 2 | 0.03 | 1 | 0.01 | 1 | 0.02 | 2 | 0.01 |
| | Max Event | 54 | 54.0 | 69 | 69.4 | 114 | 76.1 | 14 | 14.0 | 4 | 1.5 | 4 | 3.4 |
| QLFP = 3 cfs<br>QHFP = 1% Annual = 200 cfs | Total | 124 | 126.1 | 119 | 118.8 | 131 | 133.6 | 59 | 58.4 | 8 | 6.3 | 6 | 5.3 |
| | Min Event | 1 | 0.01 | 1 | 0.05 | 1 | 0.03 | 1 | 0.01 | 1 | 0.02 | 2 | 0.01 |
| | Max Event | 54 | 53.8 | 67 | 67.0 | 78 | 7.00 | 14 | 13.9 | 4 | 1.5 | 4 | 3.4 |

**- A median value is not reported when there are only two events during the year or migration period.

**Table B- 19. Sespe River storm characteristics and passage summary for median Wet, Dry and Average years determined comparing results using the mean daily and 15-minute flow records. The $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater and results are summarized for various $Q_{HFP}$ criteria as indicated.**

| Water Year/Type | | 1995/Wet[1] | | 1992/Wet | | 2003/Ave | | 2000/Ave | | 2007/Dry | | 2002/Dry | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank of 78 (Percentile) | | 6 (0.935) | | 10 (0.883) | | 34 (0.571) | | 39 (0.506) | | 71 (0.090) | | 74 (0.051) | |
| (Data Interval) | | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) | (Daily) | (15-min) |
| **Number of Storm Events** | | 7 | | 9 | | 8 | | 6 | | 6 | | 3 | |
| Storm Qpeak (cfs) | Median | 2610 | 5390 | 727 | 1440 | 968 | 1910 | 1120 | 2280 | 36 | 84.5 | 23 | 31 |
| | Min | 573 | 1270 | 468 | 944 | 111 | 163 | 174 | 542 | 29 | 66 | 16 | 26 |
| | Max | 28800 | 65000 | 17000 | 44000 | 2430 | 7230 | 2410 | 4900 | 248 | 604 | 30 | 93 |
| **Low Flow Delay (Days)** | | | | | | | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 12 cfs | Total | 19 | 28.2 | 57 | 56.8 | 38 | 32.3 | 84 | 85.2 | 7 | 6.8 | 34 | 35.0 |
| | Median Event | 4.5 | 0.02 | 57 | 0.05 | ---** | 1.00 | 6 | 0.24 | 7 | 0.09 | ---** | 0.38 |
| | Min Event | 1 | 0.01 | 57 | 0.03 | 7 | 0.01 | 1 | 0.05 | 7 | 0.01 | 12 | 0.01 |
| | Max Event | 9 | 12.00 | 57 | 56.70 | 31 | 31.10 | 77 | 77.57 | 7 | 6.30 | 22 | 11.70 |
| **High Flow Delay (Days)** | | | | | | | | | | | | | |
| $Q_{HFP}$ = 50% Q2-yr = 4392 cfs | Total | 4 | 5.38 | 4 | 4.34 | 0 | 0.54 | 0 | 0.07 | 0 | 0 | 0 | 0 |
| | Median Event | ---** | 0.06 | 4 | 0.18 | 0 | 0.14 | 0 | 0.07 | 0 | 0 | 0 | 0 |
| | Min Event | 2 | 0.01 | 4 | 0.01 | 0 | 0.09 | 0 | 0.07 | 0 | 0 | 0 | 0 |
| | Max Event | 2 | 2.53 | 4 | 2.12 | 0 | 0.22 | 0 | 0.07 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 1% MigPer = 3708 cfs | Total | 7 | 6.24 | 5 | 4.84 | 0 | 1.00 | 0 | 0.20 | 0 | 0 | 0 | 0 |
| | Median Event | 3 | 0.28 | ---** | 0.51 | 0 | 0.10 | 0 | 0.10 | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 0.01 | 1 | 0.01 | 0 | 0.02 | 0 | 0.08 | 0 | 0 | 0 | 0 |
| | Max Event | 3 | 4.05 | 4 | 3.76 | 0 | 0.27 | 0 | 0.11 | 0 | 0 | 0 | 0 |
| $Q_{HFP}$ = 1% Annual = 2031 cfs | Total | 11 | 10.09 | 8 | 7.96 | 3 | 2.20 | 1 | 1.49 | 0 | 0 | 0 | 0 |
| | Median Event | 2.5 | 0.44 | | 0.79 | 1 | 0.38 | 1 | 0.07 | 0 | 0 | 0 | 0 |
| | Min Event | 1 | 0.01 | 1 | 0.14 | 1 | 0.01 | 1 | 0.01 | 0 | 0 | 0 | 0 |
| | Max Event | 5 | 4.05 | 7 | 4.41 | 1 | 0.75 | 1 | 0.34 | 0 | 0 | 0 | 0 |
| **Passage Window (Days)** | | | | | | | | | | | | | |
| $Q_{LFP}$ = 50% Annual = 12 cfs<br>$Q_{HFP}$ = 50% Q2-yr Peak = 4392 cfs | Total | 173 | 141.10 | 136 | 135.8 | 158 | 156.3 | 113 | 105.7 | 189 | 186.6 | 162 | 147.0 |
| | Min Event | 4 | 0.01 | 44 | 0.01 | 7 | 0.01 | 2 | 0.01 | 189 | 0.01 | 162 | 0.02 |
| | Max Event | 110 | 53.40 | 92 | 53.7 | 151 | 58.1 | 84 | 82.4 | 189 | 185.0 | 162 | 137.3 |
| $Q_{LFP}$ = 50% Annual = 12 cfs<br>$Q_{HFP}$ = 1% MigPer = 3708 cfs | Total | 170 | 140.20 | 135 | 135.3 | 158 | 155.8 | 112 | 105.6 | 189 | 186.6 | 162 | 147.0 |
| | Min Event | 4 | 0.01 | 1 | 0.01 | 7 | 0.01 | 2 | 0.01 | 189 | 0.01 | 162 | 0.02 |
| | Max Event | 53 | 53.40 | 44 | 53.6 | 151 | 58.1 | 84 | 82.2 | 189 | 185.0 | 162 | 137.3 |
| $Q_{LFP}$ = 50% Annual = 12 cfs<br>$Q_{HFP}$ = 1% Annual = 2031 cfs | Total | 166 | 136.4 | 132 | 132.2 | 155 | 154.6 | 113 | 104.3 | 189 | 186.6 | 162 | 147.0 |
| | Min Event | 4 | 0.01 | 35 | 0.01 | 7 | 0.01 | 2 | 0.01 | 189 | 0.01 | 162 | 0.02 |
| | Max Event | 53 | 52.90 | 53 | 52.8 | 58 | 58.0 | 97 | 40.1 | 189 | 185.0 | 162 | 137.3 |

** - A median value is not reported when there are only two events during the year or migration period.

[1] - The 15-minute data for water year 1995 is not complete but it was the most complete available near the median wet year.

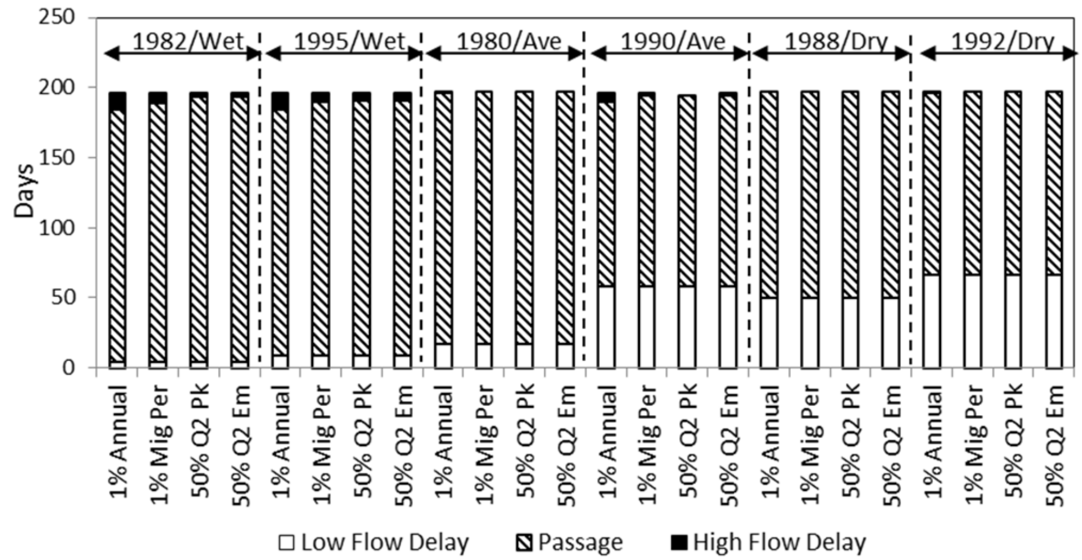



**Figure B- 1. Jetty Creek (Pacific NW region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

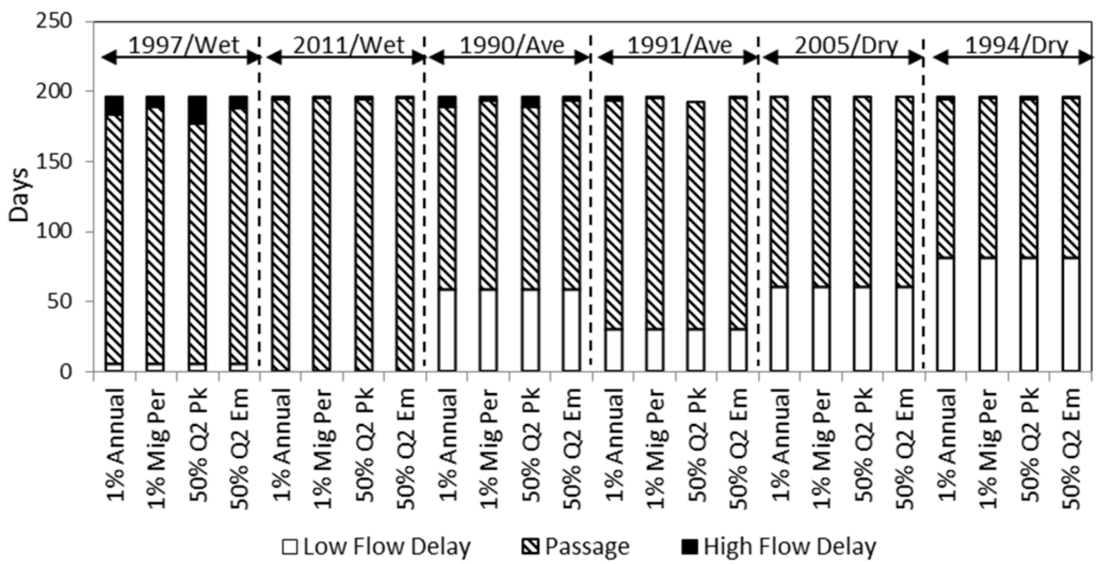



**Figure B- 2. Tucca Creek (Pacific NW region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

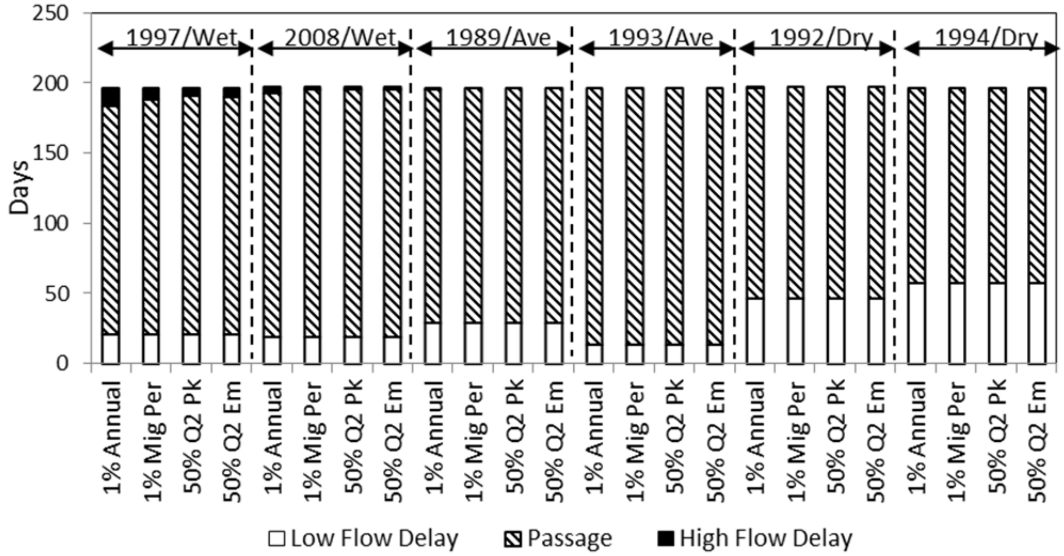



**Figure B- 3. East Fork Lobster Creek (Pacific NW region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

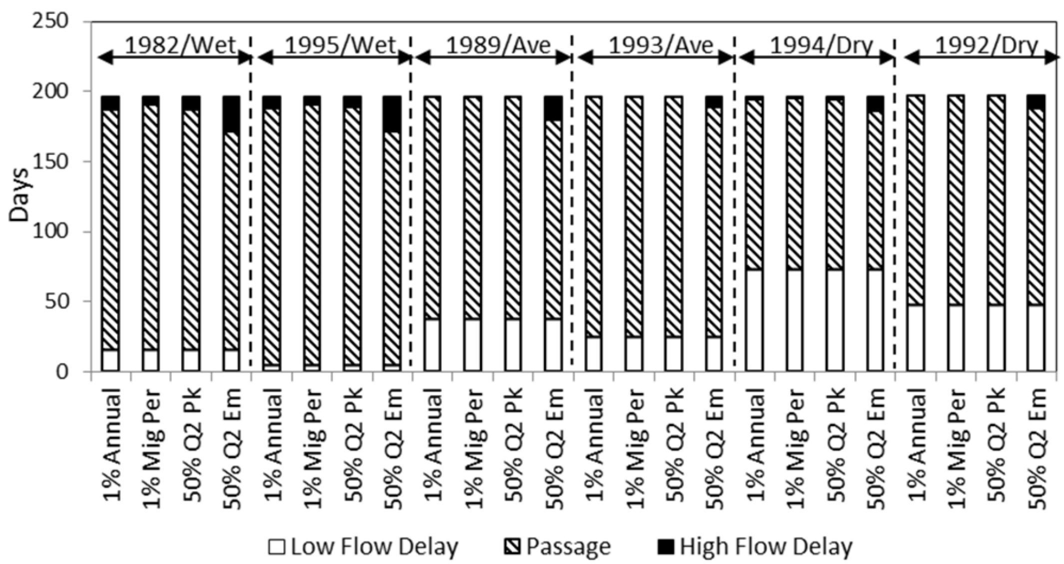



**Figure B- 4. Salmon River (Pacific NW region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

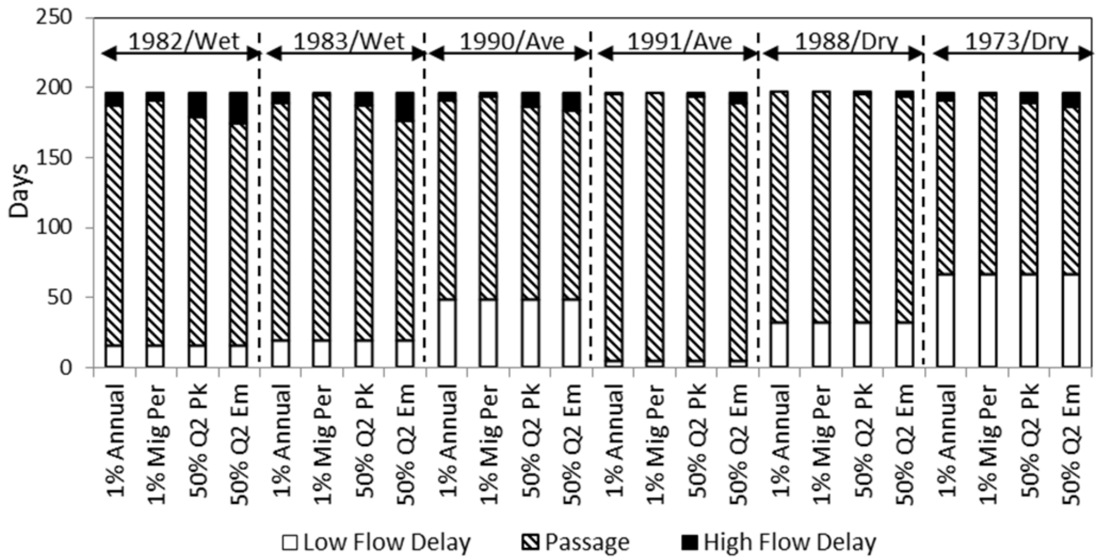



**Figure B- 5. Big Creek (Pacific NW region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

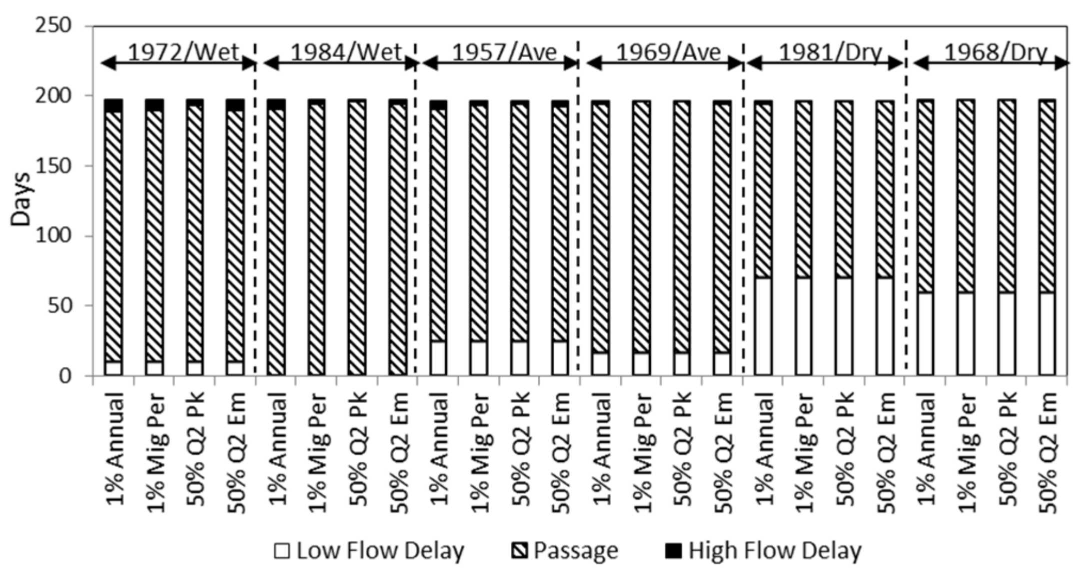



**Figure B- 6. Little River (Northern California region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

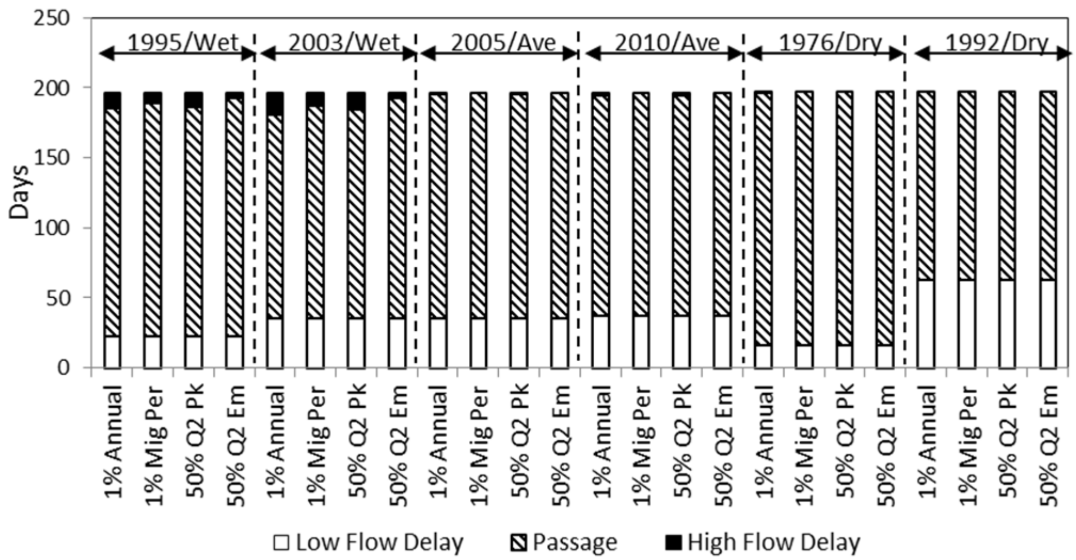



**Figure B- 7. Elder Creek (Northern California region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

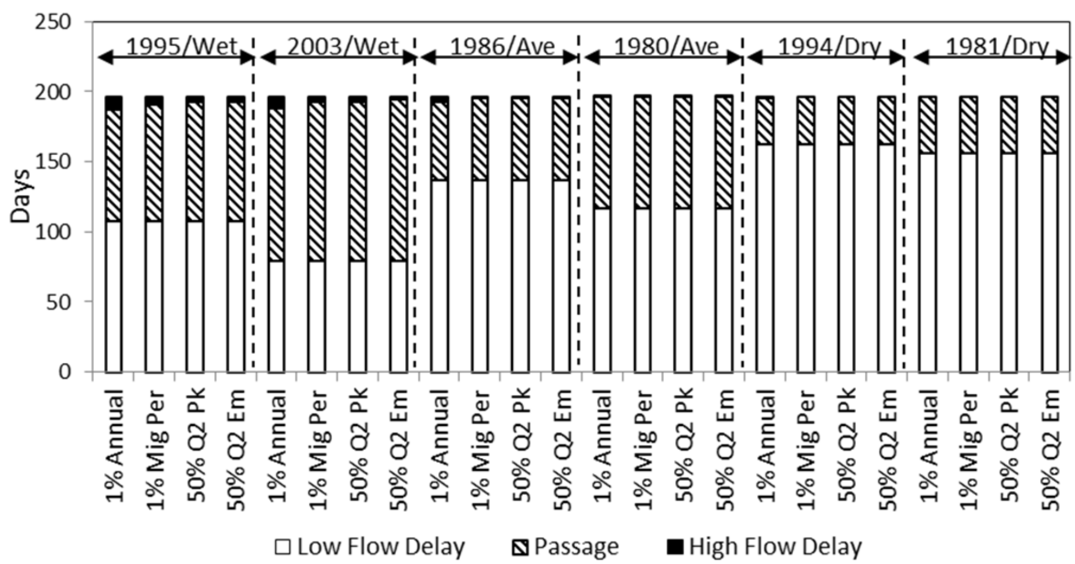



**Figure B- 8. North Fork Caspar Creek (Northern California region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

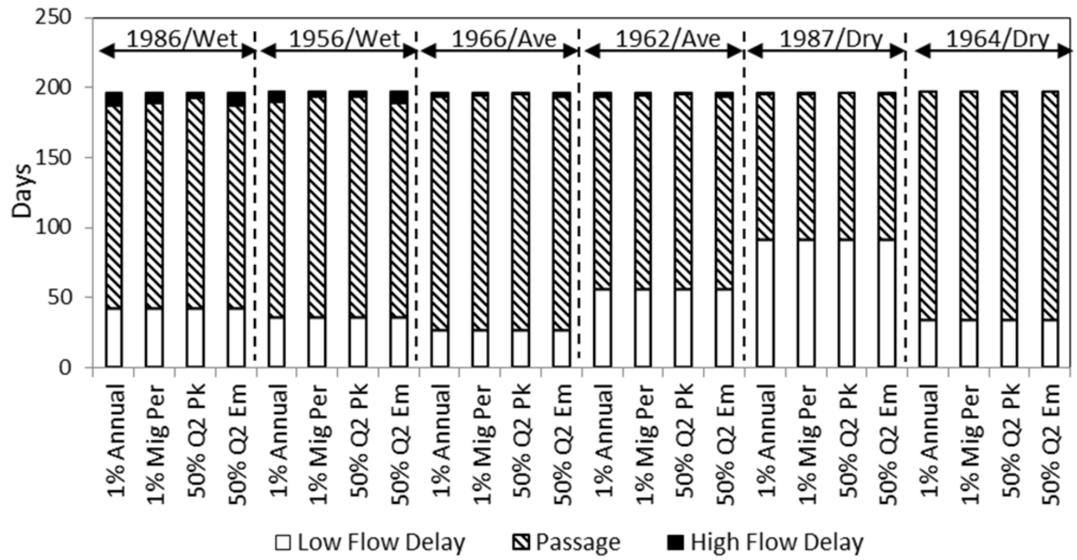



**Figure B- 9. Corte Madera Creek (Northern California region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

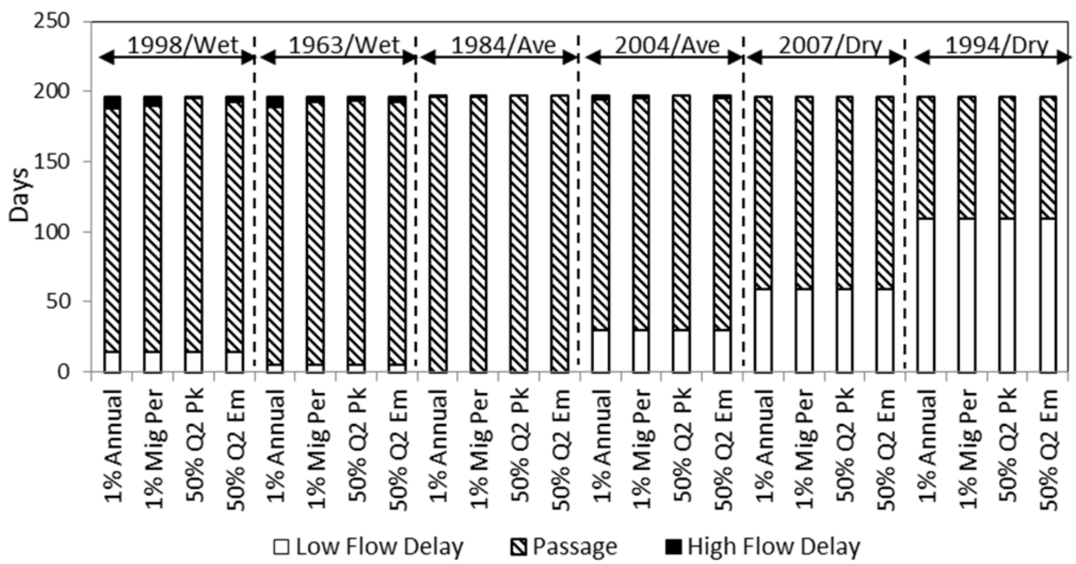



**Figure B- 10. Soquel Creek (Northern California region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

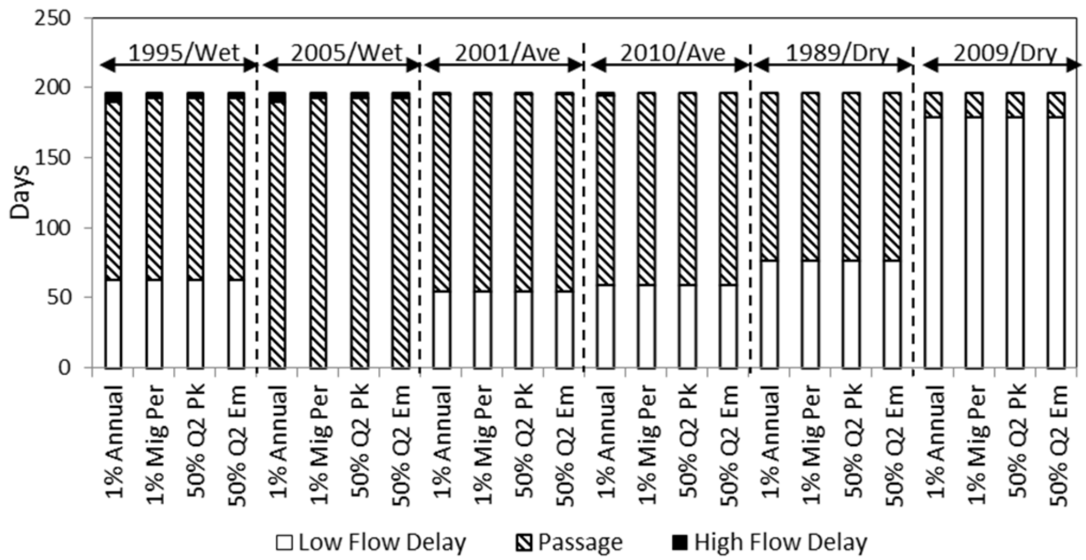



**Figure B- 11. Lopez Creek (Southern California region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

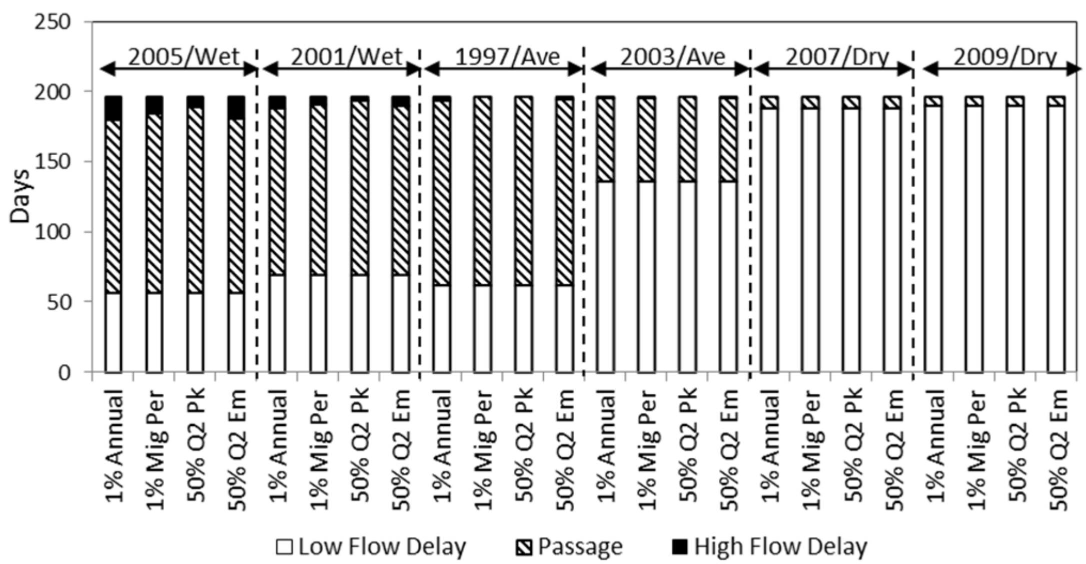



**Figure B- 12. Salsipuedes Creek (Southern California region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

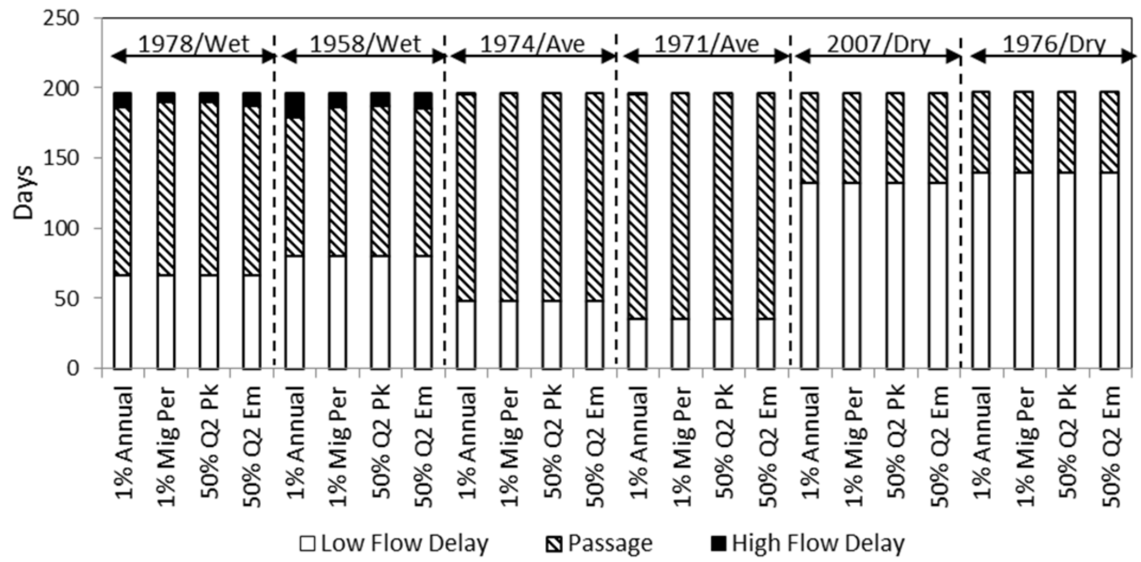



**Figure B- 13. Santa Cruz Creek (Southern California region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

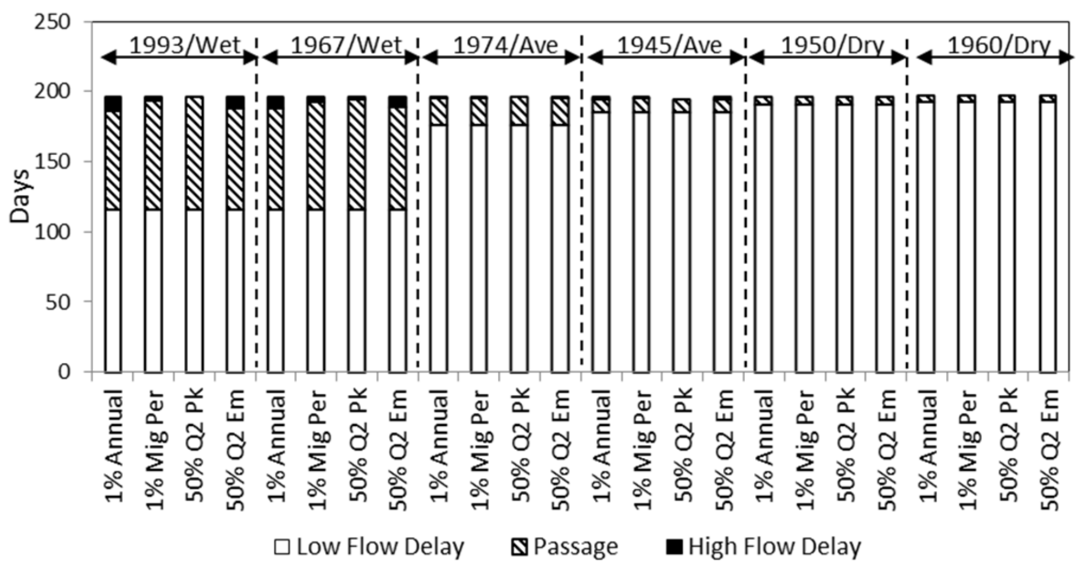



**Figure B- 14. San Jose Creek (Southern California region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

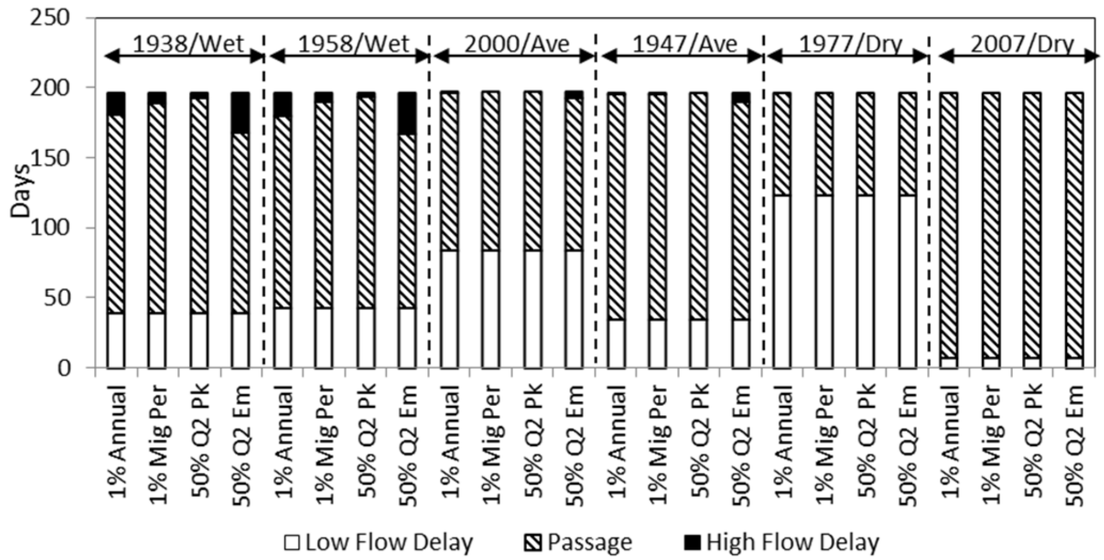



**Figure B- 15. Sespe River (Southern California region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

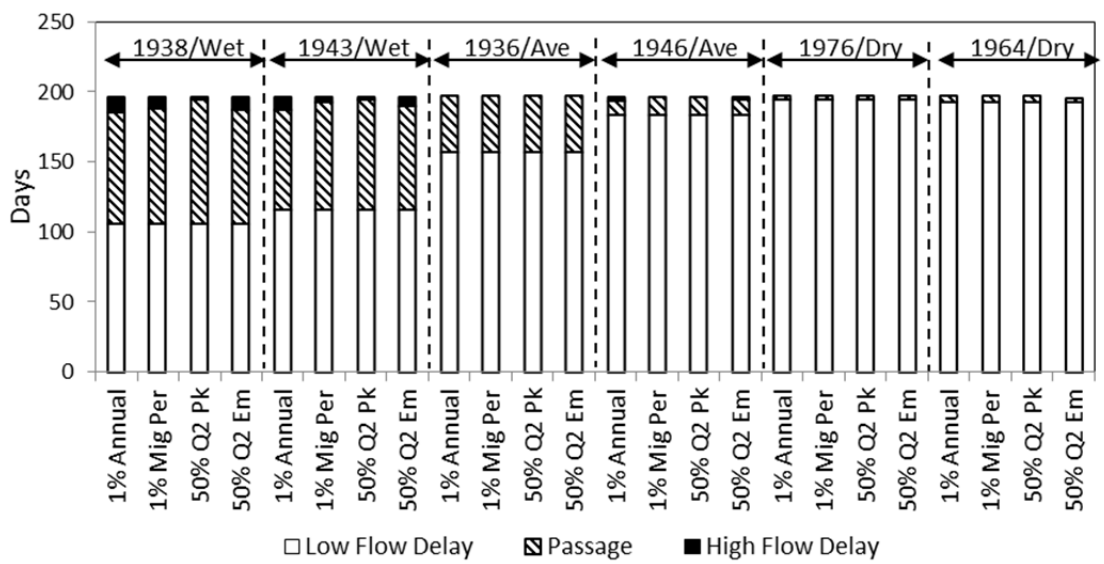



**Figure B- 16. Topanga Creek (Southern California region) adult salmonid passage summary for median Wet, Average and Dry years during the assumed steelhead migration period (Nov 1 – May 15). The x-axis shows the $Q_{HFP}$ criteria. $Q_{LFP}$ was either the 50% annual exceedance flow or 3 cfs whichever was greater.**

# APPENDIX C – SITE SPECIFIC PASSAGE SUMMARIES

Appendix C supplements material presented in Section 5.2 and presents analysis of the high and low flow delay resulting from different $Q_{HFP}$ and $Q_{LFP}$ criteria determined using the program described in Section 5 and the mean daily flow record for each of the 16 project study sites.

Figure C- 1 through Figure C- 4 summarize the range of high flow delay by study site for the four highest value $Q_{HFP}$ criteria for adult salmonid passage over the assumed steelhead migration period of Nov 1 – May 15. The figures are presented in approximate order of decreasing magnitude for $Q_{HFP}$ such that Figure C- 1 ($Q_{HFP}$ = $Q_{2\text{-year}}$ from peak flow data) shows results for the highest $Q_{HFP}$ value and Figure C- 4 ($Q_{HFP}$ = 1% annual exceedance flow) shows the lowest value for most sites. The sites are also arranged from north-to-south moving from the left to right on the plot x-axis. These results show how the number of days of high flow delay per year increases as $Q_{HFP}$ decreases. This increase in high flow delay with a change in $Q_{HFP}$ is greater for the more southern sites because of the larger variation in $Q_{HFP}$ magnitude for the different criteria definitions (see Section 4.2). This result is most prevalent in the number and magnitude of outlier values as $Q_{HFP}$ decreases.

Figure C- 5 through Figure C- 16 use the same data as Figure C- 1 through Figure C- 4 but present it for the Wet, Average, and Dry years at the southern California, northern California and Pacific Northwest study sites, respectively. The Wet, Average and Dry water years are determined as described above in Section 3.1. This set of regional result figures are ordered with the $Q_{HFP}$ criteria of 50% of $Q_{2\text{-year}}$ from peak flow data as the first figure in each set. This $Q_{HFP}$ value is the highest $Q_{HFP}$ for all of the southern California sites and the highest or approximately equal to the 2-year recurrence interval flow determined using USGS regression equations for the northern California and Pacific Northwest study sites.

Figure C- 17 through Figure C- 20 also present the same results but composite the delay in Wet, Average and Dry years by region. These result figures confirm the observations from all years composited together in Figure C- 1 through Figure C- 4 but more explicitly quantify the decrease in high flow delay (increase in fish passage window) for adult salmonids over the assumed steelhead migration period of Nov 1 – May 15 that would occur in the wet and average years for the different $Q_{HFP}$ criteria. As expected, no change in high flow delays was observed for the Dry years.

Figure C- 21 and Figure C- 22 compare the adult salmonid low flow delay for the Wet, Average, and Dry years at each of the southern and northern California study sites over the assumed steelhead migration period, respectively. The $Q_{LFP}$ criteria used for these analyses were the current California criteria, 50% of the annual exceedance or 3 cfs whichever is greater. As expected, low flow delays are longest in dry years and at the more southern sites. Watershed area is also an influence on low flow delay with the smaller watersheds [NF Caspar Ck (DA= 1.83 sq. mi.), San Jose Ck (DA= 5.51 sq. mi.), and Topanaga Ck (DA= 18.0 sq. mi.)] showing the longest low flow delays in their respective regions.

Figure C- 23 through Figure C- 28 show the adult salmonid percent time of high passage delay relative to passage time for the Southern California study sites for the various $Q_{HFP}$ values analyzed. This percentage is calculated for each water year as:

$$100\% \times \frac{\#\ of\ days\ exceeding\ Q_{HFP}}{\#\ of\ days\ meeting\ passage\ criteria\ (Q_{LFP} \leq Q \leq Q_{HFP})}$$

These box plots were created using all years of each site's data and do not distinguish the Wet, Average or Dry water years.

Figure C- 29 to Figure C- 33 summarize the percent of passage time for the Southern California region sites during a Nov.1 to May 15 migration period calculated as:

$$100\% \times \frac{\#\ of\ days\ meeting\ passage\ criteria\ (Q_{LFP} \leq Q \leq Q_{HFP})}{migration\ period\ (196\ day)}$$

These box plots were also created using all years of each site's data and do not distinguish the Wet, Average or Dry water years.

# List of Figures

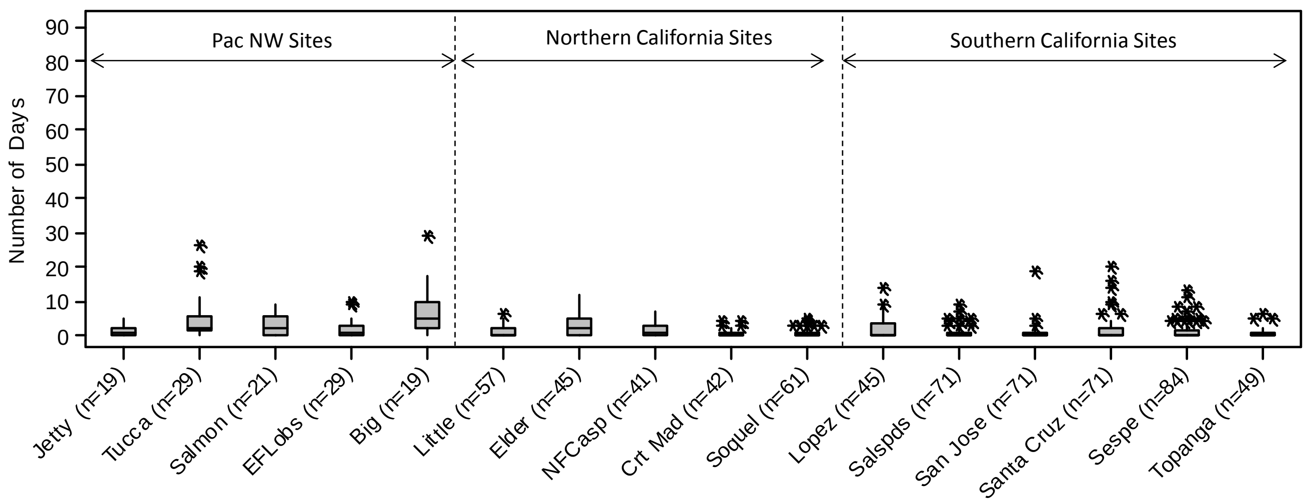



**Figure C- 1. High flow delay - number of days per year above $Q_{HFP}$ = 50% of $Q_{2\text{-year}}$ flow from peak data over the assumed steelhead migration period of Nov 1 – May 15.**

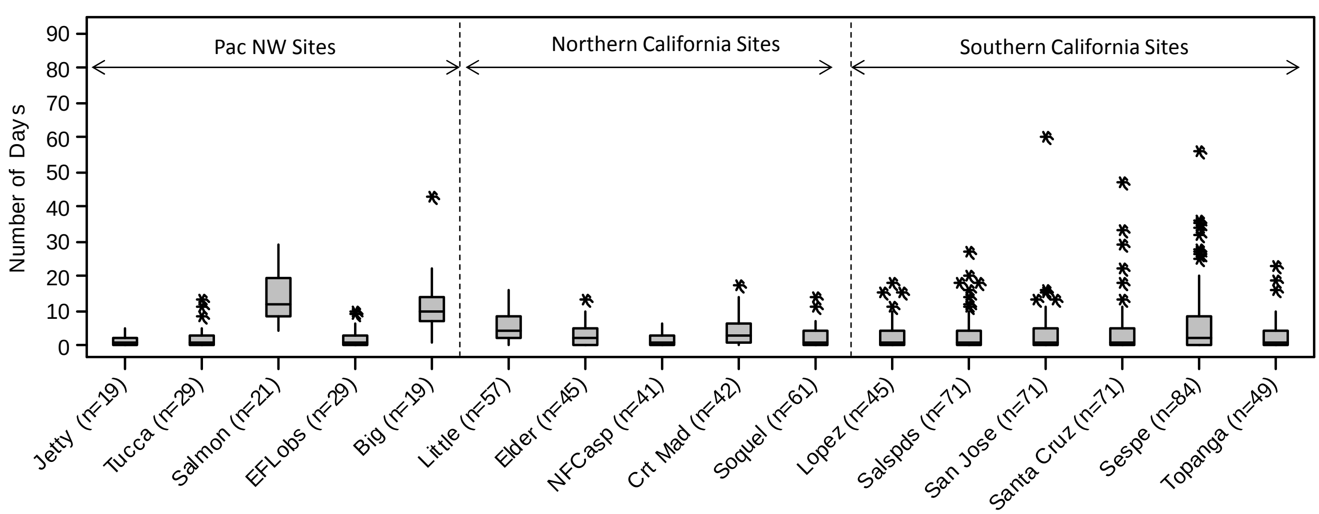



**Figure C- 2. High flow delay - number of days per year above $Q_{HFP}$ = 50% of $Q_{2\text{-year}}$ estimated using USGS regression equations over the assumed steelhead migration period of Nov 1 – May 15.**

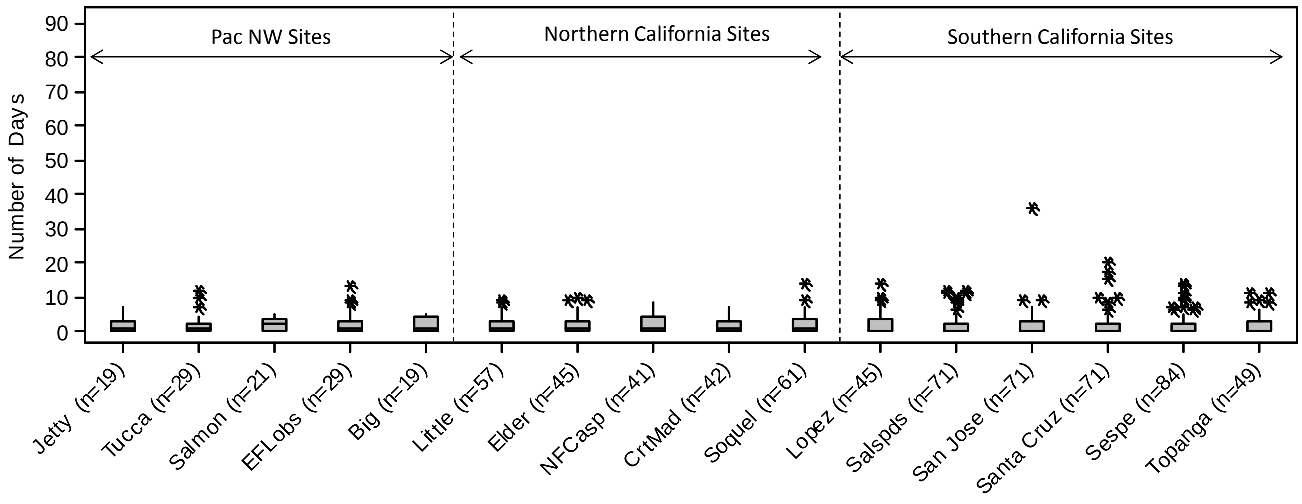



**Figure C- 3. High flow delay – number of days per year above $Q_{HFP}$ = 1% steelhead migration period exceedance flow over the assumed steelhead migration period of Nov 1 – May 15.**

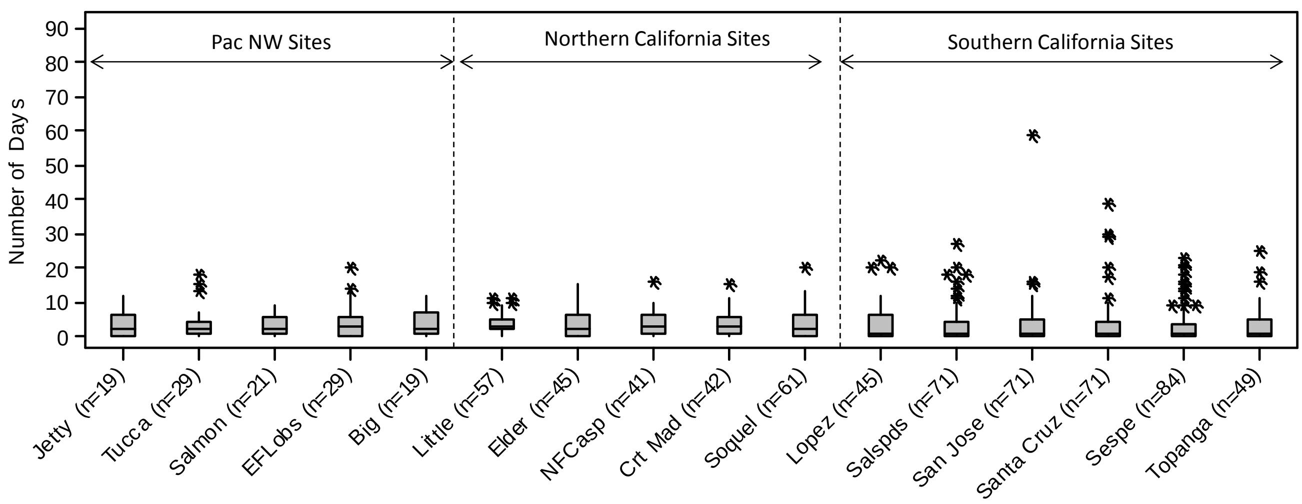



**Figure C- 4. High flow delay – number of days per year above $Q_{HFP}$ = 1% annual exceedance flow over the assumed steelhead migration period of Nov 1 – May 15.**

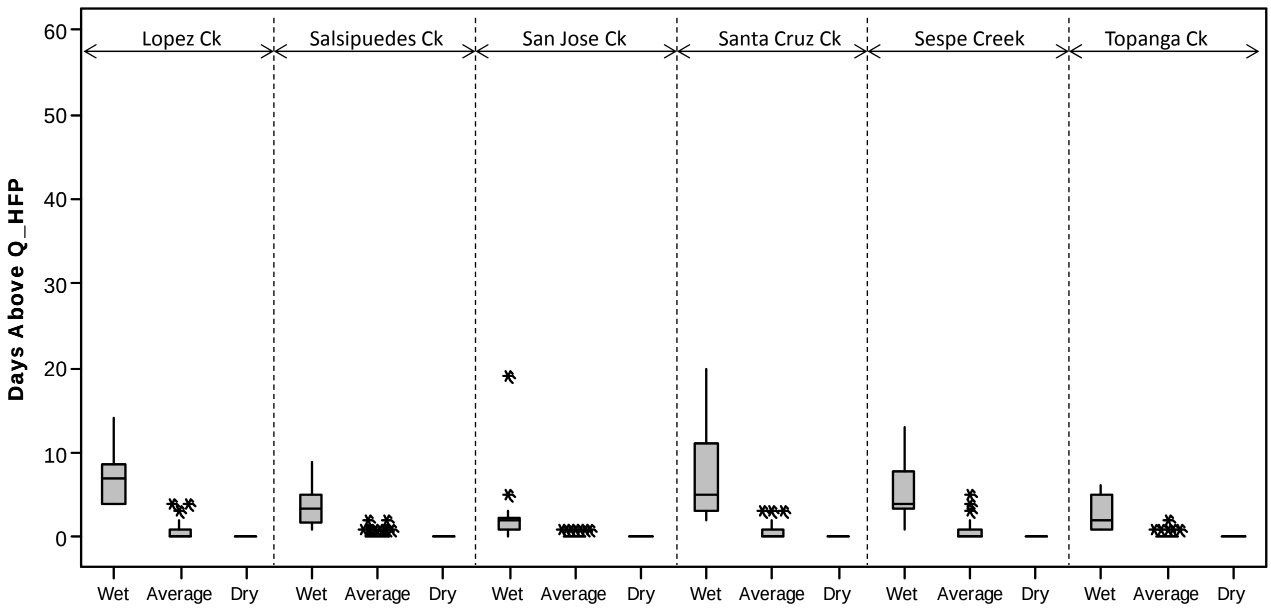



**Figure C- 5. Southern California site high flow delays (number of days per year above $Q_{HFP}$ = 50% of $Q_{2\text{-}year}$ flow from peak data) by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

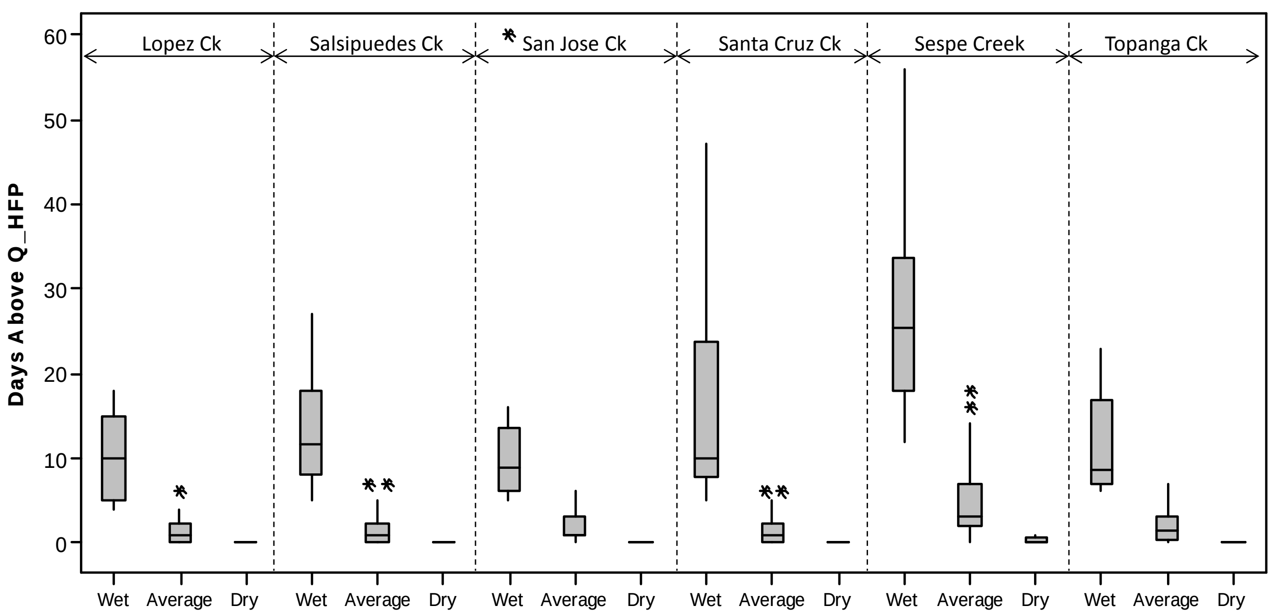



**Figure C- 6. Southern California site high flow delays (number of days per year above $Q_{HFP}$ = 50% of $Q_{2\text{-}year}$ flow from USGS regression equations) by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

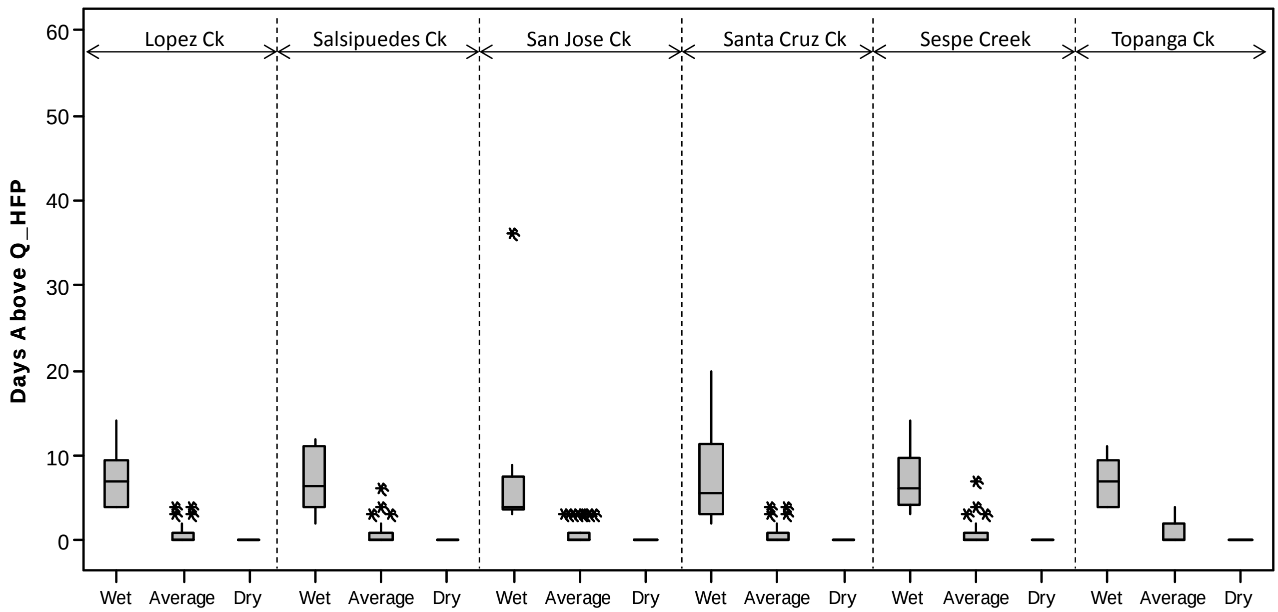



**Figure C- 7. Southern California site high flow delays (number of days per year above $Q_{HFP}$ = 1% Migration Period Exceedance flow by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

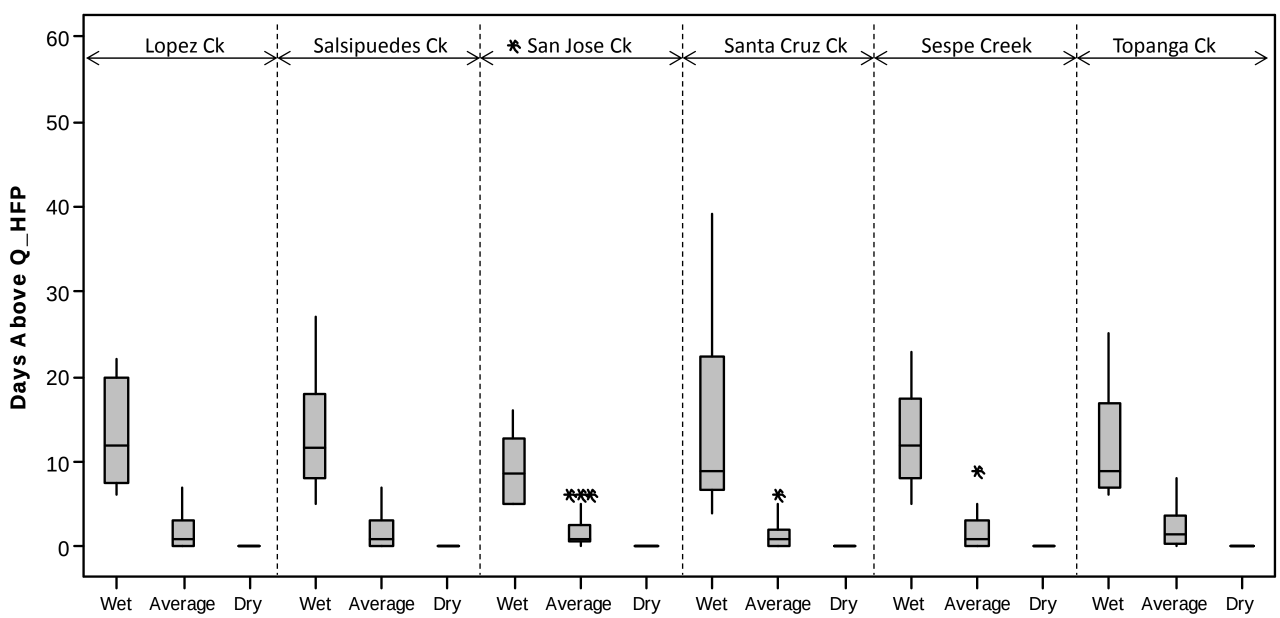



**Figure C- 8. Southern California site high flow delays (number of days per year above $Q_{HFP}$ = 1% Annual Exceedance flow by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

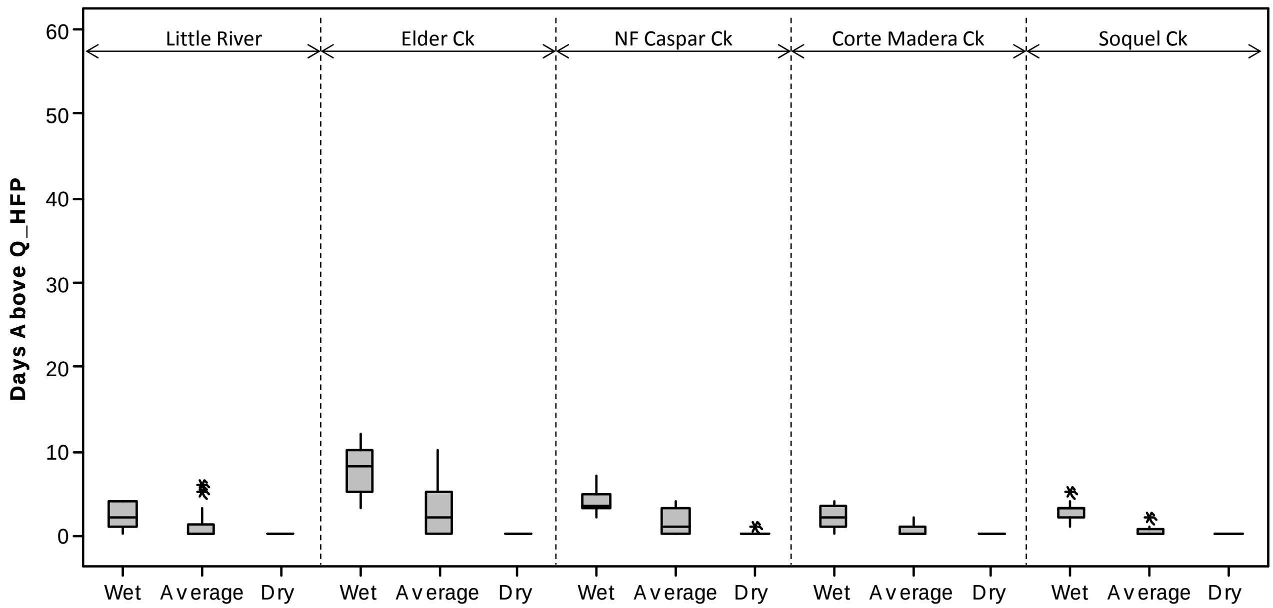



**Figure C- 9. Northern California site high flow delays (number of days per year above $Q_{HFP}$ = 50% of $Q_{2\text{-year}}$ flow from peak data) by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

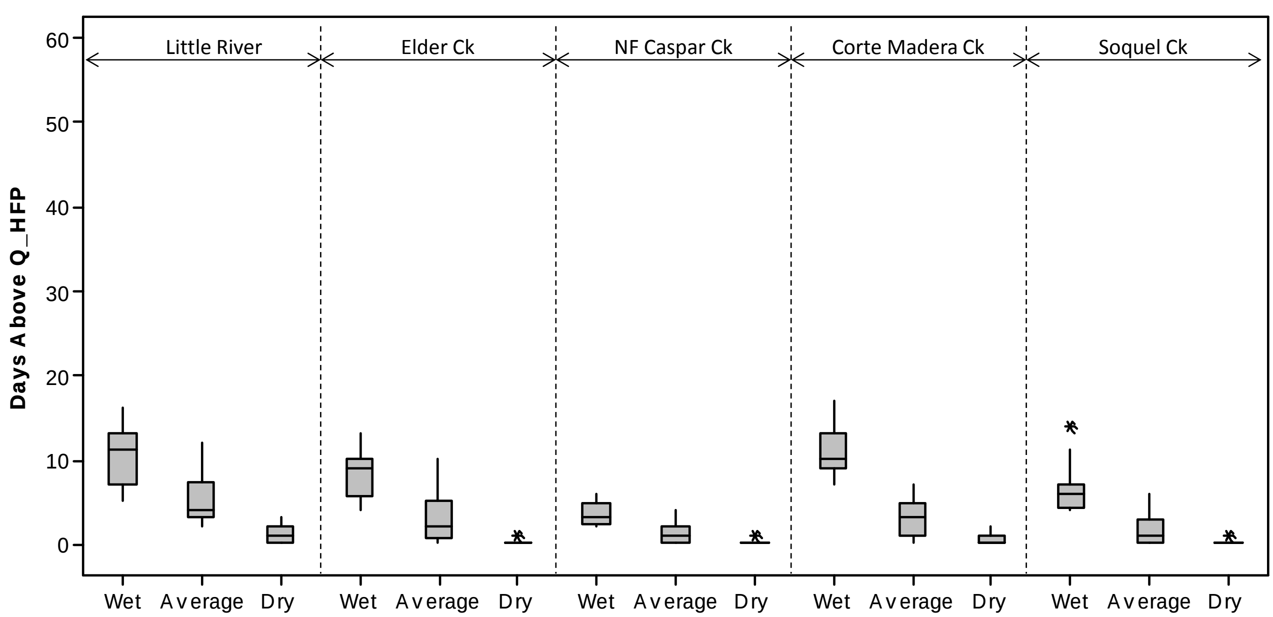



**Figure C- 10. Northern California site high flow delays (number of days per year above $Q_{HFP}$ = 50% of $Q_{2\text{-year}}$ flow from USGS regression equations) by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

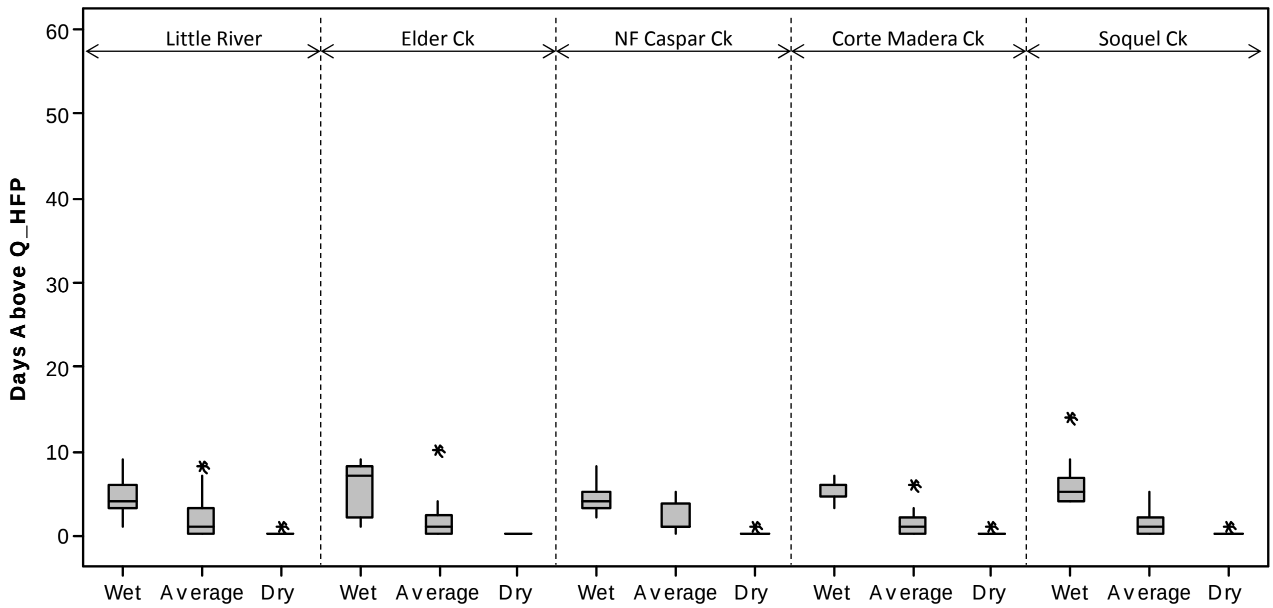



**Figure C- 11. Northern California site high flow delays (number of days per year above $Q_{HFP}$ = 1% Migration Period Exceedance flow by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

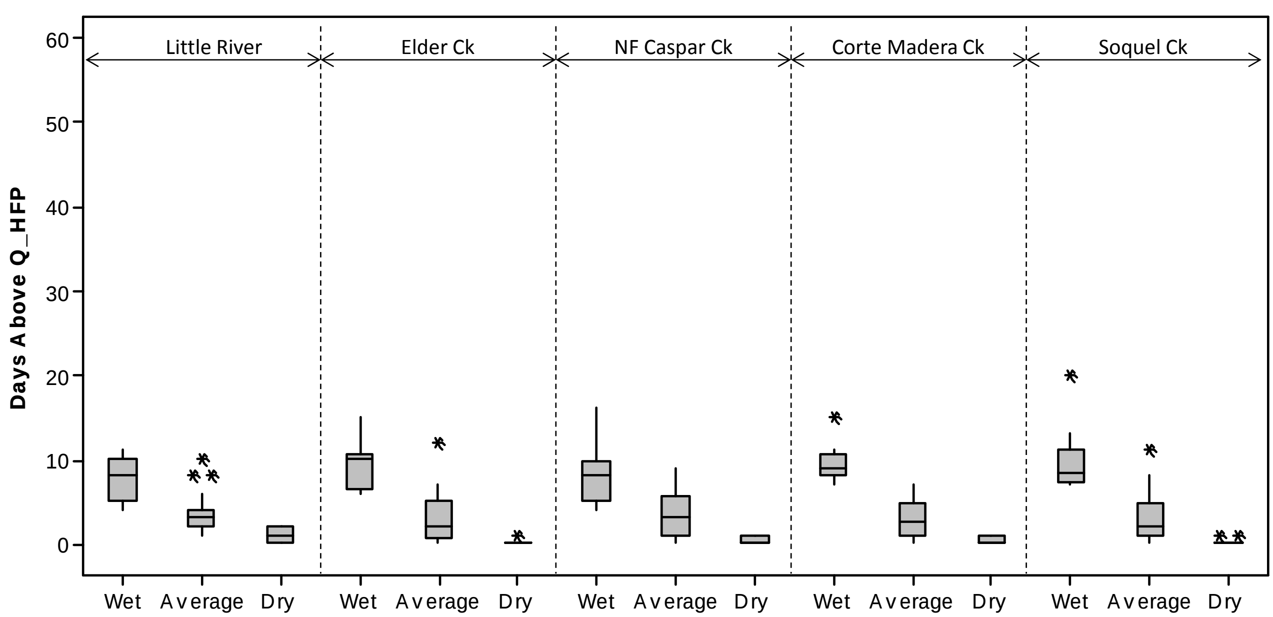



**Figure C- 12. Northern California site high flow delays (number of days per year above $Q_{HFP}$ = 1% Annual Exceedance flow by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

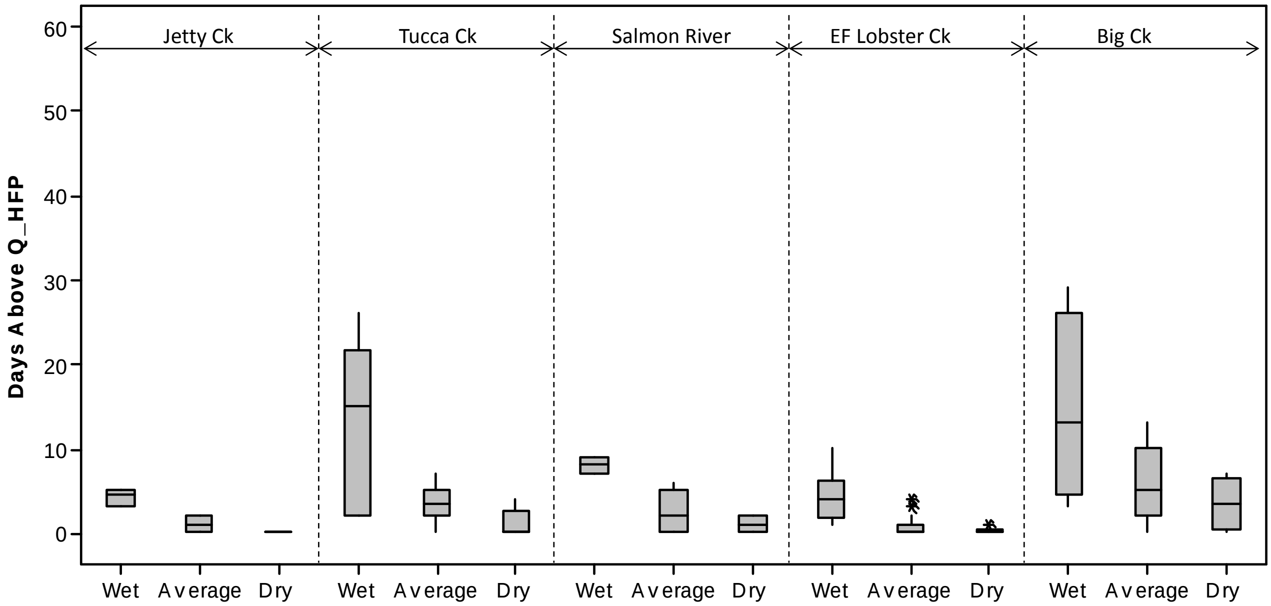



**Figure C- 13. Pacific Northwest site high flow delays (number of days per year above $Q_{HFP}$ = 50% of $Q_{2\text{-}year}$ flow from peak data) by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

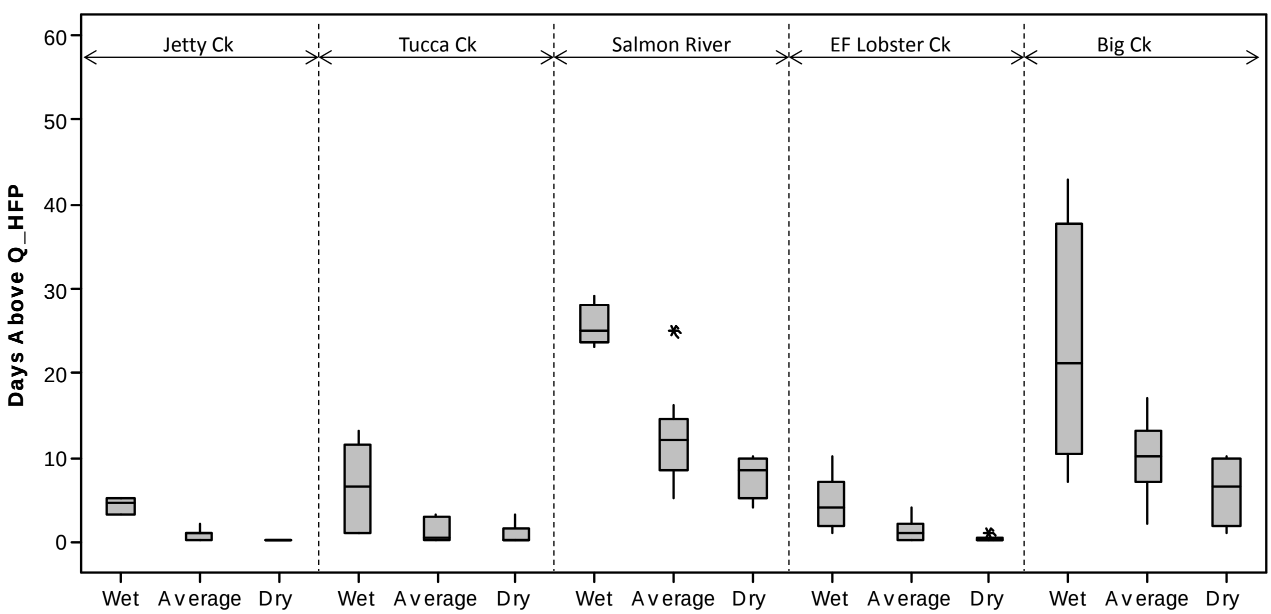



**Figure C- 14. Pacific Northwest site high flow delays (number of days per year above $Q_{HFP}$ = 50% of $Q_{2\text{-}year}$ flow from USGS regression equations) by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

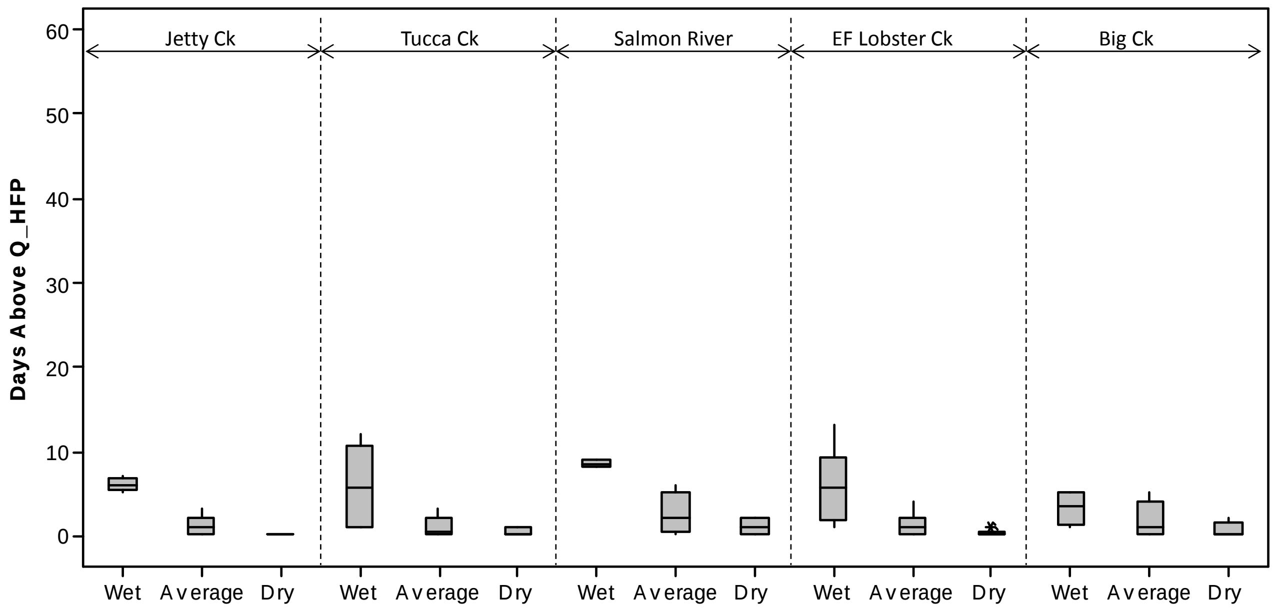



**Figure C- 15. Pacific Northwest site high flow delays (number of days per year above $Q_{HFP}$ = 1% Migration Period Exceedance flow by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

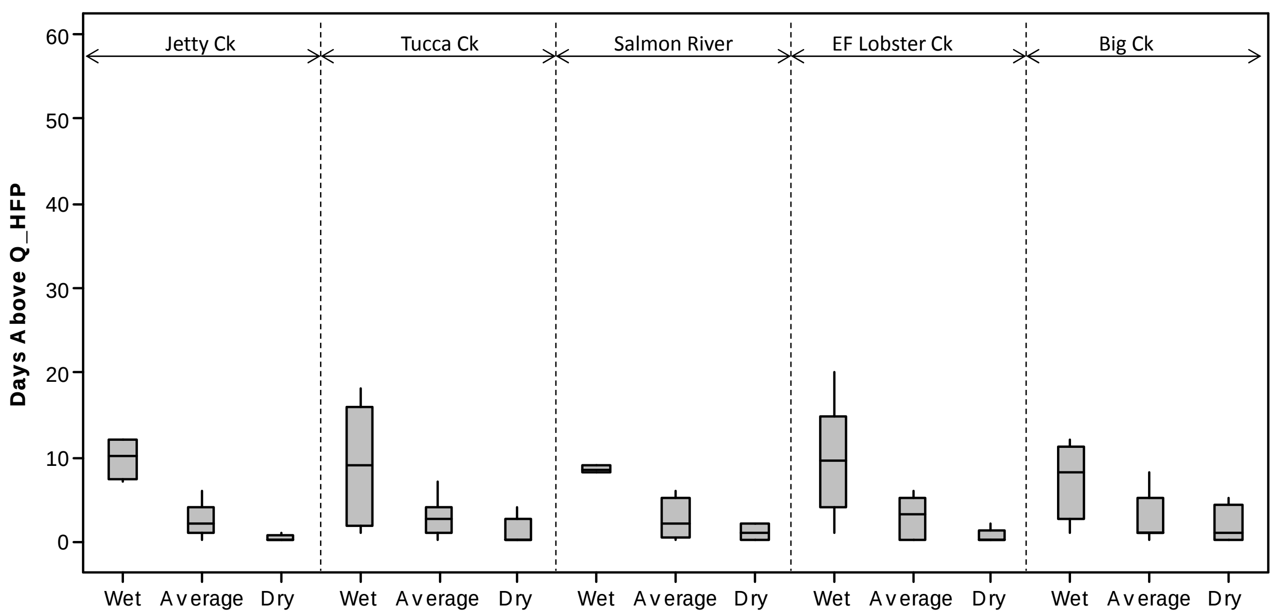



**Figure C- 16. Pacific Northwest site high flow delays (number of days per year above $Q_{HFP}$ = 1% Annual Exceedance flow by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

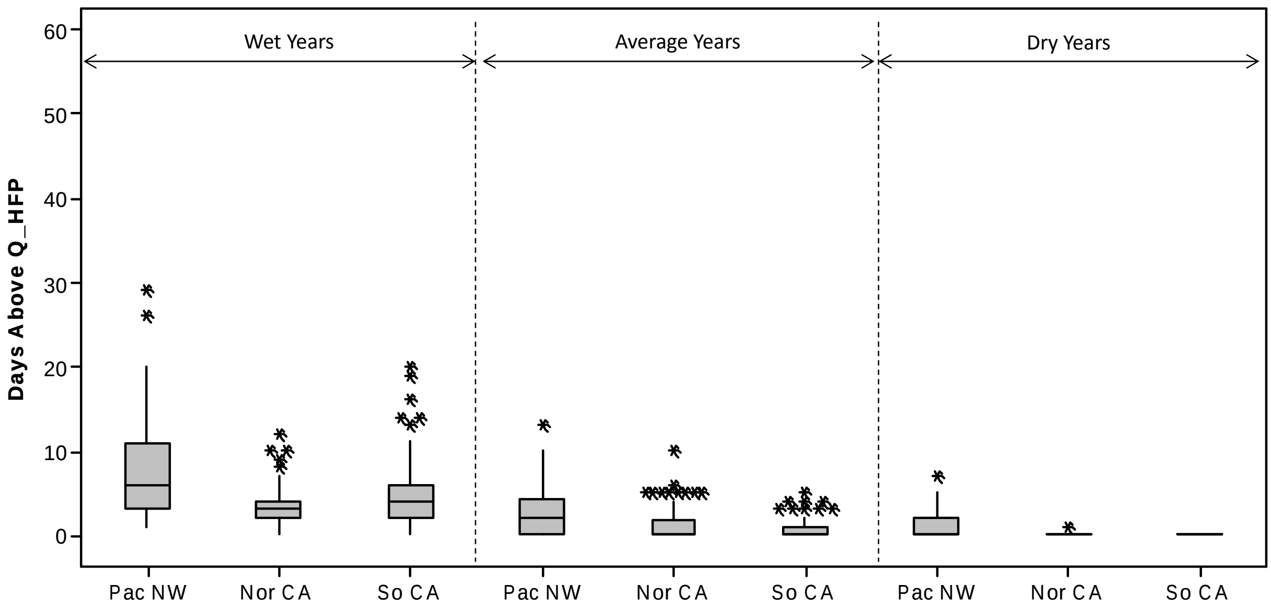



**Figure C- 17. Composite regional high flow delays (number of days per year above $Q_{HFP}$ = 50% of $Q_{2\text{-year}}$ flow from peak data) by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

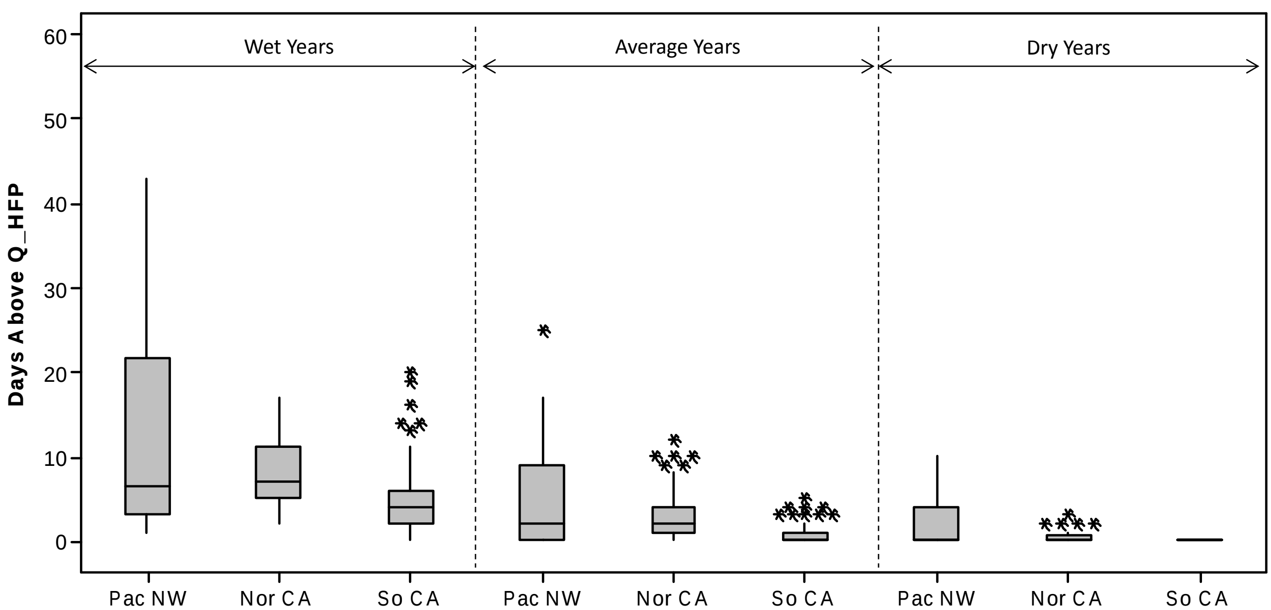



**Figure C- 18. Composite regional high flow delays (number of days per year above $Q_{HFP}$ = 50% of $Q_{2\text{-year}}$ flow from USGS regression equations) by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

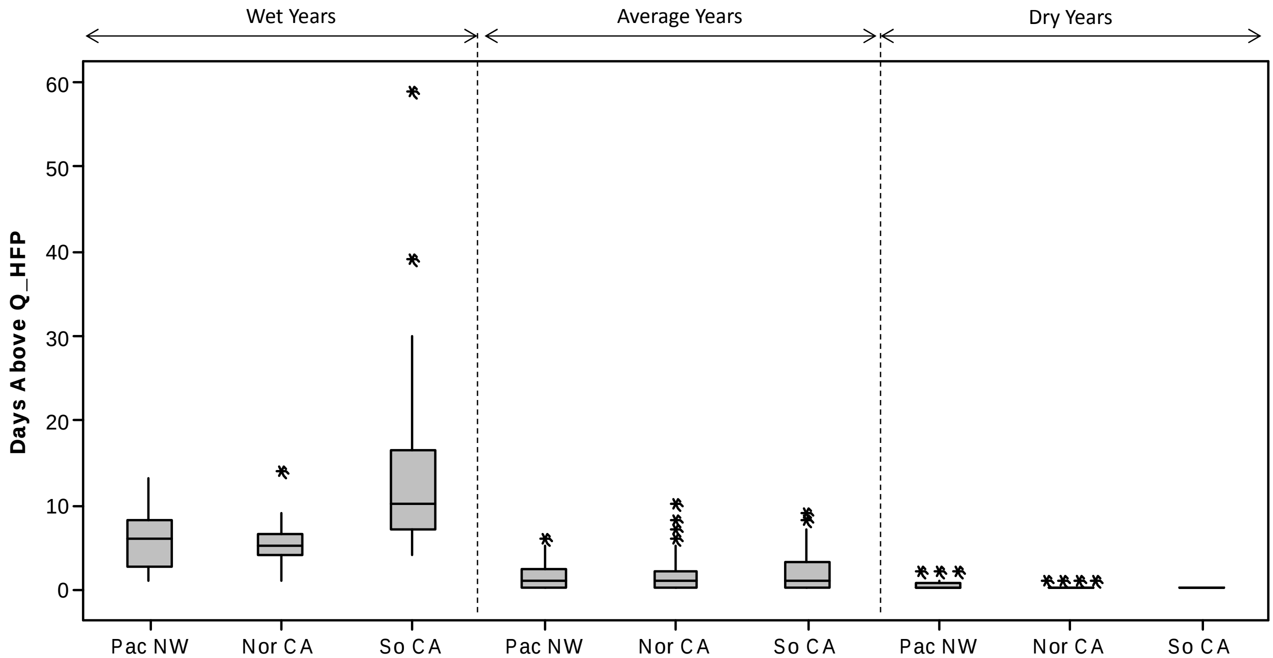



**Figure C- 19. Composite regional high flow delays (number of days per year above $Q_{HFP}$ = 1% Migration Period Exceedance flow by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

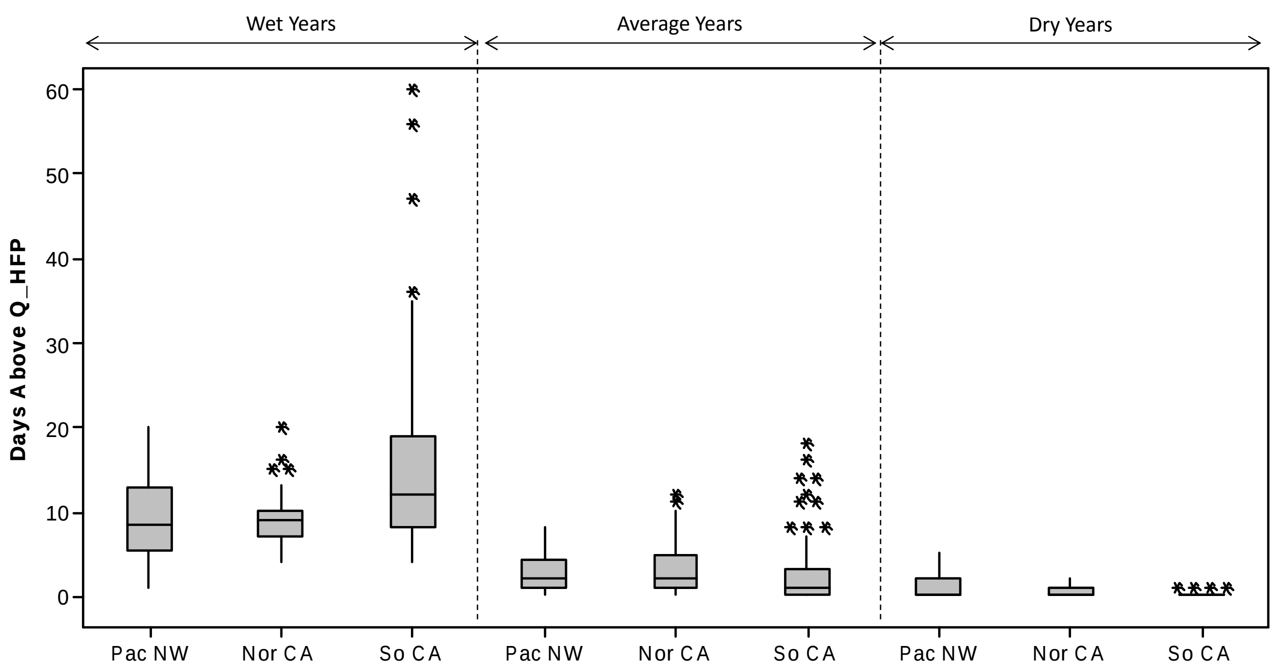



**Figure C- 20. Composite regional high flow delays (number of days per year above $Q_{HFP}$ = 1% Annual Exceedance flow by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

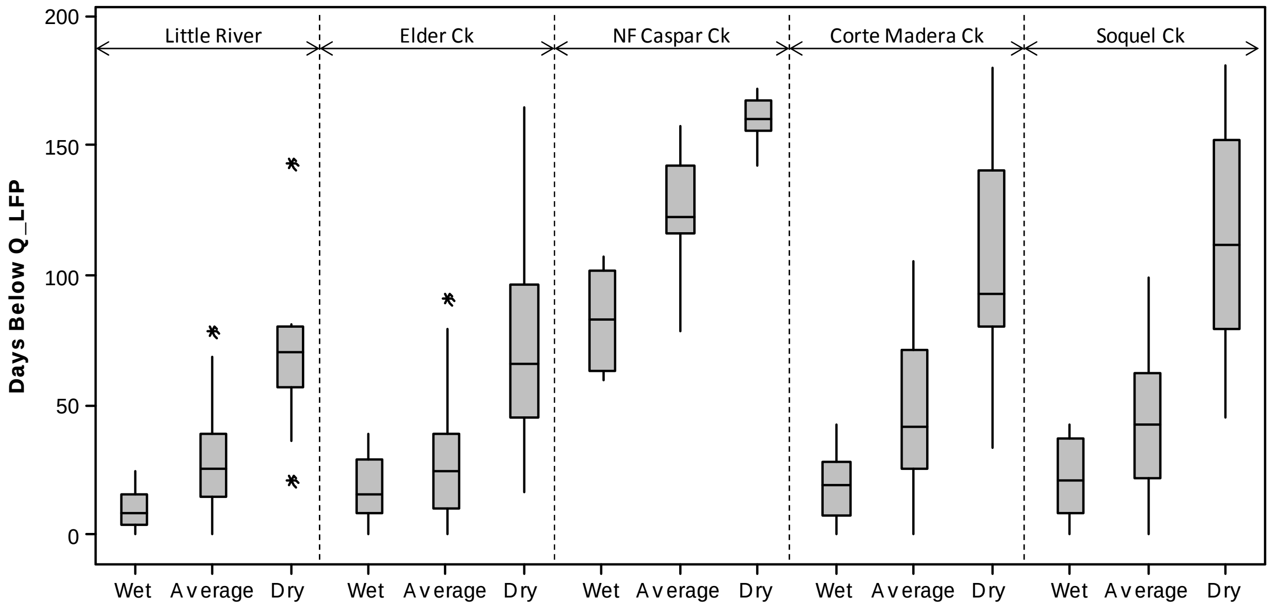



**Figure C- 21. Northern California site low flow delays (number of days per year below $Q_{LFP}$ = 50% annual exceedance flow or 3 cfs whichever is greater) by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

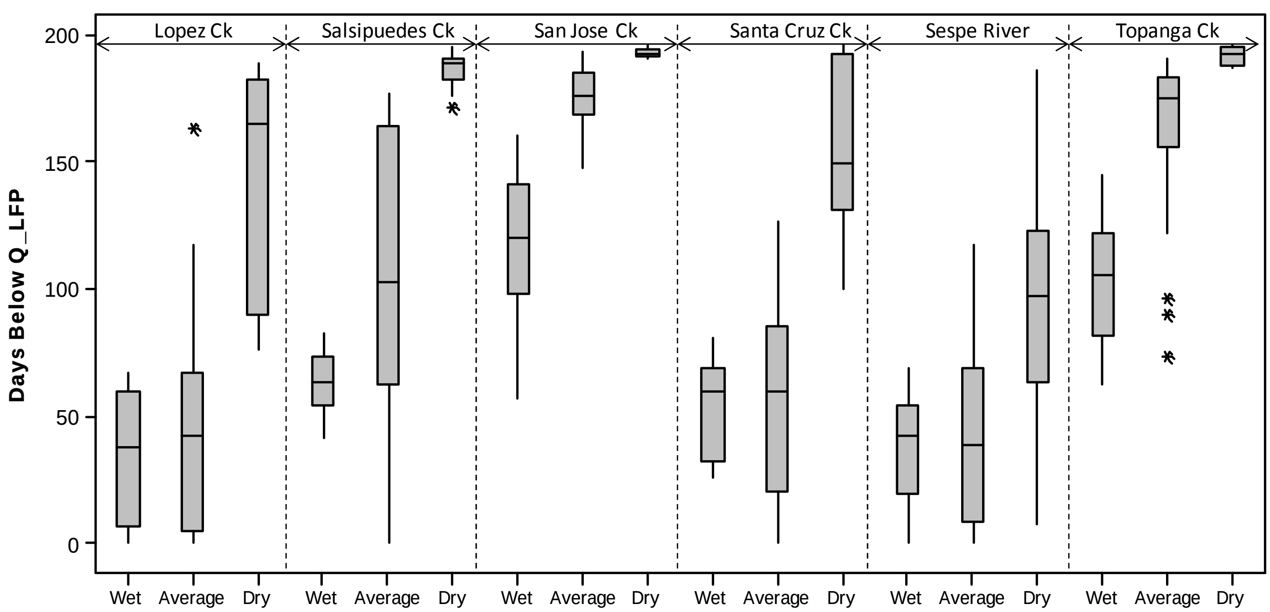



**Figure C- 22. Southern California site low flow delays (number of days per year below $Q_{LFP}$ = 50% annual exceedance flow or 3 cfs whichever is greater) by water year type over the assumed steelhead migration period of Nov 1 – May 15.**

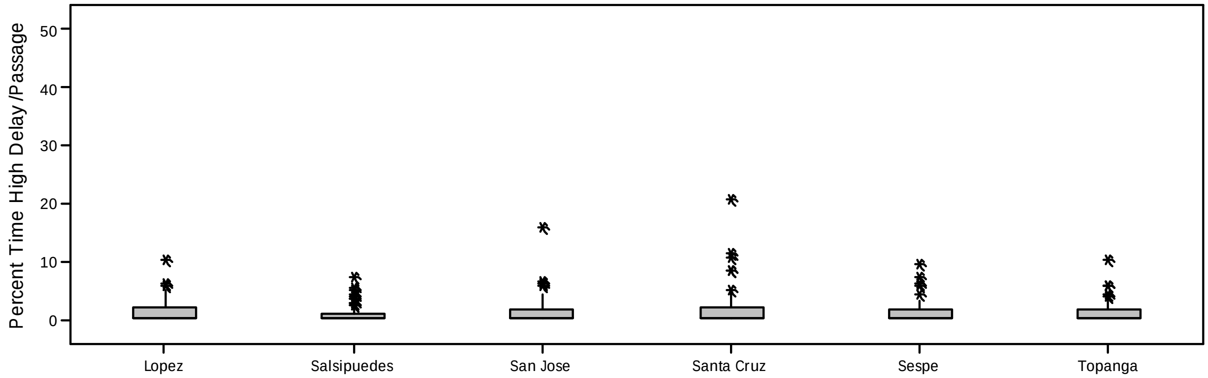



**Figure C- 23. Percent time of high passage delay relative to passage time for the Southern California study sites for $Q_{HFP}$ = 50% of Q2-Pk. These box plots were created using all years of each site's data.**

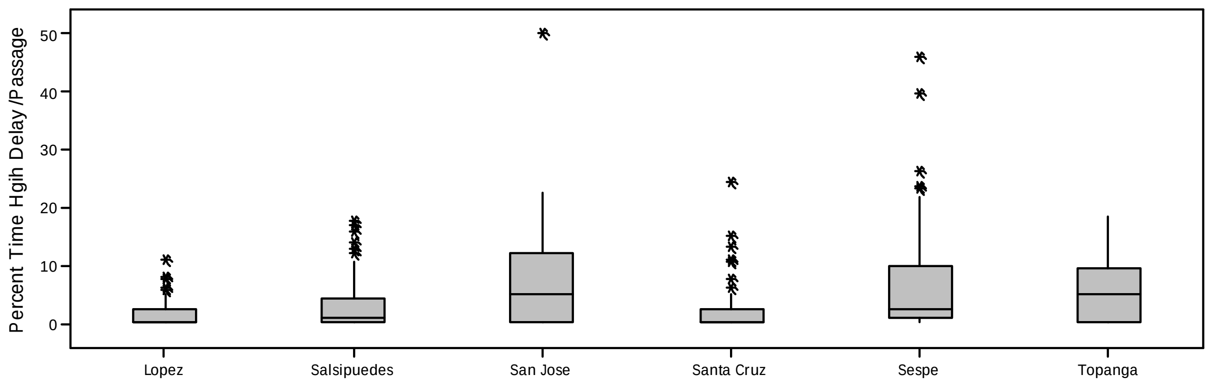



**Figure C- 24. Percent time of high passage delay relative to passage time for the Southern California study sites for $Q_{HFP}$ = 50% of Q2-Em. These box plots were created using all years of each site's data.**

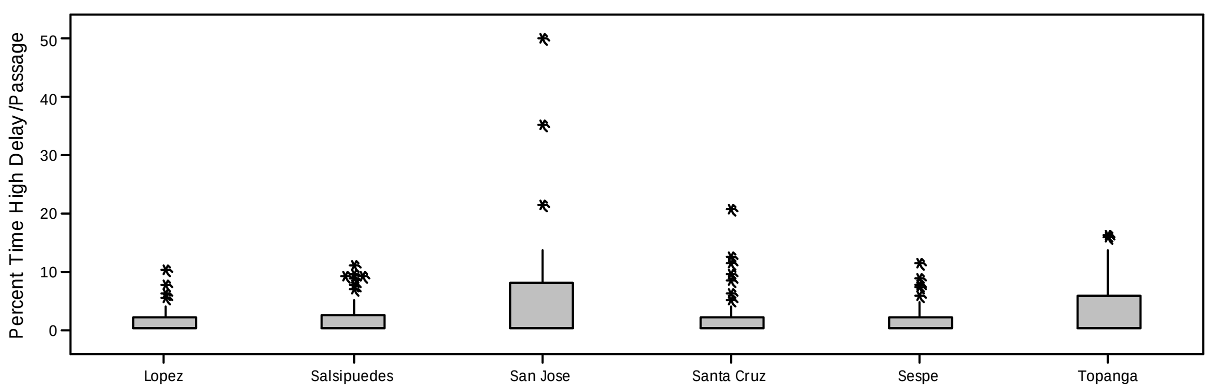



**Figure C- 25. Percent time of high passage delay relative to passage time for the Southern California study sites for $Q_{HFP}$ = 1% steelhead migration period flow. These box plots were created using all years of each site's data.**

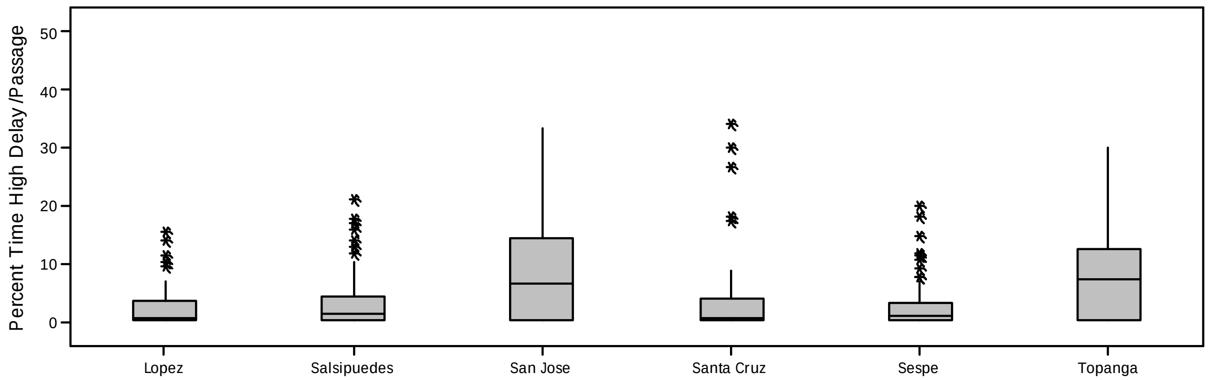



**Figure C- 26. Percent time of high passage delay relative to passage time for the Southern California study sites for $Q_{HFP}$ = 1% annual exceedance flow. These box plots were created using all years of each site's data.**

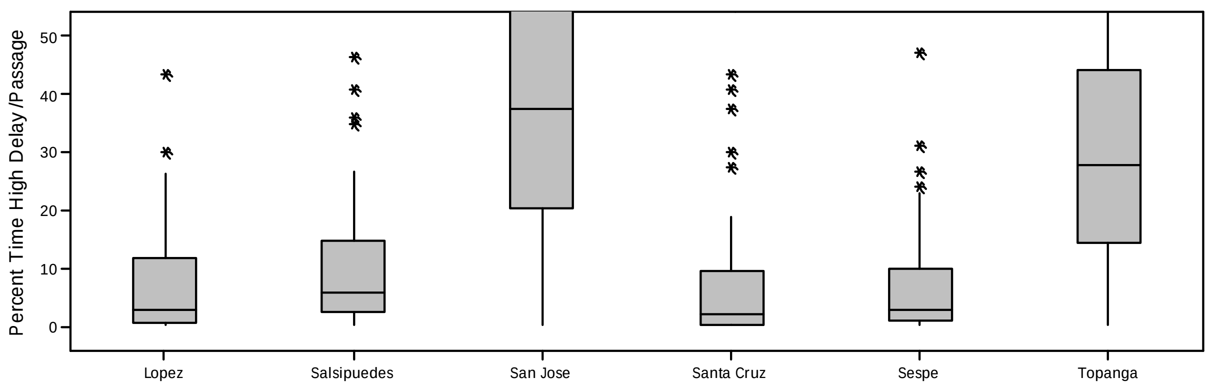



**Figure C- 27. Percent time of high passage delay relative to passage time for the Southern California study sites for $Q_{HFP}$ = 5% steelhead migration period flow. These box plots were created using all years of each site's data.**

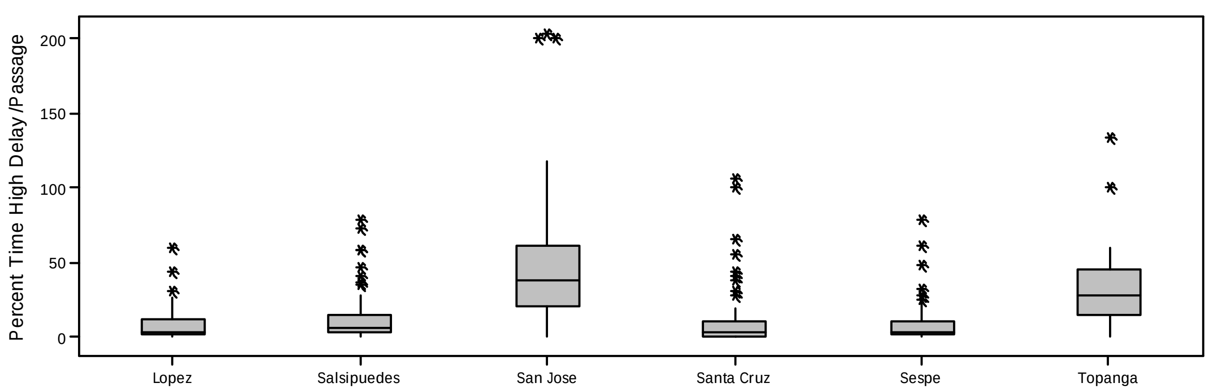



**Figure C- 28. Percent time of high passage delay relative to passage time for the Southern California study sites for $Q_{HFP}$ = 5% steelhead migration period flow. These box plots were created using all years of each site's data. This figure is the same as Figure C- 27 but with the y-axis expanded to show truncated data.**

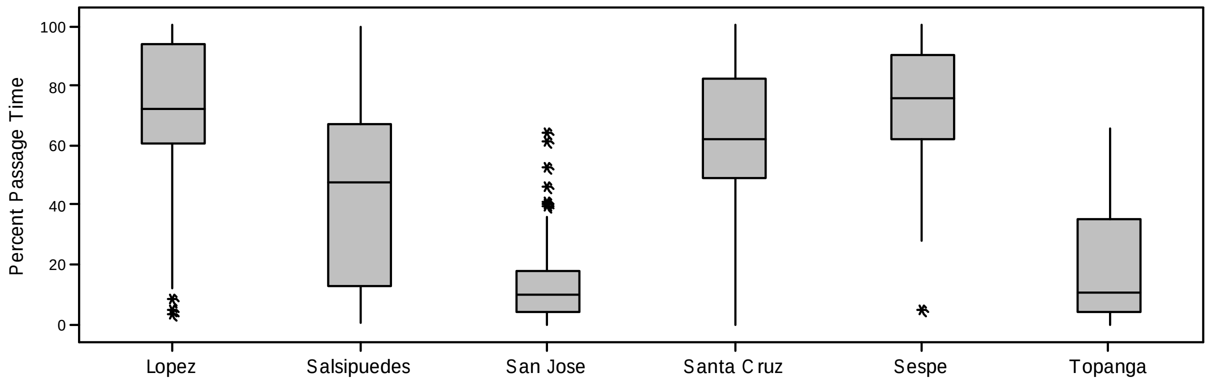



**Figure C- 29. Percent passage time relative to the 196 days of assumed steelhead migration (Nov 1 – May 15) for the Southern California study sites for $Q_{HFP}$ = 50% of Q2-Pk. These box plots were created using all years of each site's data.**

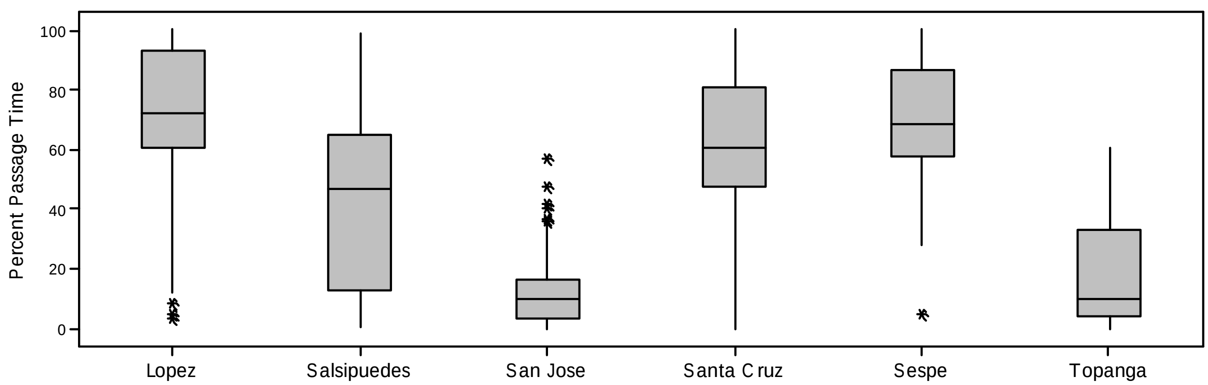



**Figure C- 30. Percent passage time relative to the 196 days of assumed steelhead migration (Nov 1 – May 15) for the Southern California study sites for $Q_{HFP}$ = 50% of Q2-Em. These box plots were created using all years of each site's data.**

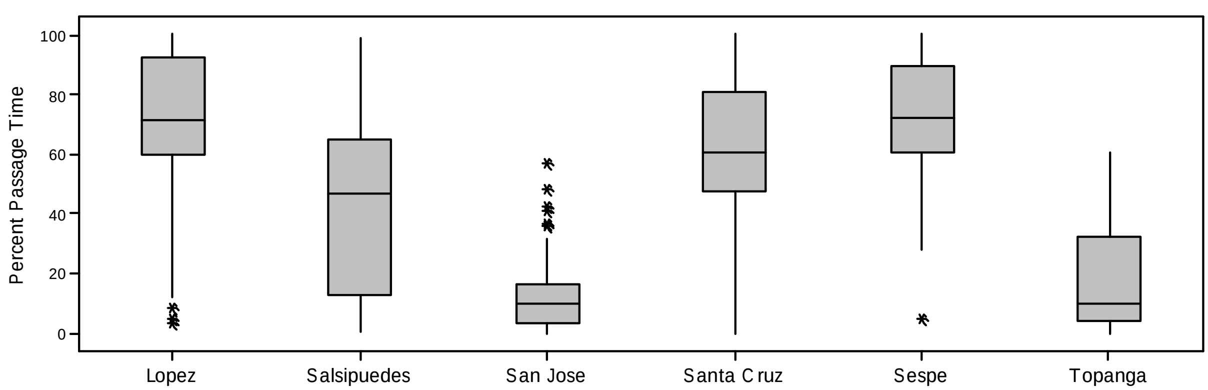



**Figure C- 31. Percent passage time relative to the 196 days of assumed steelhead migration (Nov 1 – May 15) for the Southern California study sites for $Q_{HFP}$ = 1% annual exceedance flow. These box plots were created using all years of each site's data.**

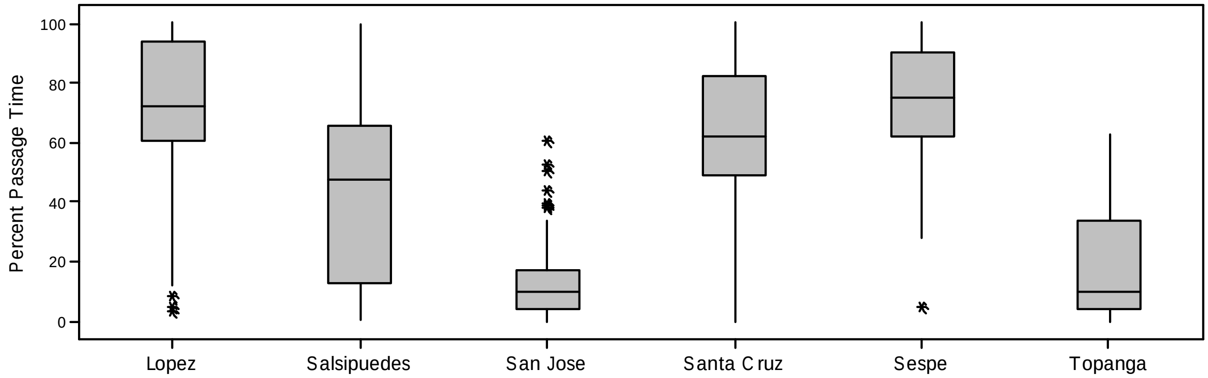



**Figure C- 32. Percent passage time relative to the 196 days of assumed steelhead migration (Nov 1 – May 15) for the Southern California study sites for $Q_{HFP}$ = 1% steelhead migration period flow. These box plots were created using all years of each site's data.**

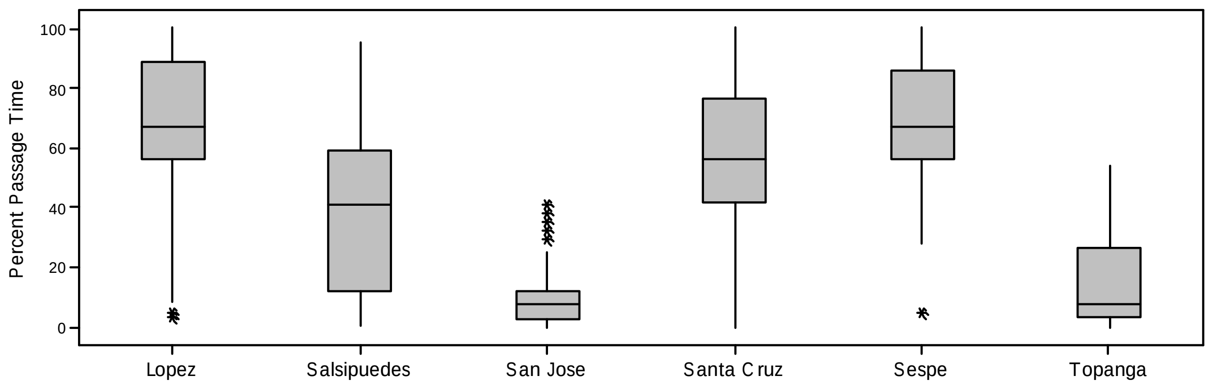



**Figure C- 33. Percent passage time relative to the 196 days of assumed steelhead migration (Nov 1 – May 15) for the Southern California study sites for $Q_{HFP}$ = 5% steelhead migration period flow. These box plots were created using all years of each site's data.**

# Appendix D – Analysis of Streamflow Data Quality on Fish Passage Criteria and Passage and Delay Estimation

Appendix D supplements material presented in Section 6.1 and contains plots comparing flow duration curves (FDCs) derived using different data record lengths (Figure D- 1 through Figure D-16) and the changes in percent passage time and percent time of high flow delay relative to passage time (Figure D- 17 through Figure D- 28) for the 1-percent annual exceedance flows estimated using flow duration curves derived from shortened data records from sequences of Wet or Dry years.

## List of Figures

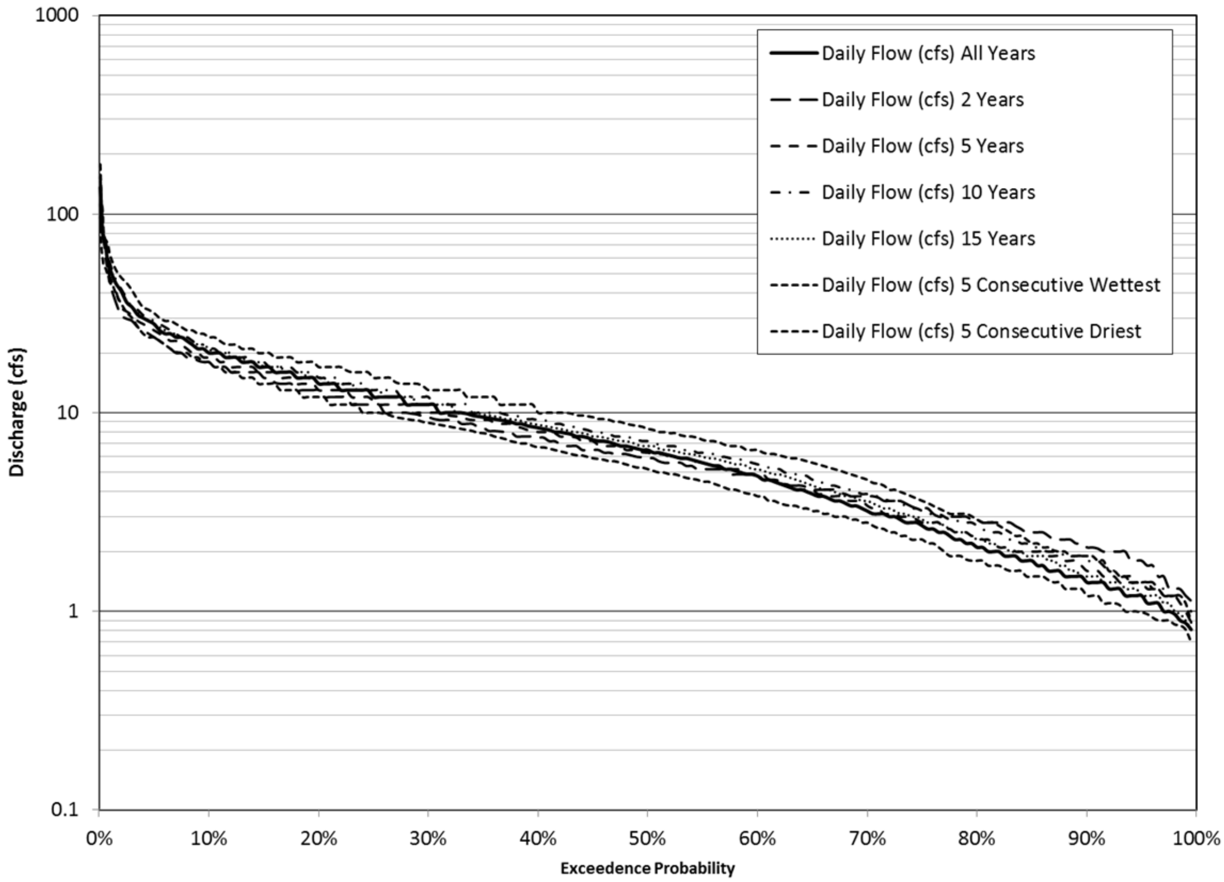



**Figure D- 1. Jetty Creek flow duration curves calculated using the mean daily flows (20 year record length).**

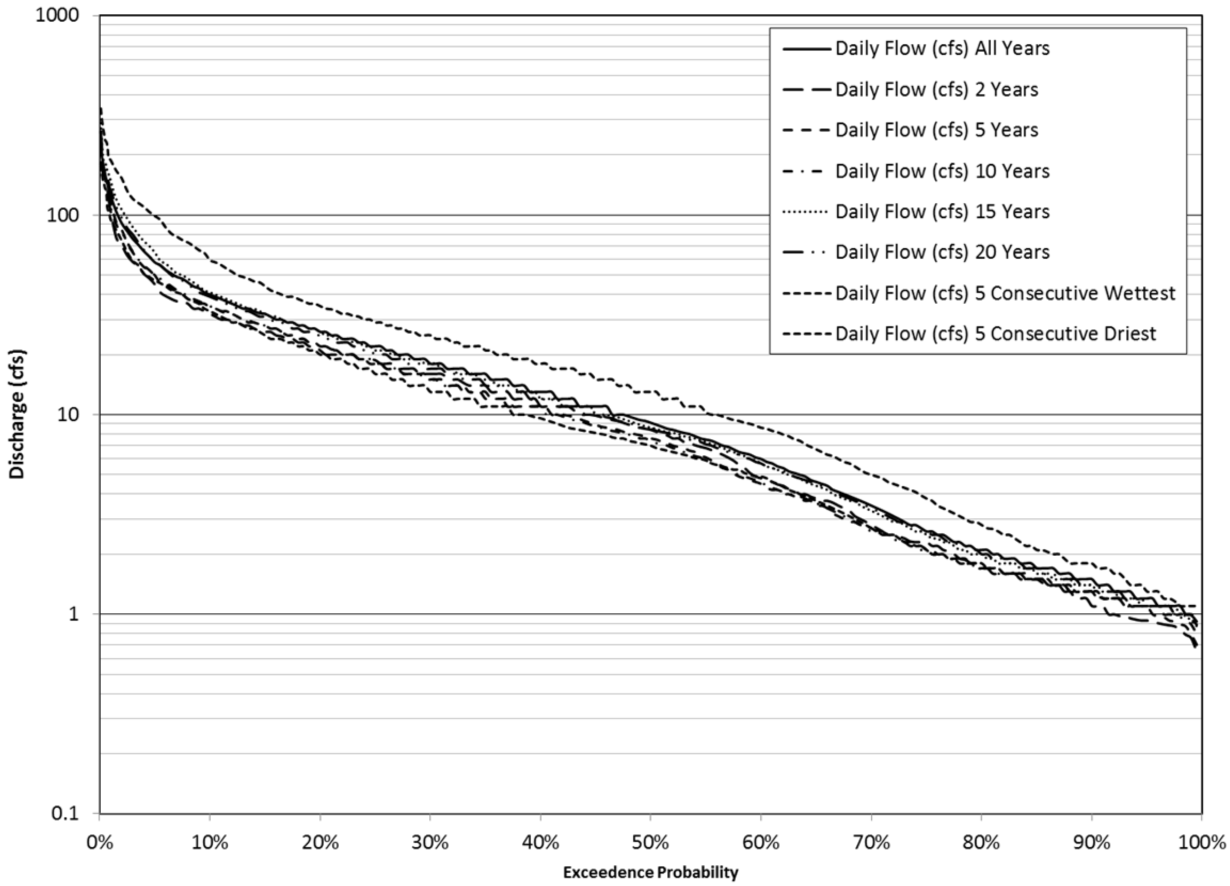



**Figure D- 2. Tucca Creek flow duration curves calculated using the mean daily flows (29 year record length)**

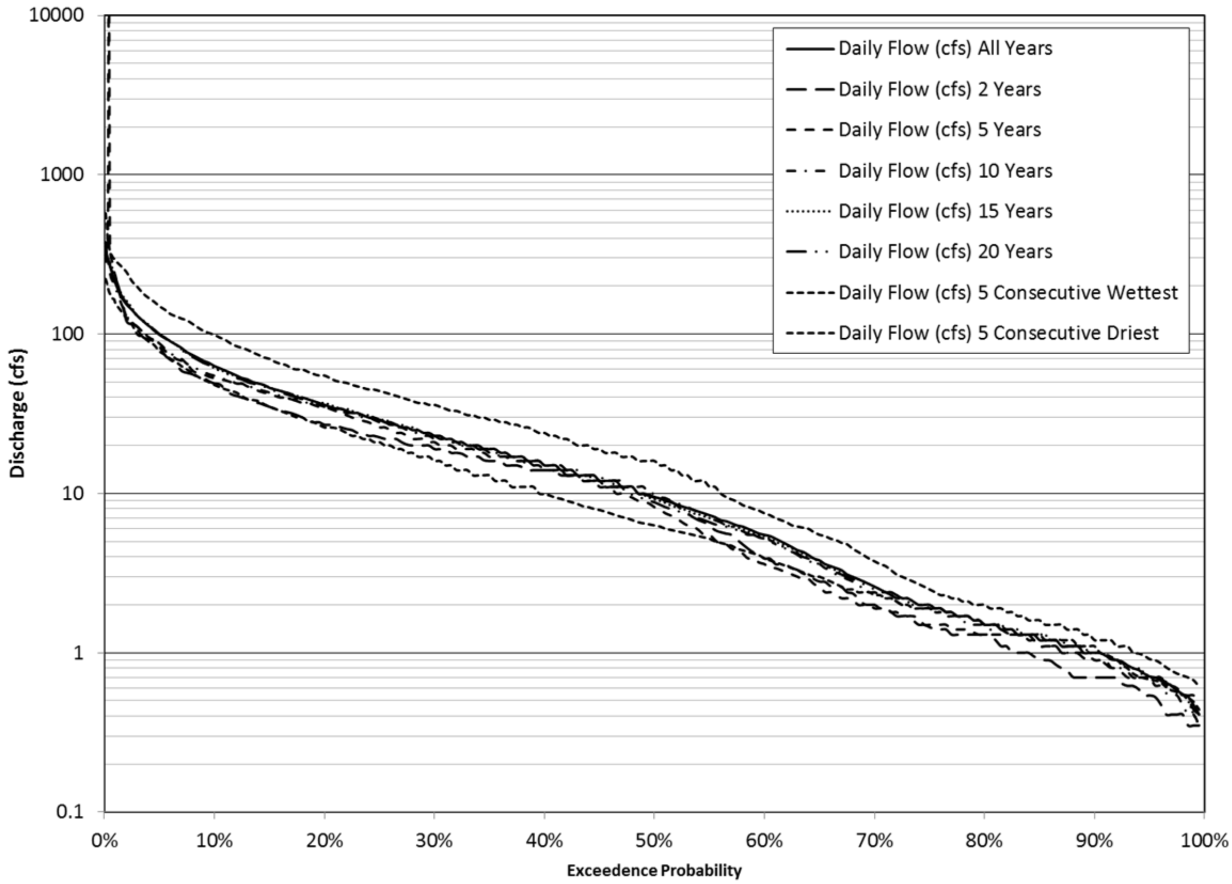



**Figure D- 3. East Fork Lobster Creek flow duration curves calculated using the mean daily flows (29 year record length)**

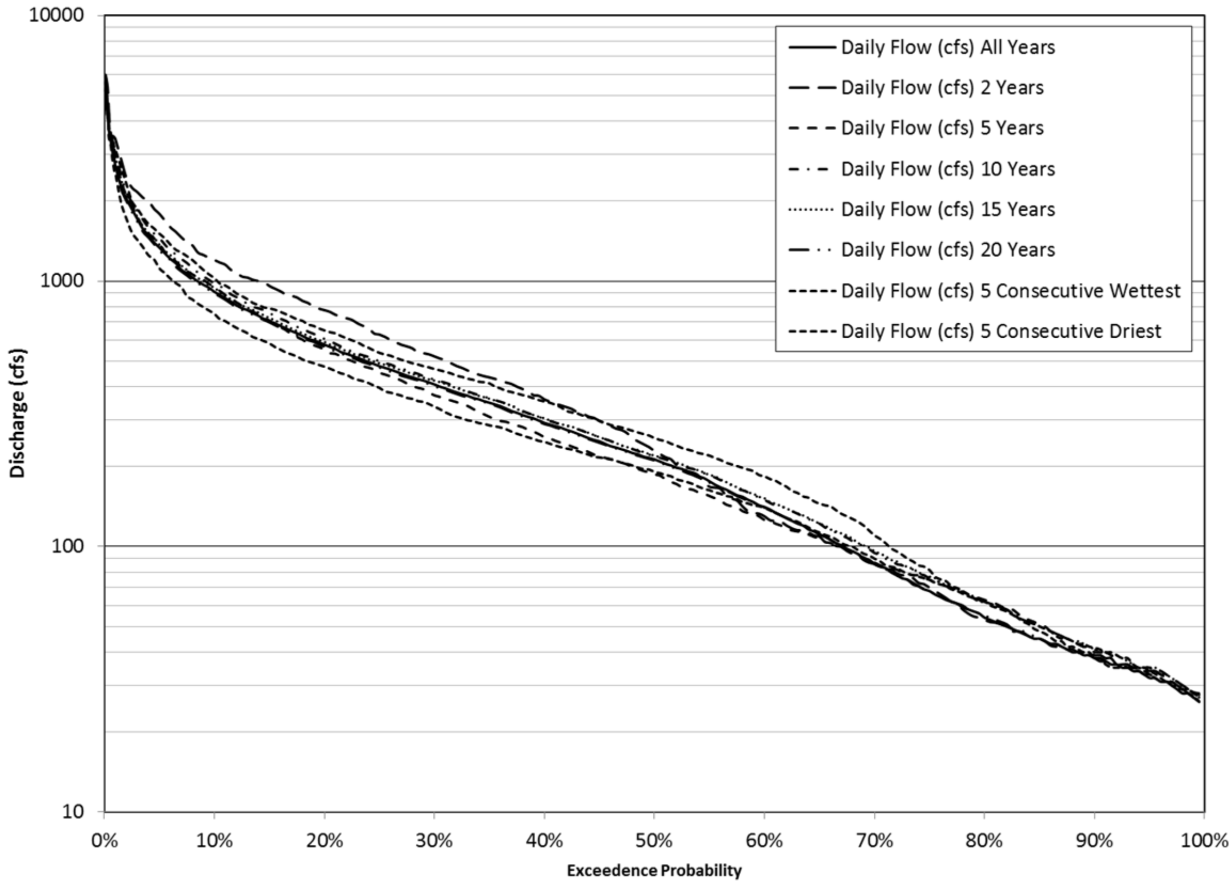



**Figure D- 4. Salmon River flow duration curves calculated using the mean daily flows (21 year record length)**

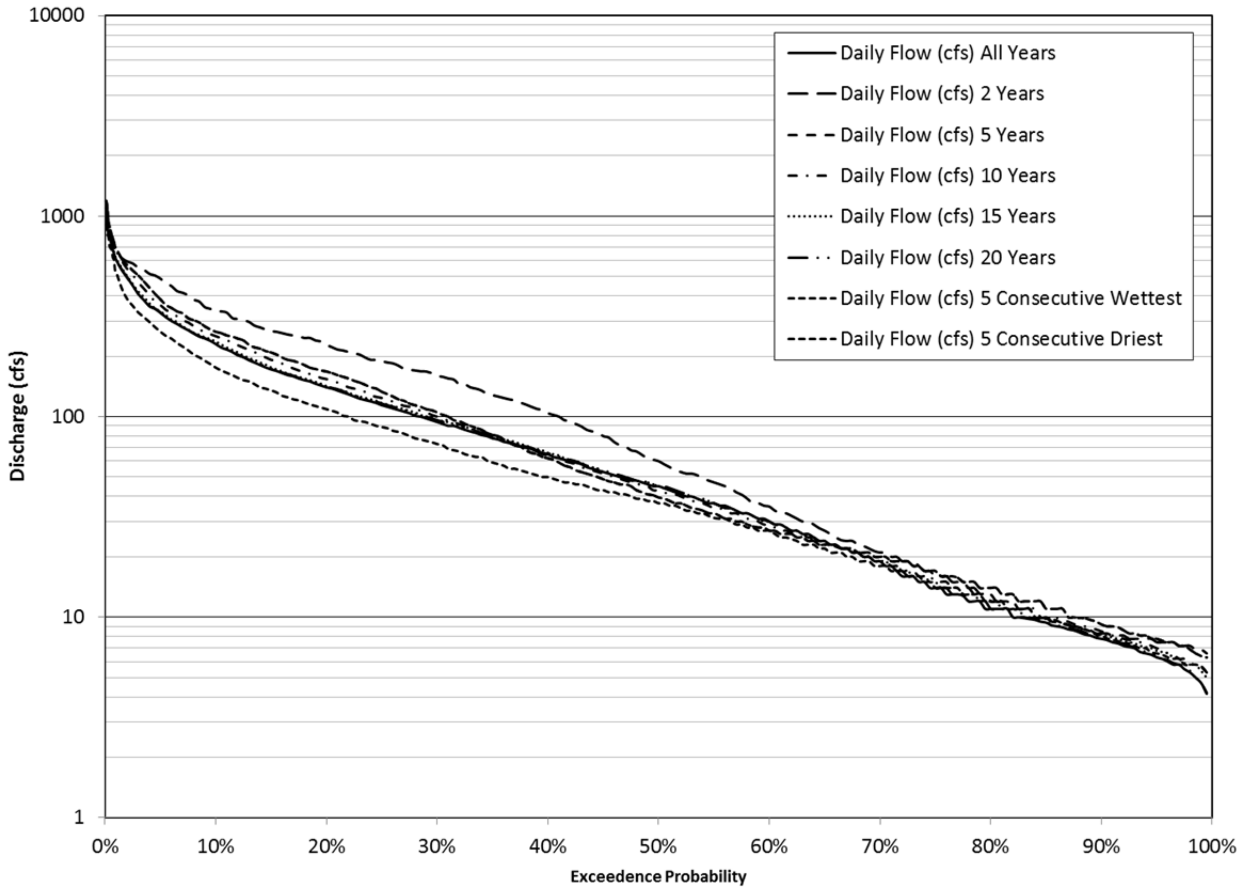



**Figure D- 5. Big Creek flow duration curves calculated using the mean daily flows (19 year record length).**

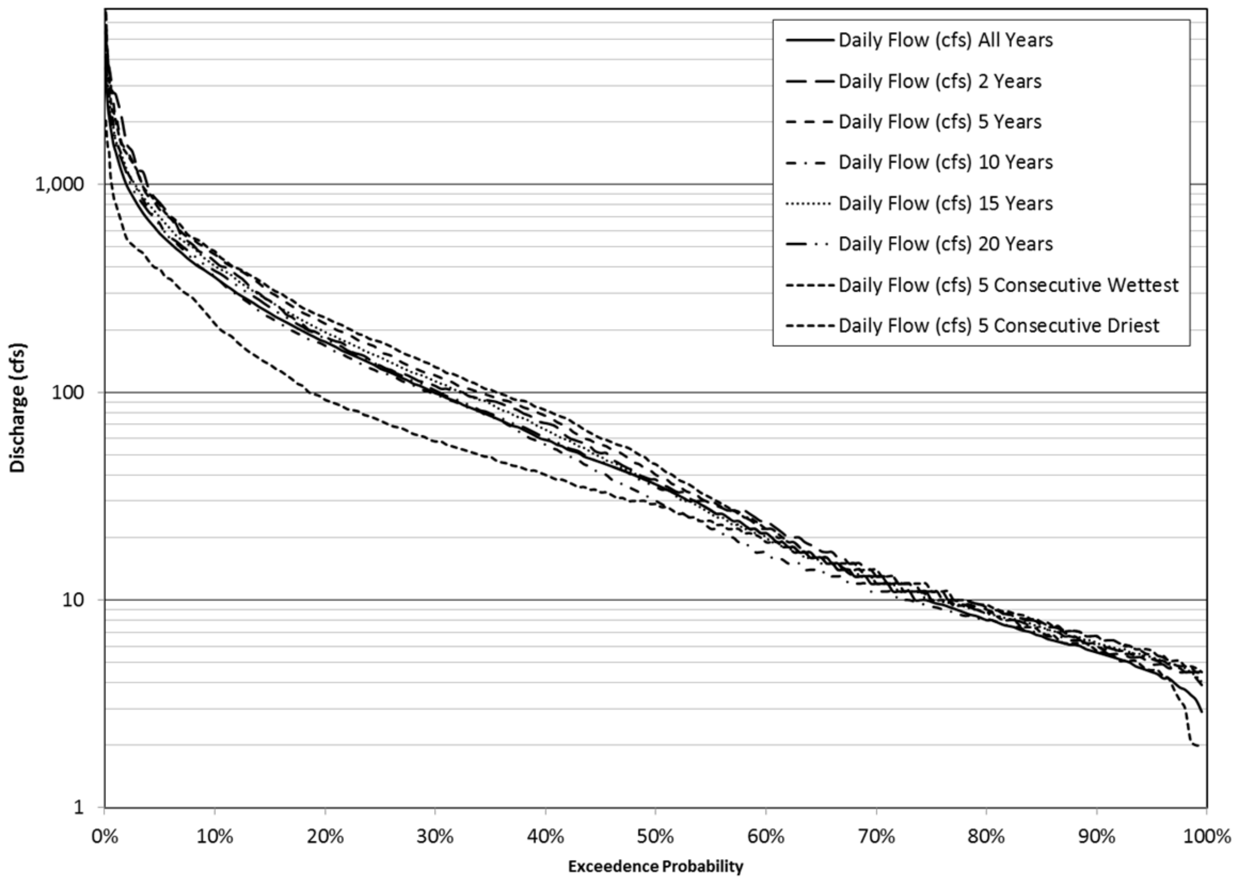



**Figure D- 6. Little River flow duration curves calculated using the mean daily flows (57 year record length).**

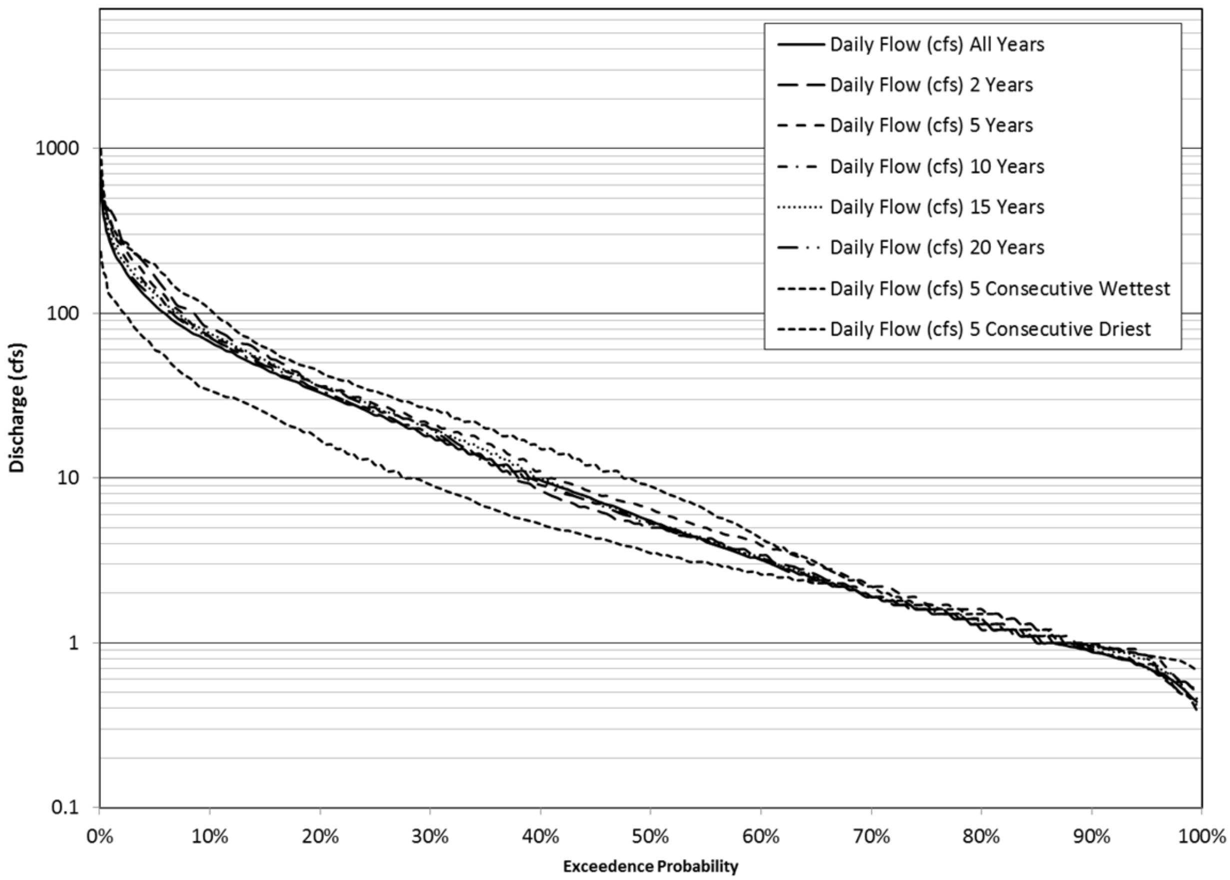



**Figure D- 7. Elder Creek flow duration curves calculated using the mean daily flows (45 year record length).**

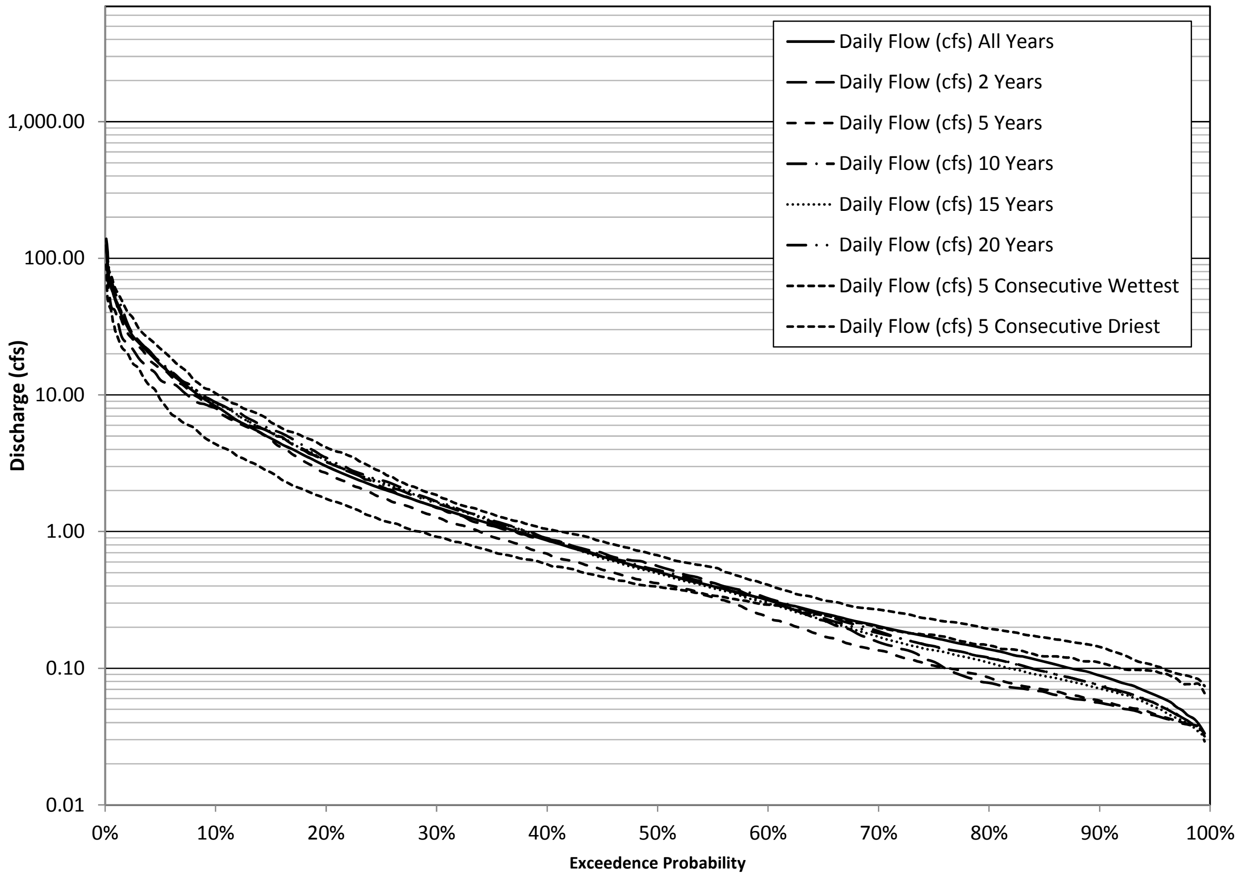



**Figure D- 8. NF Caspar Creek flow duration curves calculated using the mean daily flows (47 year record length).**

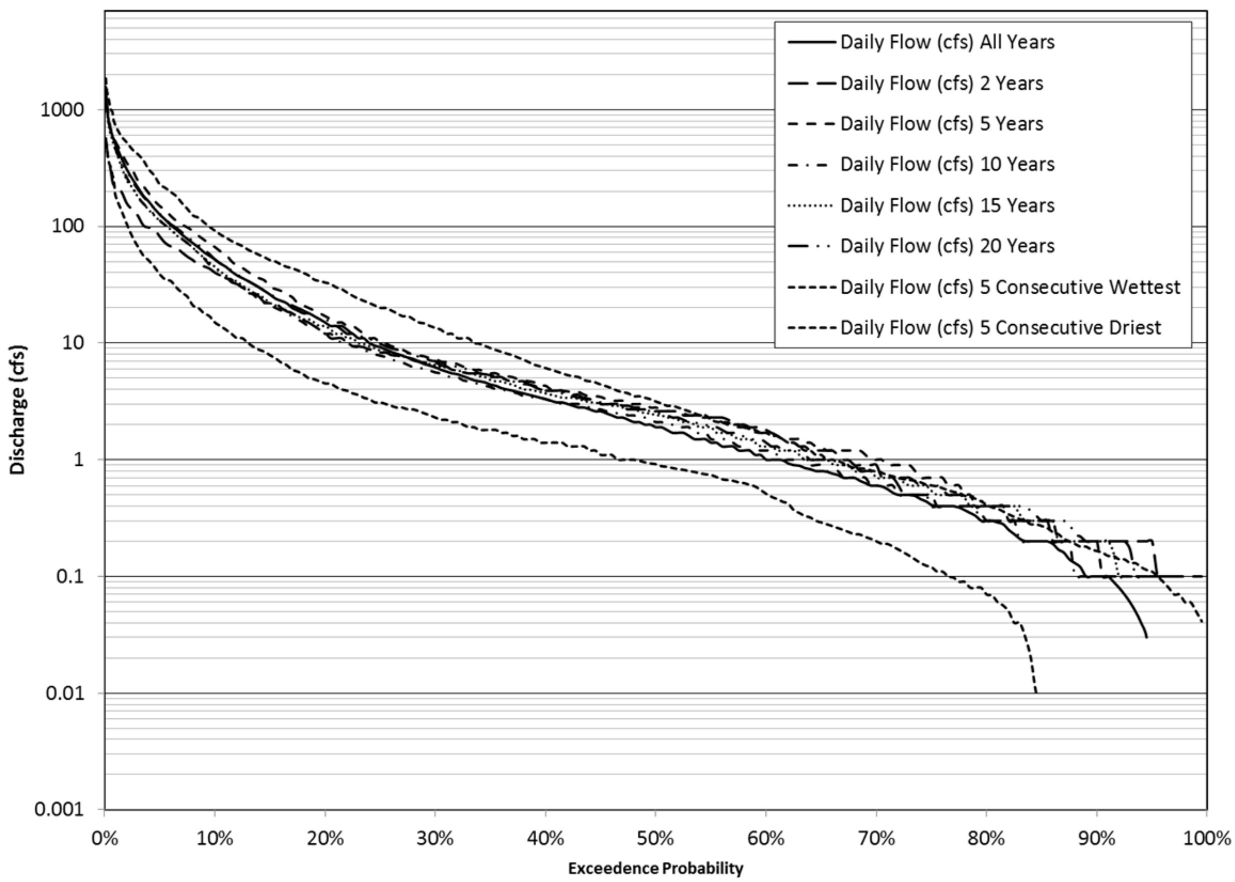



**Figure D- 9. Corte Madera Creek flow duration curves calculated using the mean daily flows (42 year record length).**

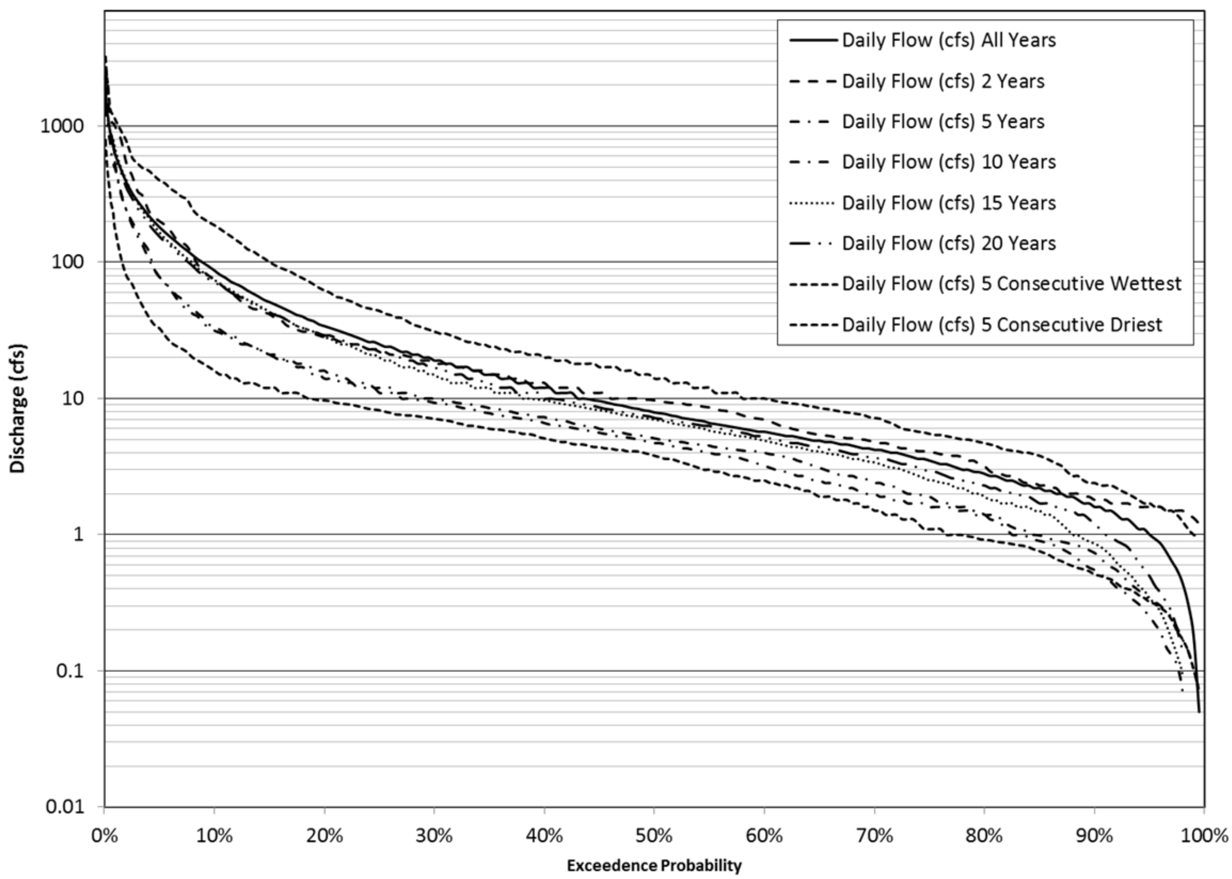



**Figure D- 10. Soquel Creek flow duration curves calculated using the mean daily flows (61 year record length).**

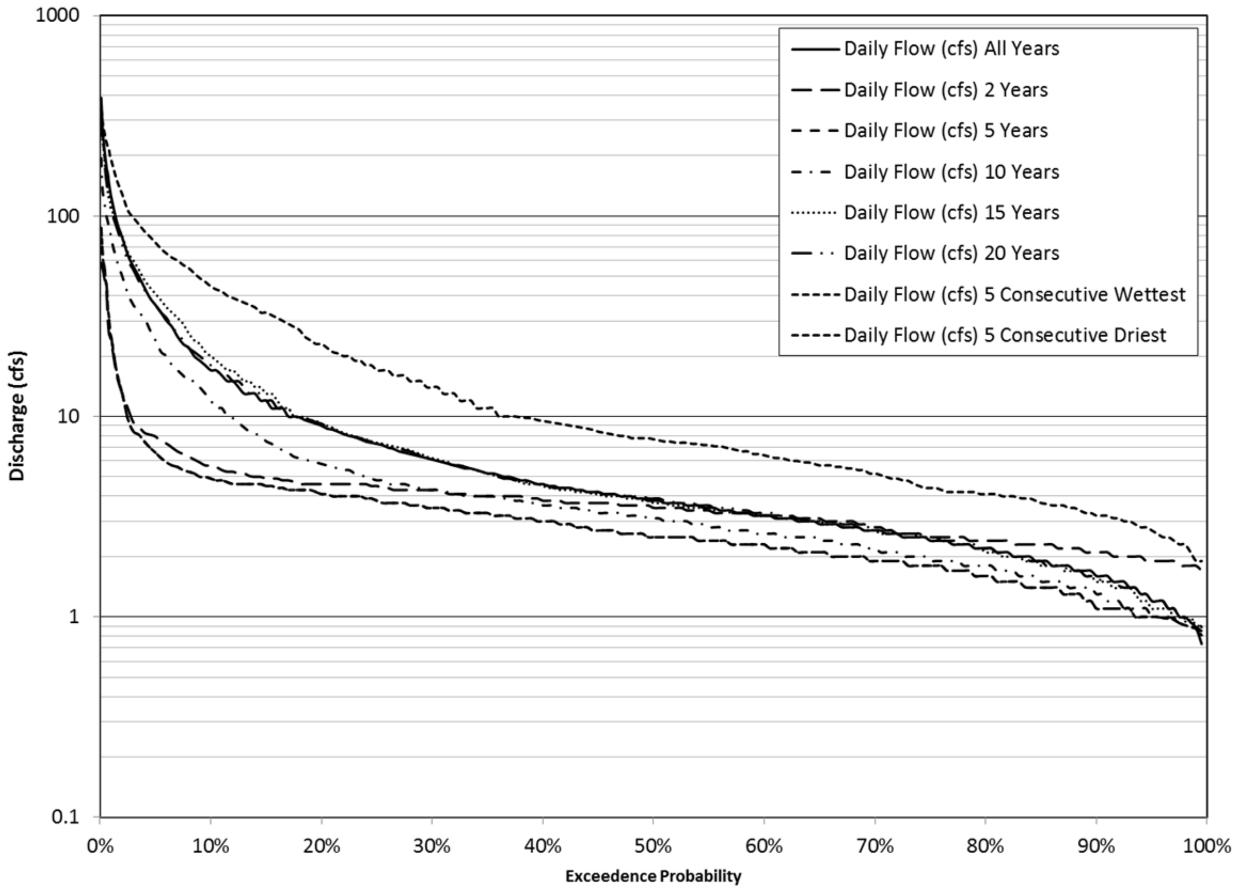



**Figure D- 11. Lopez Creek flow duration curves calculated using the mean daily flows (45 year record length).**

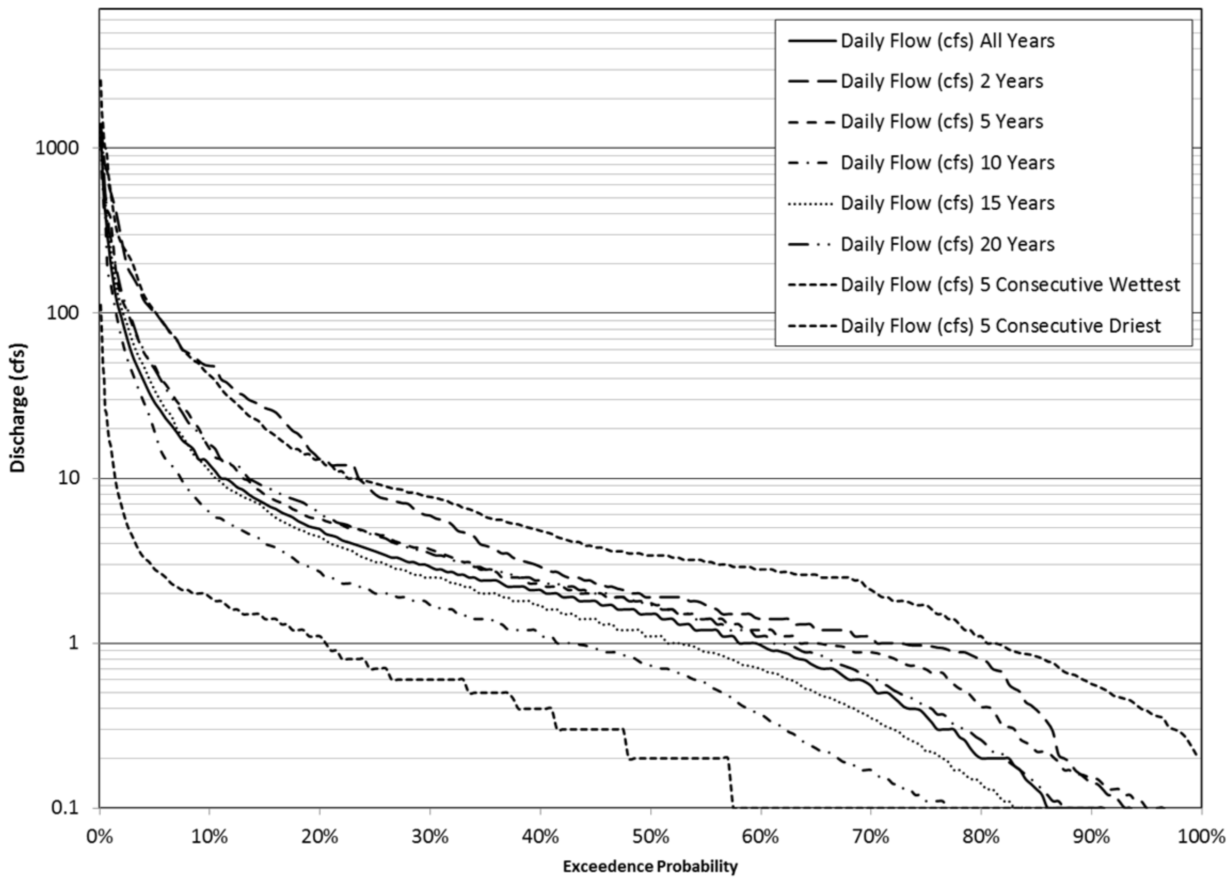



**Figure D- 12. Salsipuedes Creek flow duration curves calculated using the mean daily flows (71 year record length).**

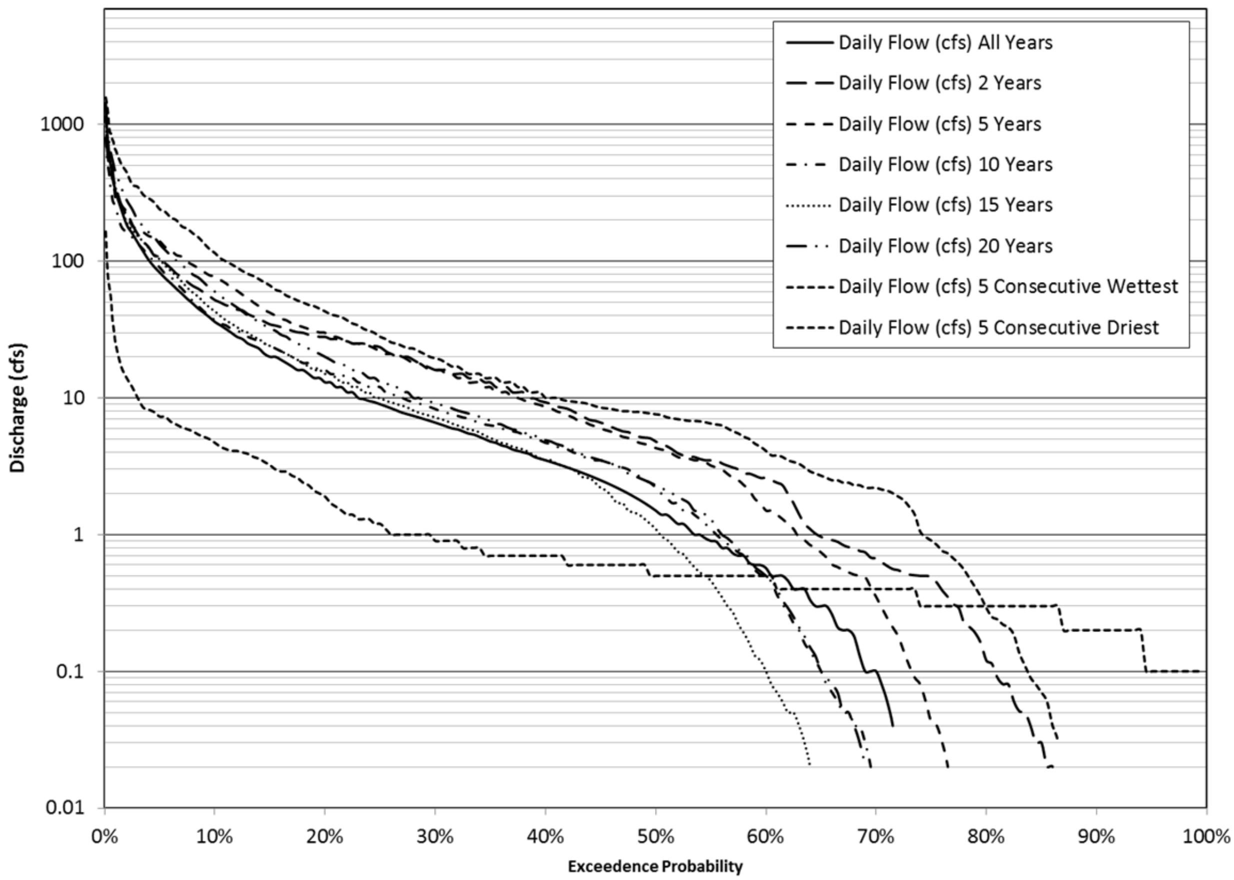



**Figure D- 13. Santa Cruz Creek flow duration curves calculated using the mean daily flows (71 year record length).**

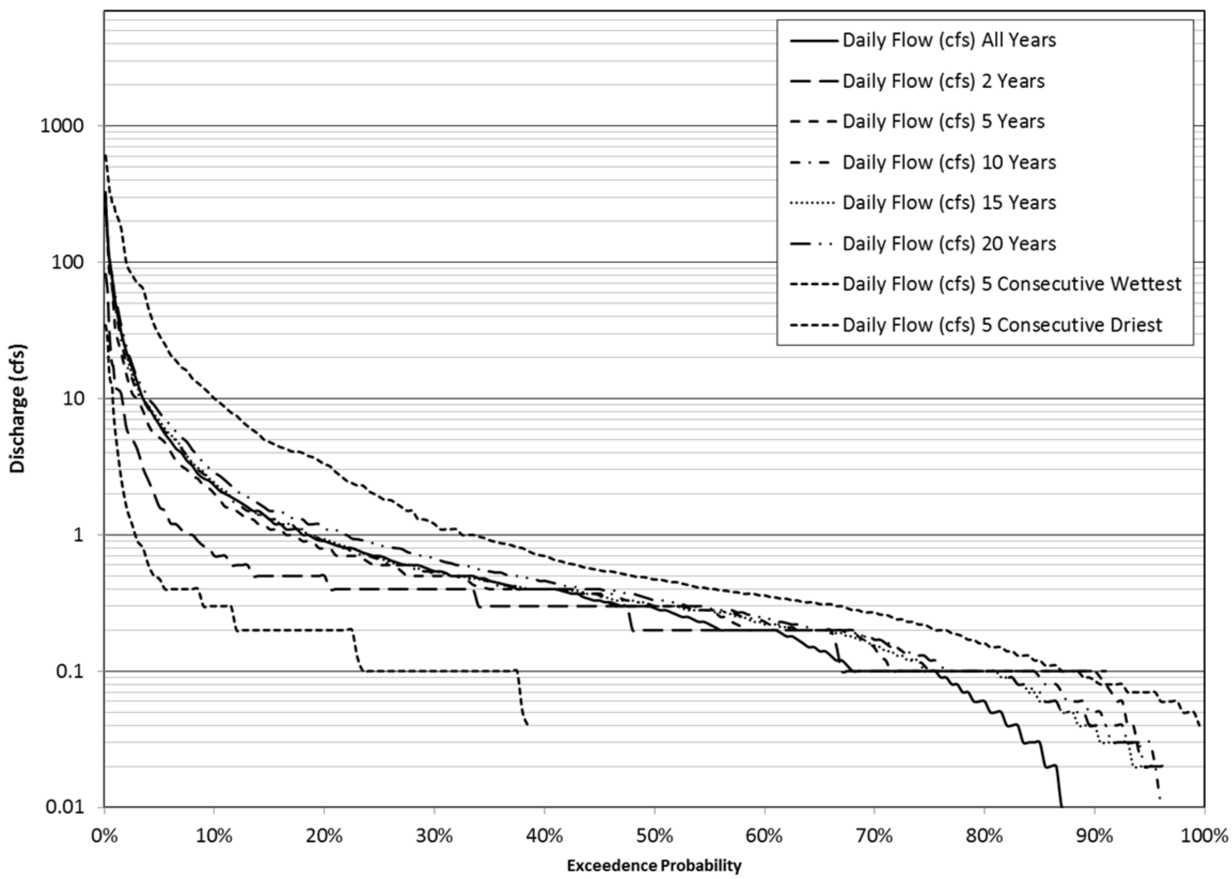



**Figure D- 14. San Jose Creek flow duration curves calculated using the mean daily flows (71 year record length).**

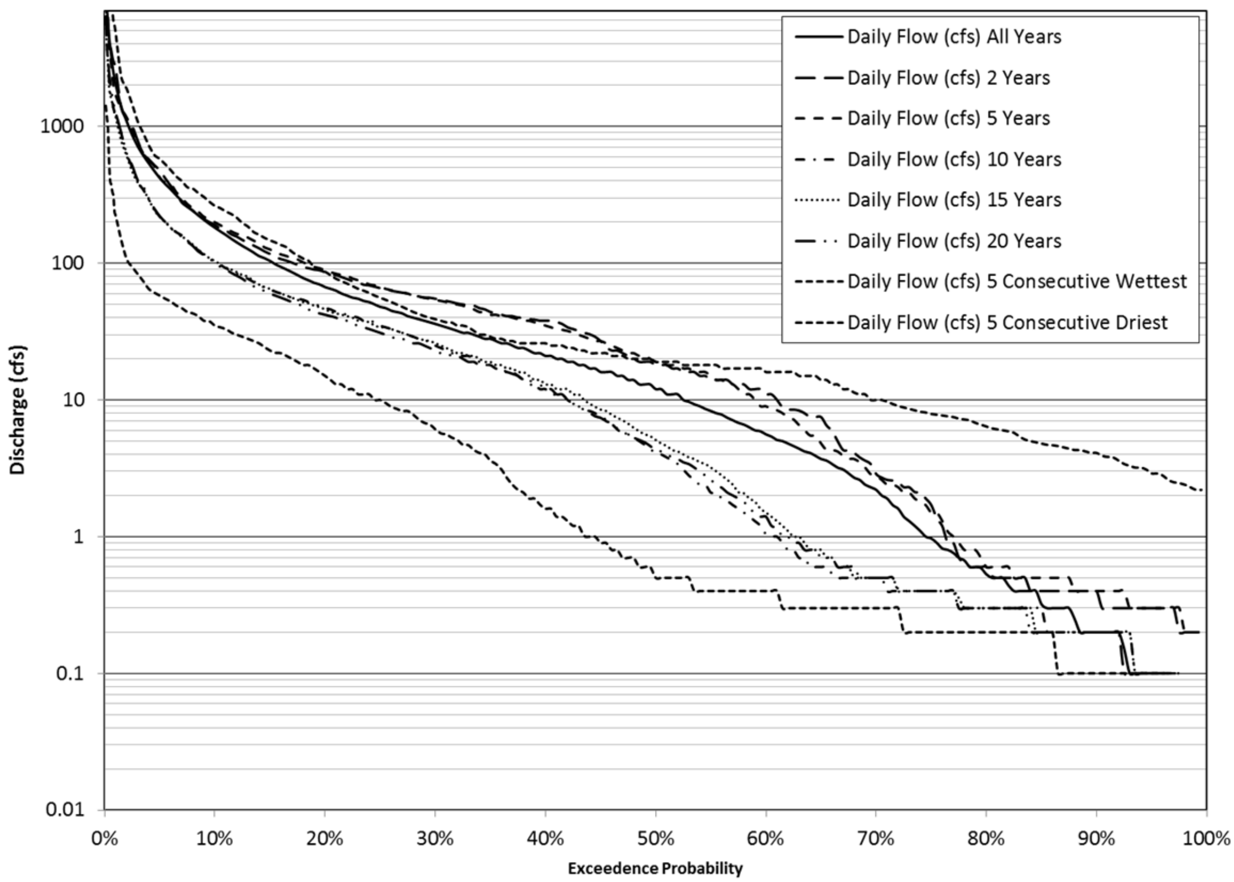



**Figure D- 15. Sespe River flow duration curves calculated using the mean daily flows (82 year record length).**

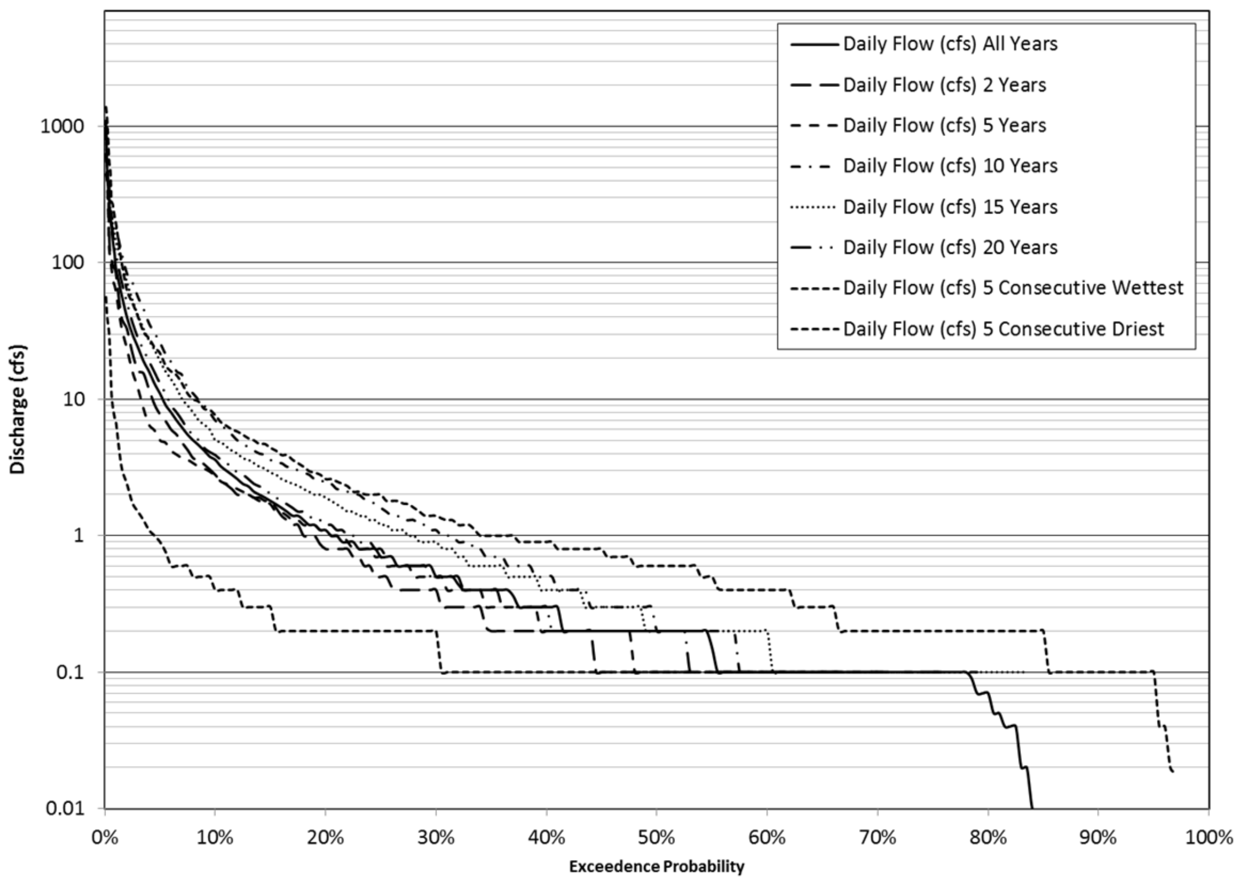



**Figure D- 16. Topanga Creek flow duration curves calculated using the mean daily flows (49 year record length).**

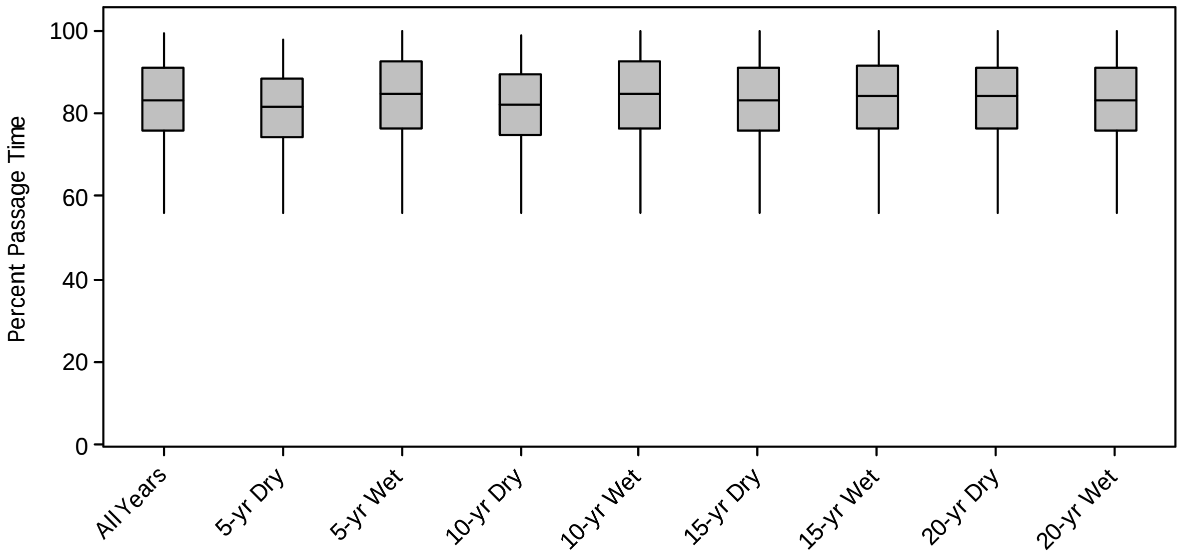



**Figure D- 17. Box plots summarizing percent passage time in all years of the data record for Tucca Creek predicted using the 1% annual exceedance values predicted from various data record lengths as $Q_{HFP}$. The low fish passage flow for all analyses is the 50% annual exceedance flow.**

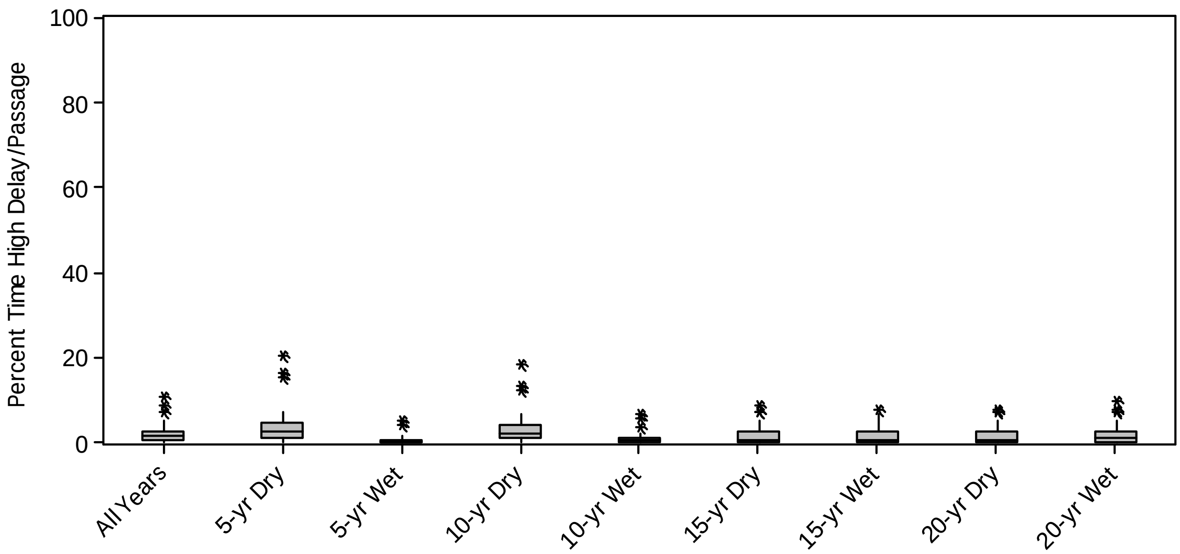



**Figure D- 18. Box plots summarizing percent time of high passage delay relative to passage time in all years of the data record for Tucca Creek predicted using the 1% annual exceedance values predicted from various data record lengths as $Q_{HFP}$. The low fish passage flow for all analyses is the 50% annual exceedance flow.**

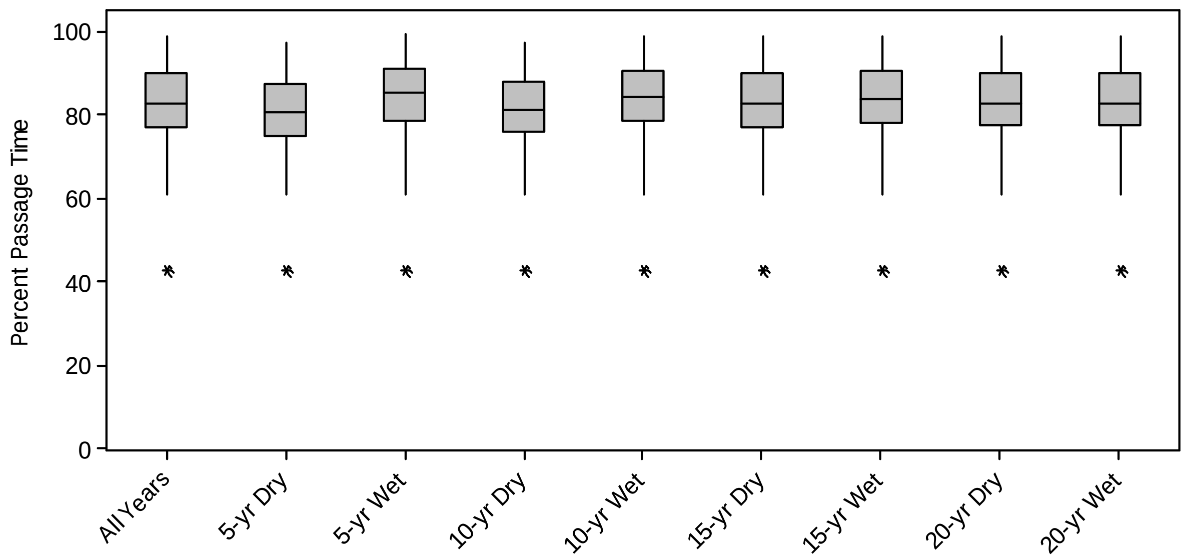



**Figure D- 19. Box plots summarizing percent passage time in all years of the data record for East Fork Lobster Creek predicted using the 1% annual exceedance values predicted from various data record lengths as $Q_{HFP}$. The low fish passage flow for all analyses is the 50% annual exceedance flow. The low outlier values represent one dry year in the data record with significantly lower time with flows in the passage flow window.**

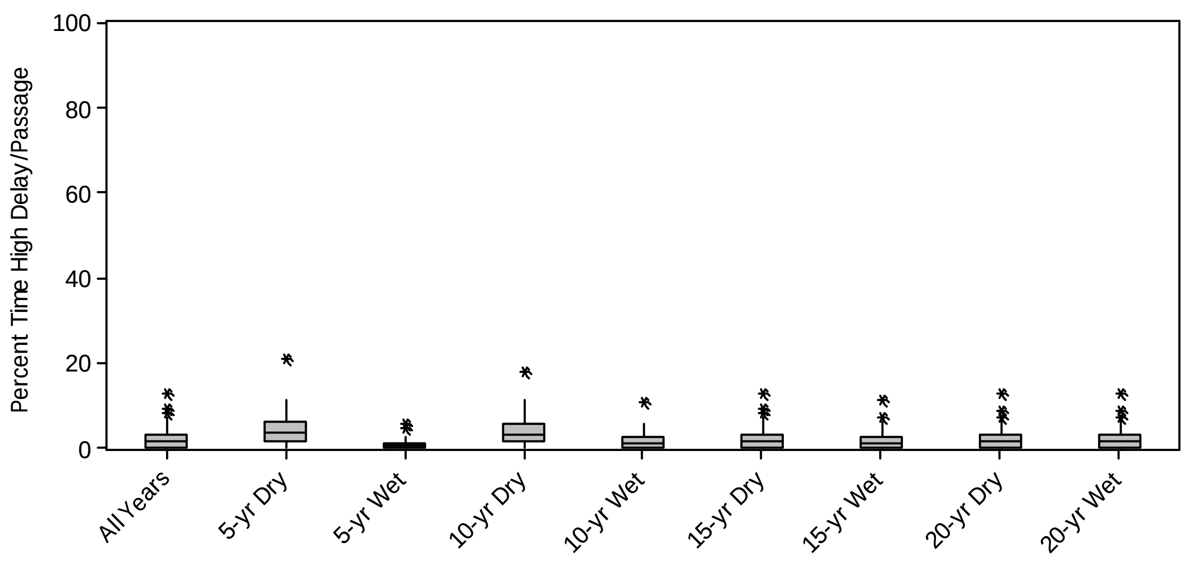



**Figure D- 20. Box plots summarizing percent time of high passage delay relative to passage time in all years of the data record for East Fork Lobster Creek predicted using the 1% annual exceedance values predicted from various data record lengths as $Q_{HFP}$. The low fish passage flow for all analyses is the 50% annual exceedance flow.**

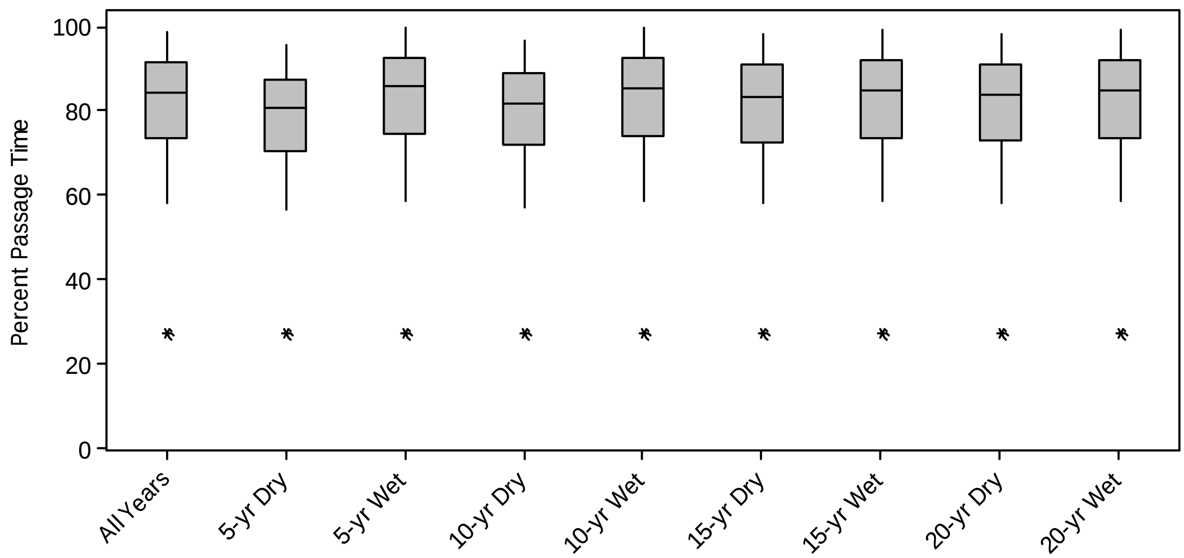



**Figure D- 21. Box plots summarizing percent passage time in all years of the data record for Little River predicted using the 1% annual exceedance values predicted from various data record lengths as $Q_{HFP}$. The low fish passage flow for all analyses is the 50% annual exceedance flow. The low outlier values represent one dry year in the data record with significantly lower time with flows in the passage flow window.**

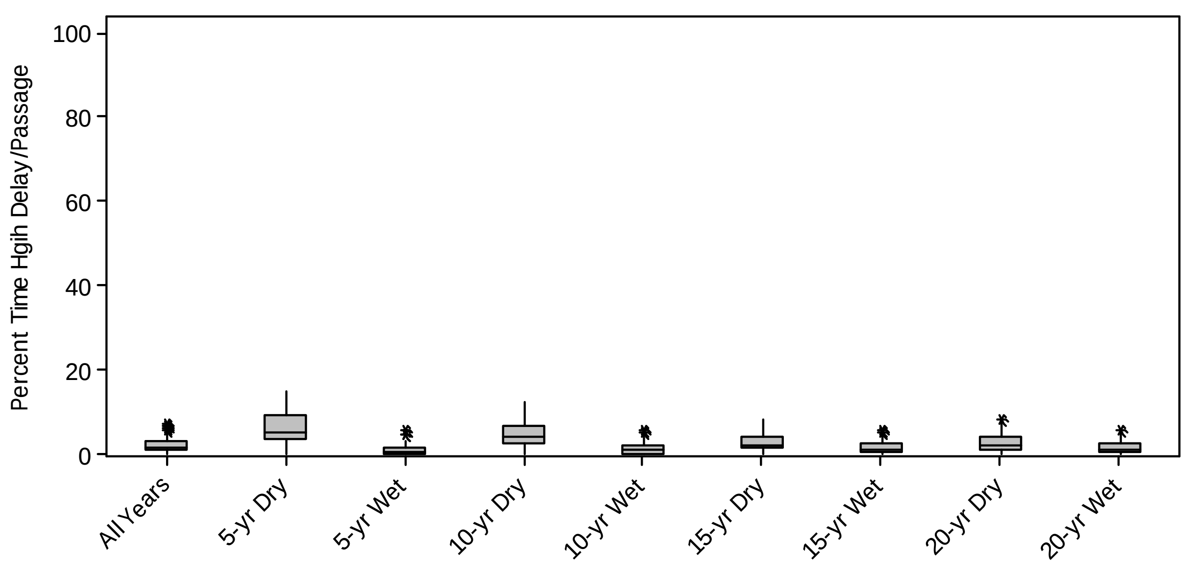



**Figure D- 22. Box plots summarizing percent time of high passage delay relative to passage time in all years of the data record for Little River predicted using the 1% annual exceedance values predicted from various data record lengths as $Q_{HFP}$. The low fish passage flow for all analyses is the 50% annual exceedance flow.**

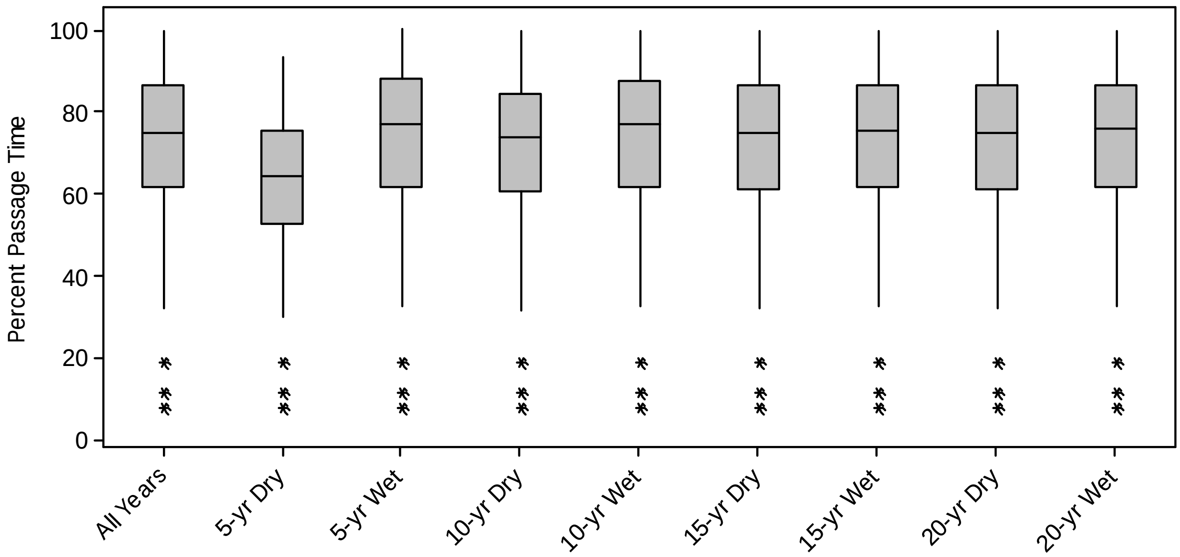



**Figure D- 23. Box plots summarizing percent passage time in all years of the data record for Soquel Creek predicted using the 1% annual exceedance values predicted from various data record lengths as $Q_{HFP}$. The low fish passage flow for all analyses is the 50% annual exceedance flow. The low outlier values represent dry years in the data record with significantly lower time with flows in the passage flow window.**

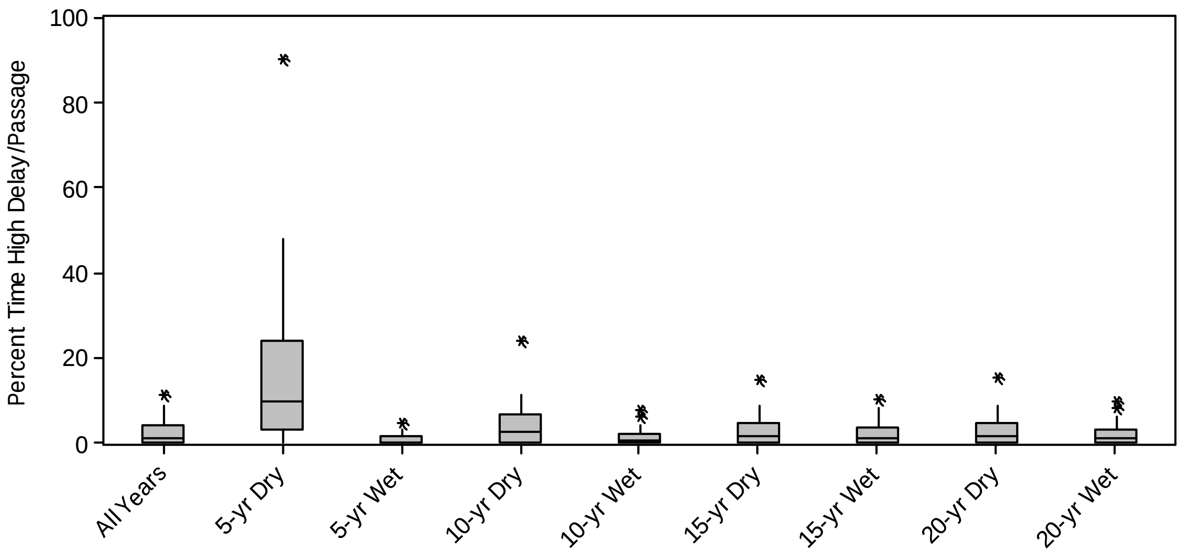



**Figure D- 24. Box plots summarizing percent time of high passage delay relative to passage time in all years of the data record for Soquel Creek predicted using the 1% annual exceedance values predicted from various data record lengths as $Q_{HFP}$. The low fish passage flow for all analyses is the 50% annual exceedance flow.**

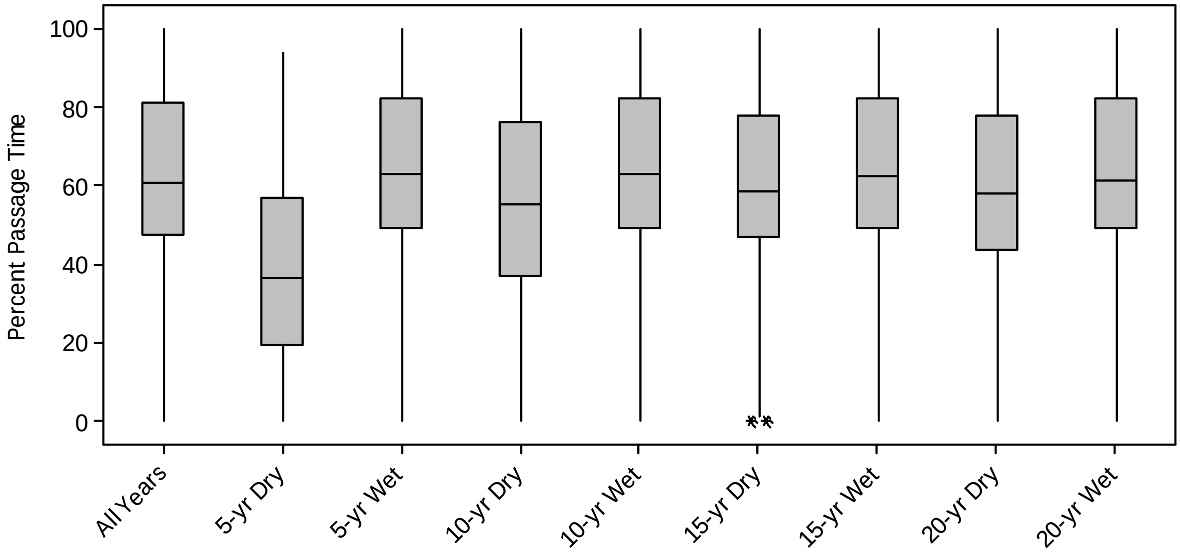



**Figure D- 25. Box plots summarizing percent passage time in all years of the data record for Santa Cruz Creek predicted using the 1% annual exceedance values predicted from various data record lengths as $Q_{HFP}$. The low fish passage flow for all analyses is the 50% annual exceedance flow. The low outlier values represent dry years in the data record with significantly lower time with flows in the passage flow window.**

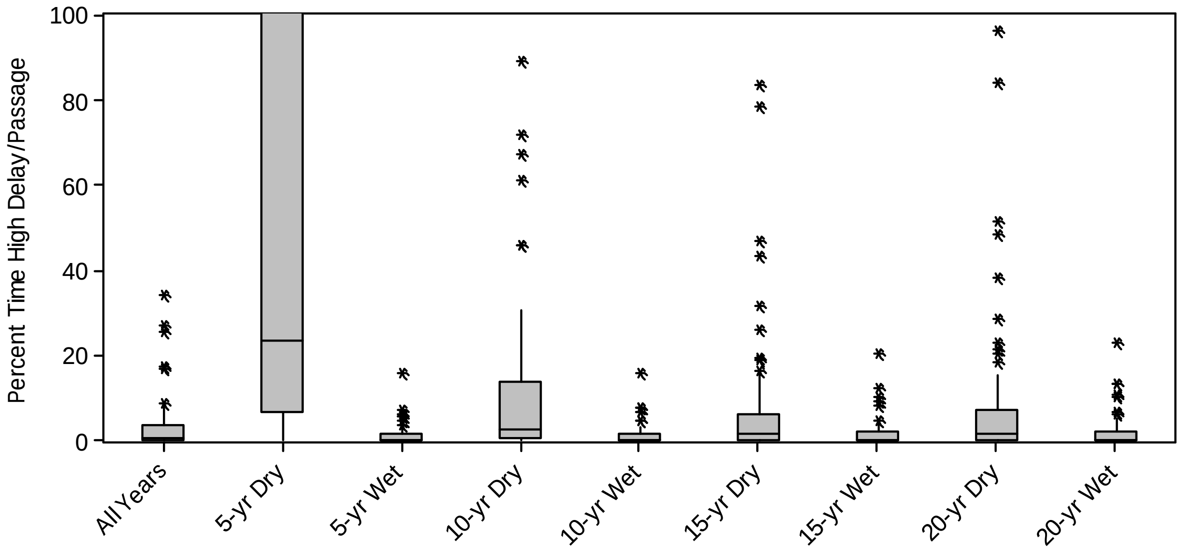



**Figure D- 26. Box plots summarizing percent time of high passage delay relative to passage time in all years of the data record for Santa Cruz Creek predicted using the 1% annual exceedance values predicted from various data record lengths as $Q_{HFP}$. The low fish passage flow for all analyses is the 50% annual exceedance flow.**

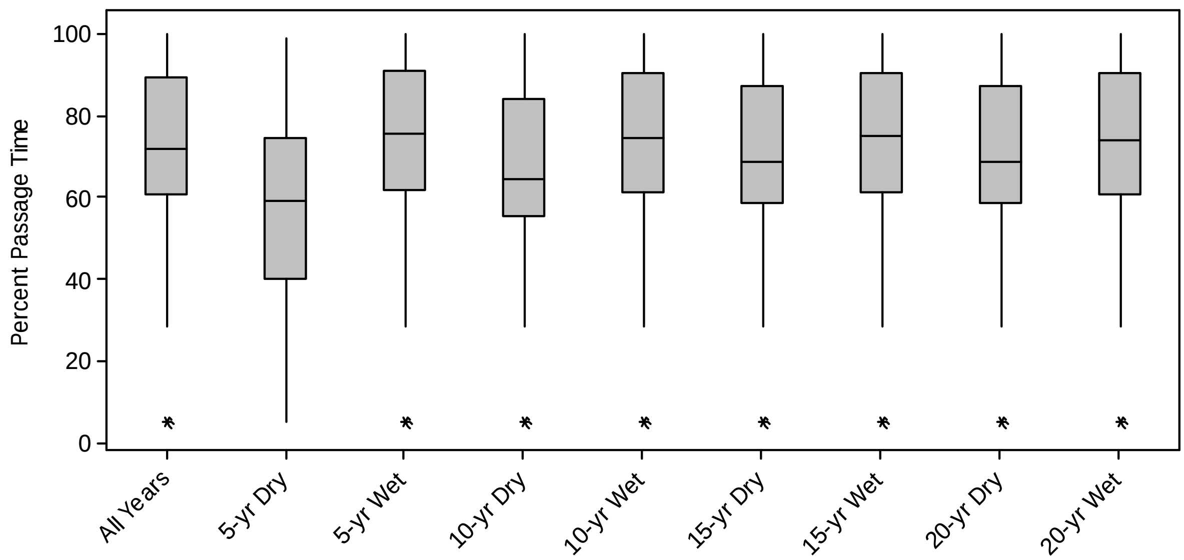



**Figure D- 27. Box plots summarizing percent passage time in all years of the data record for Sespe River predicted using the 1% annual exceedance values predicted from various data record lengths as $Q_{HFP}$. The low fish passage flow for all analyses is the 50% annual exceedance flow. The low outlier values represent dry years in the data record with significantly lower time with flows in the passage flow window.**

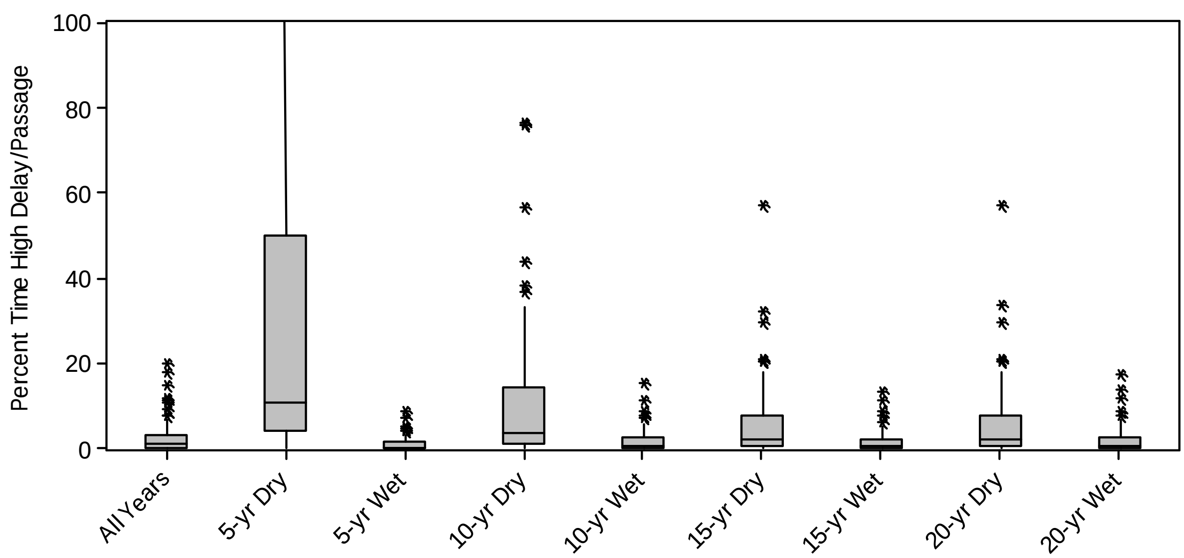



**Figure D- 28. Box plots summarizing percent time of high passage delay relative to passage time in all years of the data record for Sespe River predicted using the 1% annual exceedance values predicted from various data record lengths as $Q_{HFP}$. The low fish passage flow for all analyses is the 50% annual exceedance flow.**

# Appendix E – Analysis of Passage for the Assumed Coho and Chinook Migration Periods

Appendix E summarizes passage analyses for the variations of $Q_{HFP}$ and assumed migration periods for coho (Oct1 – Feb 28) and chinook (Sep15 – Feb15). Passage analysis for these species was conducted for the Northern California and Pacific Northwest study sites only because these species are not present at the Southern California sites. The results are presented as percent passage time for the respective migration periods calculated as:

$$100\% \times \frac{\#\ of\ days\ meeting\ passage\ criteria\ (Q_{LFP} \leq Q \leq Q_{HFP})}{\#\ of\ days\ in\ the\ migration\ period}$$

and as the percent of high flow delay relative to passage time calculated as:

$$100\% \times \frac{\#\ of\ days\ exceeding\ Q_{HFP}}{\#\ of\ days\ meeting\ passage\ criteria\ (Q_{LFP} \leq Q \leq Q_{HFP})}$$

The assumed migration periods for coho and chinook are shorter than the migration period assumed for steelhead (Nov1 – May15) and used in the analyses presented in the main report. These shorter migration periods also include earlier dates in the Fall and in many years these dates are earlier than the first rain of the water year. Thus, passage opportunity is predicted to be lower for all $Q_{HFP}$ criteria analyzed during the assumed coho and chinook migration periods.

## List of Figures

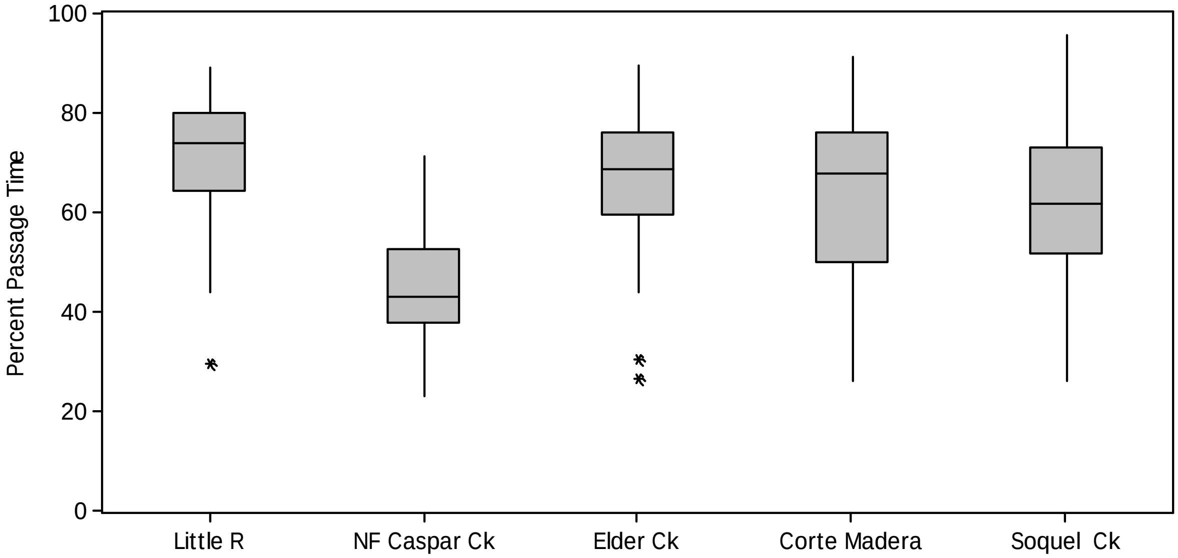



**Figure E- 1. Box plots summarizing percent passage time during the assumed coho migration period (Oct1 – Feb28) in all years of the data record for the Northern California sites. $Q_{HFP}$ is the 1% annual exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

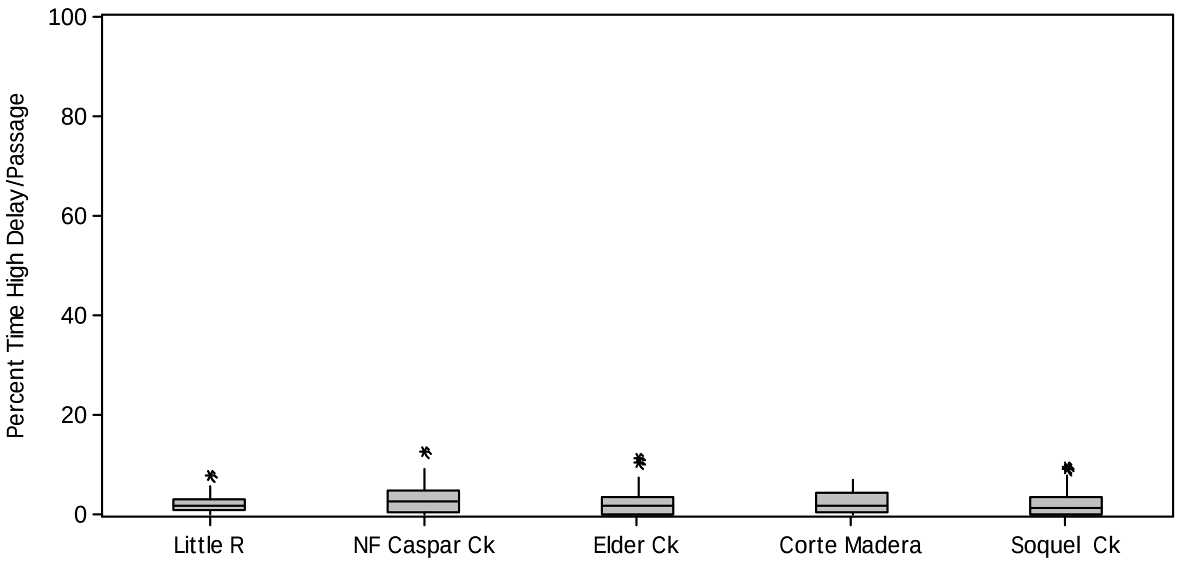



**Figure E- 2. Box plots summarizing percent time of high passage delay relative to passage time during the assumed coho migration period (Oct1 – Feb28) for all years of the data record for the Northern California sites. $Q_{HFP}$ is the 1% annual exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

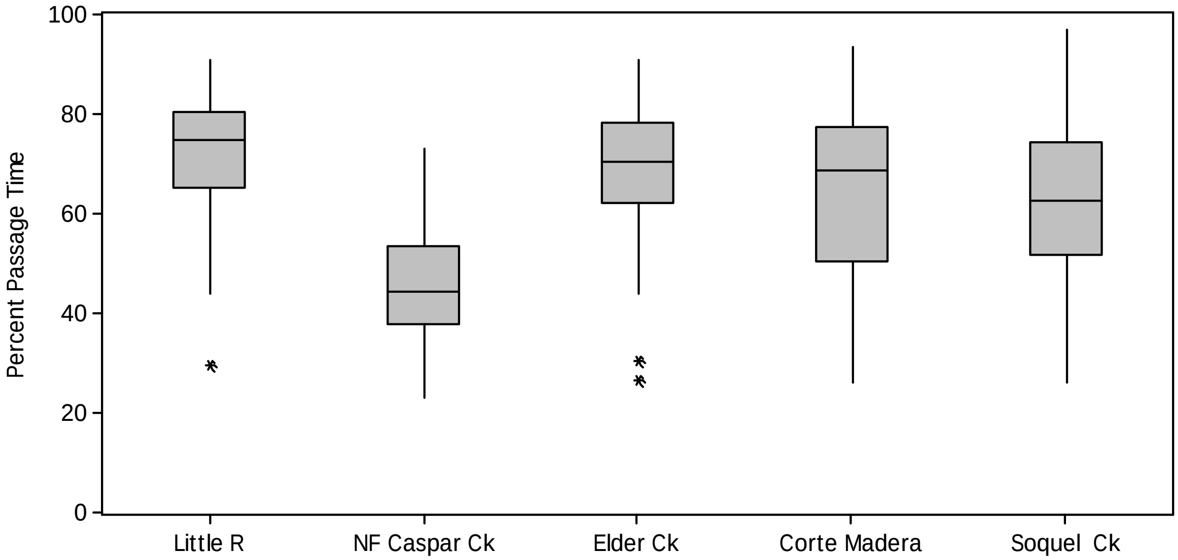



**Figure E- 3. Box plots summarizing percent passage time during the assumed coho migration period (Oct1 – Feb28) in all years of the data record for the Northern California sites. $Q_{HFP}$ is the 1% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

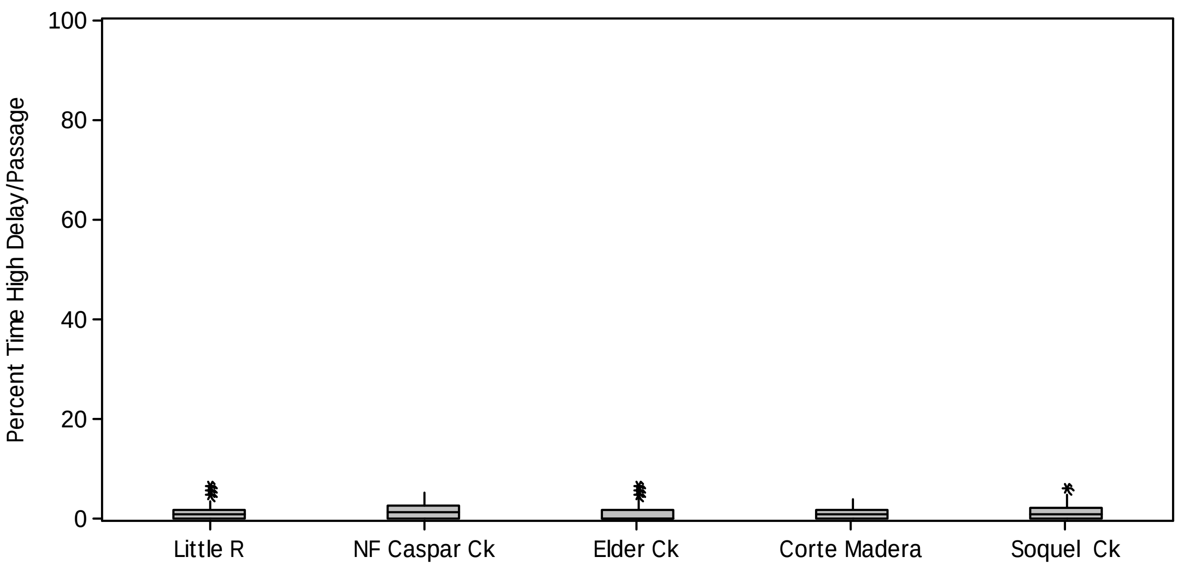



**Figure E- 4. Box plots summarizing percent time of high passage delay relative to passage time during the assumed coho migration period (Oct1 – Feb28) for all years of the data record for the Northern California sites. $Q_{HFP}$ is the 1% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

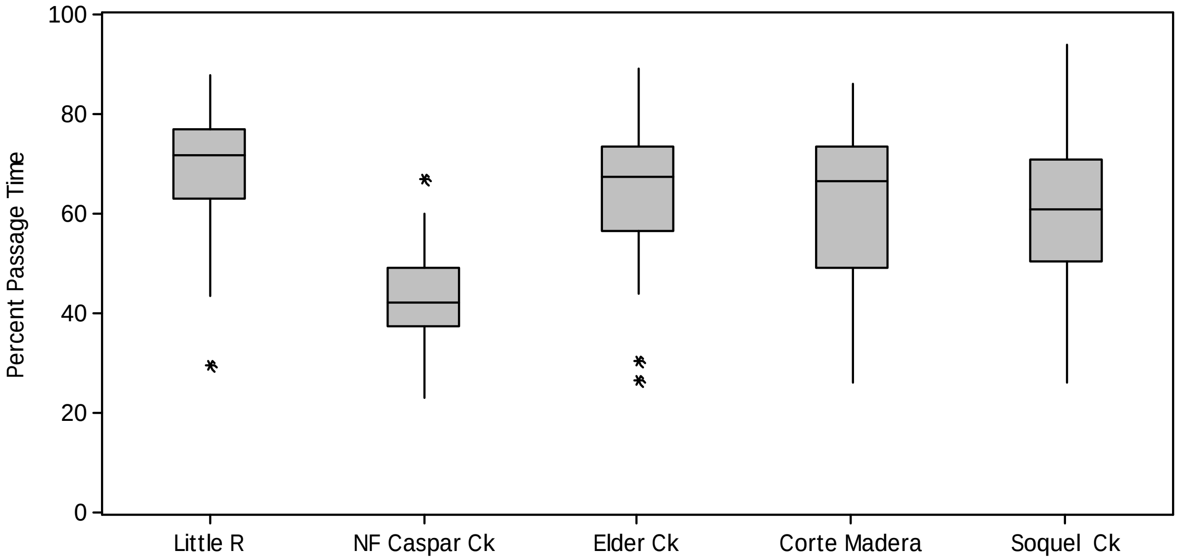



**Figure E- 5. Box plots summarizing percent passage time during the assumed coho migration period (Oct1 – Feb28) in all years of the data record for the Northern California sites. $Q_{HFP}$ is the 5% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

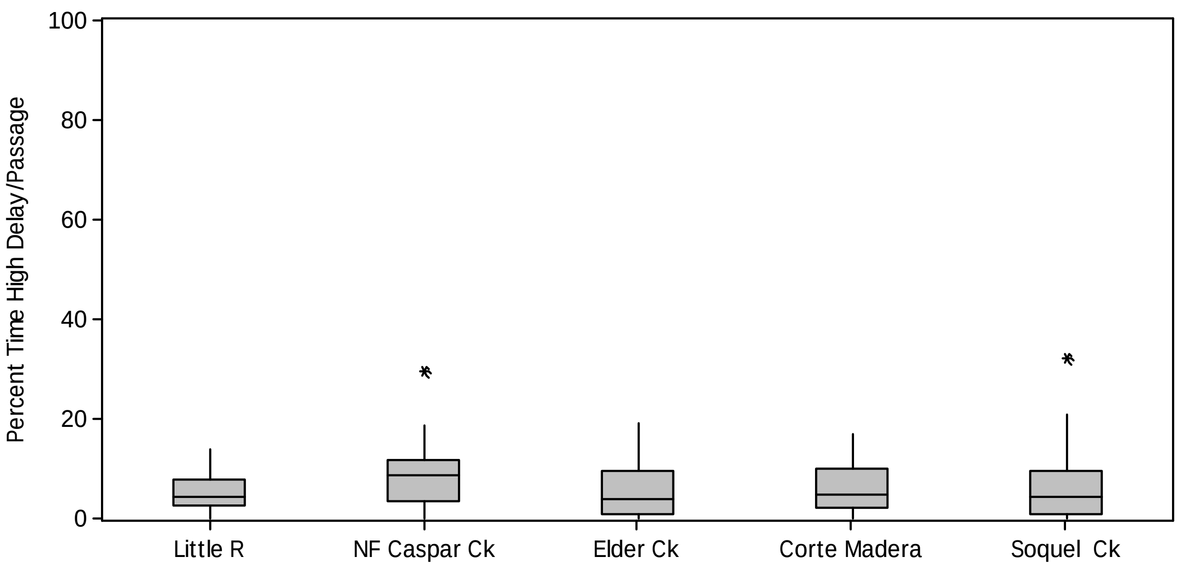



**Figure E- 6. Box plots summarizing percent passage time during the assumed coho migration period (Oct1 – Feb28) in all years of the data record for the Northern California sites. $Q_{HFP}$ is the 5% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

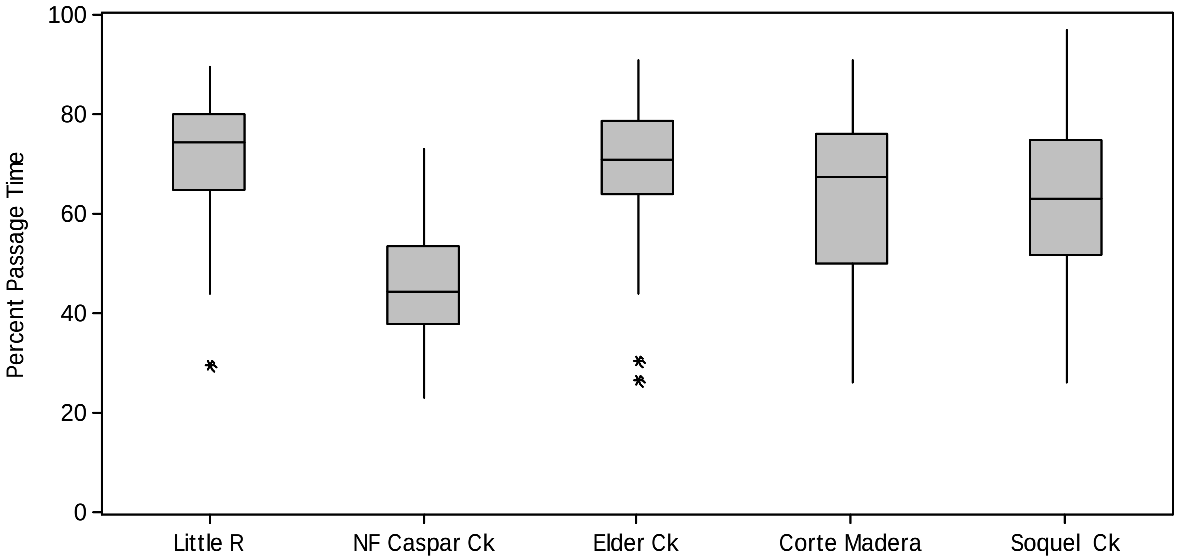



**Figure E- 7. Box plots summarizing percent passage time during the assumed coho migration period (Oct1 – Feb28) in all years of the data record for the Northern California sites. $Q_{HFP}$ is 50% of $Q_{2\text{-year}}$ determined using the USGS regression equation for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

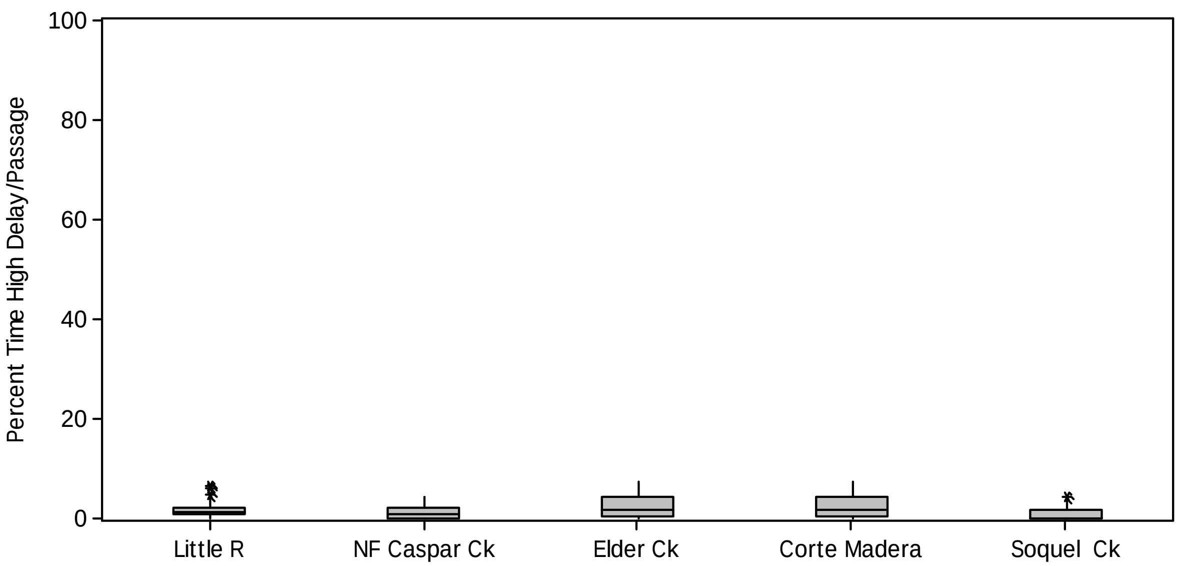



**Figure E- 8. Box plots summarizing percent time of high passage delay relative to passage time during the assumed coho migration period (Oct1 – Feb28) for all years of the data record for the Northern California sites. $Q_{HFP}$ is 50% of $Q_{2\text{-year}}$ determined using the USGS regression equation for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

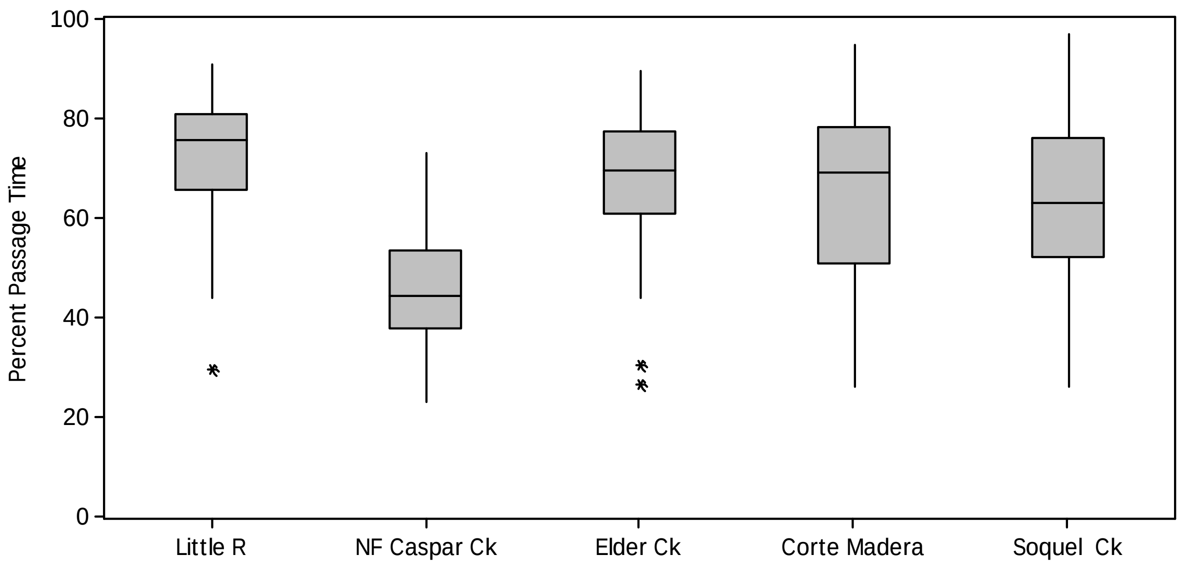



**Figure E- 9. Box plots summarizing percent passage time during the assumed coho migration period (Oct1 – Feb28) in all years of the data record for the Northern California sites. $Q_{HFP}$ is 50% of $Q_{2\text{-year}}$ determined using the peak flow data for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

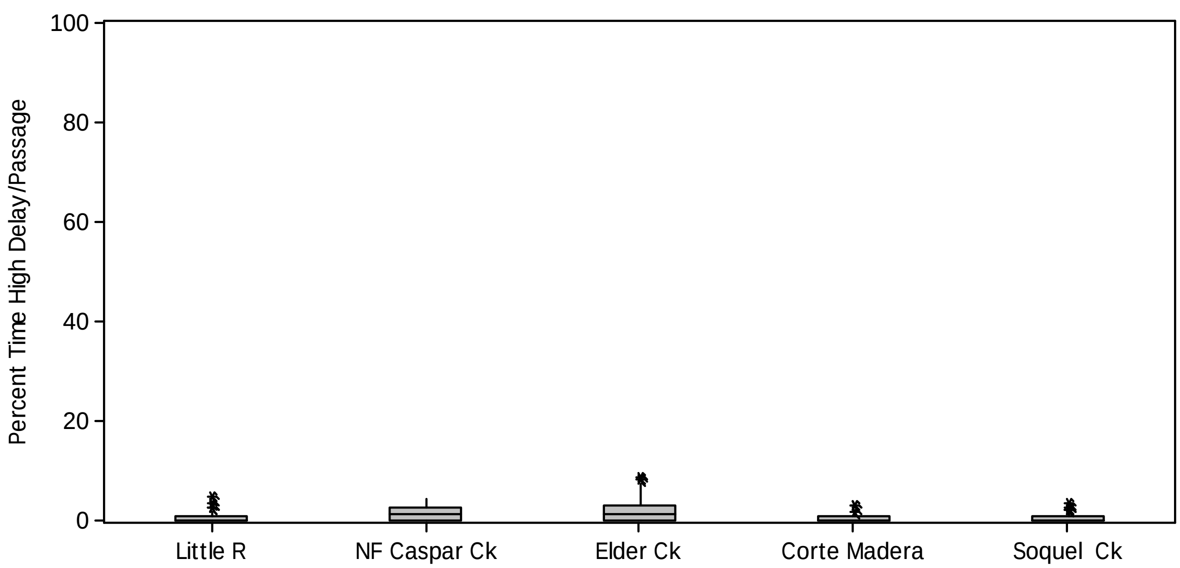



**Figure E- 10. Box plots summarizing percent time of high passage delay relative to passage time during the assumed coho migration period (Oct1 – Feb28) for all years of the data record for the Northern California sites. $Q_{HFP}$ is 50% of $Q_{2\text{-year}}$ determined using the peak flow data for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

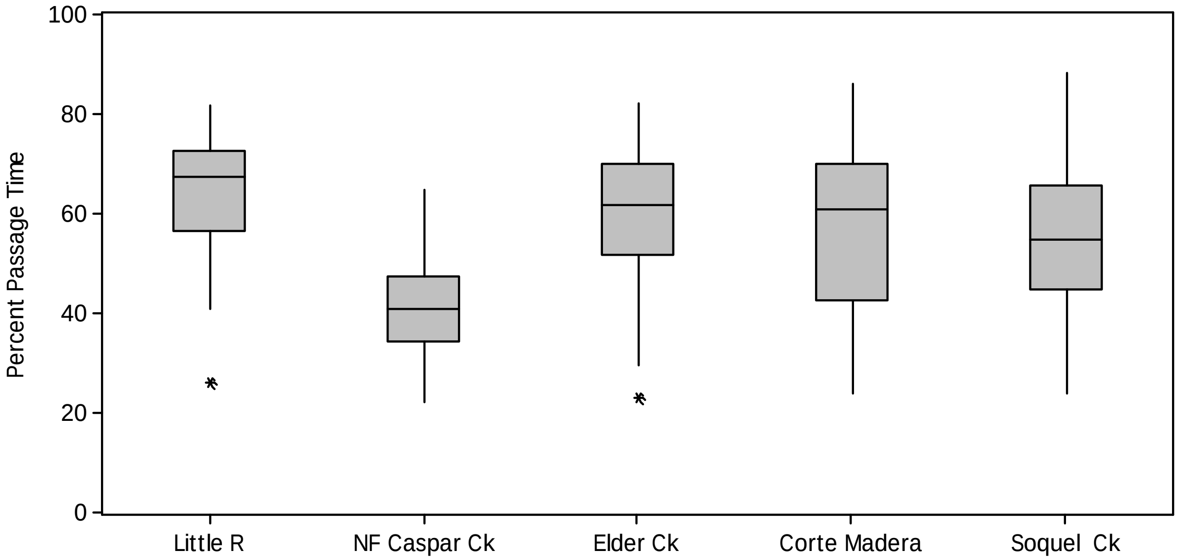



**Figure E- 11. Box plots summarizing percent passage time during the assumed chinook migration period (Sep15 – Feb15) in all years of the data record for the Northern California sites. $Q_{HFP}$ is the 1% annual exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

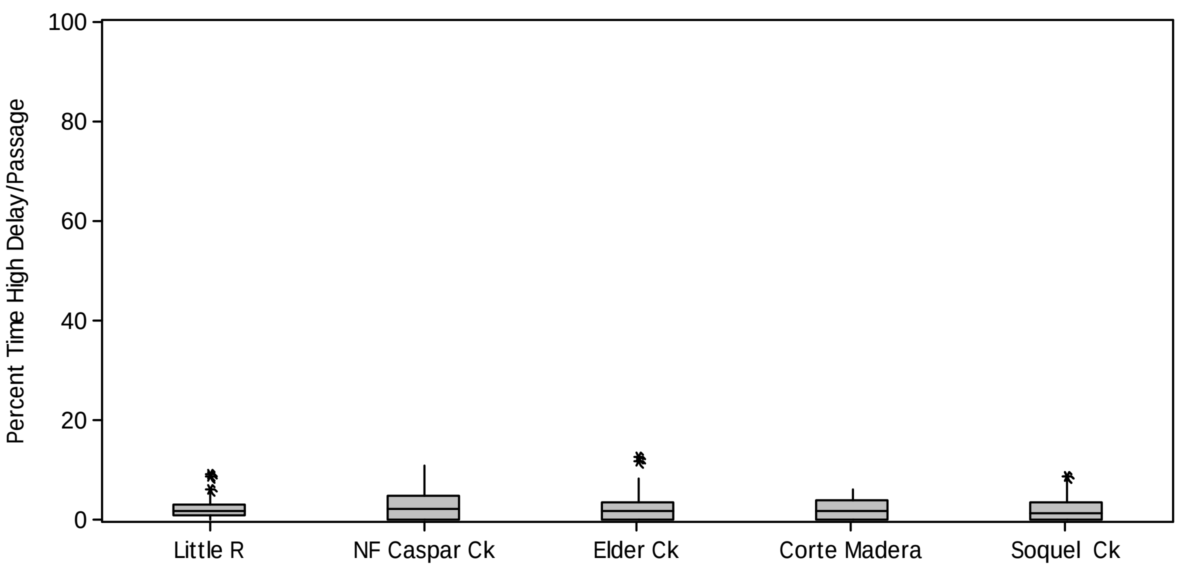



**Figure E- 12. Box plots summarizing percent time of high passage delay relative to passage time during the assumed chinook migration period (Sep15 – Feb15) for all years of the data record for the Northern California sites. $Q_{HFP}$ is the 1% annual exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

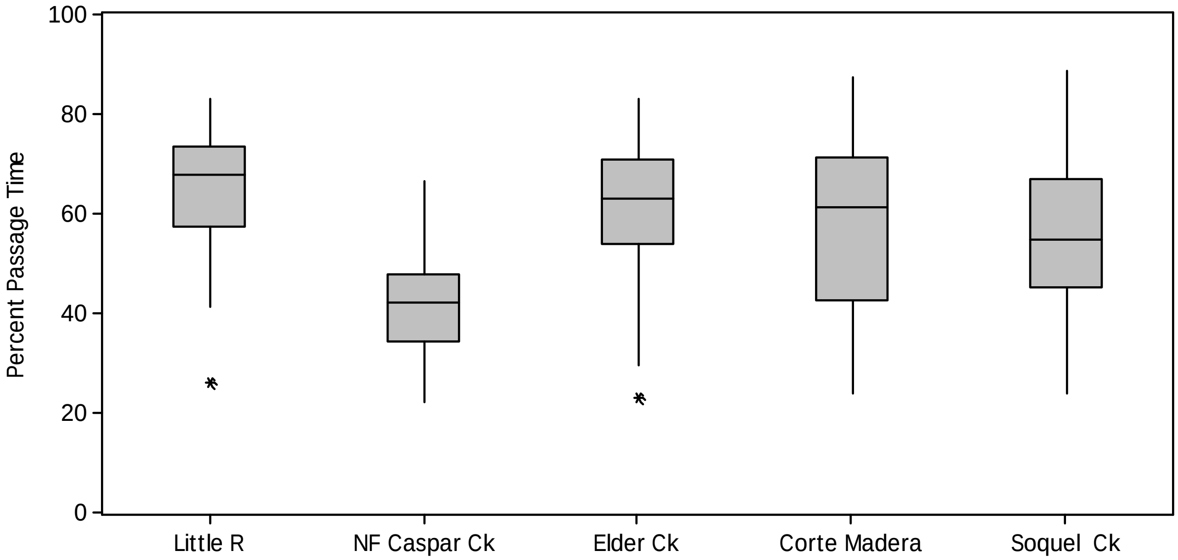



**Figure E- 13. Box plots summarizing percent passage time during the assumed chinook migration period (Sep15 – Feb15) in all years of the data record for the Northern California sites. $Q_{HFP}$ is the 1% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

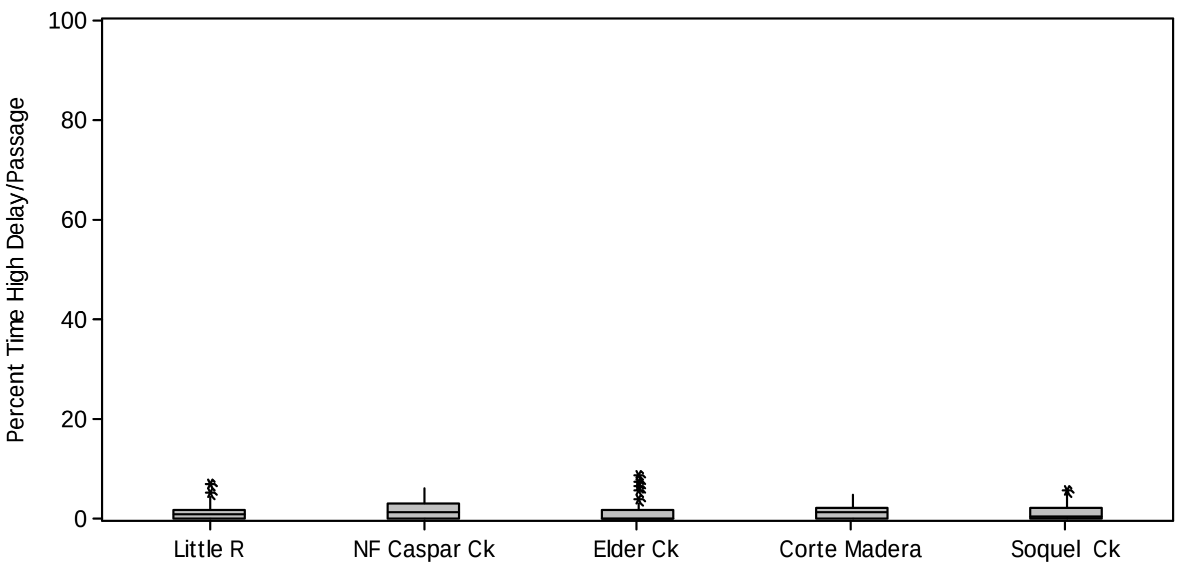



**Figure E- 14. Box plots summarizing percent time of high passage delay relative to passage time during the assumed chinook migration period (Sep15 – Feb15) for all years of the data record for the Northern California sites. $Q_{HFP}$ is the 1% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

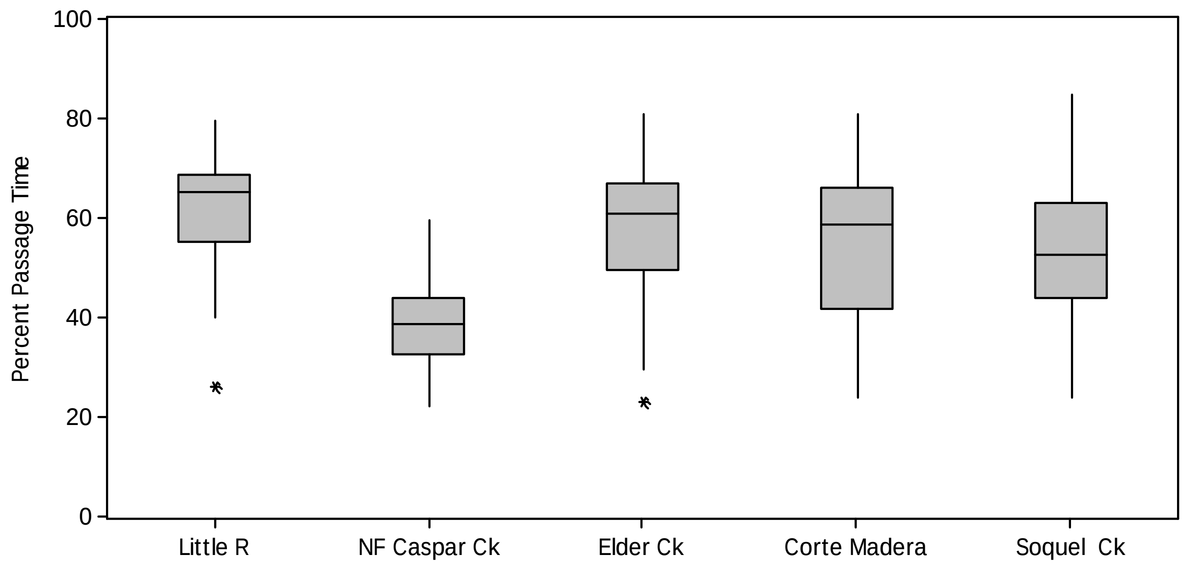



**Figure E- 15. Box plots summarizing percent passage time during the assumed chinook migration period (Sep15 – Feb15) in all years of the data record for the Northern California sites. $Q_{HFP}$ is the 5% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

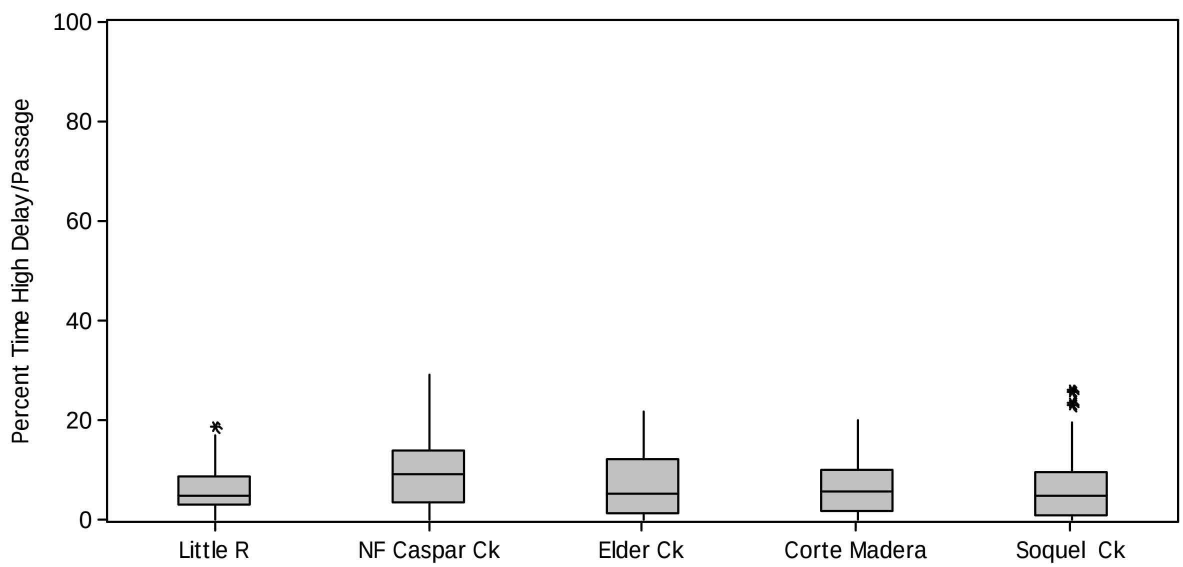



**Figure E- 16. Box plots summarizing percent time of high passage delay relative to passage time during the assumed chinook migration period (Sep15 – Feb15) for all years of the data record for the Northern California sites. $Q_{HFP}$ is the 5% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

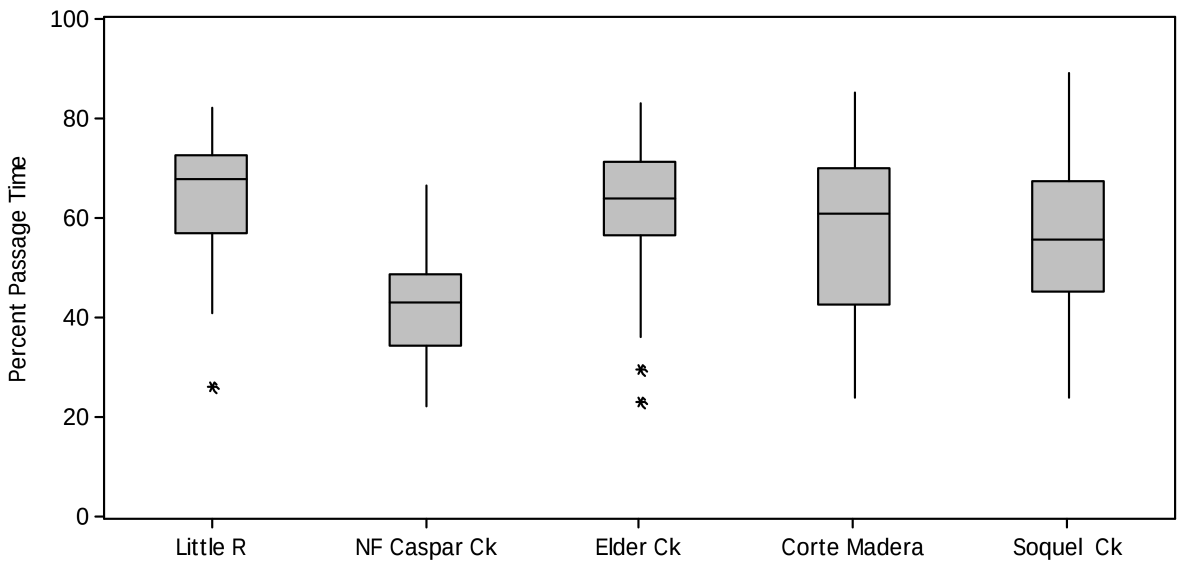



**Figure E- 17. Box plots summarizing percent passage time during the assumed chinook migration period (Sep15 – Feb15) in all years of the data record for the Northern California sites. $Q_{HFP}$ is 50% of Q2-year determined using the USGS regression equation for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

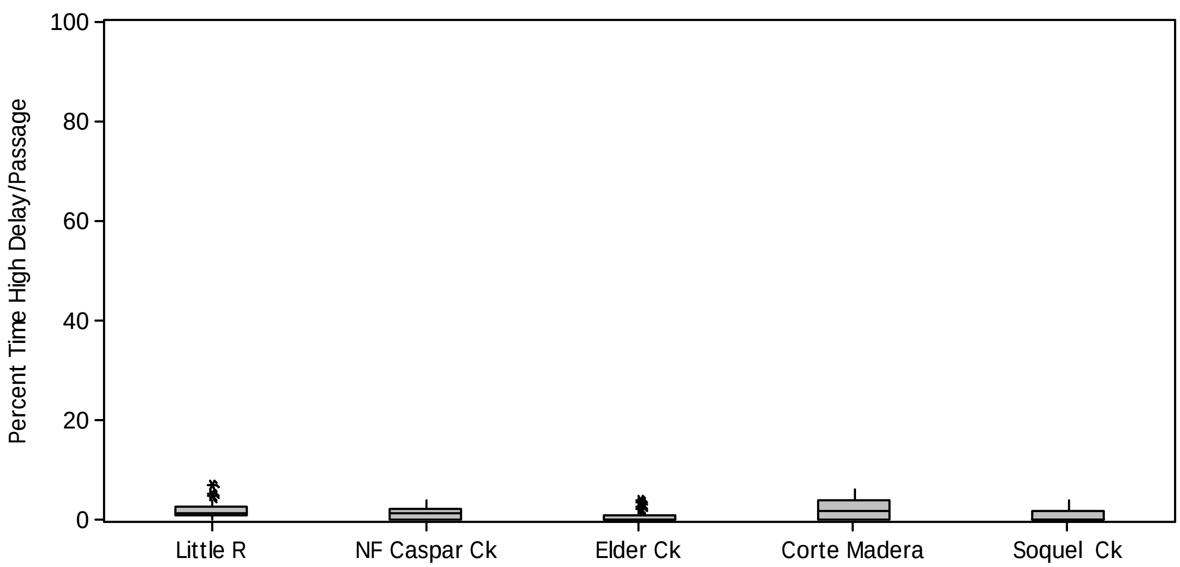



**Figure E- 18. Box plots summarizing percent time of high passage delay relative to passage time during the assumed chinook migration period (Sep15 – Feb15) for all years of the data record for the Northern California sites. $Q_{HFP}$ is 50% of Q2-year determined using the USGS regression equation for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

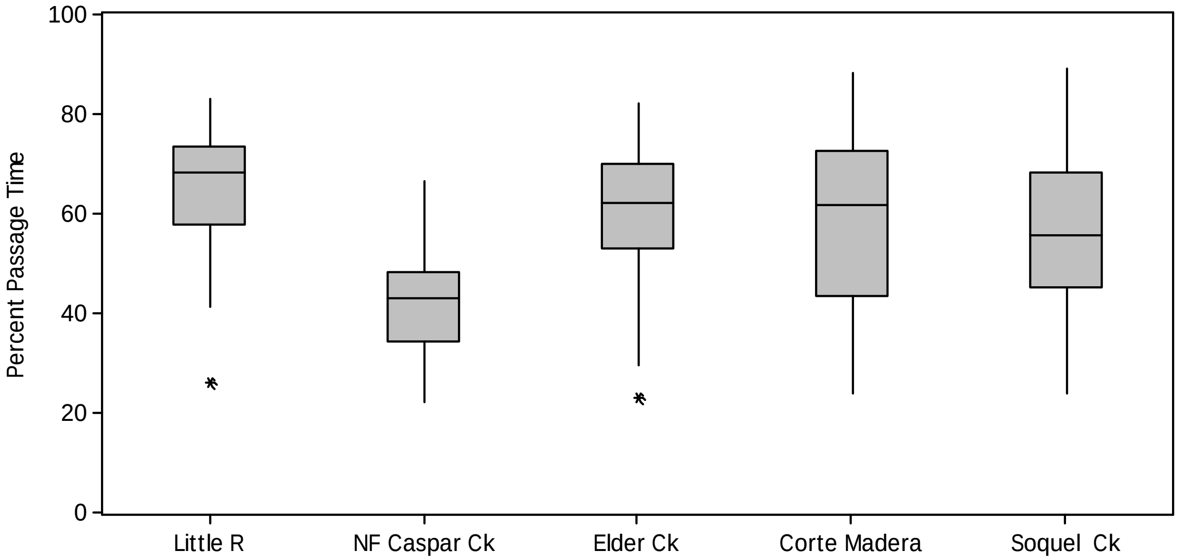



**Figure E- 19. Box plots summarizing percent passage time during the assumed chinook migration period (Sep15 – Feb15) in all years of the data record for the Northern California sites. $Q_{HFP}$ is 50% of Q2-year determined using the peak flow data for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

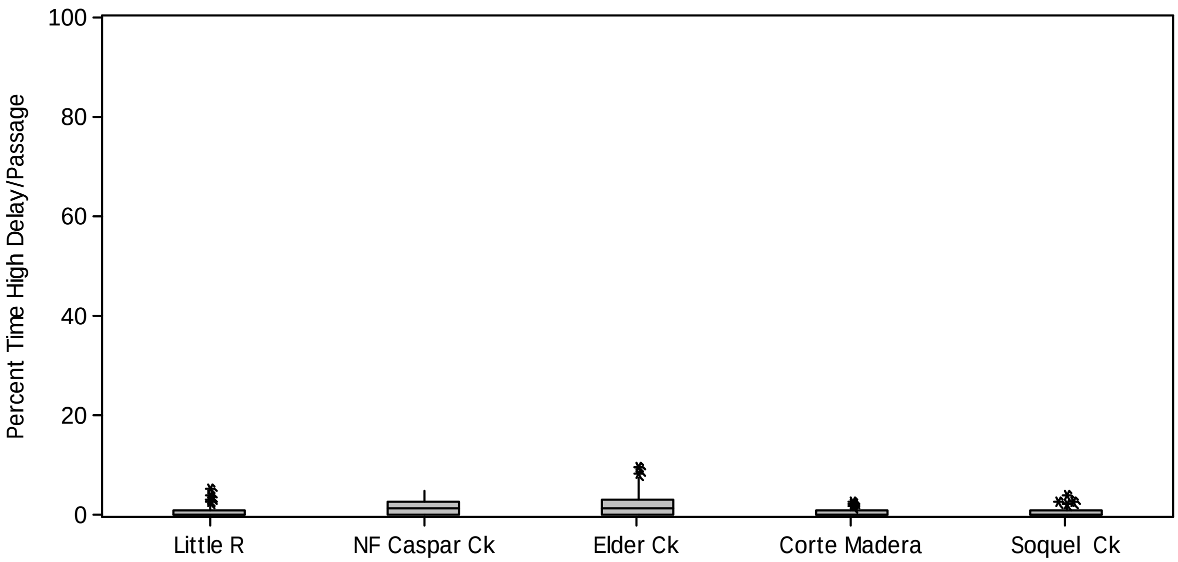



**Figure E- 20. Box plots summarizing percent time of high passage delay relative to passage time during the assumed chinook migration period (Sep15 – Feb15) for all years of the data record for the Northern California sites. $Q_{HFP}$ is 50% of Q2-year determined using the peak flow data for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

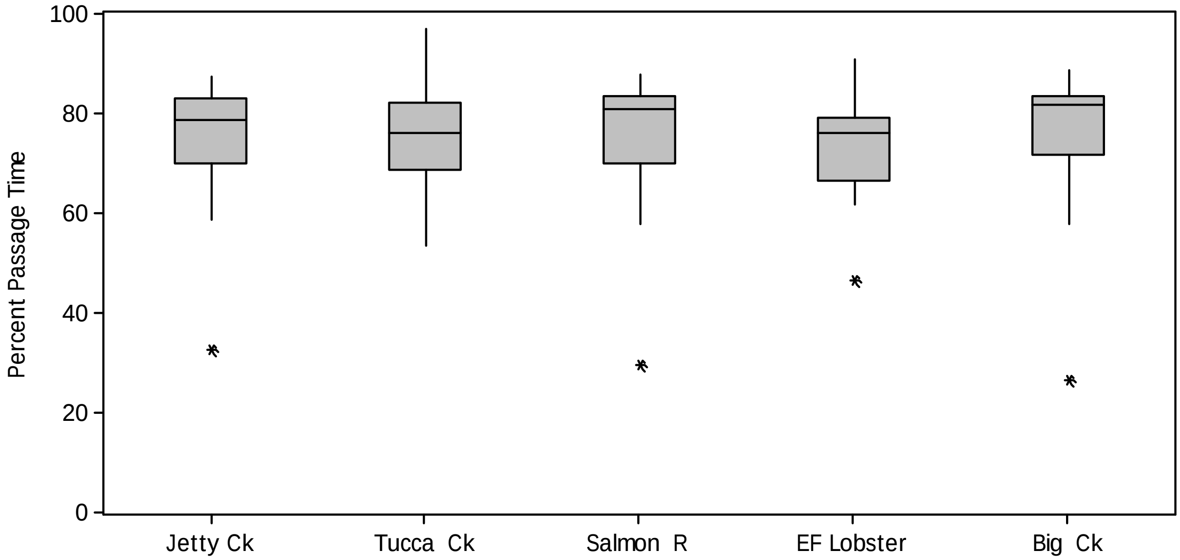



**Figure E- 21. Box plots summarizing percent passage time during the assumed coho migration period (Oct1 – Feb28) in all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is the 1% annual exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

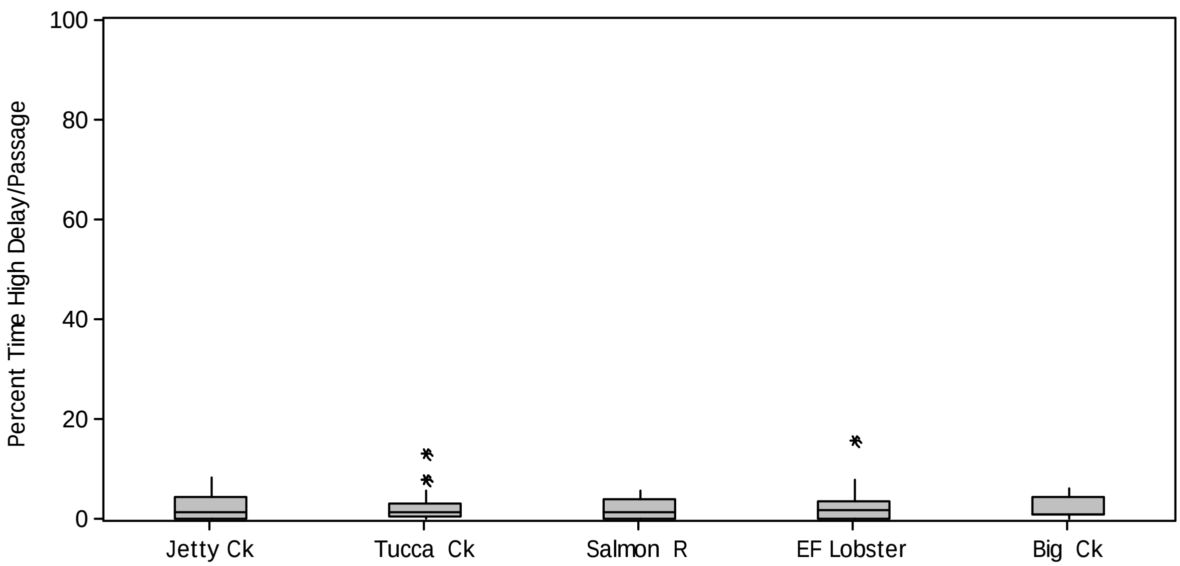



**Figure E- 22. Box plots summarizing percent time of high passage delay relative to passage time during the assumed coho migration period (Oct1 – Feb28) for all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is the 1% annual exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

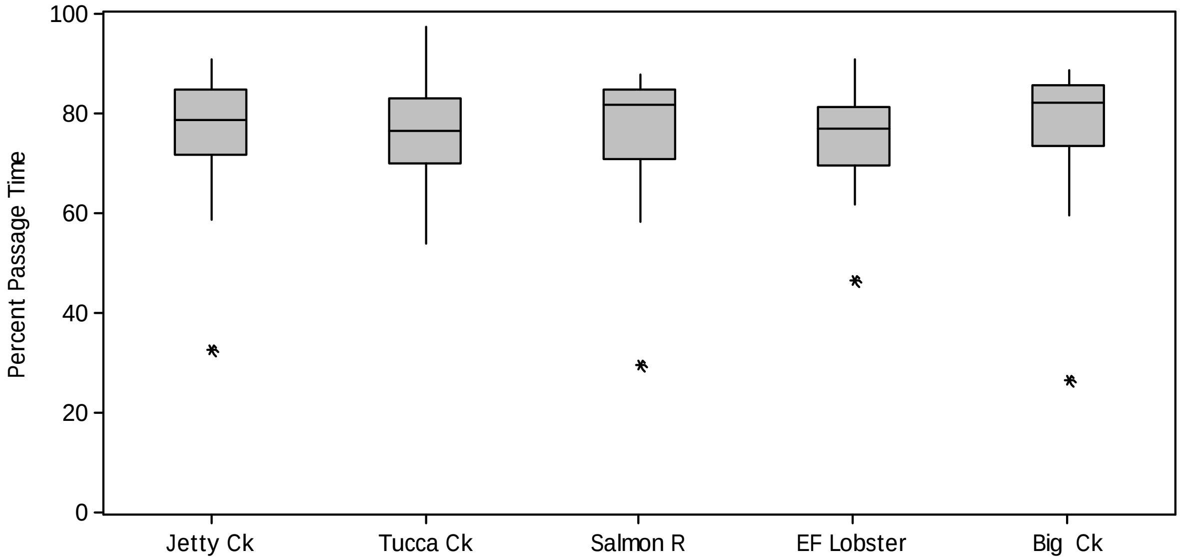



**Figure E- 23. Box plots summarizing percent passage time during the assumed coho migration period (Oct1 – Feb28) in all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is the 1% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

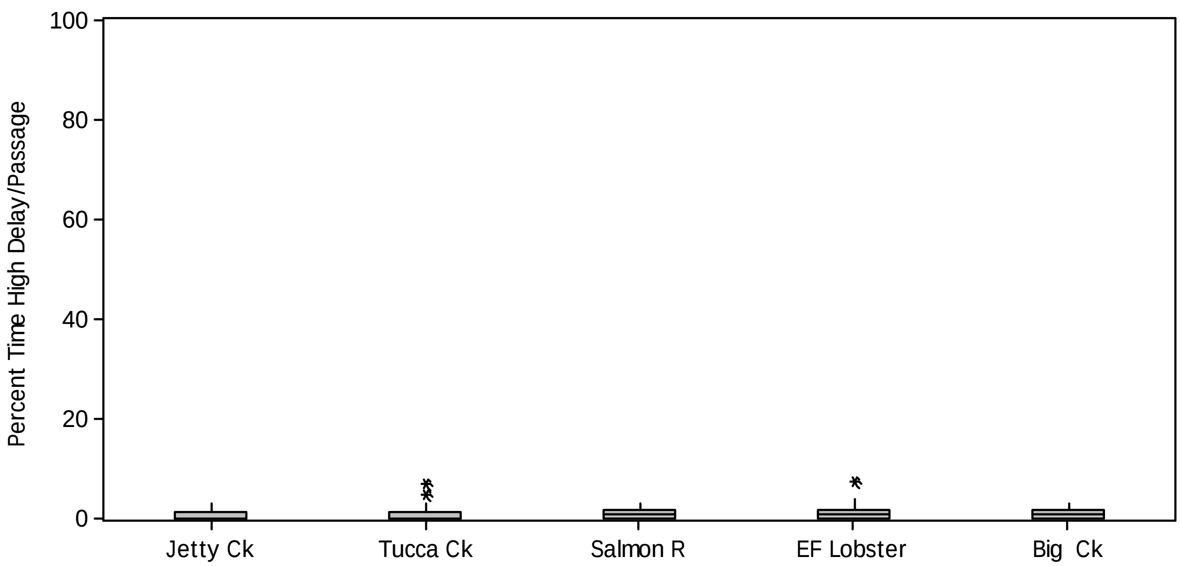



**Figure E- 24. Box plots summarizing percent time of high passage delay relative to passage time during the assumed coho migration period (Oct1 – Feb28) for all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is the 1% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

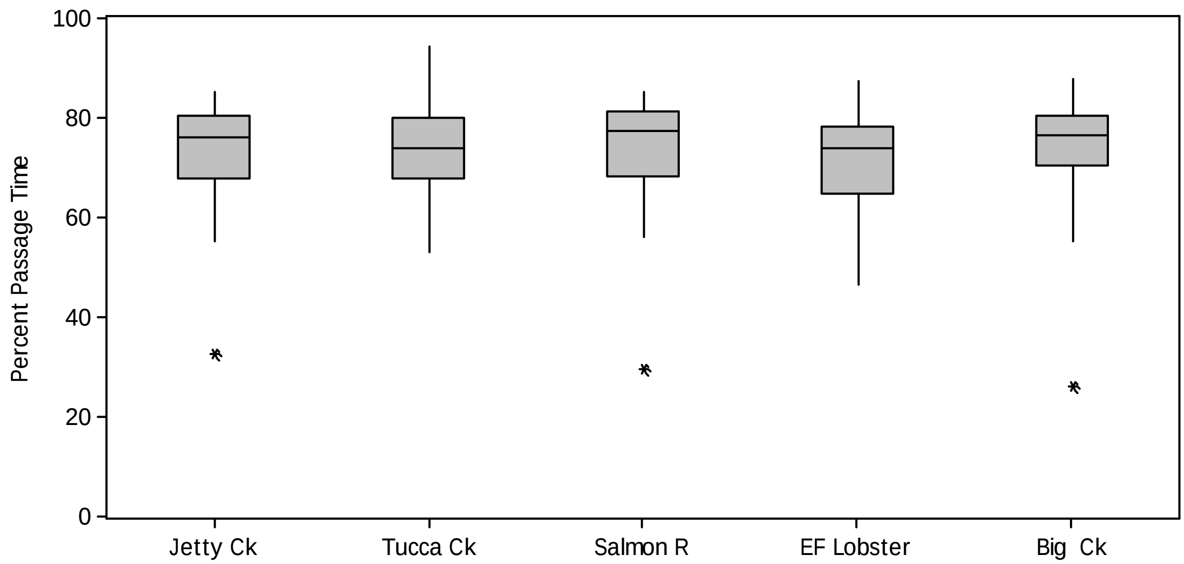



**Figure E- 25. Box plots summarizing percent passage time during the assumed coho migration period (Oct1 – Feb28) in all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is the 5% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

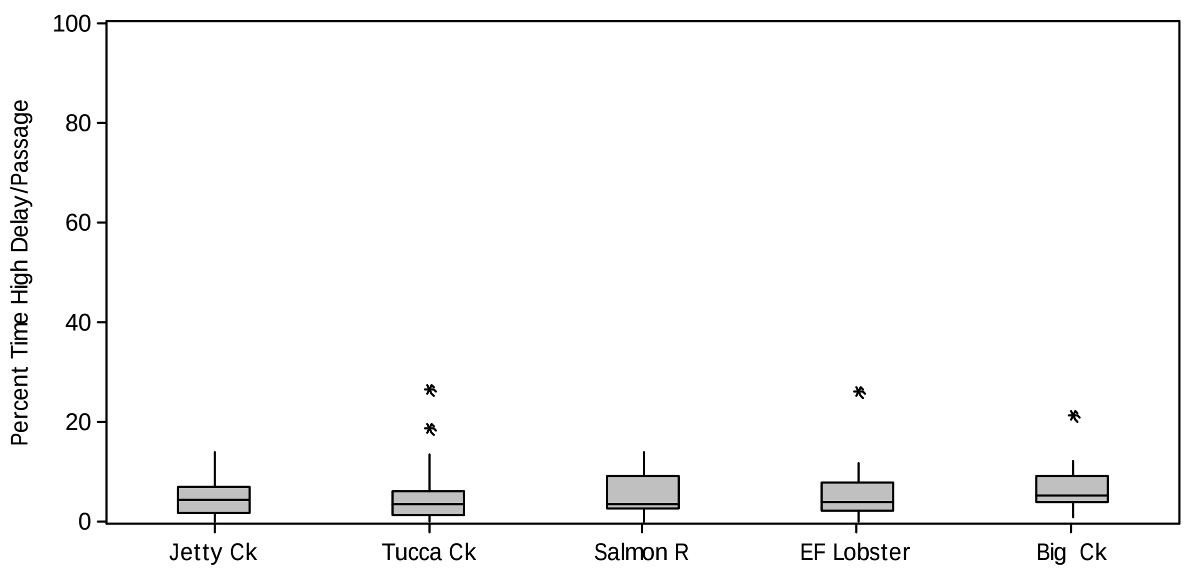



**Figure E- 26. Box plots summarizing percent time of high passage delay relative to passage time during the assumed coho migration period (Oct1 – Feb28) for all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is the 5% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

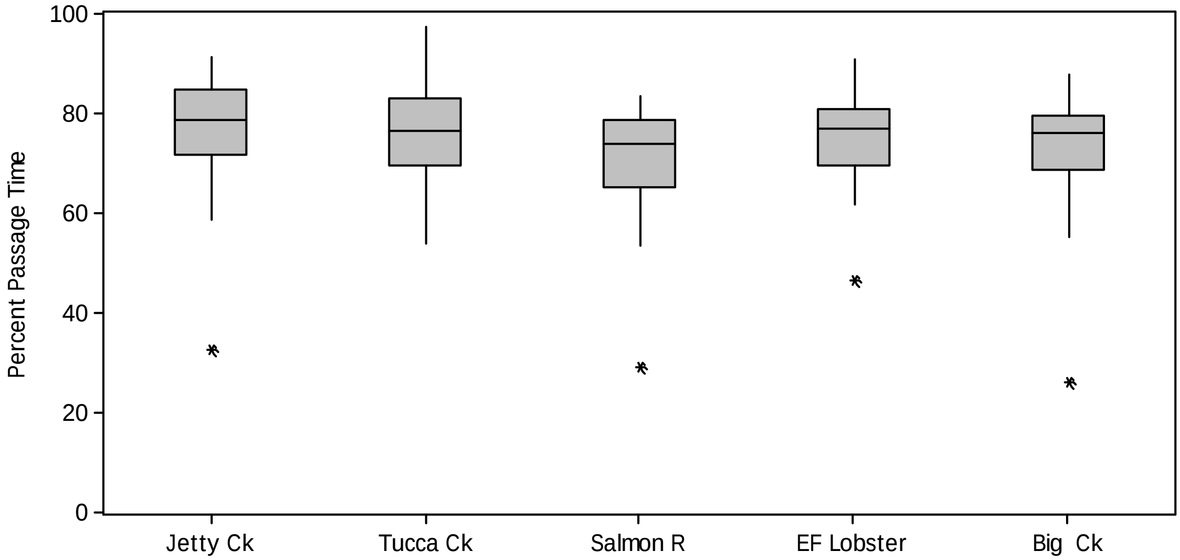



**Figure E- 27. Box plots summarizing percent passage time during the assumed coho migration period (Oct1 – Feb28) in all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is 50% of Q2-year determined using the USGS regression equation for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

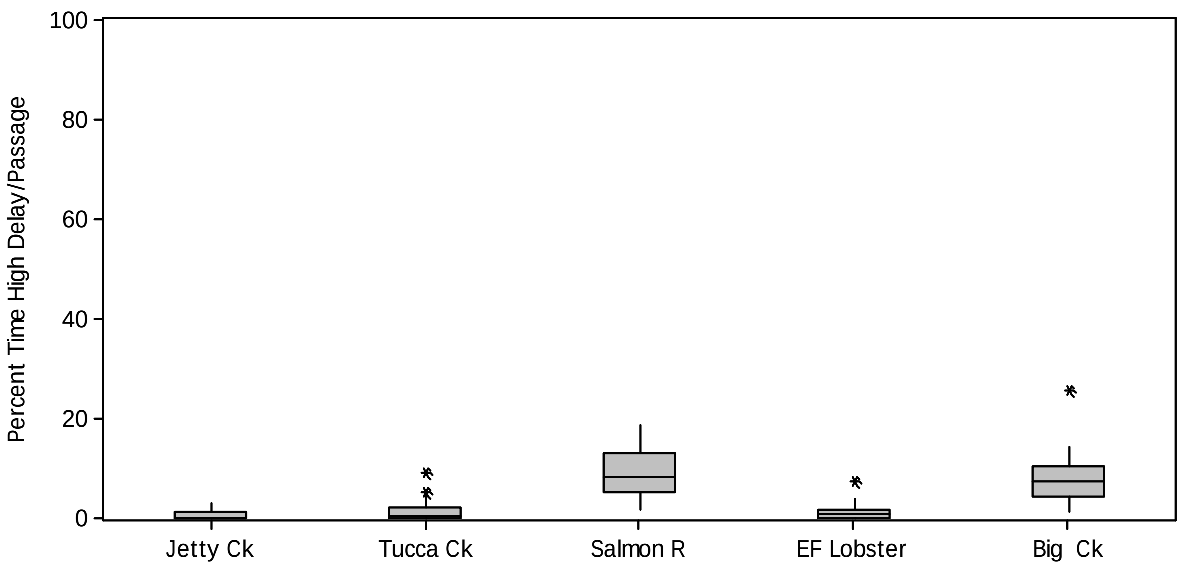



**Figure E- 28. Box plots summarizing percent time of high passage delay relative to passage time during the assumed coho migration period (Oct1 – Feb28) for all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is 50% of Q2-year determined using the USGS regression equation for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

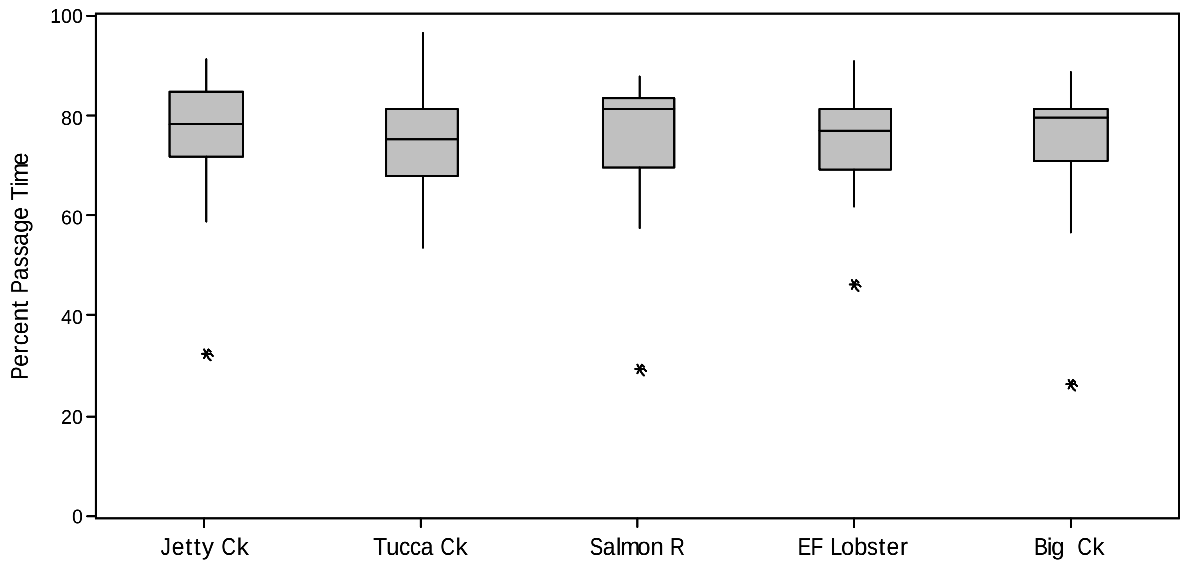



**Figure E- 29. Box plots summarizing percent passage time during the assumed coho migration period (Oct1 – Feb28) in all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is 50% of Q2-year determined using the peak flow data for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

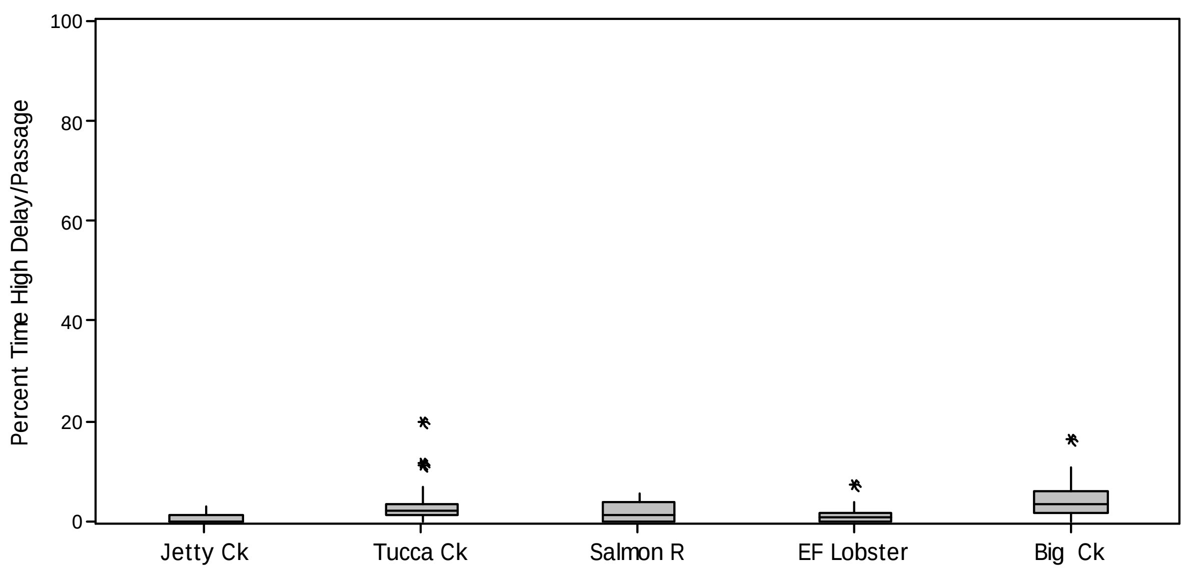



**Figure E- 30. Box plots summarizing percent time of high passage delay relative to passage time during the assumed coho migration period (Oct1 – Feb28) for all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is 50% of Q2-year determined using the peak flow data for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

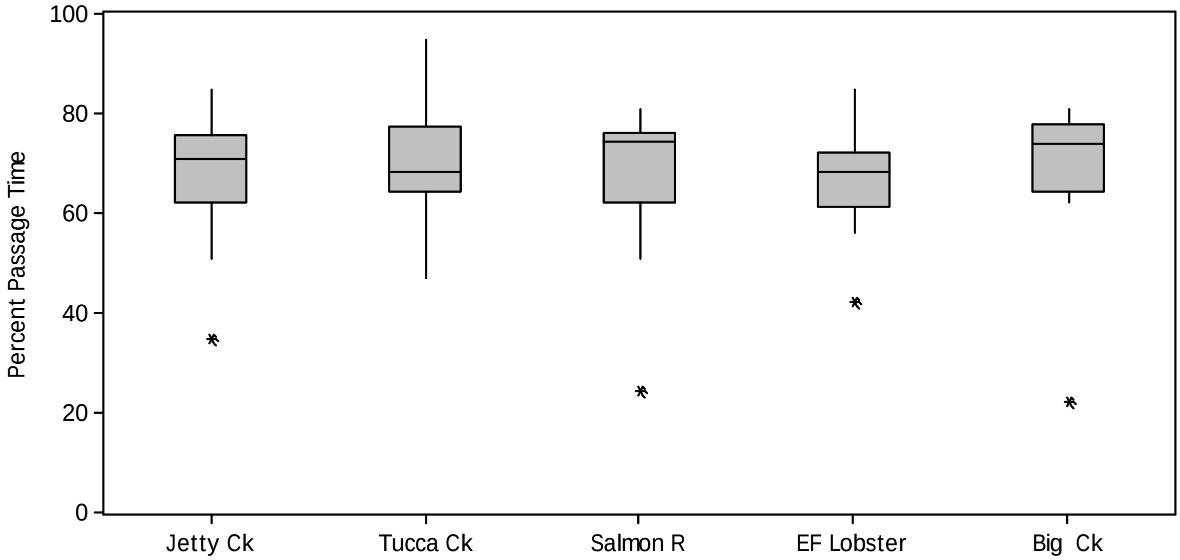



**Figure E- 31. Box plots summarizing percent passage time during the assumed chinook migration period (Sep15 – Feb15) in all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is the 1% annual exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

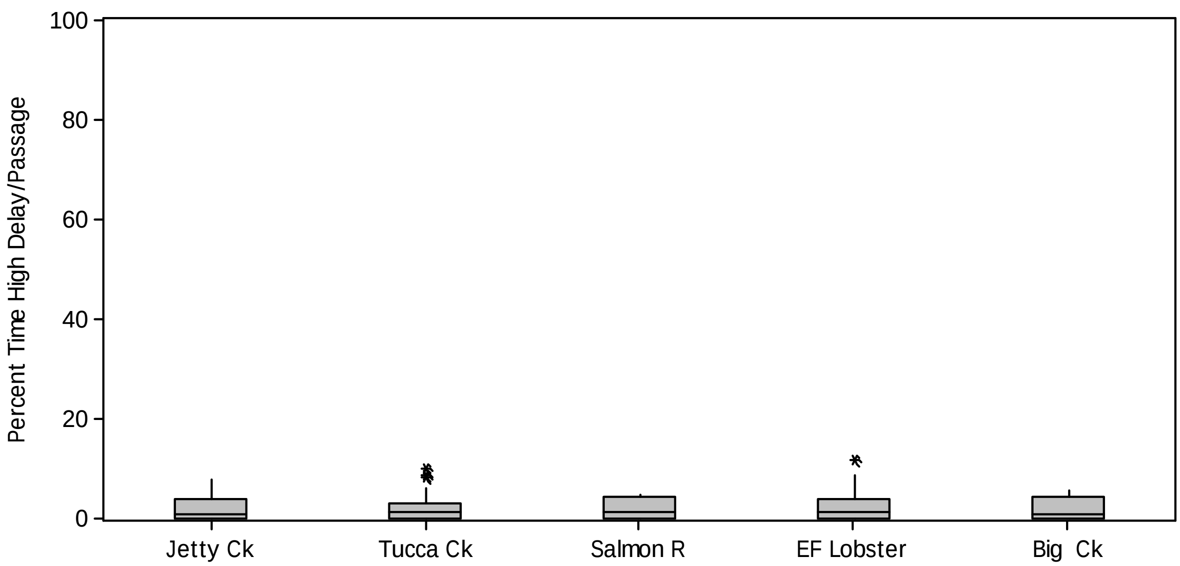



**Figure E- 32. Box plots summarizing percent time of high passage delay relative to passage time during the assumed chinook migration period (Sep15 – Feb15) for all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is the 1% annual exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

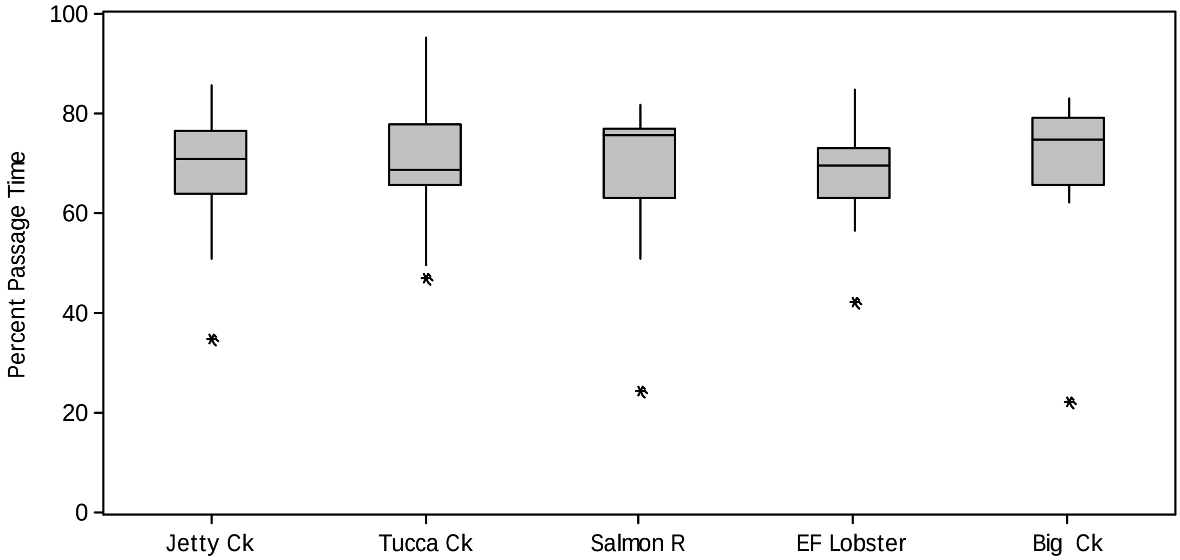



**Figure E- 33. Box plots summarizing percent passage time during the assumed chinook migration period (Sep15 – Feb15) in all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is the 1% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

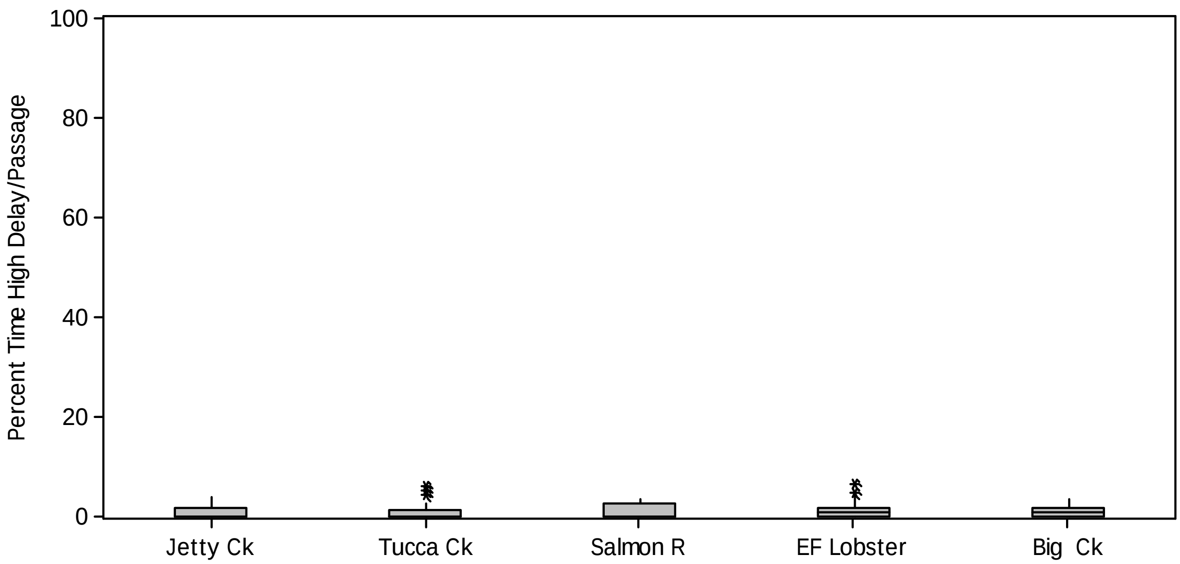



**Figure E- 34. Box plots summarizing percent time of high passage delay relative to passage time during the assumed chinook migration period (Sep15 – Feb15) for all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is the 1% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

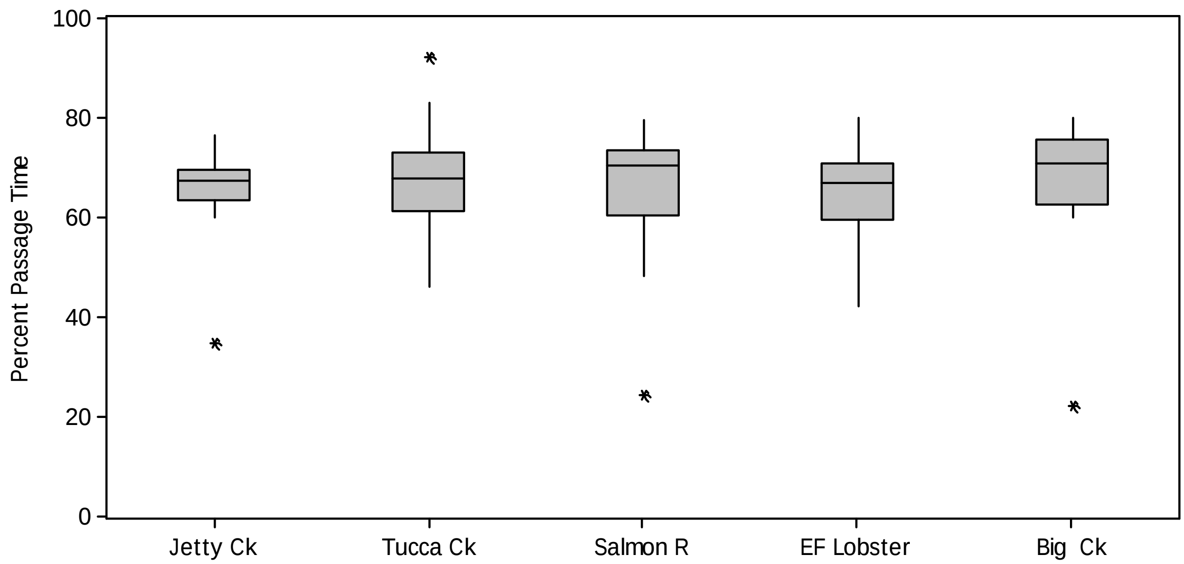



**Figure E- 35. Box plots summarizing percent passage time during the assumed chinook migration period (Sep15 – Feb15) in all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is the 5% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

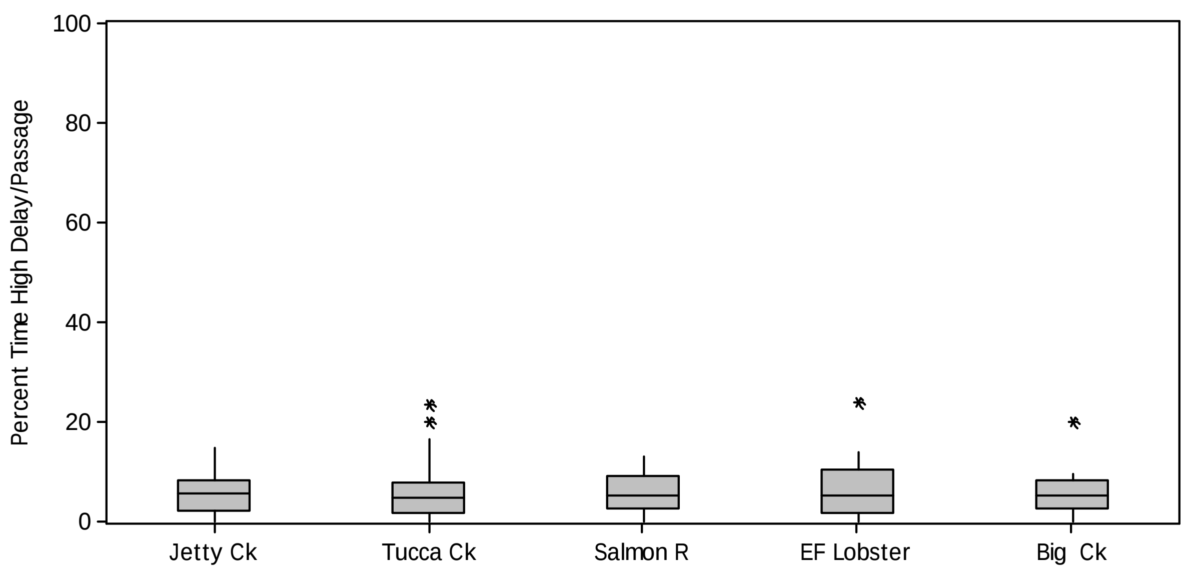



**Figure E- 36. Box plots summarizing percent time of high passage delay relative to passage time during the assumed chinook migration period (Sep15 – Feb15) for all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is the 5% migration period exceedance flow for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

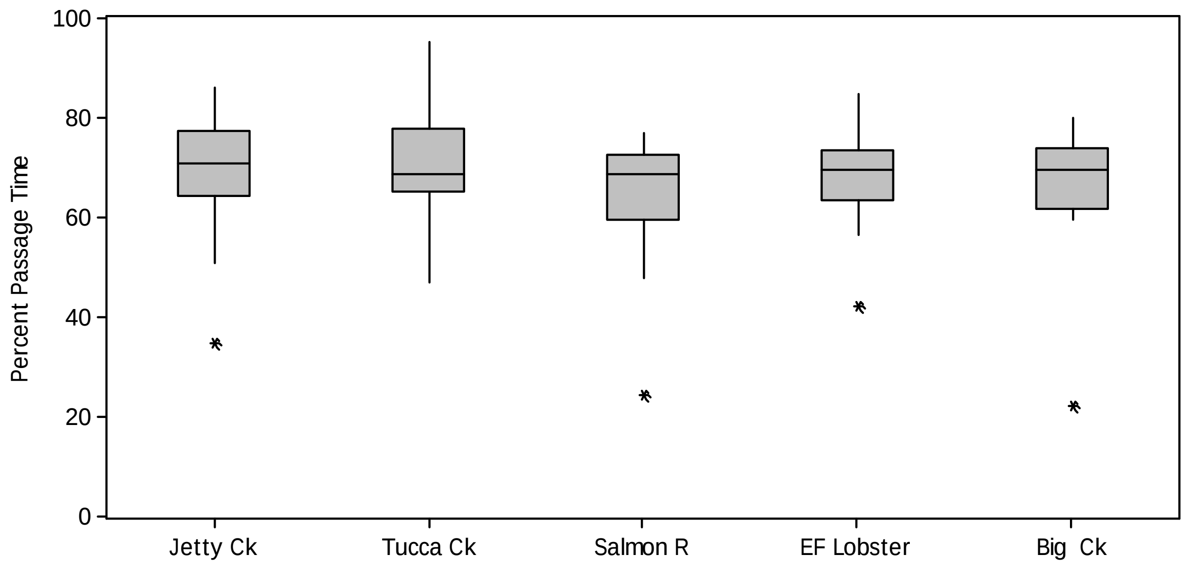



**Figure E- 37. Box plots summarizing percent passage time during the assumed chinook migration period (Sep15 – Feb15) in all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is 50% of Q2-year determined using the USGS regression equation for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

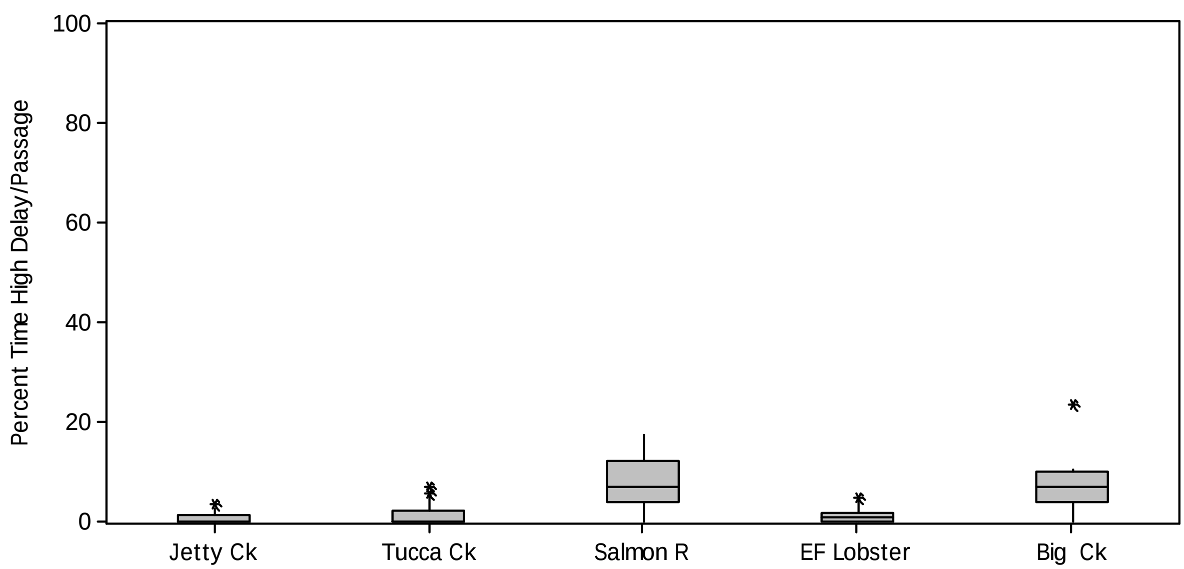



**Figure E- 38. Box plots summarizing percent time of high passage delay relative to passage time during the assumed chinook migration period (Sep15 – Feb15) for all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is 50% of Q2-year determined using the USGS regression equation for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

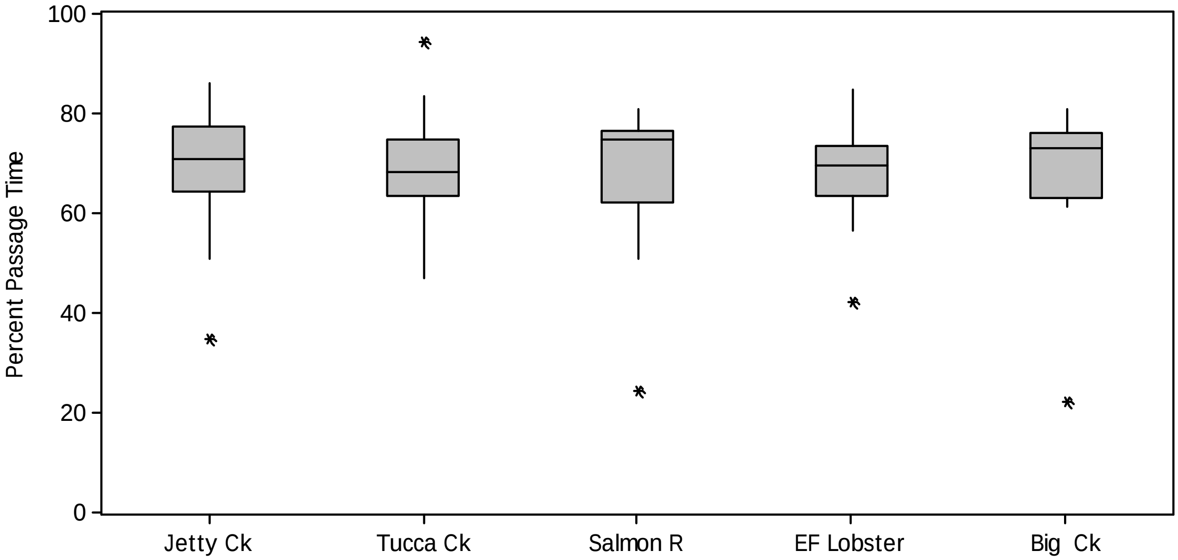



**Figure E- 39. Box plots summarizing percent passage time during the assumed chinook migration period (Sep15 – Feb15) in all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is 50% of Q2-year determined using the peak flow data for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**

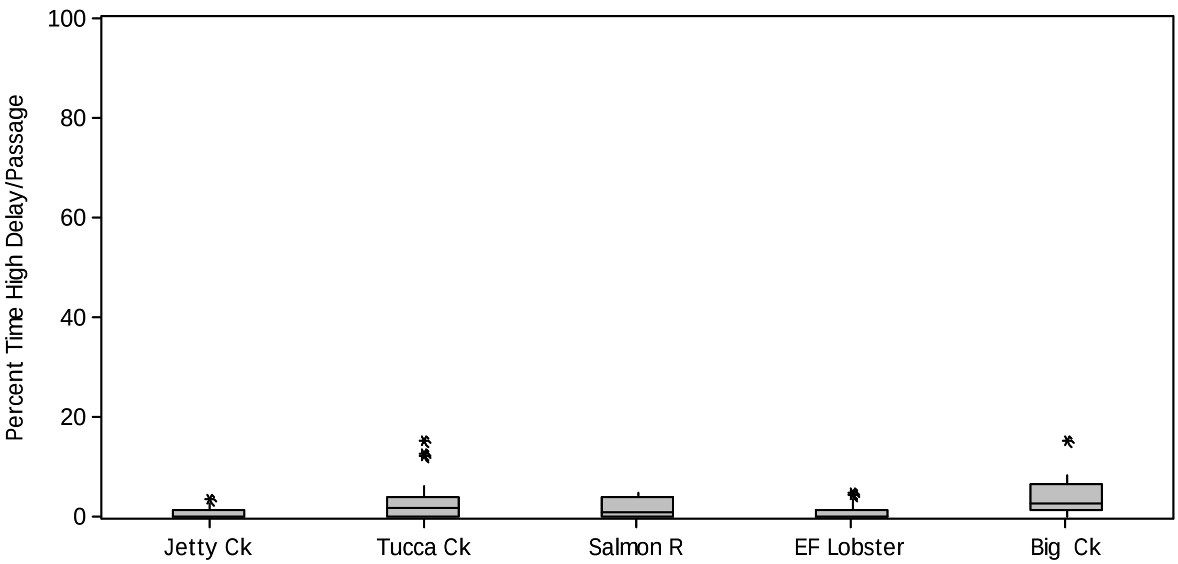



**Figure E- 40. Box plots summarizing percent time of high passage delay relative to passage time during the assumed chinook migration period (Sep15 – Feb15) for all years of the data record for the Pacific Northwest sites. $Q_{HFP}$ is 50% of Q2-year determined using the peak flow data for each site and $Q_{LFP}$ is the 50% annual exceedance flow or 3 cfs whichever is greater.**