Sierra Water Trust Project
Assessment of Flow Augmentation Needs in the Deer Creek Watershed

Sierra Streams Institute/Friends of Deer Creek and American Rivers

FODC/SSI

Friends of Deer Creek are partnering with American Rivers on the Sierra Water Trust project, with a focus on the Deer Creek watershed in Nevada County, California. One of the Sierra Water Trust Project tasks is to assess flow augmentation needs in the Deer Creek watershed. The assessment of flow augmentation needs includes:

1. Compiling historical flow data for Deer Creek.
2. Working with American Rivers to analyze and assess flow augmentation needs using appropriate assessment methodology.

The flow augmentation assessment uses a combination of field investigations and desktop analysis, incorporating hydrological and geomorphological data, to investigate the need for flow augmentation as well as needs for additional data or study in the Deer Creek watershed.

Hydrology of the Deer Creek Watershed

A. Introduction

The climate, geography and geology largely determine the natural hydrology of the Deer Creek watershed. The Deer Creek watershed is located in northern California, northeast of Sacramento in the foothills of the Sierra Nevada Mountains. The watershed ranges from 5,000 ft at the highest elevations to approximately 300 ft at Deer Creek's confluence with the Yuba River. The watershed is subject to a Mediterranean climate, with a distinct cool wet season (November-May) and warm dry season (June-October). Precipitation is greatest from November through May (**Figure 1.1**), with an annual average precipitation of 58 inches in Nevada City from 1967 – 2004 (**Figure 1.2**). The higher elevations (>3,000 ft) of the watershed receive an average of 60 inches of precipitation annually, with 45 – 50 inches in the middle elevations (1,500 – 3,000 ft), and 40 – 45 inches in the lower elevations (<1,500 ft) of the watershed. Each year a portion of the precipitation falls as snow, typically above 2500 ft. The hydrograph is dominated by rainfall and occasional rain on snow or snowmelt events (see **Figure 1.3**).

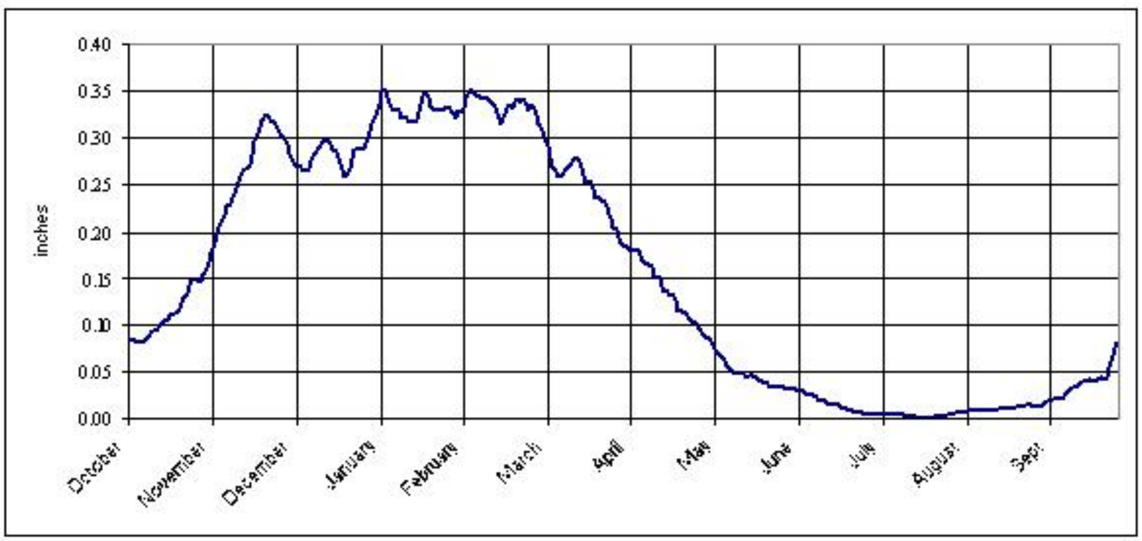


Figure 1.1: Nevada City Average Daily Precipitation, 1967 to 2004.

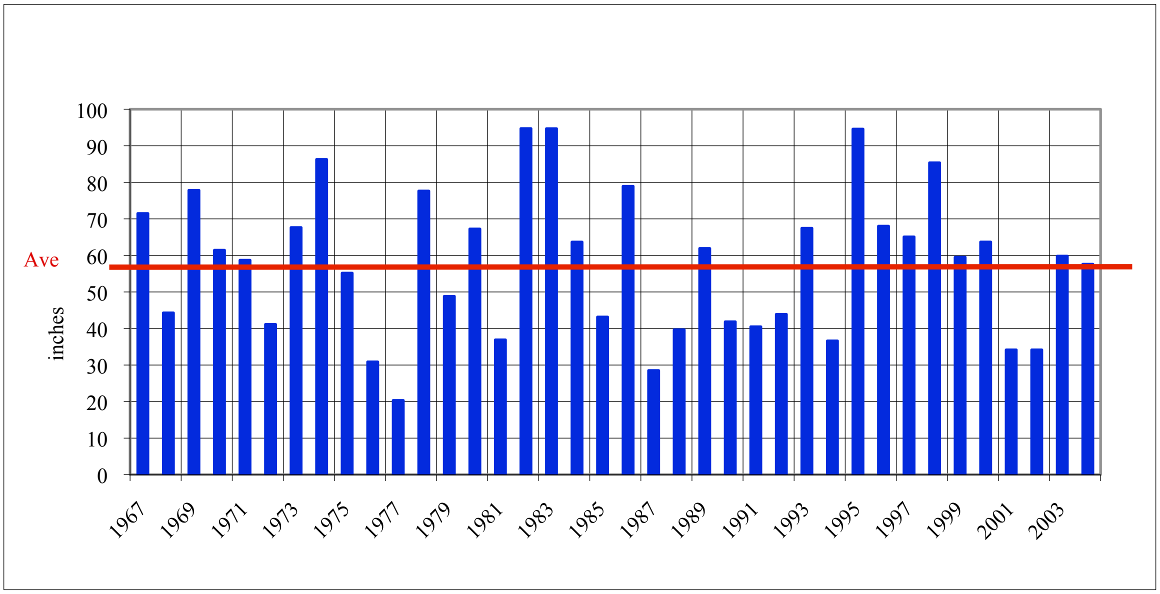


Figure 1.2: Annual Nevada City precipitation, calendar years 1967 – 2004. Red line is the average for the period of record.

Storms that cause rain to fall on snow typically generate the highest flows each year. **Figure 1.3** shows the highest daily mean flow in the Deer Creek watershed for water year 2002, of 1,050 cfs on February 20, 2002, when 2.3 inches of rain fell on several inches of snow that had accumulated in the upper watershed above 3500 ft elevation. In addition to rain on snow precipitation events, the highest flows often occur after Scotts Flat reservoir fills and begins to spill into Deer Creek. Once the reservoir begins to spill, surface water is allowed to flow through the watershed in a manner that more closely resembles the natural flow regime.

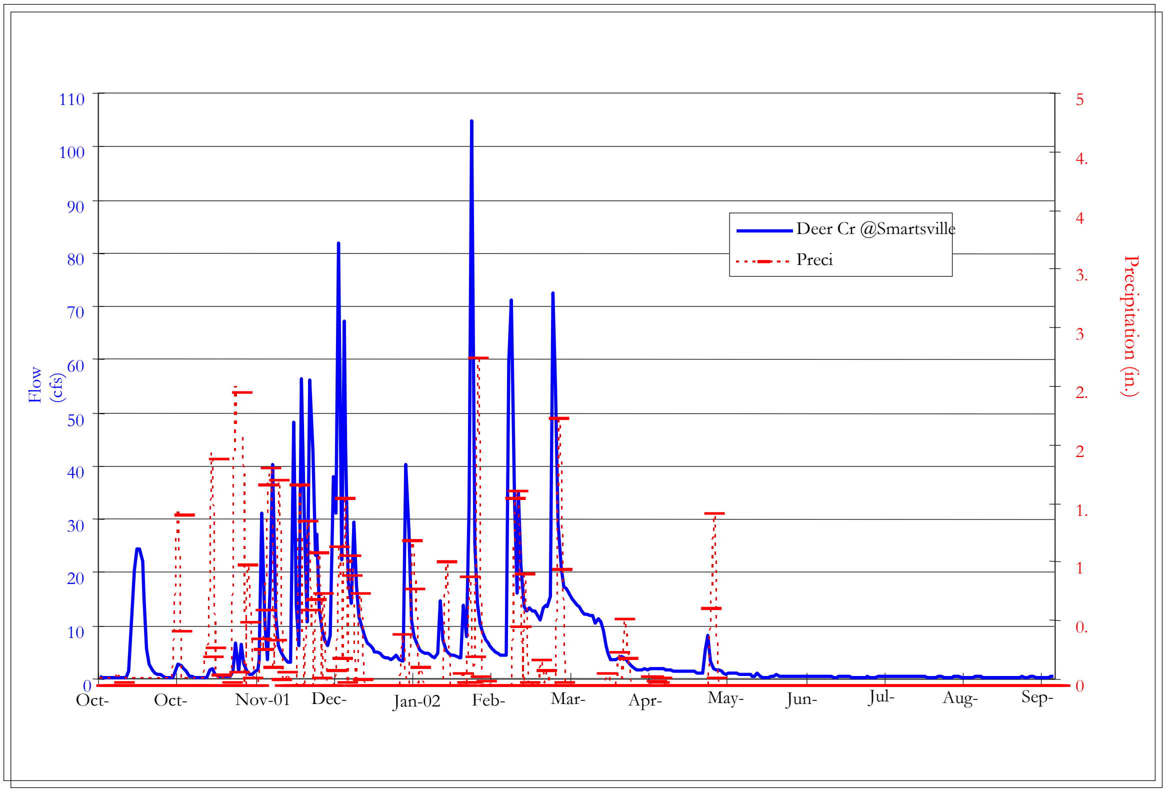


Figure 1.3: Water Year 2002 precipitation at Nevada City (right axis) and Deer Creek stream flow at Smartsville (left axis; USGS #11418500, daily mean discharge).

B. Stream Flow Gauges

Justin Wood

Several agencies and organizations monitor stream flow in the Deer Creek watershed, providing a stream flow dataset that can be analyzed to investigate stream flow augmentation needs. Flow gauging capacity in the watershed derives from NID, USGS, and Sierra Water Trust equipment, as follows:

NID Stream Flow Gauges

Nevada Irrigation District estimates natural flow into Scotts Flat reservoir by monitoring reservoir storage levels, volume of imported water from the South Yuba River, and water deliveries from Scotts Flat reservoir. Estimates are made on a daily basis, with monthly average flow estimates shown in **Figure 1.4**. Inflows to Scotts Flat reservoir (**Figure 1.4**) follow a similar trend to the Nevada City average daily precipitation plot (**Figure 1.1**), with the one exception being that snowmelt drives inflow during the low precipitation months of May, June, and July. This dataset from NID can be useful for investigating flow augmentation needs in the upper Deer Creek watershed, upstream of Lake Wildwood reservoir.

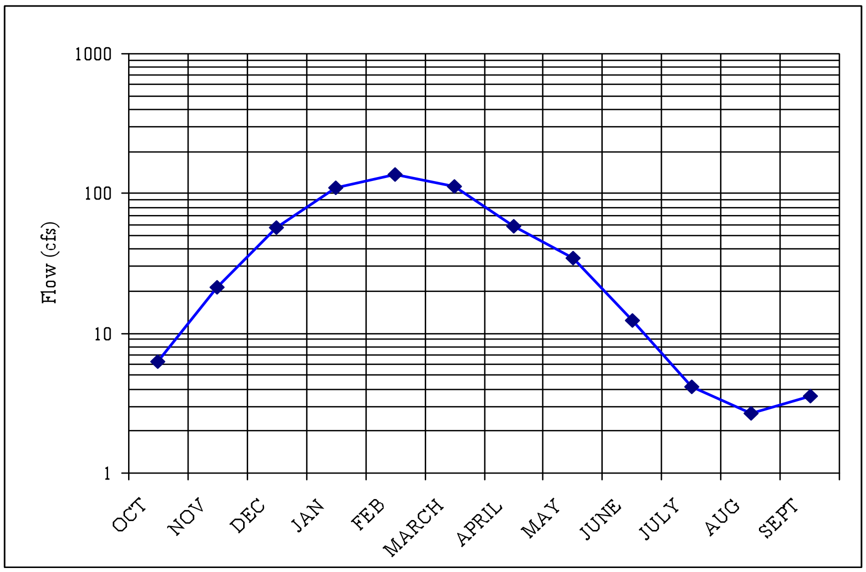


Figure 1.4: Average monthly natural stream flow into Scotts Flat reservoir (NID data, 1984-2004).

USGS Stream Flow Gauges

The United States Geological Survey (USGS) operates a long-term stream flow gauging station in the Deer Creek watershed, located on the main stem of Deer Creek at river mile 0.9, downstream of all three dams (see **Figure 1.5**). In addition, the USGS operates a long-term stream flow gauging station on Oregon Creek near Camptonville. These two gauges provide the majority of the data used in the assessment of stream flow augmentation needs. The period of record for the Deer Creek and Oregon Creek gauge data used in this report is shown in **Table 1.1**.

Gauge Number	Gauge Location (River Mile)	Period of Record
USGS 11418500	Deer Creek near Smartsville (RM 0.9)	10/1/1935* – present
USGS 11409300	Oregon Creek near Camptonville (RM 5.5)	10/1/1967 – 4/21/2001

Table 1.1: Stream flow gauges and periods of record

******This includes an estimated peak flow discharge outside of the period of record, for March 1928, based on high water marks.***

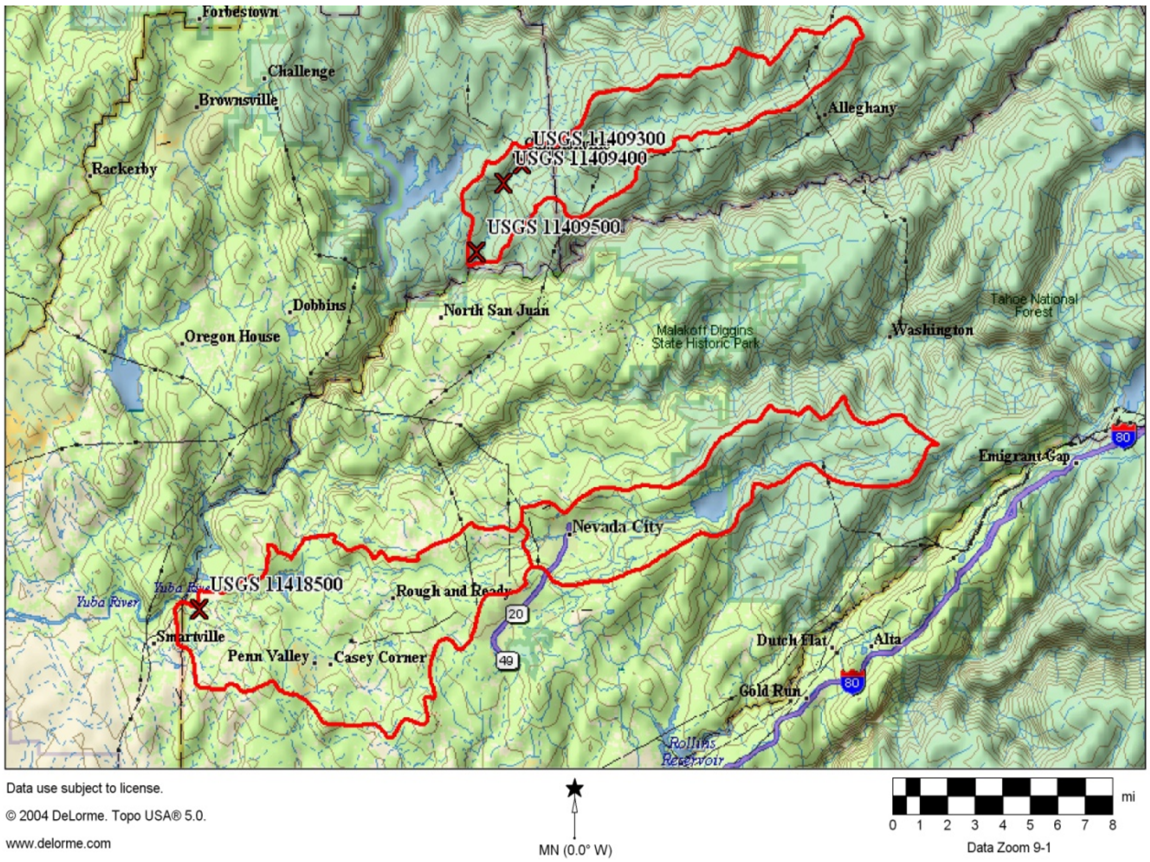


Figure 1.5: Locations of USGS stream flow gauges (marked with red Xs) on Deer Creek and Oregon Creek. There are three gauges on Oregon Creek and one on Deer Creek.

Sierra Water Trust Gauging Stations

In November 2010 as part of the Sierra Water Trust project, FODC and American Rivers worked to install additional stream flow gauging stations in the Deer Creek watershed (**Figure 1.6**). Gauging stations target major tributaries in the watershed and several locations on the main stem of Deer Creek that are in close proximity to NID diversion points. Major tributaries where gauging stations were installed were, from upstream to downstream in the watershed, Little Deer Creek at Nimrod Street, Gold Run Creek at Flume's End, and Squirrel Creek at Pleasant Valley Road. Gauging these major tributaries will provide an important dataset that is currently lacking, and will help to inform in-stream flows throughout the watershed. Gauging stations on the main stem of Deer Creek are located in Nevada City at Nevada Street, at the Bitney Springs Road bridge over Deer Creek, and the

Lake Wildwood reservoir spillway. Gauging these locations on the main stem of Deer Creek will help quantify irrigation season flows and in-stream flow requirements downstream of Lake Wildwood Reservoir, and provide an important dataset for comparison with water quality and other parameters monitored in the watershed.

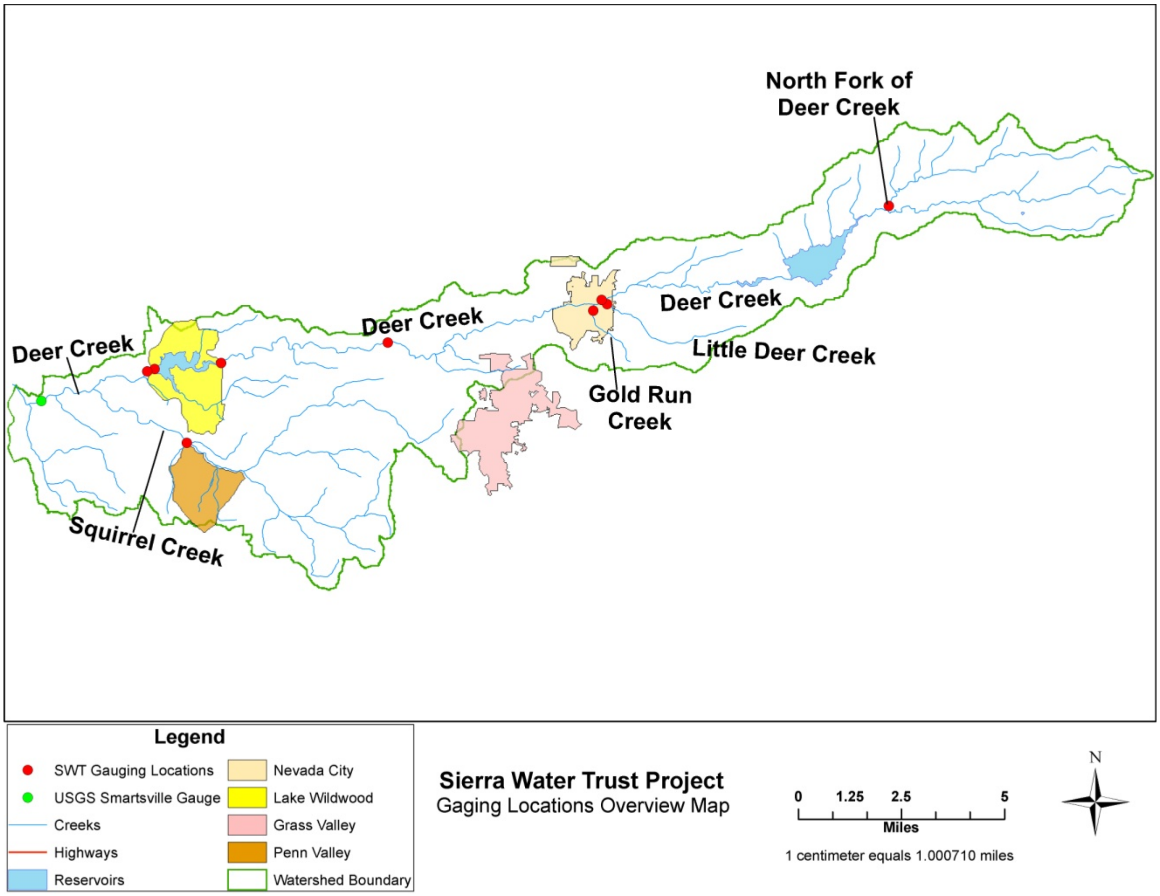


Figure 1.6: Sierra Water Trust gauging station locations.

Additional gauging infrastructure will be installed in the late summer or early fall of 2011, when stream flows are lower. These additional gauges will be located on the North Fork of Deer Creek upstream of Scotts Flat reservoir, at the Lake Wildwood Reservoir inlet, and at the Lake Wildwood Reservoir weir. Gauging the North Fork of Deer Creek will allow for comparison of unregulated stream flows with the regulated South Fork of Deer Creek, and provide data for natural flows in the upper watershed, which can subsequently be used to inform in-stream flow augmentation needs. Gauging the Lake Wildwood Reservoir weir will provide an important dataset for evaluating in-stream flow and water rights requirements, as well as impacts on aquatic habitat caused by reservoir and water management. Overall, the increase in stream flow gauging capacity will provide an important set of data for monitoring and assessments, informing in-stream flow needs, investigating climate change impacts, and formulating restoration and management plans.

C. Methods and Results

Matt Freitas

Hydrologic regimes play a significant role in determining the biotic composition, structure and function of aquatic and riparian ecosystems (Richter et al. 1996). Intra-annual variation in flows is essential to lifecycle success of many aquatic and riparian organisms because it influences reproductive success, natural disturbance and biotic competition (Poff and Ward 1990). Modification of hydrologic regimes can indirectly alter the composition, structure and function of aquatic and riparian ecosystems by changing the physical habitat characteristics such as water temperature, oxygen content, water chemistry and substrate particle size (National Research Council 1992; Sparks 1992). To better understand the hydrologic dynamics of Deer Creek, field assessments and desktop analysis were performed. Understanding the hydrology of Deer Creek is important because hydrologic regimes have a significant influence on the biotic structure, composition, and function of aquatic and riparian ecosystems (Richter et al. 1996). Knowledge of the variations in Deer Creek's flow regime and how the natural hydrologic regime has been altered is critical to the formulation of successful restoration and management recommendations.

Natural flows, prior to reservoir development and water management, were estimated for specific locations in the watershed using a variety of methods. USGS stream flow data for Deer and Oregon Creeks were analyzed to investigate modifications to Deer Creek's hydrologic regime. There are no diversions or dams on Oregon Creek upstream of USGS gauge #11409300, where a natural flow regime is present. In addition, Oregon Creek has a similar watershed size, orientation, climate, elevation, vegetation, and topography to the upper Deer Creek watershed, which allows Oregon Creek to serve as a proxy for estimating flows in the upper Deer Creek watershed. The focus of the analyses was primarily on the five fundamental characteristics exhibited by hydrologic regimes. The following are some examples of how these five characteristics can influence the environment:

Magnitude of flows – can determine the availability and suitability of habitat;
Timing of flows – can determine the life-cycle success or degree of stress or mortality on aquatic and riparian organisms;
Frequency of flow events – can affect population dynamics by influencing reproduction or mortality events;
Duration of flow conditions – may determine whether a certain life-cycle can be completed or the degree to which stressful effects such as inundation or desiccation accumulate;
Rate of change of flows – can affect the stranding of certain organisms or the ability of plant roots to maintain contact with water in soils.

Chinook salmon runs provide a perfect example of how these characteristics influence the Deer Creek watershed and why each characteristic is important to assess. Chinook salmon runs are influenced by the timing and magnitude of flows. The magnitude, duration, and rate of change of flows are important for potential stranding of Chinook salmon and redds, with stranding of salmon redds observed on Deer Creek in association with previous Lake Wildwood reservoir drawdown releases. The frequency, timing, and magnitude of peak flows can influence success of spawning as large floods can initiate considerable bedload sediment transport, potentially causing mortality to salmon redds and altering population dynamics.

Deer Creek Predicted Natural Flows Methods

The goal of this analysis was to use a variety of methods, combining fieldwork and desktop analysis, to predict or estimate natural stream flows in the Deer Creek watershed for comparison with current flows. This type of analysis is helpful for determining needs for flow augmentation. The analysis focused on the magnitude and frequency of peak stream flows under current conditions, and under hypothetical conditions unaffected by dams, diversions, and reservoirs. Fieldwork consisted of conducting longitudinal and cross section surveys, measuring stream flows, and documenting channel and water conditions on six tributaries to Deer Creek. Each of the tributaries except Woods Ravine flows into Deer Creek in the Nevada City area between Scotts Flat Reservoir and the wastewater treatment plant (WWTP). Woods Ravine flows into Deer Creek just downstream of the WWTP. **Figure 1.7** shows the location of five of these tributaries. The water surface slope was obtained from the longitudinal profile surveys, and was used to calculate discharge. During each longitudinal profile survey the channel was walked, and channel characteristics were observed and recorded. For each tributary, cross sections were surveyed, and at each cross section the water depth and velocity were measured with a flow meter and recorded.

Additional fieldwork included measurements of active channel width at several locations on main stem Deer Creek and one location on Squirrel Creek.

In addition to fieldwork, stream flow data from NID and the USGS were analyzed for Deer and Oregon Creeks, to estimate natural and current flows on the main stem of Deer Creek. A flood frequency analysis was performed on NID data related to occurrences of uncontrolled spill and controlled discharges from the Scotts Flat reservoir complex (NID 2005) to determine the magnitude and frequency of annual peak flows released from Scotts Flat reservoir. To determine the degree to which reservoirs and water management operations have altered flood flows, several methods were used to estimate the magnitude and frequency of flows that would be expected without dams on Deer Creek. Below is a summary of the methods used in the flood frequency analysis, with a map of the locations in the Deer Creek watershed provided in **Figure 1.7**.

Method 1: Analysis of NID estimates of Deer Creek flows into Scotts Flat reservoir and data on uncontrolled spill and controlled releases from Scotts Flat.

Method 2: Flow estimates based on equations of Waananen and Crippen (1977) that predict flows based on watershed area, elevation, and average annual rainfall.

Method 3: Equations of Hedman and W.R. Osterkamp (1982) that predict flows based on the size of a stream's active channel.

Method 4: Estimates of runoff per watershed area based on surveys of the key tributaries and application of equations that relate channel geometry and area to estimated flood flows, e.g. the "Mannings equation" (Limerinos 1970; Hedman and Osterkamp 1982).

Method 5: Analysis of USGS gauge records for Oregon Creek, a watershed with similar characteristics to upper Deer Creek, used as a proxy for unimpaired Deer Creek flows.

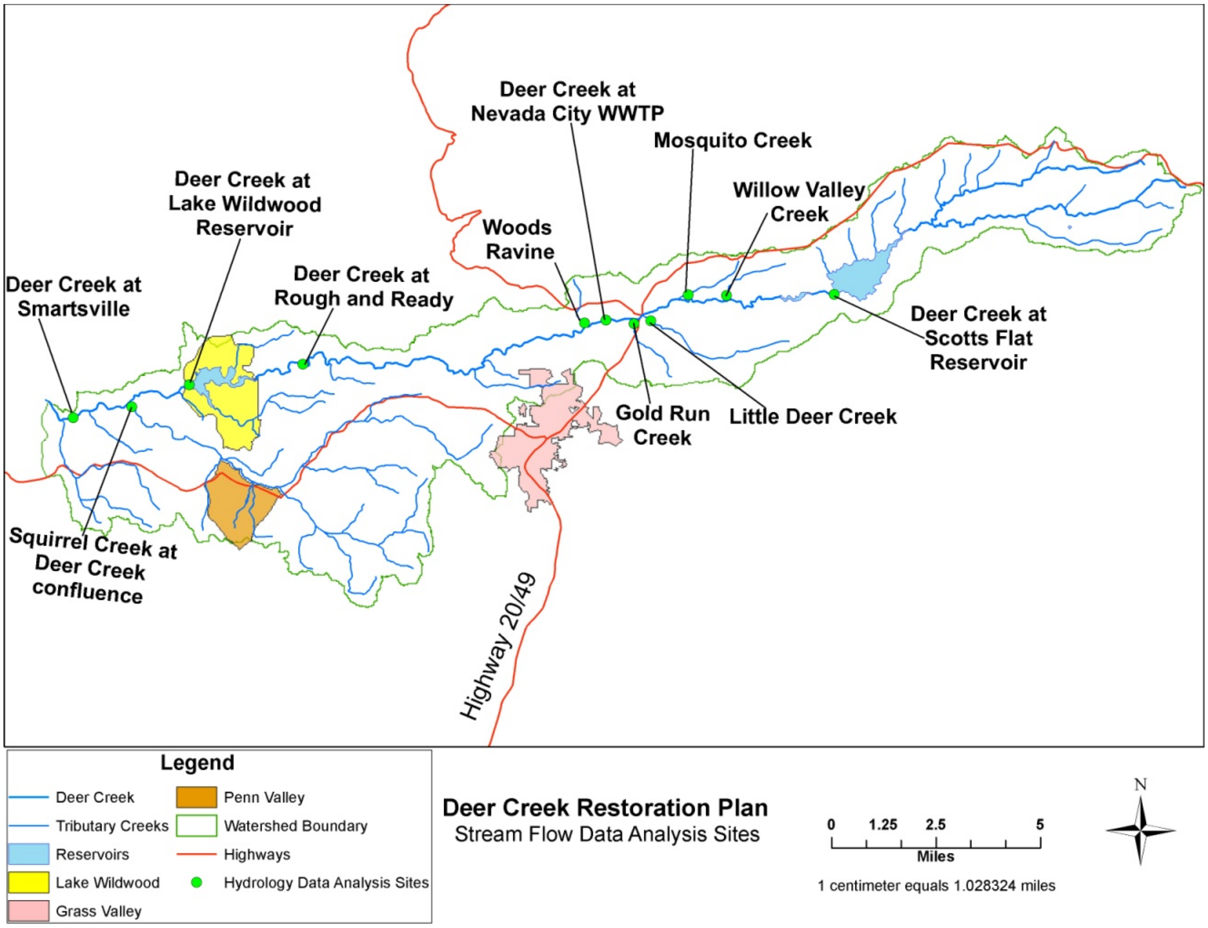


Figure 1.7: Map showing the locations at which natural high flows were predicted in the Deer Creek watershed. Note: Eagle Ravine tributary is not shown.

Deer Creek Predicted Natural High Flows Results and Discussion

Results of methods 2-5 are shown in **Tables 1.2** and **1.3** and detail the predicted natural peak flows for common hydrologic return intervals. A 2-yr flow (Q2) event is a flow of a magnitude that is statistically expected to occur once every two years, and a 5-yr flow (Q5) would be expected to occur once every five years, on average, and so on up to the 100-yr (Q100) event.

Location	Method/Source	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
Predicted peak flow at Scotts Flat (area = 20.8 mi^2)	Average of Methods 2, 3, and 5	930	1,802	2,391	3,367	4,076	5,033
Predicted peak flows at Nevada City WWTP (area = 32 mi^2)	Average of Methods 2, 3, 4, and 5	1,241	2,433	3,239	4,633	5,621	6,999
Predicted peak flows at Rough and Ready (area = 47.3 mi^2)	Average of Methods 2, 3	2,465	4,463	5,703	7,759	8,988	10,618
Predicted peak flows at Lake Wildwood Reservoir (area = 54.5 mi^2)	Average of Methods 2, 3	2,867	5,150	6,548	8,862	10,217	12,015
Predicted peak flows for Squirrel Creek at Deer Creek confluence (area = 24.8 mi^2).	Average of Methods 2, 3	1,405	2,589	3,359	4,653	5,464	6,515
Predicted peak flows for Deer Creek at Smartsville (area = 84.6 mi^2)	Average of Methods 2, 3	4,584	8,021	10,047	13,432	15,313	17,791

Table 1.2: Comparison of peak flows at locations on Deer and Squirrel Creeks.

Estimates are provided for one location on Squirrel Creek at the Deer Creek confluence and five specific locations on Deer Creek: Scotts Flat reservoir, the Nevada City wastewater treatment plant (WWTP), Rough and Ready, Lake Wildwood reservoir, and the USGS Smartsville gauge. The estimates for each method produce results that are within an order of magnitude of each other at each site. As you move downstream, peak flow magnitudes increase as expected.

The sum of discharge for Scotts Flat reservoir and the tributary flows (excluding Woods Ravine) results in greater flow values than for the Nevada City WWTP. Doing a basic mass balance calculation the sum of the Scotts Flat reservoir and tributary flow data accounts for 116.8% of the Nevada City WWTP flow at the Q2, 122.3% at the Q5, 125.6% at the Q10, 127.0% at the Q25, 129.7% at the Q50, and 131.7% at the Q100. These results indicate that further analysis is needed to accurately quantify peak flows at these locations, and that the methods used to calculate flows at these locations should be re-evaluated. Deer Creek discharge at the USGS Smartsville gauge is approximately equal to the sum of flows from Deer Creek at the Lake Wildwood reservoir and Squirrel Creek at the Deer Creek confluence. Doing a basic mass balance calculation, the sum of the Lake Wildwood reservoir and Squirrel Creek at the Deer Creek confluence data accounts for 93.2% of the USGS Smartsville gauge flow at the Q2, 96.5% at the Q5, 98.6% at the Q10, 100.6% at the Q25, 101.9% at the Q50, and 104.2% at the Q100.

Tributary estimates in **Table 1.3** do not exceed the estimates for main stem Deer Creek at the Nevada City WWTP, and estimates for tributaries using two different methods are within an order of magnitude of each other for each tributary (Skrtic 2005). The unimpaired tributaries contribute a significant volume of water to main stem Deer Creek downstream of Scotts Flat reservoir, which helps to mitigate potential impacts associated with water storage in the reservoir. The significance of reduced flood peaks is explored further in the Geomorphology of the Deer Creek Watershed section of the Flow Augmentation Assessment.

Tributaries	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
Little Deer Creek (area = 3.71 mi^2)	153	333	463	694	874	1,132
Gold Run Creek (area = 1.99 mi^2)	114	247	345	512	641	822
Willow Valley Creek (area = 1.2 mi^2)	59	134	192	291	372	489
Mosquito Creek (area = 1.0 mi^2)	85	180	252	371	462	587
Woods Ravine (area = 0.75 mi^2)	38	90	129	197	254	337
Eagle Ravine (area = 0.5 mi^2)	32	74	107	163	209	275
Total Tributaries (area = 9.15 mi^2)	480	1,057	1,486	2,227	2,811	3,641

Table 1.3: Flow estimates for tributaries in the upper Deer Creek watershed (data from Skrtic 2005).

Deer Creek Current High Flows Methods

A frequent application of stream flow records is to predict the magnitude and frequency of annual peak flow and flood events. The magnitude and frequency of annual peak flows were analyzed under current conditions and under hypothetical conditions unaffected by NID reservoirs. To determine the magnitude and frequency of current peak flows in the upper Deer Creek watershed at Scotts Flat reservoir, a flood frequency analysis was performed using NID data related to occurrences of uncontrolled spill and controlled discharges from the Scotts Flat complex (**Table 1.4**) (NID 2005). Flood frequency analysis was conducted using the US Army Corps of Engineers Hydrologic Engineering Center Statistical Software

Package (HEC-SSP), following guidelines outlined in Bulletin 17B, "Guidelines for Determining Flood Flow Frequency" (IACWD 1982; USACE 2008). This analysis provides data on current peak flows in upper Deer Creek in reaches near Scotts Flat reservoir, which can be evaluated against the predicted natural flows at Scotts Flat reservoir to determine if reservoir management has impacted the peak flow regime at this location and if flow augmentation is necessary downstream of the reservoir.

To determine the magnitude and frequency of peak flows at the watershed outlet, flood frequency analysis was performed using data from the USGS Smartsville stream gauge on Deer Creek. Data from this gauge describe peak flows leaving the watershed, as this gauge is located at river mile 0.9 on Deer Creek and captures the majority of water flowing out of the watershed. **Table 1.5** provides results of the one period flood frequency analysis using the USGS Smartsville gauge on Deer Creek downstream of Lake Wildwood reservoir. These results can be evaluated against the predicted natural flows at the USGS Smartsville gauging station to determine if reservoir management has impacted the peak flow regime at this location and thus flow augmentation is necessary. The following is a summary of methods used in the flood frequency analysis of the USGS Smartsville gauge:

- Analysis of USGS gauge records for Deer Creek near the confluence with the Yuba River, using the Weibull plotting method (Dalrymple 1960);
- Analysis of USGS gauge records for Deer Creek near the confluence with the Yuba River, using a modified Weibull plotting method (Cunnane 1978);
- Analysis of USGS gauge records for Deer Creek near the confluence with the Yuba River, using multiple methods available within the HEC-SSP based on Bulletin 17B (IACWD 1982; USACE 2008).

Deer Creek Current High Flows Results and Discussion

The results of the Scotts Flat reservoir flood frequency analysis, using NID data related to occurrences of uncontrolled spill and controlled discharges, are provided in **Table 1.4**. The computed and expected results are in good agreement at the Q2, Q5, Q10, and Q25 peak flows. The results begin to diverge at the Q50 and Q100 flows, with the expected results an order of magnitude or greater than the computed results. This can be attributed to the expected curve analysis attempting to correct for bias in the short period of record. The data used in this analysis were from 1973 – 2007, a thirty-four year period of record. As a longer period of record becomes available it is probable that the computed and expected results will come into better agreement. This analysis is useful for determining what the annual peak flows discharged from Scotts Flat reservoir are. These values can be compared against predicted natural flows for the Scotts Flat location, to evaluate whether peak flows are being achieved with the current water management system in place or if there is a need for flow augmentation downstream of Scotts Flat reservoir.

Location	Method/Source	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
Releases from Scotts Flat	HEC-SSP-Computed (NID Data)	245	695	1,309	2,758	4,643	7,619
Releases from Scotts Flat	HEC-SSP-Expected (NID Data)	245	718	1,400	3,145	5,658	10,049

Table 1.4: Comparison of annual peak flows at Scotts Flat reservoir, using NID data from 1973-2007.

The results of the Deer Creek USGS gauge flood-frequency analysis are provided in **Table 1.5**. The calculated flow values for each return interval are in good agreement through the 100-year flood flow (Q100) for each method. Above the Q100 the weighted skew option (HEC-SSP 2) diverges from the other methods, resulting in greater Q200 and Q500 flows than from the other analyses. This could be due to the use of the weighted skew in the HEC-SSP 2 analysis, which uses a generalized regional skew to determine flows (USACE 2008). In the seventy-four year period of record, the greatest peak flow was 16,000 cfs on December 31, 2005. This observed peak flow is comparable to the Q100 values derived by each method.

Method	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)	Q200 (cfs)	Q500 (cfs)
Weibull	5,410	7,650	11,030	12,150	14,750	16,300	X	X
Cunnane	5,410	7,640	11,000	11,800	14,100	15,600	X	X
HEC-SSP 1 Computed	5,160	8,072	9,939	12,179	13,750	15,238	16,653	18,426
HEC-SSP 1 Expected	5,160	8,114	10,030	12,363	14,023	15,618	17,151	19,112
HEC-SSP 2 Computed	5,062	8,055	10,107	12,725	14,674	16,612	18,545	21,101
HEC-SSP 2 Expected	5,062	8,100	10,211	12,951	15,027	17,126	19,256	22,138

Table 1.5: Comparison of peak flows at USGS gauge #11418500 on Deer Creek in Smartsville.

The analysis is important because it determines what the magnitude and frequency of annual peak flows on Deer Creek are for the overall period of record. These values can be compared against the predicted natural flows for the Scotts Flat reservoir and USGS Smartsville gauging station location, to determine whether current high flows are within the estimated natural range, or whether water management and reservoir development and other impacts have altered the natural flood regime.

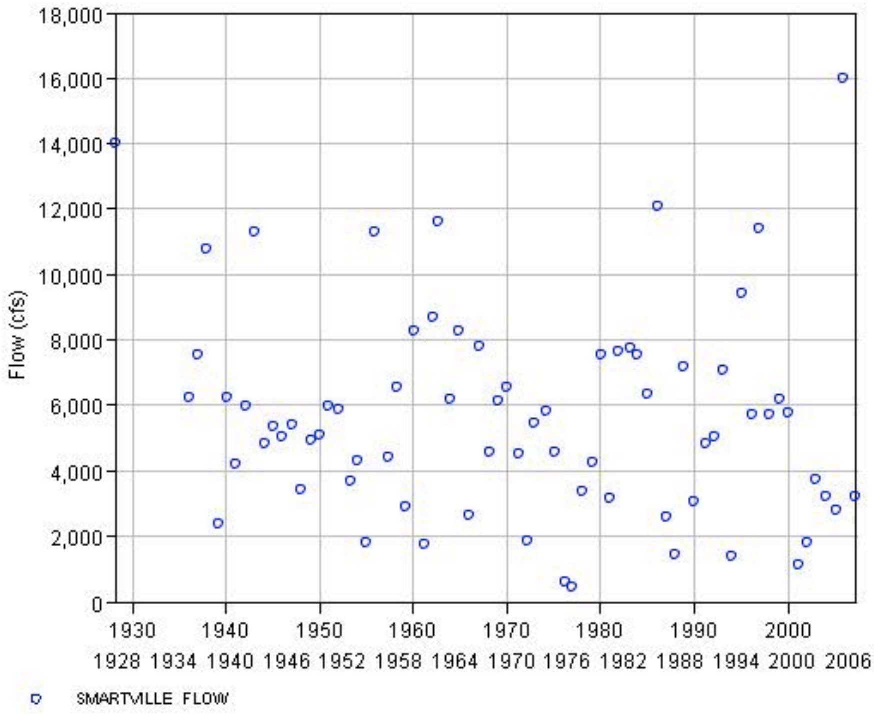


Figure 1.8: Annual peak stream flow data, USGS gauge #11418500 on Deer Creek in Smartsville.

The peak stream flow record at this gauge can be evaluated to determine whether reservoir development has affected the magnitude and frequency of flows on Deer Creek. **Figure 1.8** plots the peak annual stream flow from the beginning of the gauge record but provides minimal insight into whether the magnitude and frequency of Deer Creek flood flows have been impacted by reservoir development. To investigate alterations to the annual peak flow regime further, two analyses were employed:

- Current and predicted annual peak flows were compared for two locations on main stem Deer Creek using the results from the previous sections.
- Two-period flood frequency analysis was conducted from water years 1935-1964 and 1965-2009. These date ranges coincide with the period before and after the change to Deer Creek's base flow, as indicated by the USGS Smartsville gauging station record. In addition, July 1964 was when the major upgrade to Scotts Flat reservoir was completed. The two-period flood frequency analysis is provided in the two-period flood frequency analysis section.

Deer Creek Natural and Current High Flows Discussion

Natural annual peak discharges were predicted for several locations on the main stem of Deer Creek, for comparison with current peak discharges at two locations on Deer Creek.

Comparisons of current and predicted natural peak flows are available for Scotts Flat reservoir and the USGS gauge at Smartsville. **Table 1.6** shows that Scotts Flat reservoir reduces annual peak flows in upper Deer Creek for the 2-yr (Q2), 5-yr (Q5) and 10-yr (Q10) flood events and that augmentation of peak stream flows is potentially necessary for flows in the Q2 – Q10 range. Current Scotts Flat reservoir releases for the 25-yr (Q25) flow fall within the range of estimates for unaltered natural stream flows at the reservoir's location. The data indicate that the Q50 and Q100 flows are being achieved at the Scotts Flat reservoir location, as is evidenced by the releases from Scotts Flat reservoir for the Q50 and Q100 producing greater peak flows than the predicted natural flows method. It is important to compare the confidence intervals for current annual peak flows against the predicted peak flows at Scotts Flat reservoir, to look for overlap between the confidence intervals and predicted data.

Location	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
Current releases from Scotts Flat reservoir	245	706	1,355	2,952	5,150	8,834
Predicted peak flow at Scotts Flat reservoir	930	1,802	2,391	3,367	4,076	5,033

Table 1.6: Comparison of current and predicted natural annual peak flows for Scotts Flat reservoir.

The confidence intervals (**Table 1.7**) for the current Q2, Q5, and Q10 peak flows at Scotts Flat reservoir do not overlap with the predicted peak flows (**Table 1.6)** at the reservoir's location, further indicating that Scotts Flat reservoir has reduced the magnitude and frequency of small flood flows and that releases are outside of the predicted natural range for Q2 – Q10 events. This indicates a need for augmenting flows out of Scotts Flat reservoir so that small flood flows of greater magnitude occur more frequently. The confidence intervals for current releases from Scotts Flat reservoir overlap with the predicted peak flows for the reservoir's location at the Q25, Q50, and Q100, indicating that current releases are potentially within the predicted natural range for the larger flood events (Q25 – Q100). A larger period of record is needed for analyzing current releases from Scotts Flat reservoir, in order to increase the accuracy of results for the Q50 and Q100 flows.

Q2 (cfs)		Q5 (cfs)		Q10 (cfs)	
.95 Confidence Limit	.05 Confidence Limit	.95 Confidence Limit	.05 Confidence Limit	.95 Confidence Limit	.05 Confidence Limit
177	336	498	1,042	890	2,177

Q25 (cfs)		Q50 (cfs)		Q100 (cfs)	
.95 Confidence Limit	.05 Confidence Limit	.95 Confidence Limit	.05 Confidence Limit	.95 Confidence Limit	.05 Confidence Limit
1,719	5,313	2,699	9,999	4,129	18,318

Table 1.7: Confidence intervals for releases from Scotts Flat reservoir, for comparison with predicted natural peak flows at Scotts Flat reservoir.

NID generally captures all inflow to Scotts Flat reservoir from approximately mid-October until the reservoir fills completely, which can be as late as March or April in some years (S. Sindt, pers. comm.). Therefore, unless a flow event of significant magnitude occurs after Scotts Flat reservoir has filled, the contribution of flow from the watershed upstream of Scotts Flat reservoir (~25% of total watershed area) into Deer Creek is eliminated. The resulting reduction in peak flows would be most pronounced immediately downstream of Scotts Flat reservoir, and would diminish progressively moving downstream as tributaries (Willow Valley, Eagle Ravine, Little Deer, Gold Run Creeks) contribute unimpaired peak flows. To investigate if impacts are evident near the watershed outlet, current and predicted natural flows were compared for the USGS gauge at Smartsville, with results provided in **Figure 1.16**.

The data in **Table 1.8** provide a comparison of current and predicted annual peak flows near the Deer Creek watershed outlet, with peak flow magnitudes for return intervals up to Q100. The Q2, Q5, and Q10 natural estimates are in good agreement with the current peak flows using each analysis method, with results within an order of magnitude of each other. This suggests that in this portion of the watershed small floods (Q2 – Q10) are currently occurring as frequently as they would under natural circumstances. At the Q25, Q50, and Q100, natural peak flow estimates are greater than the methods based on the period of record. Confidence intervals (not shown) for the Q25, Q50, and Q100 overlap with the current annual peak flows, indicating that although the current results are slightly less than the natural predicted values, current flows are potentially within the predicted natural range. This could potentially be due to the reduction of small flood flows (Q2, Q5, Q10) out of Scotts Flat reservoir, as the reduction in small floods could translate to a reduction in larger floods downstream. The results suggest that the current magnitude and frequency of annual peak flow events is potentially less than would have been expected under natural stream flow conditions, but more data and further analysis are needed to verify the significance of the reduction.

Method	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
Weibull	5,410	7,650	11,030	12,150	14,750	16,300
Cunnane	5,410	7,640	11,000	11,800	14,100	15,600
HEC-SSP 1 Computed	5,160	8,072	9,939	12,179	13,750	15,238
HEC-SSP 1 Expected	5,160	8,114	10,030	12,363	14,023	15,618
HEC-SSP 2 Computed	5,062	8,055	10,107	12,725	14,674	16,612
HEC-SSP 2 Expected	5,062	8,100	10,211	12,951	15,027	17,126
Deer Creek at Smartsville (area=84.6 mi^2)	4,584	8,021	10,047	13,432	15,313	17,791

Table 1.8: Flood frequency analysis results comparing current and natural discharges at the USGS gauge on Deer Creek.

Overall the predicted natural and current peak flow analysis indicates that alterations to the annual peak flood regime have occurred. On upper Deer Creek (**Table 1.6**) Scotts Flat reservoir reduces peak flows at the Q2, Q5, and Q10, while in lower Deer Creek (**Table 1.8**) Q2, Q5, and Q10 peak flows are being achieved, due to the contribution of unimpaired flow from numerous perennial tributaries around Nevada City and from Squirrel Creek downstream of Lake Wildwood reservoir. Potential impacts to the Q25, Q50, and Q100 flows at Scotts Flat reservoir and the USGS Smartsville gauge should be investigated further. The results indicate that efforts should be undertaken to restore the magnitude and frequency of peak flood flows in the Deer Creek watershed, focusing on small flood flows (Q2 – Q10) in the upper watershed out of Scotts Flat reservoir. Flow augmentation could possibly be achieved through strategic releases from Scotts Flat reservoir during wet water years, when Scotts Flat is already spilling, and there is a high probability there will be adequate rainfall and late-season runoff to quickly regain water lost through the release.

Low Flow Analysis Introduction

Low stream flows are the dominant flow condition in most creeks and rivers (Richter et al. 1996). After a rainfall event or snowmelt period has passed and the associated surface runoff has flowed through the catchment, the creek returns to base or low flow level (Richter et al. 1996; TNC 2009). Low flows are sustained by groundwater discharge into the river and by perennial tributaries in a natural system, and potentially by water management activities in a managed system. Seasonal variations in low flow levels impose constraints on a river's aquatic communities as these variations determine the amount of available aquatic habitat for the majority of the year (TNC 2009). The availability of aquatic habitat strongly influences the diversity and number of organisms that can inhabit a reach of creek.

Three methods were used to estimate low flows along sections of main stem Deer Creek. Two methods were used to estimate low flows in upper Deer Creek, and Deer Creek between Scotts Flat and Lake Wildwood reservoirs. The first method employs NID's estimates of natural flows, while the second method uses Oregon Creek flow data as a proxy. The third method, low flow frequency analysis of the USGS Smartsville gauge data, was used to investigate low flows in Deer Creek downstream of Lake Wildwood, at the outlet of the watershed.

Low Flow Analysis Methods and Results

Method 1: Low Flow Analysis of NID Natural Flow Data

Since 1972, NID has estimated the amount of runoff into Scotts Flat reservoir by determining the increase in Scotts Flat reservoir storage that cannot be attributed to imports from the South Yuba River. These estimates are made approximately every day by monitoring the change in storage for Scotts Flat reservoir, the measured volume of transfers into the reservoir from the South Yuba River through the South Yuba Canal, and the releases from the Scotts Flat complex into the D-S Canal and Deer Creek. It is unlikely that this method produces accurate estimates of low flows considering NID data indicate that inflows can remain at zero for many days during the summer, then jump up to 5 or 10 cfs for one or two days, before dropping back to zero. These rapid pulses of flow do not correspond to rainfall events and thus these low flow estimates may be prone to substantial error or do not provide a high enough resolution to capture the actual daily flows.

The 30-plus years of data NID has collected suggest that under natural conditions Deer Creek summer low flows at Scotts Flat reservoir would have dropped to under 5 cfs in most years (**Figure 1.9**). Natural summer low flows downstream of Scotts Flat would have been higher than this because of groundwater inputs and stream flow contributions from numerous perennial tributaries including Willow Valley, Mosquito, Little Deer, Gold Run, Woods Ravine, and Slate Creeks. Under current circumstances NID water management influences summer flows downstream of Scotts Flat reservoir, with Deer Creek used as a "canal" to convey water for irrigation.

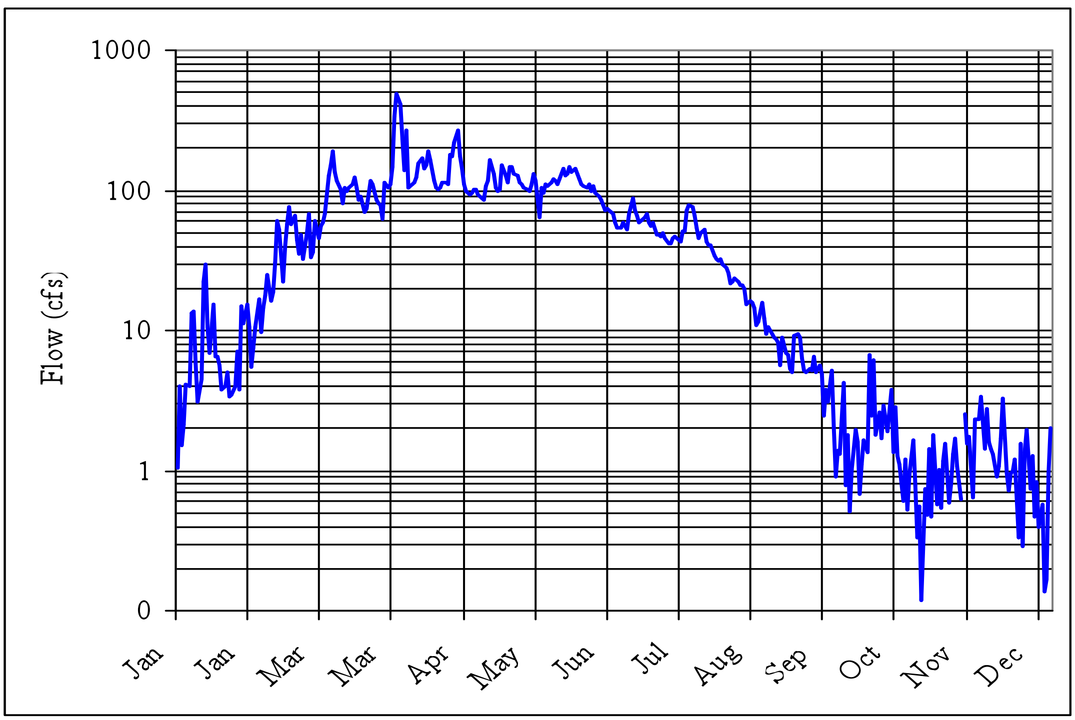


Figure 1.9: 30-year average of NID estimates of natural inflow to Scotts Flat reservoir.

Summer low flows in upper Deer Creek between Scotts Flat and Lake Wildwood reservoirs are artificially high because NID uses the creek to deliver water from Scotts Flat to the Newtown and Tunnel canals, and to Lake Wildwood reservoir to maintain water levels. During the irrigation season (April 15th – October 15th) flows between Scotts Flat reservoir and the Newtown Canal diversion dam (4.5 mi.) are approximately 20 – 30 cfs. Flows from the Newtown Canal diversion to Tunnel Canal diversion dam (~8 mi.) typically do not drop much below 10.0 cfs. At this point NID diverts much of the flow into the Tunnel Canal. Summer flows in the four miles from the Tunnel canal to Lake Wildwood reservoir are approximately 4.0 cfs (S. Sindt, pers. comm.). At Lake Wildwood reservoir irrigation water is diverted into the Keystone Canal. There is a water rights requirement for the Lake Wildwood Association of 5.0 cfs or the natural flow, whichever is less, downstream of Lake Wildwood reservoir, but it is unclear whether this requirement is being met or what the natural flow is.

Method 2. Low Flow Analysis of Oregon Creek Flows As A Proxy

Oregon Creek, a tributary to the Middle Yuba River, is similar to the upper, higher elevation portions of the Deer Creek watershed in many respects (e.g. size, shape, orientation, elevation and vegetation). USGS gauge #11409300 captures 23 mi^2 of the Oregon Creek watershed, similar to the 22 mi^2 area upstream of Scotts Flat Reservoir. With many characteristics similar to the upper portions of Deer Creek, Oregon Creek serves as a useful proxy for estimating low flows in the upper quarter of the Deer Creek watershed under natural conditions. One can see that the flows are fairly similar in magnitude and timing, with Oregon Creek exhibiting slightly higher flows from February through September (**Figure 1.10**). Deer Creek appears to experience lower and more variable summer low flows, but NID's method of estimating Deer Creek inflows is less accurate at lower flow levels, and there are more rise and fall changes due to NID water management, which leads to a less smooth hydrograph than Oregon Creek.

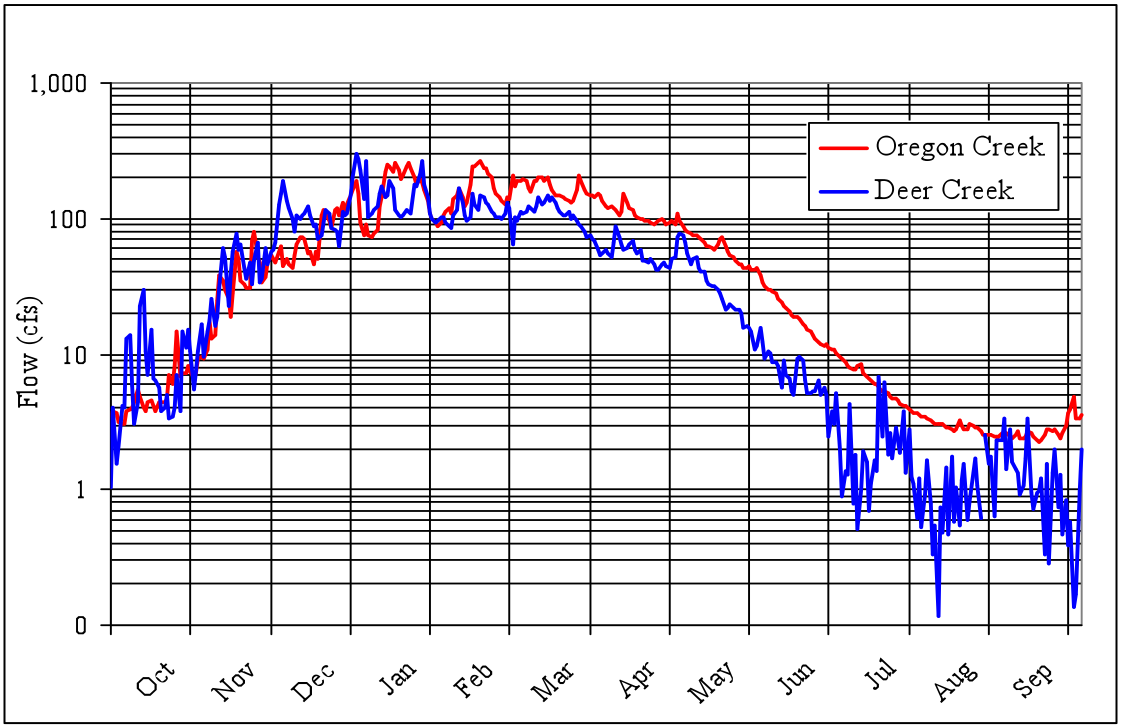


Figure 1.10: Average Daily Flows in Deer Creek (into Scotts Flat) and in Oregon Creek at Camptonville (USGS gauge #11409300, 1967-2001)

Figure 1.11 shows average daily flow levels for Oregon Creek at USGS gauge #11409300 over a 35-year period from 1967 – 2002. The 5th percentile curve represents the lowest 5% of daily flows for each date over the 35-year record, i.e. 95% of flows for each day were greater than those in the 5th percentile curve. The 50th percentile curve is the median flow value for that date over the 35-year period. The 5th percentile and 25th percentile curves can be used as an index of extreme low flow and low flow conditions respectively. The 50th percentile (median) can be used as an index of base flow conditions, the 75th percentile can be used as an index of high flow pulses, and the 95th percentile can be used to investigate high flow peaks.

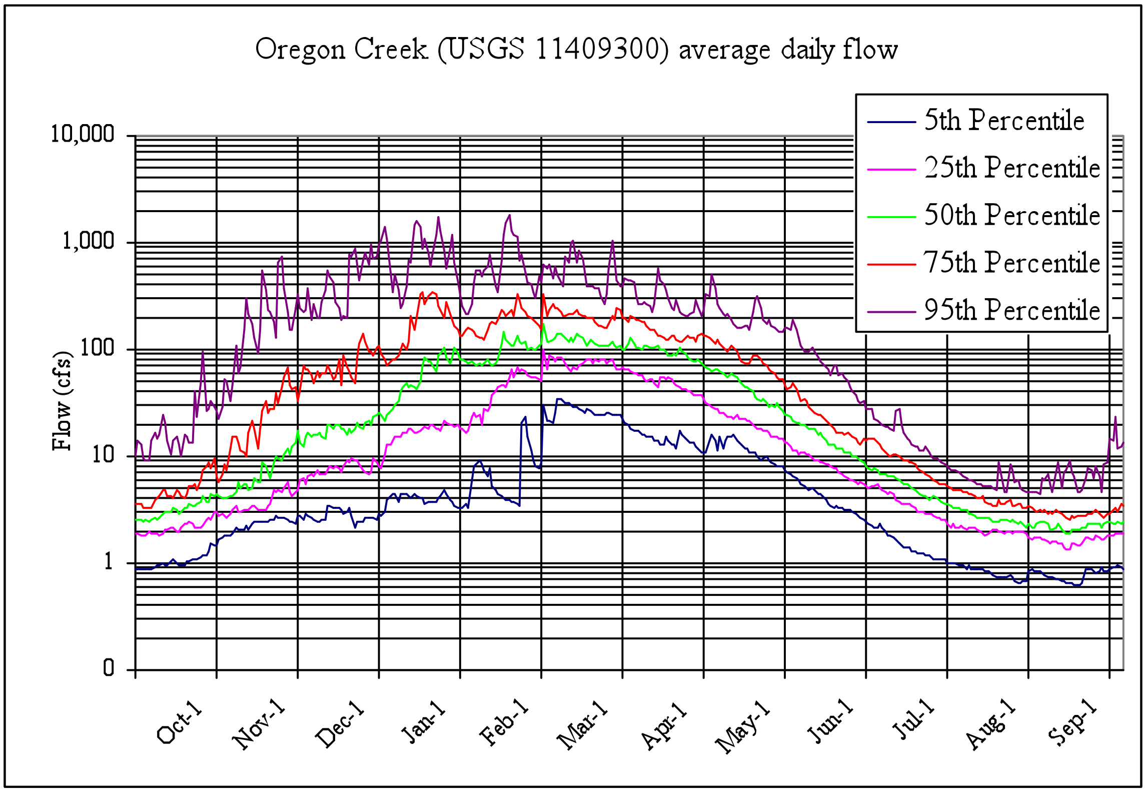


Figure 1.11: Oregon Creek average daily flows at USGS gauge #11409300.

In dry (5th percentile) and below normal (25th percentile) water years, flows in Oregon Creek from August through October fluctuated between 0.5-2 cfs. In average (50th percentile) water years, flows in Oregon Creek from August-October ranged from 2-4 cfs. In above normal (75th percentile) and wet (95th percentile) water years, flows ranged from 3-9 cfs. It seems possible therefore that from August to October, Deer Creek upstream of Scotts Flat would experience flows in the 3-9 cfs range in above normal to wet years, 2-4 cfs range in average years, less than 2 cfs in below normal and dry years, and less than 1 cfs in critically dry years. Considering these data represent percentiles over a 35-year flow record it seems likely that surface flows occasionally reduced to a trickle in Oregon Creek during dry and critical water years. However, it is probable Oregon Creek or Deer Creek would not dry up even in the driest years, unless there were numerous consecutive critically dry years. As you move downstream through the watershed from Scotts Flat reservoir, summer low flows increase due to the contribution of numerous downstream perennial tributaries as well as possible groundwater contributions. No other gauges exist to enable the assessment of low flows on Deer Creek until USGS gauge #11418500, 0.9 miles upstream from the Yuba River, downstream of Lake Wildwood and of the last major tributary Squirrel Creek.

Method 3. Low Flow Frequency Analysis using the Deer Creek USGS Gauge at Smartsville

Low flow frequency analysis was performed using mean daily flow data from the USGS Smartsville gauge on Deer Creek downstream of Lake Wildwood reservoir. Data used in this analysis were from water years 1935 – 2009. For this analysis water year 2005 is defined as 4/1/2004 – 3/31/2005, a period of high flow to high flow, instead of 10/1/2004 – 9/30/2005, a period of low flow to low flow.

The goal of low flow frequency analysis was to estimate the frequency or probability with which a given magnitude of daily stream flow would be less than a certain volume in a given reach (Dingman 2002). This analysis was most applicable to reaches of Deer Creek downstream of Lake Wildwood reservoir. For the low flow frequency analysis the annual minimum flows were averaged over consecutive periods of varied length, referred to as *d*-days or *d*-day averages. One of the most common averaging periods is *d*=7, with analysis often carried out for *d*=1, 3, 7, 15, 30, 60, 90, and 180 days (Dingman 2002; Pyrce 2004). The *d*= 1, 3, 7 day analyses are important for assessing the frequency of low flows over the short term, while the *d*= 15, 30, 60, 90, and 180 day analyses are important for assessing the frequency of low flows over the long term. Short-term flows are important for assessing acute stressors to the aquatic ecosystem, while long term flows are important for evaluating drought conditions and sustained periods of low flow. The 1-day average flow with a return interval of once in every ten years is the 1Q10 flow, the 1-day average flow with a return interval of once in every fifty years is the 1Q50, the 7-day average flow that has a return interval of once in every ten years is the 7Q10, and so on. The 1Q10 and 7Q10 are often used as low-flow design values for protection or regulation of water quality, water supply decisions, chronic criteria for aquatic life, and habitat protection during drought conditions (Dingman 2002; Pyrce 2004).

The low flow analysis employed *d*=1, 3, 7, 15, 30, and 90 day averaging periods, with figures provided for the *d*=1 and *d*=15 analysis, to demonstrate how different *d*-day averages influence the results. The analysis was first conducted on the entire data record, then comparing two periods before and after a change to base flow, to investigate alteration of the hydrologic regime. The analysis using the entire period of record is presented in this section, with the two period low flow frequency analysis presented in the Two Period Stream Flow Data Analysis section. Low flow frequency analysis employs a non-parametric approach similar to the flood frequency analysis, but with the low flow analysis the non-exceedance probability is used to determine how often flows are not exceeded (Dingman 2002; Pyrce 2004). Both the Weibull and Cunnane plotting methods are used in this analysis.

The low flow analysis on the entire period of record is useful for determining the probability of low flows in Deer Creek. The Cunnane method plots slightly greater flows at the low flow end of the non-exceedance probability, with the two methods overlapping in the middle, and the Weibull method plotting slightly greater flows at the high flow end of the non-exceedance probability. Flows are lowest in the 1-day analysis and increase through the 90-day analysis, which makes sense considering the use of moving averages, with flows averaged for one day in the *d*=1 analysis, and flows averaged over 90 days in the *d*=90 analysis. As the averaging period increases, so do low flow values, as a larger date range is used. The averaging of a larger date range also leads to a smoother low flow frequency curve, as low or high flow peaks are averaged with many other values, leading to a curve that is smoother and with fewer peaks. **Figure 1.12** and **Table 1.9** provide examples of 1-day and 15-day plots, with return intervals provided in **Figure 1.13** and **Table 1.10**.

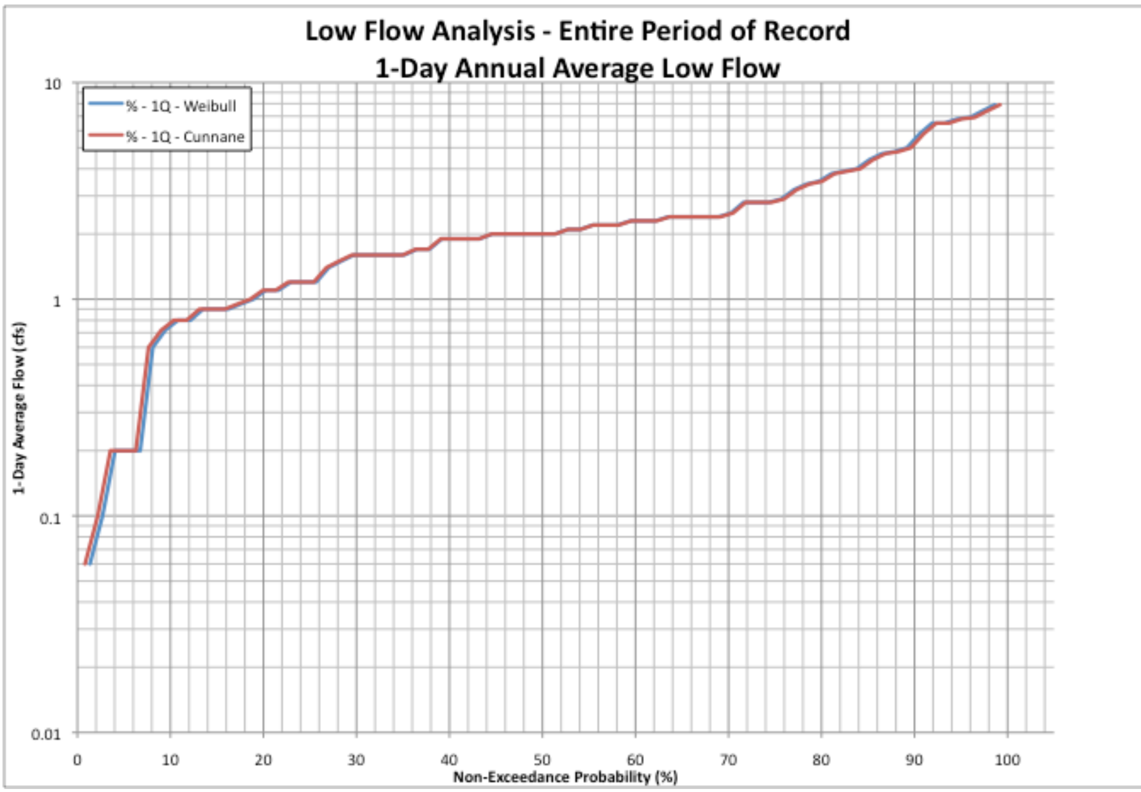


Figure 1.12: Low flow frequency analysis for USGS gauge #11418500 on Deer Creek, d=1, using the Weibull (blue) and Cunnane (red) plotting methods.

Non-Exceedance Probability (%)	Return Interval (years)	Discharge (cfs)
1	100	0.06
2	50	0.1
5	20	0.2
10	10	0.8
20	5	1.1
50	2	2.0
99	1.01	7.9

Table 1.9: Results of the low flow frequency analysis, d=1, non-exceedance probability estimates.

Figure 1.12 and **Table 1.9** provide results of the 1-day low flow frequency analysis. The data indicate that Deer Creek has not exhibited any intermittent flow in the period of record, with stream flows of less than 0.06 cfs expected to occur approximately once every one hundred years. The lowest flow in the period of record, 0.06 cfs, coincides with a two-year drought period during the late 1970's, with no other daily stream flows below 0.1 cfs. In any given year it is probable that stream flows would fall below 7.9 cfs, with stream flows expected to fall below 2.0 cfs once every two years. The steep nature of the low discharge end of the curve, below the 10% non-exceedance probability and approximately 0.8 cfs, indicates that extreme low flows (< 1.0 cfs) occur infrequently, on the order of once every ten to one hundred years. These data are useful for planning purposes as they provide information regarding the frequency of extreme low flows associated with droughts and subsequent water availability for aquatic habitat. Extreme low flows can result in stressful conditions for aquatic and riparian organisms. In addition, these data reflect low flow conditions in a managed system, downstream of all reservoirs and diversion points. It is therefore important to compare the *d*=1 Deer Creek low flow frequency results with the results from the natural flow analysis in the previous sections, which incorporated NID and Oregon Creek data to estimate low flows in upper Deer Creek. This will allow investigation into whether managed flows are less than would be expected in a natural system.

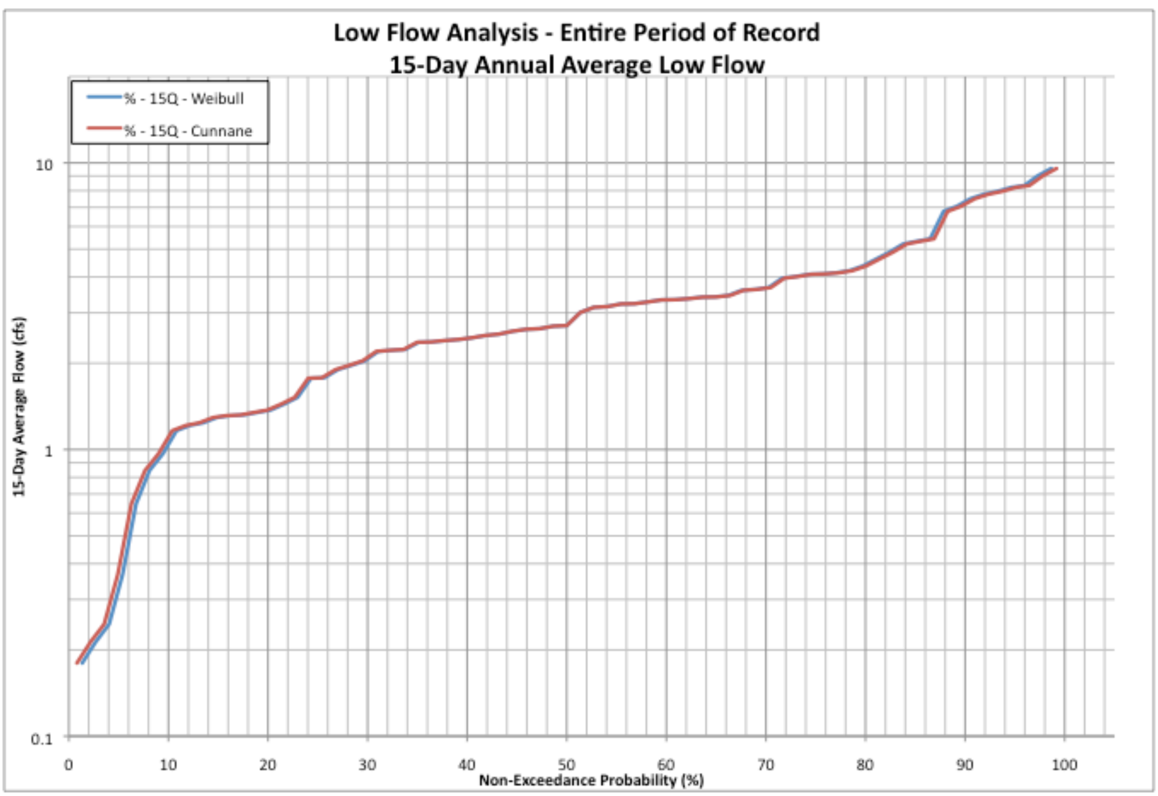


Figure 1.13: Low flow frequency analysis for USGS gauge #11418500 on Deer Creek, d=15, using the Weibull (blue) and Cunnane (red) plotting methods.

Figure 1.13 and **Table 1.10** provide results of the 15-day low flow frequency analysis. As expected, the shape of the curve in **Figure 1.13** is quite similar to that of **Figure 1.12**, although the curve in **Figure 1.13** is smoother and shifted up on the graph, due to 15-day moving averages being used in the analysis. The data indicate that 15-day average stream flows of less than 0.18 cfs are expected to occur once every one hundred years, 0.21 cfs every fifty years, 0.37 cfs every twenty years, and 1.16 cfs every ten years (15Q10). In any given year it is probable that the 15-day average stream flow will fall below 9.56 cfs, with stream flows falling below 2.71 cfs once every two years, and below 1.37 cfs once every five years. As with the 1-day plot, the steep nature of the low discharge end of the 15-day curve, below the 10% non-exceedance probability and approximately 1.0 cfs, indicates that extreme low flows of extended duration occur infrequently, from once every ten to one hundred years. While analysis of the entire period of record provides details regarding the observed flow record in this section of Deer Creek, comparing these results with the estimated natural flows in the upper Deer Creek watershed is important for investigating whether historical low-flow conditions are present in lower Deer Creek at the gauging station and watershed outlet. In addition, conducting low flow frequency analysis on two periods of record (pre- and post-Scotts Flat reservoir) is important for investigating whether reservoir development and water management have caused alterations to the low flow regime and the aquatic ecosystem.

Non-Exceedence Probability (%)	Return Interval (years)	Discharge (cfs)
1	100	0.18
2	50	0.21
5	20	0.37
10	10	1.16
20	5	1.37
50	2	2.71
99	1.01	9.56

Table 1.10 Results of the low flow frequency analysis, d=15, non-exceedance probability estimates.

Low Flow Analysis Discussion

Three separate methods were used to investigate the frequency of low flows in sections of the Deer Creek watershed, focusing on the upper watershed around Scotts Flat reservoir, and the lower watershed near the watershed outlet at the USGS Smartsville gauge. The first method used NID data to investigate natural flows in the upper watershed and indicated that under natural conditions summer low flows at Scotts Flat reservoir would typically drop below 5 cfs in most years. This analysis also determined that summer flows are artificially high in upper Deer Creek, with water transferred from the South Yuba River into Scotts Flat reservoir, and subsequently into Deer Creek to convey water to downstream diversion points. This results in a lack of natural low-flow conditions in these sections of Deer Creek.

Periodic low flow conditions can be important for inducing stress on aquatic and riparian organisms.

The second method compared NID data with USGS data from Oregon Creek, as the Oregon Creek USGS gauge exhibits a hydrograph similar to that of Deer Creek upstream of Scotts Flat (**Figure 1.10**). The similar hydrograph and other features, such as topography, vegetation, watershed size, and climate, allow Oregon Creek to serve as a useful reference for estimating natural flows on Deer Creek at Scotts Flat reservoir. The results (**Figure 1.11**) indicated that during summer months Deer Creek would experience year round flow at Scotts Flat reservoir, with flows of 3-9 cfs expected in above normal to wet years, 2-4 cfs during normal or below normal years, and 1-3 cfs in dry and critically dry years. The results from method 2 are in line with those from method 1, with both methods concluding that at Scotts Flat reservoir in above normal and wet years stream flows of greater than 5 cfs would be expected, normal years would produce flows near 5 cfs, with drier years potentially producing stream flows of less than 1-2 cfs. These results are important because both methods indicate that there would be stream flow at Scotts Flat, even in critical or dry water years. Additionally, the fact that summer low flow conditions could be greater than 5 cfs, and are greater than 1 or 2 cfs except for dry or critical water years in this portion of the watershed, indicates that downstream at the USGS gauge, near the watershed outlet, stream flows of at least this magnitude would be expected during low-flow periods. This is based on the amount of natural flow estimated at Scotts Flat, plus contributions from numerous perennial tributaries between Scotts Flat and the Deer Creek watershed outlet. These results can potentially inform in-stream flow requirements and flow augmentation needs downstream of Scotts Flat reservoir. Comparing the results from method 1 and 2 with the results from method 3 allows for further investigation into low-flow patterns in the watershed.

The results of the low flow frequency analysis in Method 3 (**Figures 1.12, 1.13, Tables 1.9, 1.10**) indicate that stream flows of less than 1.0 cfs are uncommon and occur on the order of once every ten to one hundred years at the USGS Smartsville gauge near the Deer Creek watershed outlet. Annually stream flows are expected to fall below 7.9 cfs, with stream flows of less than 2.0 cfs expected once every two years based on the period of record. When compared with the results from method 1 and 2 it is apparent that low stream flows at the watershed outlet are less than naturally would be present. Method 3 indicates that flows of less than 7.9 cfs are expected to occur each year at the watershed outlet (a=84.6 mi^2), with Method 2 indicating that flows of between 3-9 cfs would be present at Scotts Flat (a=20.8 mi^2) during above normal and wet years and flows of 2-4 cfs in normal years. These estimates, combined with the contributions of numerous perennial tributaries and surface and groundwater storage flows from an increasing watershed size, suggest that flows in lower Deer Creek are not meeting natural values. This indicates that opportunities to ensure that a greater volume of natural flow is delivered to lower Deer Creek should be explored through working with Lake Wildwood Association, NID, and the California Division of Water Rights.

It is important to explore the possibilities for flow augmentation, specifically increased in-stream flows downstream of Lake Wildwood reservoir, because flows downstream of Lake Wildwood reservoir are often dominated by effluent from the Lake Wildwood WWTP, leading to excessive algal blooms and dramatic swings in pH. Lower Deer Creek is 303d listed for pH as a result of the low flows being highly concentrated with effluent. Increased in-stream flows would be important for diluting the effluent in lower Deer Creek and would improve water quality and provide benefits to the impaired biological community.

Flow Duration Curves – Methods

Hydrographs allow for the examination of watershed characteristics that influence conditions such as runoff and storage (Morisawa 1968). Hydrographs are also useful for investigating the timing, duration, and management of flows (Searcy 1959). Flow regime and duration analysis was performed using mean daily discharge data from USGS gauge #11418500. Flow duration curves (FDCs) provide a conceptually simple yet highly informative way to summarize the variability of a time series (Dingman 2002). Duration curves are cumulative frequency curves that show the fraction or percent of the time that the magnitude of a given variable exceeds a value, over a period of extended observation that includes a wide range of seasonal and inter-annual variability (Dingman 2002). For hydrology purposes, duration curves are typically used to depict the temporal variability of daily stream flow. FDCs are a plot of the daily average flow magnitude against exceedance probability. FDCs can be used to gain insight into the temporal variability of stream flow for a given watershed or catchment, with the shape of the curve representing watershed characteristics. Searcy (1959) and Vogel and Fennessey (1994) provided comprehensive reviews of FDCs (Dingman 2002). FDCs were constructed for the entire period of record using Microsoft Excel, to investigate how different methods for constructing FDCs produce unique results for Deer Creek.

There are two approaches to construction of FDCs, including period of record FDCs and median-annual (or mean-annual) FDCs. Period of record FDCs are the conventional method but the median-annual FDCs represent the preferred method (Dingman 2002). Median-annual FDCs are the preferred method because period-of-record FDCs depict the historical variability of stream flows without providing information regarding the inter-annual variability of flows or the uncertainty of the estimated exceedance frequencies due to a finite record length (Vogel and Fennessey 1994; Dingman 2002). This often leads to the low flow end of the period-of-record FDC being significantly influenced by the water years in which flow was measured (Vogel and Fennessey 1994; Dingman 2002). Median-annual FDCs are less influenced by the particular period of record and are useful for estimating the inter-annual variability and uncertainty of FDCs (Vogel and Fennessey 1994). For this analysis FDCs were computed using the period-of-record method, median-annual, and mean-annual methods.

Daily flows were ranked 365*N from lowest (rank I = 1) to highest (rank *I* = 365*N) and the *i*th-ranked flow was designated as q(i). The non-exceedance frequency of each flow was calculated using equations 2 and 3, for the period-of-record and median-annual FDCs respectively. Each method used equation 1 to determine the exceedance probability, with the period-of-record curve constructed by plotting the q(i) values against the EPQ(q(i)) values. The median-annual FDC curve was constructed by applying equation 3 to each water year of record and equation 1 to compute the corresponding EPQ(q(i)) values for the flows of each year. Then the median (or mean) of the N values of q(i) that are associated with each exceedance probability was computed and plotted as the FDC. For this analysis both the median and the mean of the N values were computed.

EPQ(q) = 1 – FQ(q), where EPQ(q) is the exceedance probability; q is the daily average flow magnitude; and FQ(q) is the cumulative distribution function (non-exceedance probability) of q.
FQ(q(i)) = I / 365 * N + 1, for the period-of-record FDCs.
FQ(q(i)) = I / 365 + 1, applied to each water year of record, for the median-annual and mean-annual FDCs

Flow Duration Curves – Results and Discussion

Figure 1.14 provides an example of the FDCs generated from this analysis. **Figure 1.14** shows that the three methods for constructing FDCs each produce different results. In addition, **Figure 1.14** shows the general shape of the FDC for Deer Creek. The analysis method and data record significantly influence the low flow end ($q_{.85}$ – $q_{.99}$) of the period-of-record FDC, with the median and mean annual FDC resulting in higher low flows. Fennessey and Vogel (1990) found that the median FDC plots greater flows than the period-of-record FDC in the low range and reflects more typical behavior of the stream. Between $q_{.70}$ – $q_{.85}$ the period-of-record and mean/median-annual FDC coincide quite well, with the mean-annual and period-of-record coinciding better than with the median-annual from $q_{.01}$ – $q_{.25}$.

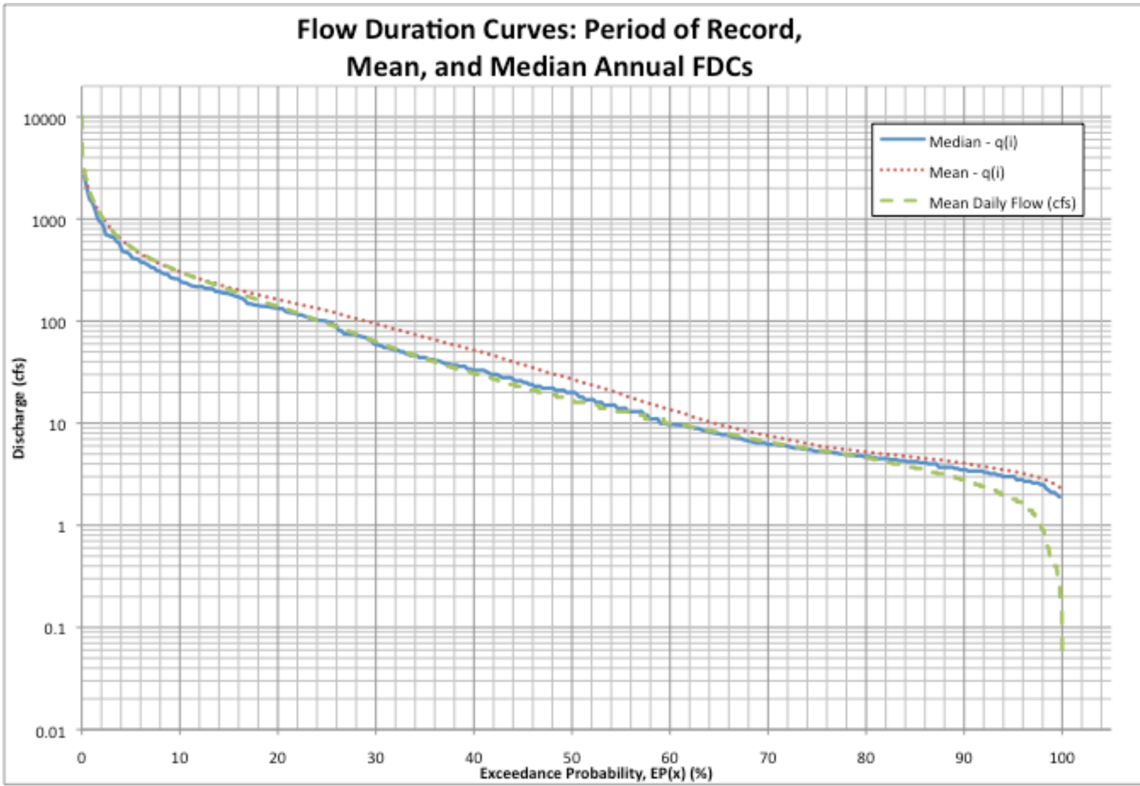


Figure 1.14: Flow Duration Curves: Period-of-record (green-Mean Daily Flow (cfs)), median-annual (blue-Median – q(i)), and mean-annual (red-Mean – q(i)).

The FDCs in **Figure 1.14** show that for the period of record FDC (green curve-Mean Daily Flow) there is a steep slope at both ends of the curve, with this FDC exhibiting the highest and lowest values and the steepest curve due to the FDC being influenced by the period of record. The steep nature of the low discharge end (>90%) of the period of record FDC indicates minor base flows, potentially due to minimal amounts of ground water storage or impacts associated with water management, with the Deer Creek gauge located downstream of multiple reservoirs and water diversion points. The blue median and red mean annual FDC's are also steep at the high discharge end of the curves (0-10%), indicating that daily flow values greater than 1000 cfs (0 – 2%) do not occur most of the time and that floods are caused by direct runoff from rainfall. In addition, a steep curve at the high discharge end of the FDC indicates Deer Creek is a relatively small watershed with little natural surface storage in swamps, wetlands, floodplains, and natural depressions. The blue median and red mean annual FDCs exhibit a relatively flat curve at the low discharge end when compared to the period of record FDC, indicating the median and mean annual FDCs are less influenced by the period of record, that flows generally are greater than 2.0 cfs at the gauging station, and that groundwater or water management helps sustain perennial flows.

The USGS gauge has been recording data since 1935, and thus data exist before the development and expansion of many of the major impoundments on Deer Creek, including Scotts Flat reservoir (1948 & 1964) and Lake Wildwood reservoir (1969). Although the natural flow of Deer Creek was affected prior to the installation of the USGS gauge on Deer Creek by mining activities and development of Lower Scotts Flat (Deer Creek Diversion Dam, 1928) the gauging data provide an opportunity to investigate flows before and after the major reservoirs were constructed.

Two-Period Stream Flow Data Analysis

Methods

USGS records for gauge #11418500 on Deer Creek indicate a change to base flow occurred in water year 1965, coinciding with the 1964 upgrade of Scotts Flat reservoir from 27,000 to 48,547 acre-feet (S. Sindt, pers. comm.). Such a change provides an appropriate point to separate the stream flow record into two periods, one before the base flow change and one after the base flow change, to determine to what extent the overall hydrograph has been altered. A detailed analysis was undertaken for water years before (1935-1964-PreSF period) and after (1965-2009-PostSF period) the base flow change, using multiple methods to analyze annual peak flow and mean daily flow data. This included a flood frequency analysis, low flow frequency analysis, and construction of FDCs. Flood and low flow frequency analysis was conducted to investigate whether the base flow change associated with the construction of Scotts Flat reservoir has led to an alteration in the frequency and magnitude of the annual flow maxima and minima. FDCs were constructed using the mean-annual, median-annual, and period of record FDCs methods, to investigate changes to the flow regime.

In addition to the two period analysis provided in this section, analysis of Deer Creek's stream flow gauging record was conducted using the Indicators of Hydrologic Alteration software package. The Indicators of Hydrologic Alteration (IHA) software (Version 7.1) was used to calculate sixty-seven statistical parameters, including thirty-three IHA parameters and thirty-four Environmental Flow Component (EFC) parameters (TNC 2009). Non-parametric data analysis was conducted for two periods of record (1935-1964, 1965-2009) to analyze alterations to the hydrologic regime, with results and discussion provided in the IHA section.

Deer Creek High Flows – Two-Period Flood Frequency Results and Discussion

Table 1.11 provides results from the HEC-SSP tabular output for the period before (PreSF) and after (PostSF) the Scotts Flat reservoir upgrade and base flow change and allows for quick comparison of flow values for each exceedance probability and return interval. **Figures 1.15** and **1.16** provide HEC-SSP plots of the flood frequency analysis results for each period. Each graph shows the observed events (Weibull method), the computed and expected probability curves, and the $5^{th}/95^{th}$ confidence limits. The results of the two-period flood frequency analysis indicate that reservoir development and water management have potentially impacted the flood regime.

Table 1.11 and **Figures 1.15,** and **1.16** show that the flood regime has potentially been altered through reservoir development and water management, with computed and expected peak flows greater in the PreSF period than in the PostSF period for each return interval, despite the highest flow on record and more wet water years occurring in the PostSF period. The confidence intervals for the PreSF and PostSF periods overlap for each peak flow return interval, indicating that alterations have not been significant from the PreSF to PostSF period and that further analysis is needed to make definitive conclusions about the extent of alterations.

There are five flow events Q>10,000 cfs in the PreSF period and only three PostSF, with the shorter period of record (PreSF) having more frequent Q>10,000 cfs annual peak flow events than the longer period of record (PostSF). There are no annual peak flow events less than 1,000 cfs in the PreSF period, with two annual peak flows of less than 1,000 cfs in the PostSF period, which influences the analysis. The combination of shorter record length, Q>10,000 cfs flows, and the lack of Q<1,000 cfs flows in the PreSF period results in greater peak flow estimates when compared with the PostSF period, indicating that record length and water year types should be considered in this analysis. The HEC-SSP program attempts to correct the bias introduced by analyzing a shorter period of record, which could partially explain the greater magnitudes calculated for the PreSF period expected curve.

% Chance Exceedance	Return Interval (years)	PreSF-Computed Curve Flow (cfs)	PostSF-Computed Curve Flow (cfs)	PreSF-Expected Curve Flow (cfs)	PostSF-Expected Curve Flow (cfs)
0.2	500	19,086	16,029	21,031	16,683
0.5	200	17,213	14,969	18,595	15,498
1	100	15,744	14,028	16,769	14,473
2	50	14,221	12,946	14,940	13,295
5	20	12,105	11,251	12,514	11,486
10	10	10,399	9,719	10,625	9,859
20	5	8,554	7,904	8,656	7,973
50	2	5,682	4,823	5,682	4,823
90	1.11	2,773	1,724	2,686	1,665
99	1.01	1,415	568	1,252	490

Table 1.11: HEC-SSP flood frequency results.

The period of record length and the quantity of specific water years in the observed period of record can influence the flood frequency analysis. The length of record influences the flood frequency statistical analysis, as a large sample size is necessary for an accurate analysis.

The PreSF period has an n=30 with the PostSF n=42. The period of record lengths should accurately capture most large-scale variations in climate, such as the Pacific Decadal Oscillation and the El Niño/Southern Oscillation, with thirty years a typical time period used for analyzing climate data. Although the thirty-year time period potentially reflects large-scale climate variations this is likely not an adequate record length for the flood frequency analysis, particularly for values that must be extrapolated from the small data record, such as the Q50, Q100, Q200, and Q500-year floods. The shorter period of record often introduces bias in the expected results, as the analysis attempts to compensate for the short period of record. Although the PreSF period of record length is fixed, the PostSF period of record length will increase through the future allowing for more accurate predictions of peak stream flows. In addition to the period of record influences on the analysis, there is a lack of critical water years during the PreSF period, with the PostSF period having several water years classified as critical.

Critical water years, such as 1976 and 1977, often result in low annual peak flows (peak < 2,000 cfs). The PreSF period had no critical water years, eight dry water years, and eight below normal water years, with the PostSF period having seven critical water years, eight dry water years, and six below normal water years. The PreSF period had no annual peak flows below 1,000 cfs whereas the PostSF period had two years below this threshold; the PreSF period had two annual peak flows below 2,000 cfs with the PostSF period having seven; and the PreSF period had four annual peak flows below 3,000 cfs with the PostSF period having ten. There appears to be a relationship between water year type and annual peak flow magnitude, with critical water years in 1976 and 1977 resulting in flows of less than 1,000 cfs and critical water years in 1988 and 1994 resulting in flows less than 2,000 cfs. This relationship is further evidenced by the fact that every annual peak flow of greater than 10,000 cfs occurred in wet water years. The relationship is less clear when comparing annual peak flows in dry, below normal, and above normal water years.

Overall the data suggest that alterations to the peak flow regime have occurred from the PreSF to PostSF period, but more investigation into the extent of these alterations is necessary.

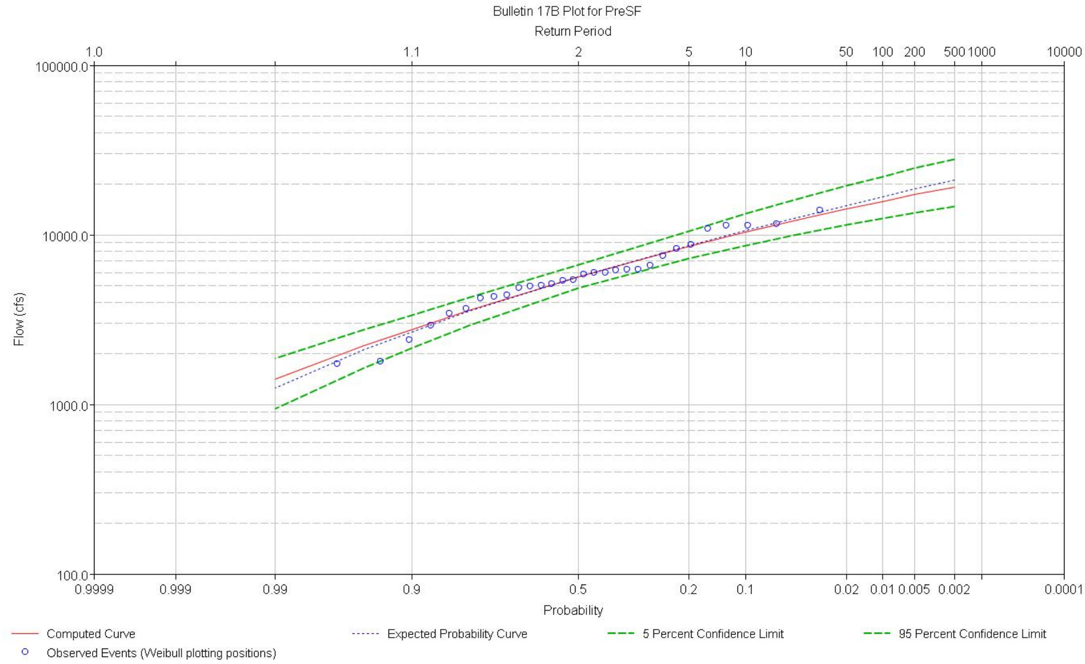


Figure 1.15: Results of the PreSF period (1935-1964) flood frequency analysis, n=30.

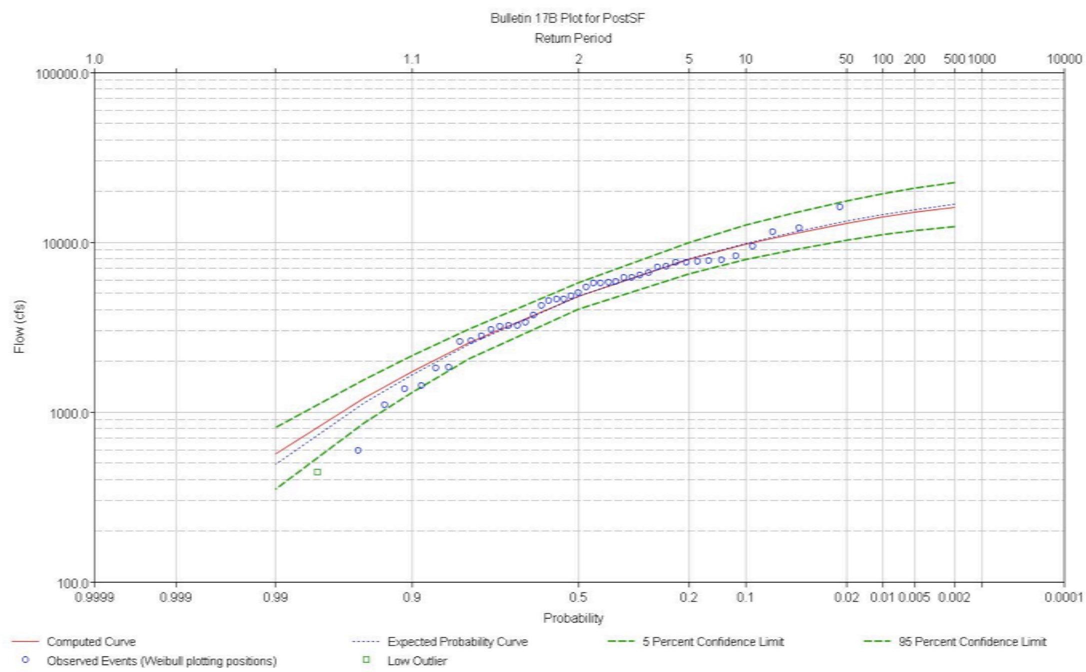


Figure 1.16: Results of the PostSF period (1965-2009) flood frequency analysis, n=42.

Deer Creek Low Flows – Two Period Low Flow Frequency Results and Discussion

As mentioned previously the two-period low flow frequency analysis is important for assessing impacts and alterations to the hydrologic regime, which are associated with the upgrade of Scotts Flat Reservoir and subsequent base flow change in water year 1965. Additionally the low-flow analysis is based upon stream flow records from the USGS gauge at Smartsville, in the downstream-most reaches of Deer Creek. This allows for analysis of how water management and reservoir development have impacted critical low-flows in this section of creek. This section of Deer Creek downstream of Lake Wildwood reservoir is subject to the most adverse impacts of water management and development, is 303(d) listed for pH, and is home to threatened and endangered species of Chinook salmon and steelhead trout. Assessing the impacts to stress-inducing low flows is therefore critical to planning aquatic ecosystem and flow regime restoration efforts.

Results of the two-period low flow frequency analysis indicate that reservoir development and water management have impacted low flows in Deer Creek. This is evident when plotting the 1, 3, 7, 15, and 30-day annual average low flows for the PreSF and PostSF periods. **Figures 1.17** and **1.18** provide results of the 1-day and 15-day analysis, with results of both the 1 and 15-day analysis provided in **Figure 1.19**, using the Weibull plotting method.

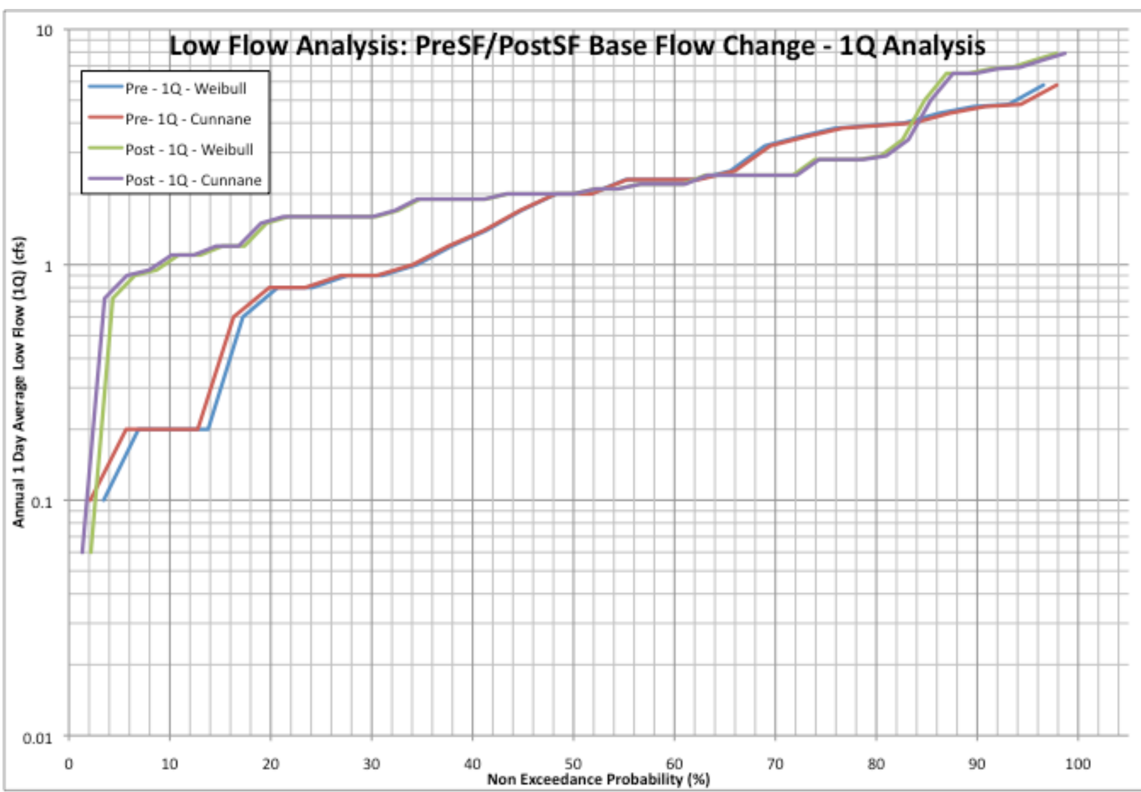


Figure 1.17: Results of the two-period low flow frequency analysis, d=1, annual 1-day average low flow.

Certain trends are apparent and persist in each *d*-day analysis with the PostSF period annual *d*-day low flows generally greater from about the 0-50th non-exceedance probability, similar from the 50-60th, lower from 60-84th, and greater from 84-100th when compared against the PreSF period. With the 15-day (**Figure 1.18**) and 30-day averages the PostSF period low flows are generally greater from about the 0-55th non-exceedance probability, similar through the 80th, and greater from the 80-100th. The differences between the PreSF and PostSF period low flow frequency results are quite small, typically on the order of less than 1.0 cfs. This indicates that minor alterations to the magnitude and frequency of low flows have occurred in this section of Deer Creek as a result of the 1964 Scotts Flat reservoir upgrade, with the slight flow increase possibly attributed to the development of the Lake Wildwood reservoir WWTP in the PostSF, which continually discharges effluent into lower Deer Creek immediately downstream of Lake Wildwood reservoir. In summer months the Lake Wildwood WWTP often discharges at a rate of 0.62 cfs, potentially accounting for more than half of the 1.0 cfs or less flow increase (Scott Joslyn, pers. comm.).

While the volume of low stream flows tends to be slightly higher in the PostSF period, the increase potentially results from effluent discharged by the Lake Wildwood WWTP, and thus an increase in flow quantity does not necessarily equate to an improvement in water quality or habitat conditions. These alterations to the low flow regime have important consequences for Deer Creek, as the magnitude and duration of annual minimum flows can influence the ecosystem in the following ways (TNC 2009):

· Balance of competitive, ruderal, and stress- tolerant organisms
· Structuring of aquatic ecosystems by abiotic vs. biotic factors
· Soil moisture stress in plants
· Dehydration in animals
· Anaerobic stress in plants
· Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments
· Distribution of plant communities in lakes, ponds, floodplains

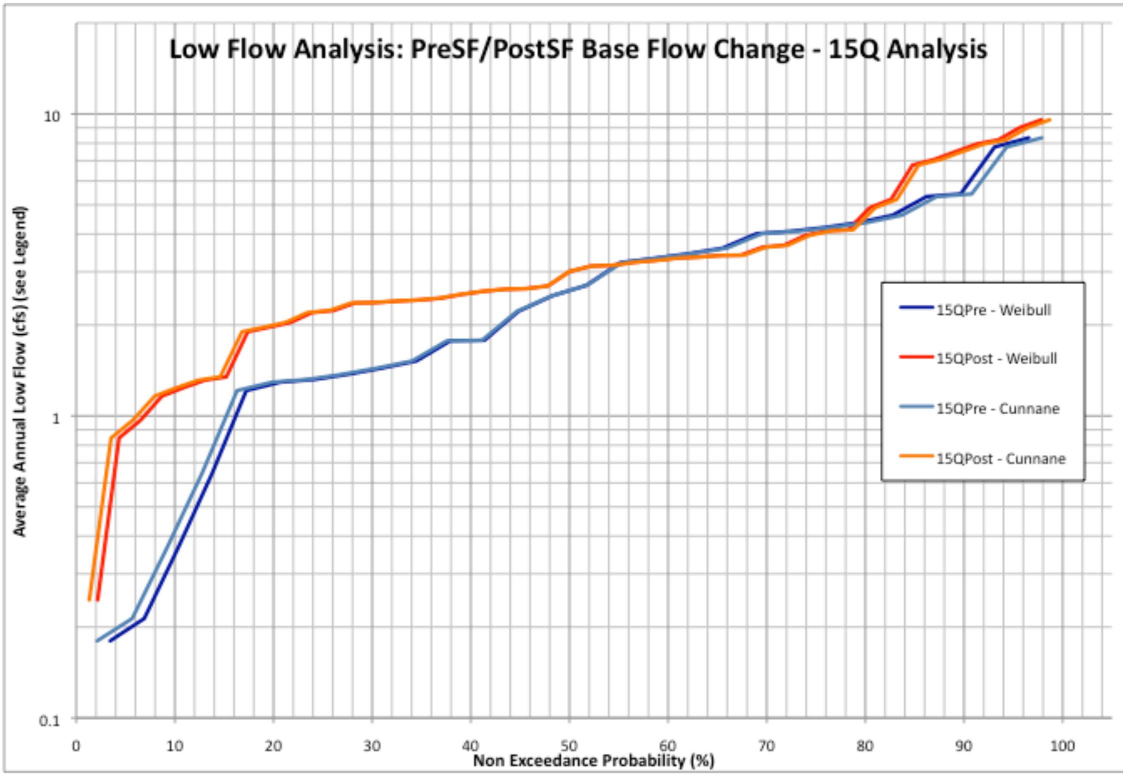


Figure 1.18: Results of the two period low flow frequency analysis, d=15, annual 15-day average low flow.

Low flow conditions can create stressors or even barriers for certain aquatic organisms, with high temperatures, low oxygen levels, and high nutrient concentrations often associated with low flow conditions. Elevated levels of nutrients in the water, resulting from wastewater treatment effluent discharges and agricultural and urban runoff, can promote excessive algal growth at low flows. This is a common problem in Deer Creek downstream of Lake Wildwood reservoir during the summer months, as the majority of the water is removed for management activities such as irrigation and maintaining reservoir levels. Algal blooms can lead to dramatic fluctuations in dissolved oxygen levels and pH, with the possibility of periods with little to no oxygen in the water column. Such anaerobic conditions can kill fish and macroinvertebrates. These factors combined indicate the need for augmenting summer low flows in the section of Deer Creek downstream of Lake Wildwood reservoir.

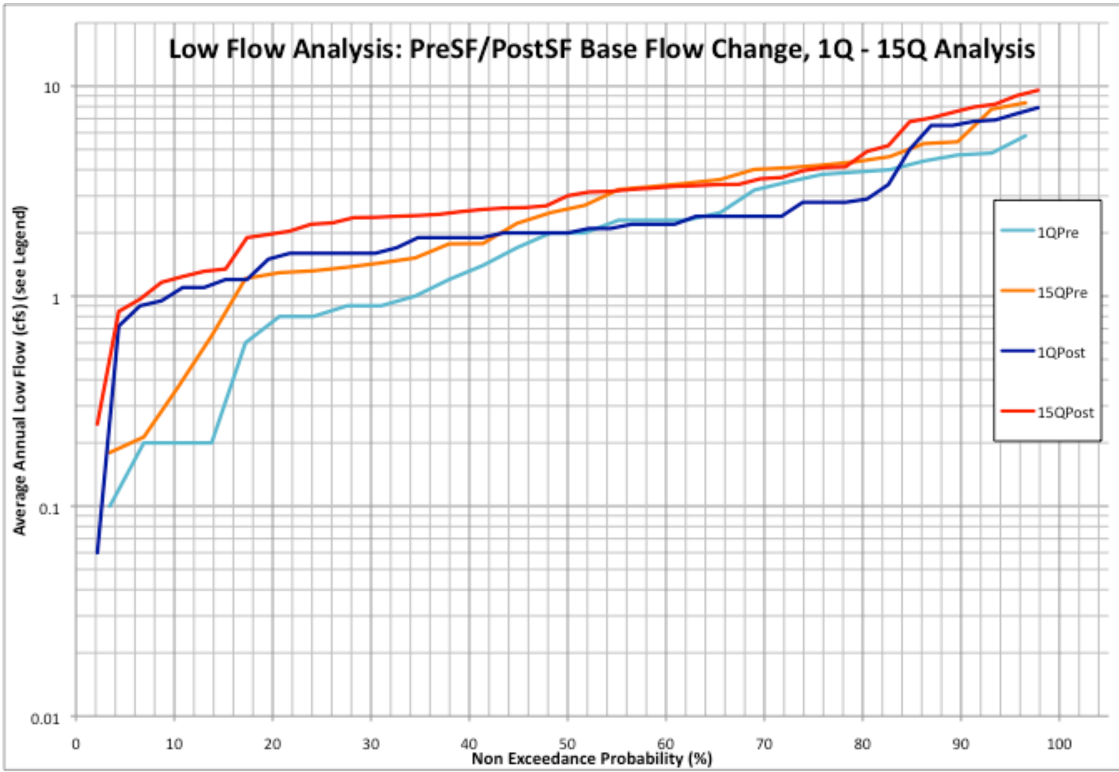


Figure 1.19: Results of the two-period low flow frequency analysis, d=1 and d=15, using the Weibull plotting method.

Two-Period Flow Duration Curves Analysis Results and Discussion

FDCs were constructed for two time periods, from water years 1935-1964 and 1965-2009, to investigate impacts to the flow regime associated with the upgrade of Scotts Flat reservoir from 27,000 to over 48,000 acre-feet in 1964 and base flow change in water year 1965. The period-of-record, median-annual, and mean-annual methods were used in this analysis. **Figures 1.20** and **1.21** provide examples of the FDCs generated from this analysis.

Figure 1.20 provides median and mean-annual FDCs for the periods before (PreSF) and after (PostSF) the base flow change in water year 1965. Upon assessing **Figure 1.20** it is evident that the hydrologic regime is different now than prior to the 1964 Scotts Flat reservoir upgrade. The median and mean-annual FDCs in **Figure 1.20** generally coincide with each other and follow similar patterns at the high and low flow ends of the plots, but there are distinct differences between the PreSF and PostSF periods. In the PostSF period at the low flow end the mean-annual results in greater low flows ($q_{.75} - q_{.99}$) with the median-annual PostSF also resulting in greater low flows ($q_{.88} - q_{.99}$). This indicates that there was a greater probability of lower discharge flows PreSF and the base flow change. As discussed previously, this slight increase in low or base flow conditions (< 1.0 cfs) could be attributed to the Lake Wildwood reservoir WWTP, which began discharging effluent into lower Deer Creek during the PostSF period. On a typical day during the summer months the WWTP discharges approximately 400,000 million gallons per day of effluent into Deer Creek, which equates to an average of 0.62 cfs (Scott Joslyn, pers. comm.). In winter months on days with high precipitation and usage the WWTP discharges up to 800,000 million gallons per day of effluent into Deer Creek, equating to an average of 1.24 cfs (Scott Joslyn, pers. comm.).

In **Figure 1.20**, for the mean-annual FDC above $q_{.75}$ there was a greater probability of higher discharge flows in the PreSF period than PostSF, with the median-annual FDC following the same pattern of a greater probability of higher discharge flows in the PreSF period from $q_{.15}$ – $q_{.88}$. Above $q_{.15}$ the mean and median annual FDCs generally coincide, with no significant differences between the mean PreSF and PostSF or median PreSF and PostSF. The greater probability of high flows and base flows, above $q_{.75}$ for the mean-annual and above $q_{.88}$ for the median-annual FDC, indicates that there is less water flowing through the watershed outlet in the PostSF period. This suggests, as do previous analyses, that reservoir development and water management have altered the flow regime in the Deer Creek watershed.

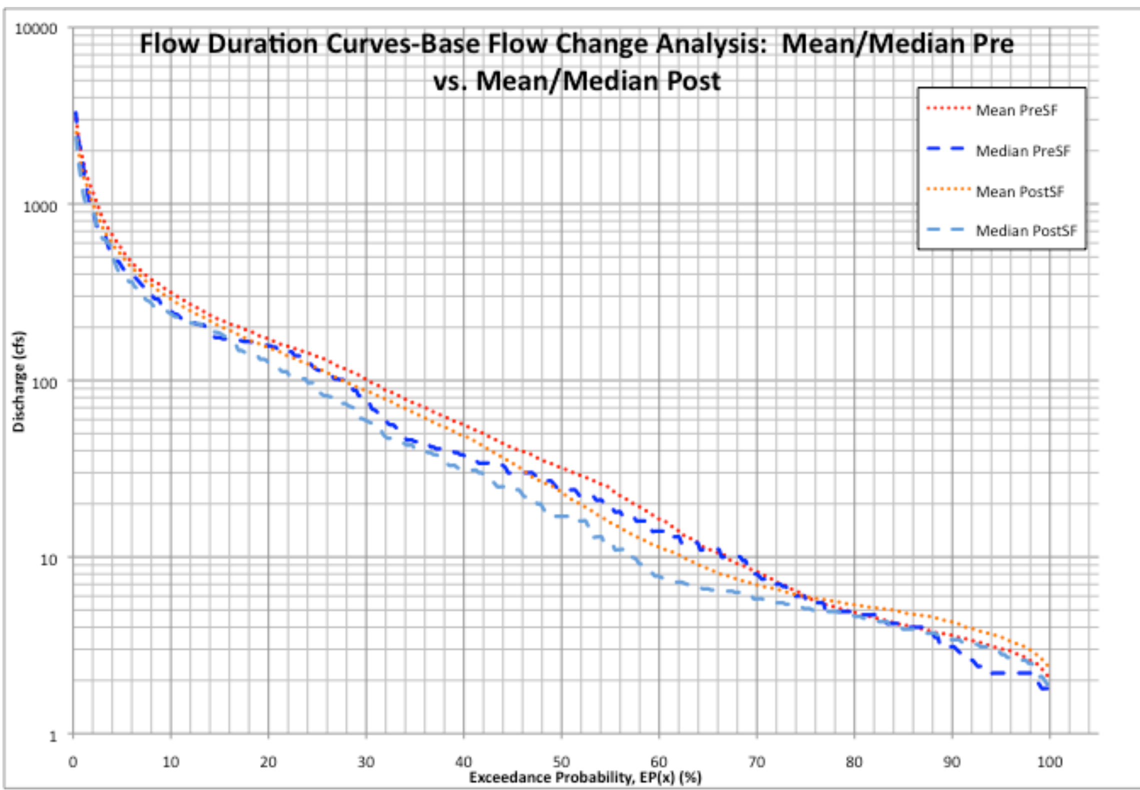


Figure 4.20: Flow Duration Curves: comparison of before and after base flow change in water year 1965, using the median-annual method and plotting mean and median daily flows.

The period-of-record FDCs in **Figure 1.21** follow a similar trend to the median and mean-annual FDCs (**Figure 1.20**) with a greater probability of lower discharge flows PreSF ($q_{.90}$ – $q_{.99}$), a greater probability of higher base and high pulse discharge flows ($q_{.15}$ – $q_{.90}$) in the PreSF period, with the curves coinciding above $q_{.15}$. The lowest flows on record occurred in the PostSF period, which is evident from the period-of-record FDC (**Figure 1.32**). For comparison, **Figure 1.21** was evaluated against the two-period annual FDC generated by the IHA software analysis (**Figure 1.31**). The IHA software also uses the period-of-record method to calculate FDCs and therefore can be used to independently assess the success of the analysis. The curves in **Figure 1.21** and **Figure 1.31** are essentially identical and confirm the success of the FDC analysis through independent methods, as well as the fact that the hydrologic regime has been altered through reservoir development and water management.

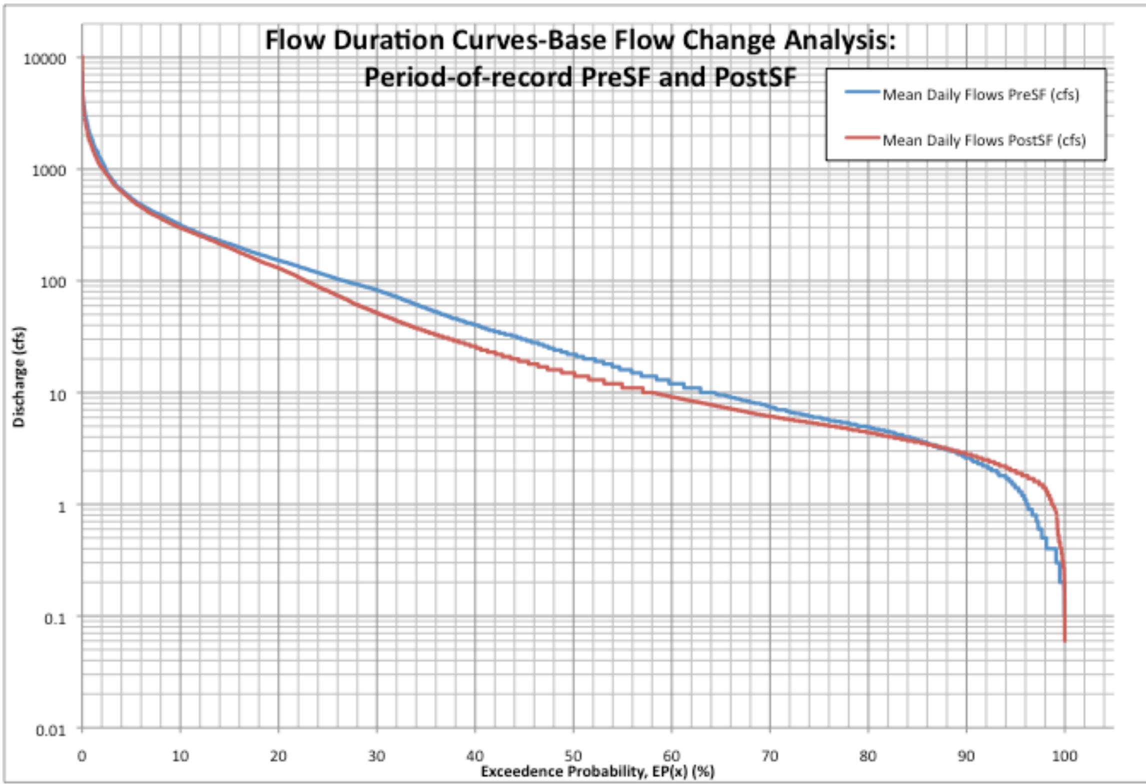


Figure 1.21: Flow duration curves to compare the period before (PreSF) and after (PostSF) water year 1965, using the period-of-record method and plotting mean daily flows.

Indicators of Hydrologic Alteration (IHA) Flow Data Analysis

Indicators of Hydrologic Alteration – High Flows

The IHA software calculates a variety of parameters that are applicable to the high flow analysis. This includes analysis of the annual flow maxima, frequency and duration of high flow pulses, timing of annual maximum flows, high flow pulses, small floods, and large floods. Two period analysis was conducted for each of these parameters, from 1935-1964 and 1965-2009, to investigate alterations to the hydrologic regime through reservoir development and water management. Annual maximum flows, frequency and duration of high flow pulses, and the Julian date of annual minimum flows use the Range of Variability Approach (RVA), to assess the degree of hydrologic alteration to each parameter (Richter et al. 1997; TNC 2009). The high flow pulse, small flood, and large flood are part of the

Environmental Flow Components (EFC) analysis, which does not allow for the RVA to assessing hydrologic alteration. For these methods hydrologic alteration was assessed through changes to the 25th, 50th (median), and 75th percentiles from the PreSF to PostSF period.

The following is taken from the IHA Tutorial and describes the RVA methodology used in this analysis (Richter et al. 1997; TNC 2009):

The RVA uses the pre-development (PreSF) natural variation of IHA parameter values as a reference for defining the extent to which natural flow regimes have been altered. The pre-development (PreSF) variation can also be used as a basis for defining initial environmental flow goals. Richter et al., (1997) suggests that water managers should strive to keep the distribution of annual values of the IHA parameters as close to the pre-impact distributions as possible. RVA analysis also generates a series of Hydrologic Alteration factors, which quantify the degree of alteration to the thirty-three IHA flow parameters.

In the RVA analysis, the full range of pre-impact data (PreSF) for each parameter was divided into three different categories. The boundaries between categories are based on percentile values, which are specified by the user. The default non-parametric RVA analysis places the category boundaries 17 percentiles from the median, which yields an automatic delineation of three categories of equal size: the lowest category contains all values less than or equal to the 33rd percentile; the middle category contains all values falling in the range of the 34th to 67th percentiles; and the highest category contains all values greater than the 67th percentile. The program then computes the expected frequency with which the post-impact (PostSF) values of the IHA parameters should fall within each category (in the non-parametric default, this would be 33% for each of the three categories). The program then computes the frequency with which the post-impact (PostSF) annual values of IHA parameters actually fell within each of the three categories. This expected frequency is equal to the number of values in the category during the pre-impact (PreSF) period multiplied by the ratio of post-impact (PostSF) years to pre-impact years (PreSF). Finally, a Hydrologic Alteration factor is calculated for each of the three categories as:

(observed frequency – expected frequency) / expected frequency

A positive Hydrologic Alteration value means that the frequency of values in the category has increased from the pre-impact (PreSF) to the post-impact (PostSF) period, with a maximum value of infinity, while a negative value means that the frequency of values has decreased, with a minimum value of -1.

While it is possible to use parametric statistics for RVA analysis and to adjust the RVA boundaries, the recommended way to run an RVA analysis is to use the non-parametric defaults, because of the skewed or non-normal nature of many hydrological datasets and to ensure an equal number of data points are distributed outside of the RVA boundaries for assessing alterations in the two period analysis (TNC 2009). Using the 33rd and 67th percentiles ensures that in most situations an equal number of pre-impact values will fall into each category, which makes the results easier to understand and interpret.

Method 1. Annual Maximum Flow Analysis

The IHA software calculates the magnitude and duration of annual extreme water conditions using 1, 3, 7, 30, and 90-day means. Comparing these hydrologic parameters for two time periods allows for analysis of how the Scotts Flat reservoir upgrade and subsequent base flow change has altered the magnitude and duration of the annual maximum *d*-day flows. The magnitude and duration of annual maximum flows can have the following ecosystem influences (TNC 2009):

· Balance of competitive, ruderal, and stress- tolerant organisms
· Creation of sites for plant colonization
· Structuring of aquatic ecosystems by abiotic vs. biotic factors
· Structuring of river channel morphology and physical habitat conditions
· Volume of nutrient exchanges between rivers and floodplains
· Distribution of plant communities in lakes, ponds, floodplains
· Duration of high flows for waste disposal, aeration of spawning beds in channel sediments

Figure 1.33 summarizes the degree of Hydrologic Alteration (HA) for the annual flow maximum, based on the RVA analysis, with Figure 4.34 providing an example plot of the 1-day *d*-day analysis. Results of the IHA annual *d*-day maxima analysis indicate that the magnitude of annual maximum flows has been altered from PreSF to PostSF. For each of the 1, 3, 7, 30, and 90 day averages, the PreSF *d*-day median flow is greater than in the PostSF period.

Table 1.12 indicates that there have been changes to the annual flow maxima for each of the *d*-days analyzed, with **Table 1.12** detailing how the 1-day maximum has been altered. In each *d*-day analysis there is an increase in the low RVA category and in four of the five analyses (excluding the 30-day analysis) a decrease in high RVA category flows in the PostSF period, as well as a median shift downward on the plot, indicating that annual *d*-day maximum flows have decreased from the PreSF to PostSF period. The negative values for the high RVA category indicate a decrease in annual maximum flow magnitudes and the positive values for low RVA category indicate a trend of lower magnitudes for maximum flow events in the PostSF period. There is an insignificant increase to the 30-day high RVA category. The middle RVA category exhibits decreases in four of the five analyses, excluding the 3-day analysis, in which there is an insignificant increase in middle RVA category flows. This further indicates a decrease in the magnitude of annual maximum flows from the PreSF to

PostSF period. The median *d*-day annual flow maximum decreases for each *d*-day analyzed, with the magnitude of change indicated in **Table 1.12**. **Figure 1.22** shows that the annual maximum flow experiences greater variability PostSF, with both the highest and lowest annual flow maxima occurring in the PostSF period. This could possibly be influenced by the types of water years observed in the period of record.

Annual Maxima	Low RVA (HA)	Middle RVA (HA)	High RVA (HA)	Median Change (cfs)
1 day	0.5037	-0.1798	-0.284	-810
3 day	0.5753	0.05455	-0.642	-720
7 day	0.4321	-0.1212	-0.284	-260.1
30 day	0.4321	-0.4141	0.07407	-158.7
90 day	0.5753	-0.297	-0.2123	-65.9

Table 1.12: IHA software high flow analysis, annual d-day maxima, RVA and Hydrologic Alterations summary.

The alterations to the hydrologic regime in the PostSF period have important implications for aquatic and riparian organisms and the Deer Creek watershed as a whole. Annual *d*-day maximum flows in the PostSF period tend to be lower, with fewer flows in the middle and high RVA category and more in the low RVA category. A lower annual flow maximum has implications for the Deer Creek ecosystem, influencing the volume of nutrient exchanges between the creek and floodplain, the distribution of plant communities in floodplains, lakes, and ponds, and the duration of high flows for waste disposal and aeration of spawning beds (Richter et al. 1997; TNC 2009). The cause of this is probably Scotts Flat reservoir, which captures flows from one quarter of the watershed until the reservoir fills. In wet years Scotts Flat reservoir can fill as early as November, while in dry years Scotts Flat will not fill until as late as March, and sometimes only then with significant imports from the South Yuba (S. Sindt, pers. comm.). This can result in a reduction in the annual flow maxima downstream of the reservoir and shows the need for working with NID to manage flood flows for the benefit of the Deer Creek watershed.

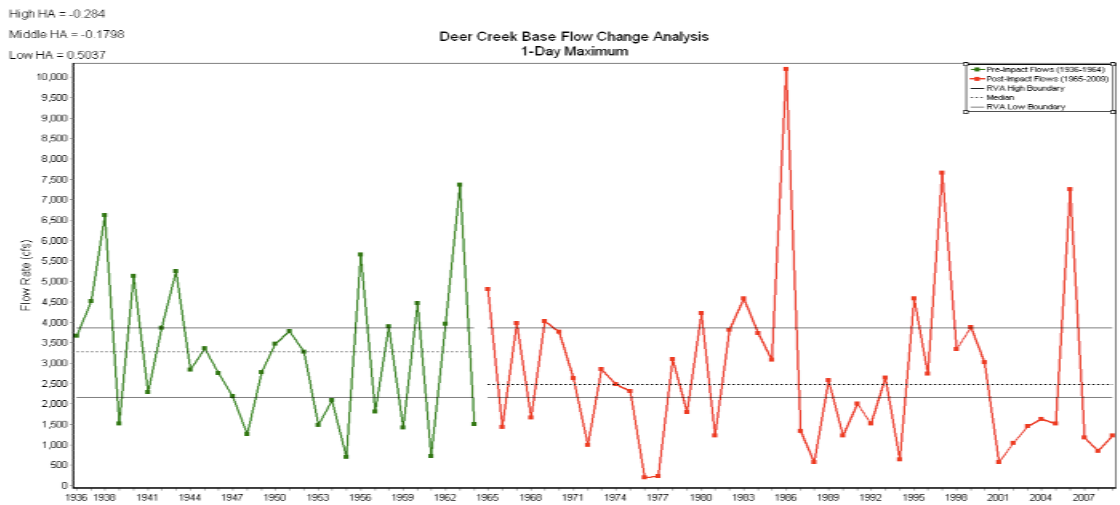


Figure 1.22: IHA software maximum flow analysis, annual 1-day maximum plot.

Method 2. High Flow Pulses: Frequency and Duration

The IHA software calculates the frequency and duration of high flow pulses during each water year. High flow pulses are classified as flows above the 75th percentile of flows for the entire period of record, with the frequency being the number (count) of high flow pulses in each water year, and high flow pulse duration the median length of high flow pulses in days (TNC 2009). The two-period high flow pulse analysis allows for investigation into the Scotts Flat reservoir upgrade and base flow change, and whether these have impacted the frequency and duration of high flow pulses at the USGS Smartsville gauge near the Deer Creek watershed outlet. The duration and frequency of flow pulses can influence many factors that are important to aquatic ecosystem function and health, including (TNC 2009):

· Frequency and magnitude of soil moisture stress for plants
· Frequency and duration of anaerobic stress for plants
· Availability of floodplain habitats for aquatic organisms
· Nutrient and organic matter exchanges between river and floodplain
· Soil mineral availability
· Access for water birds to feeding, resting, reproduction sites
· Bedload transport, channel sediment textures, and duration of substrate disturbance

Figure 1.23 provides results of the high pulse frequency (count) analysis, with results from the high pulse duration analysis provided in **Figure 1.24**. The results of the high flow pulse analysis indicate that both the frequency and duration of high flow pulses have been altered from the PreSF to PostSF period. The high flow pulse analysis suggests a slight increase in the frequency of high flow pulse events from the PreSF to PostSF period, and a decrease in the duration of high flow pulses in the PostSF period. There is considerable variability in both high pulse count datasets (**Figure 1.23**), which in part can be attributed to year-to-year variability in weather and climate and how flows are managed (hydropower, water deliveries).

The frequency of high flow pulses increases slightly from the PreSF to PostSF period, with the PostSF median increasing from seven to eight high pulses annually. This increase is also evidenced by the RVA analysis with an increase in the High Hydrologic Alteration category (0.2889) and decreases in the Middle (-0.06263) and Low (-0.2132) categories. This indicates that the frequency of high pulses in Deer Creek has increased slightly since 1964 and could have implications for the watershed including an increased frequency of bedload transport, substrate and plant disturbance, and anaerobic stress for plants (TNC 2009).

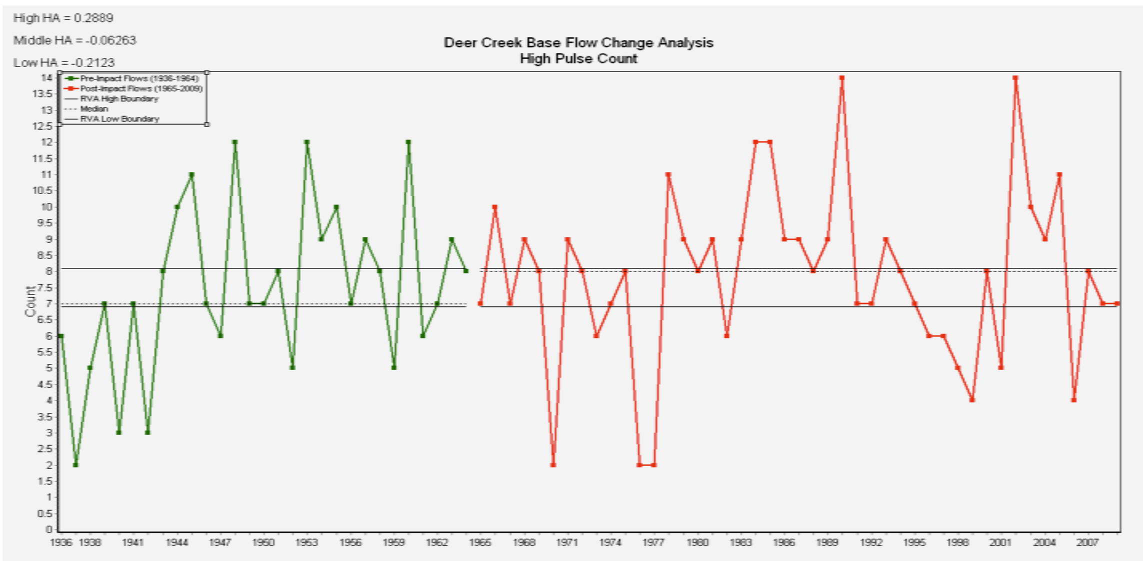


Figure 1.23: IHA software high flow pulse analysis, high pulse count (frequency) plot.

The results of the high flow pulse duration analysis in **Figure 1.24** indicate differences between the PreSF and PostSF periods. The PostSF median shifts lower by approximately 1 day, to near the PreSF low RVA boundary. In the PreSF period there are two years with high pulses of extended duration (> 50 days), which is not the case in the PostSF period with the greatest high pulse duration being forty-five days. The decreased high pulse duration in the PostSF period is further evidenced by a decrease in the High (-0.4988) and Middle (-0.1254) Hydrologic Alteration categories and a large increase in the low (1.041) category. The decrease in extended duration high flow pulses can have numerous implications for aquatic ecosystems including a reduced duration of plant and substrate inundation, a reduction in the extent of nutrient and organic matter exchange between the creek and floodplain, and a reduction in the availability of floodplain habitats (TNC 2009). Further analysis should be conducted to verify the significance of these changes and should employ the use of 15-minute stream flow data instead of mean daily flow data, as the mean daily flow data undoubtedly eliminates many of the pulses that occur throughout the day and thus should be incorporated into the high pulse frequency and duration analysis.

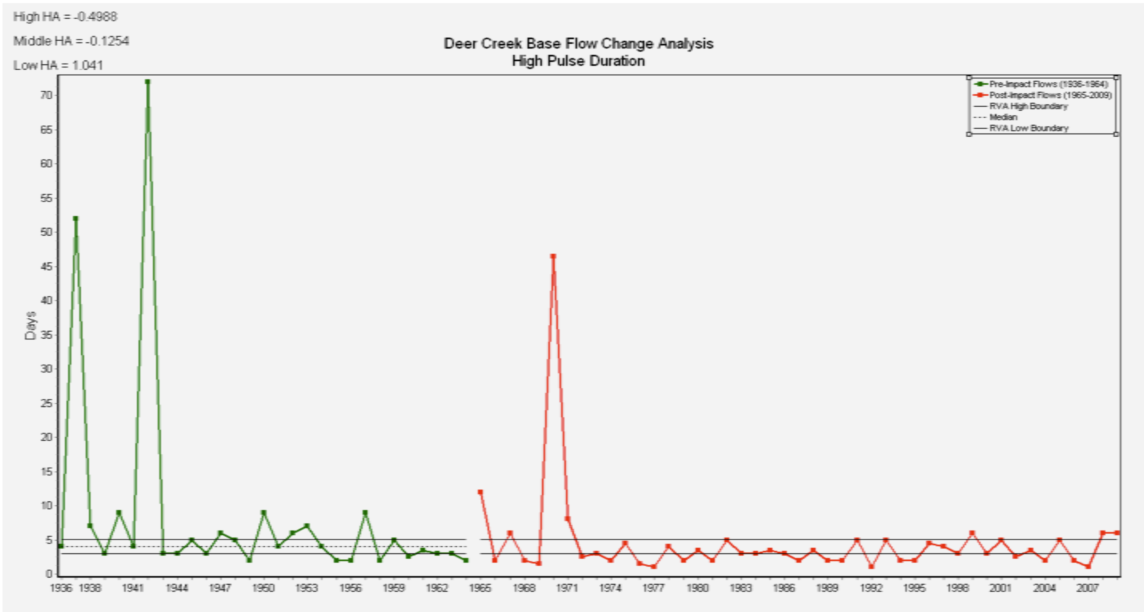


Figure 1.24: IHA software high flow pulse analysis, high pulse duration plot.

Method 3: Julian Date of Annual Maximum Flow

The IHA software analyzes the mean daily flow record to determine the Julian day of the annual maximum flow. The Julian day is used because this method simplifies calculating statistics for timing variables. Julian dates represent calendar dates by integer values, with 1 corresponding to January 1 and 366 to December 31. There are always 366 Julian days in a year, regardless of whether it is a leap year or not, with February 29 corresponding to Julian day 60 in leap years (TNC 2009). This ensures that each calendar date is represented by the same Julian date in each year. The Julian date analysis is important because the timing of annual extreme water conditions can influence many factors important to aquatic organisms, including (TNC 2009):

· Compatibility with life cycles of organisms
· Predictability/avoidability of stress for organisms
· Access to special habitats during reproduction or to avoid predation
· Spawning cues for migratory fish
· Evolution of life history strategies, behavioral mechanisms

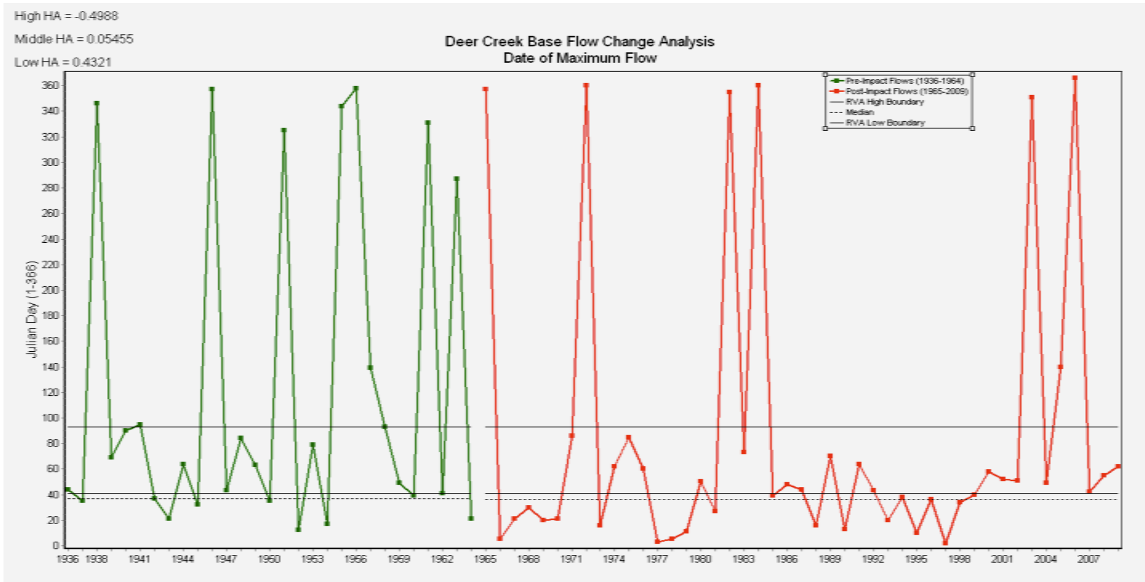


Figure 1.25: IHA software Julian date analysis, plot of the date of annual maximum flow.

The results of the IHA software Julian data analysis are displayed in **Figure 1.25** and indicate that there have not been significant alterations to the timing of the annual maximum daily flow from the PreSF to PostSF period. The PreSF and PostSF medians are very similar, with the PostSF median shifted earlier in the water year by only one day. There is an increase in the low RVA category and decrease in the high RVA category, indicating a shift in the annual flow maximum towards earlier in the water year. Further investigation should be conducted to verify the significance of alterations to the date of the annual flow maximum using additional methods, and as a larger dataset becomes available through time.

Methods 4a – 4c: Indicators of Hydrologic Alteration Environmental Flow Components Analysis

The IHA software allows for analysis of five different types of Environmental Flow Components (EFC) including extreme low flows, low flows, high flow pulses, small floods, and large floods. Three of the EFC are relevant for the IHA High Flows analysis and include high flow pulses, small floods, and large floods. EFC are based upon the fact that hydrographs can be separated into a set of hydrographic patterns, patterns that repeat themselves and are ecologically relevant. The spectrum of flow conditions, represented by the five types of flow events, should be maintained in order to sustain the health and function of the aquatic ecosystem. Hydrologic parameters calculated in the EFC analysis include the magnitude of annual peak flow, duration of the flow, frequency of EFC type, timing (Julian day) of the event, and rise and fall rates associated with the EFC type.

EFC analysis utilizes mean daily stream flow data from the USGS gauge on Deer Creek. The user calibrates the software to determine the thresholds for high flow pulses, small floods, and large floods. High flows are defined as flows that exceed 75% of daily flows for the period, with flows below 25% of daily flows for the period defined as low or base flows. Between these two flow levels a high flow begins when flow increases by more than 75% per day and will end when flow decreases by less than 20% per day. Small flood events are defined as an initial high flow with a peak flow greater than the 2-year return interval, with large floods greater than the 10-year return interval. These return intervals are based on mean daily flow data and not instantaneous peak flows, as was the case with the flood frequency analysis. The EFC parameters do not permit using the RVA analysis method, but PreSF and PostSF medians and interquartile ranges (25th and 75th percentiles) can be compared in order to assess alteration to the hydrologic regime.

<u>4a. High Flow Pulse</u>

During rainstorms or periods of snowmelt Deer Creek will often rise above its low-flow or base flow level. For the EFC analysis, high flow pulses include any water rises that do not overtop the channel banks (Q < bankfull), up to the 2-yr return interval. Pulses of this nature provide an important and necessary disruption in low flow periods, with brief pulses of fresh water providing much-needed relief from stressors such as high water temperatures, high specific conductivity, high nutrient concentrations, and low dissolved oxygen conditions, which are common in low flow periods. Additionally high flow pulses deliver organic material and food resources to support the aquatic food web, provide fish and other aquatic organisms increased access to habitat, and help to flush the system of fine sediments and algae that can reduce the quality of available habitat (TNC 2009). High pulses can have the following influences on the aquatic ecosystem (TNC 2009):

· Shape physical character of river channel, including pools, riffles
· Determine size of streambed substrates (sand, gravel, cobble)
· Prevent riparian vegetation from encroaching into channel
· Restore normal water quality conditions after prolonged low flows, flushing away waste products and pollutants
· Aerate eggs in spawning gravels, prevent siltation
· Maintain suitable salinity conditions in estuaries

The results of the High Flow Pulse analysis indicate that there have been slight alterations to the high flow pulse regime from the PreSF to PostSF period, through changes to the high flow pulse peak, duration, frequency, timing, and rise and fall rates. **Table 1.13** summarizes changes to the high flow pulse EFC.

Parameter	PostSF Median	PostSF Interquartile Range
Peak	Median decrease (~40 cfs)	Slightly larger interquartile range, shifted down on plot.
Duration	Same median (5 days)	Slightly smaller interquartile range, with 75th percentile shifted down on plot.
Frequency	Median increases, from 9 to 11 times annually.	Similar interquartile range, shifted up on plot with median.
Rise Rate	Median decrease (~10 cfs)	Similar interquartile range, shifted down on plot with median.
Fall Rate	Slight median decrease on plot (slight fall rate increase (~2 cfs)	Larger interquartile range.
Timing	Median shifts earlier in water year by 35 days.	Smaller interquartile range, 25th and 75th percentiles shifted earlier in water year.

Table 1.13: Summary of the EFC High Flow Pulse analysis, with hydrologic parameters, changes to the PostSF Median, and changes to the PostSF interquartile range.

Table 1.13 depicts changes from the PreSF to PostSF period, with a brief discussion of how the PostSF median and interquartile range has been altered for each hydrologic parameter. The annual high flow pulse peak magnitude has been altered, with a median decrease of 40.0 cfs in the PostSF period and an interquartile range shifted lower on the plot. This indicates that high flow pulses were greater during the PreSF period with a similar range of variability in the PostSF period. The duration with which high flow pulses persist has been minimally altered, with no change to the PostSF median and a slight decrease in the size of the interquartile range. The frequency with which high flow pulses occur has changed, with a slight median increase in the PostSF period and a similar interquartile range size shifted up on the plot with the median. This indicates that there potentially is a greater frequency of high flow pulses in the PostSF period. The high flow pulse rise rate has been altered, with a median decrease of 10 cfs in the PostSF period and a similar interquartile range shifted down on the plot with the median. This indicates a slight decrease in the rise rate for high flow pulses. The high flow pulse fall rate has been minimally altered, with a slight median decrease of 2 cfs in the PostSF period but a larger interquartile range. This indicates a slight increase in the fall rate for high flow pulses, with much more variability in fall rates in the PostSF period. The timing plot indicates a 35-day shift in the median Julian date for peak high flow pulse to earlier in the water year, and a smaller interquartile range that is shifted earlier in the water year. The 35-day shift is a significant alteration from the PreSF to PostSF period. The median high flow pulse peak occurred in late January or early February in the PreSF period, and in late December in the PostSF period. This smaller interquartile range indicates that there is less variability in the timing of the high flow pulse peak.

The analysis indicates that the peak, frequency, timing, and rise rate of high flow pulses are the most impacted parameters of the high pulse regime. The peak high flow pulse has decreased in the PostSF period, possibly due to dams attenuating stream flows by capturing runoff for storage. The frequency analysis indicates that while the magnitude of high flow pulses has decreased, the pulses are occurring more frequently. This could be attributed to many factors, including the presence of more wet and above normal water years in the PostSF period analysis, leading to more frequent high flow pulses in Deer Creek. It is difficult to tell whether the timing shift of over a month earlier in the water year, with less variability in the high flow pulse timing, is caused by Scotts Flat reservoir and NID water management. It is probable that drawdown releases in the PostSF period by Lake Wildwood reservoir during October has influenced the shift to the timing of high flow pulses, with high flow pulses occurring earlier in the water year in the PostSF period. The slight decrease in the high pulse rise rate in the PostSF period could potentially be attributed to dams attenuating stream flows, with increased surface storage in the watershed leading to a less flashy hydrologic regime. Overall, further investigation is needed to determine the extent of changes to the high pulse regime as a result of the Scotts Flat reservoir upgrade.

4b. Small Floods

During floods, fish and other mobile aquatic organisms are able to access increased habitat, including floodplains, flooded wetlands, secondary channels, backwaters, sloughs, and shallow flooded areas (TNC 2009). These often-inaccessible areas provide substantial food resources, with shallow flooded areas often being warmer than the main channel and full of nutrients and insects to fuel rapid aquatic organism growth (TNC 2009). For this analysis small floods include river rises that overtop the bankfull channel, with an approximate return interval of two years, but do not include the largest, most extreme and infrequent flood events. As with the high flow pulse analysis, mean daily flow data are used in this analysis, and therefore the analysis does not represent peak small flood flows in the watershed. The IHA Tutorial lists the following influences that small and large floods can have on aquatic ecosystems (TNC 2009):

· Provide migration and spawning cues for fish
· Trigger new phase in life cycle (i.e. insects)
· Enable fish to spawn in floodplain, provide nursery area for juvenile fish
· Provide new feeding opportunities for fish, waterfowl
· Recharge floodplain water table
· Maintain diversity in floodplain forest types through prolonged inundation (i.e. different plant species have different tolerances)
· Control distribution and abundance of plants on floodplain
· Deposit nutrients on floodplain
· Maintain balance of species in aquatic and riparian communities
· Create sites for recruitment of colonizing plants

· Shape physical habitats of floodplain
· Deposit gravel and cobbles in spawning areas
· Flush organic materials (food) and woody debris (habitat structures) into channel
· Purge invasive, introduced species from aquatic and riparian communities
· Disburse seeds and fruits of riparian plants
· Drive lateral movement of river channel, forming new habitats (secondary channels, oxbow lakes)
· Provide plant seedlings with prolonged access to soil moisture

The results of the small floods analysis (**Table 1.14**) indicate that the hydrologic regime has potentially been altered from the PreSF to PostSF period, through changes to the small flood peak, timing, and rise and fall rates. Each of these plots is somewhat difficult to draw strong conclusions from though, as there are not many data points, some plots are skewed (frequency plot), and some of the data do not make sense (duration plot). The duration and frequency analysis results are questionable because of the extended duration of small flood events calculated in the analysis, and because the years in which small floods do not occur skew the frequency analysis. **Table 1.14** summarizes alterations to the small floods regime, as indicated by the EFC analysis results.

Parameter	PostSF Median	PostSF Interquartile Range
Peak	Median increase (~750 cfs).	Similar interquartile range, shifted up on plot with median.
Duration	Unable to interpret.	Unable to interpret.
Frequency	Unable to interpret, data skewed by zero years.	Unable to interpret, data skewed by zero years.
Rise Rate	Median decrease (~100 cfs)	Smaller interquartile range, shifted down on plot with median.
Fall Rate	Fall rate median decrease (~80 cfs)	Significantly smaller interquartile range, shifted up on plot with median.
Timing	Median shifts earlier in water year by 15 days.	Larger interquartile range, shifted earlier in water year.

Table 1.14: Summary of the IHA EFC Small Flood analysis, with the hydrologic parameters, changes to the PostSF median, and changes to the PostSF interquartile range.

Table 1.14 summarizes changes from the PreSF to PostSF period, with a brief discussion of how the PostSF median and interquartile range has been altered for each hydrologic parameter. The small floods dataset is quite small, so the results should be interpreted with caution and further analysis of a larger dataset, as it comes available through time, should be conducted. The annual small flood peak flow has been altered, with a median increase of 750 cfs in the PostSF period and a smaller interquartile range shifted up on the plot with the median. This indicates that during the PostSF period the magnitude of small flood peaks is potentially greater and there is less variability in small flood flows. The duration plot is difficult to interpret and therefore no assessment of hydrologic alteration was made using this parameter. The frequency plot is also difficult to interpret, due to the dataset being skewed by zero years. Despite the data being skewed by zero years, it is evident that small floods were more frequent in the PreSF period based upon the number of occurrences in each period of record. Additionally there is only one year in which small floods occurred twice, which is in the PreSF period.

The small flood rise rate has been altered with a median decrease of 100 cfs in the PostSF period and a smaller interquartile range that is shifted down on the plot with the median. This indicates that the rise rate for small floods was greater in the PreSF period and that there is less variability in small flood rise rates in the PostSF period. This could potentially be attributed to reservoirs attenuating small flood flows, leading to a less flashy hydrologic regime and slower rise rates in the PostSF period. The small flood fall rate has been altered, with a median increase of 80 cfs on the plot in the PostSF period and a significantly smaller interquartile range. This indicates that the small flood fall rate was greater in the PreSF period and that there is much less variation in small flood fall rates in the PostSF period. As with the rise rate, this could be attributed to reservoirs adding additional surface water storage capacity in the watershed, with fall rates reduced due to flow contributions stored behind reservoirs. The timing results indicate that small floods have been shifted earlier in the water year by approximately fifteen days, with more variability in the timing of small flood flows in the PostSF period.

4c. Large Floods

During large floods the biological and physical structure of a river and its floodplain are typically reorganized. Large floods can flush away many aquatic and riparian organisms, potentially depleting some populations while creating new competitive advantages for other organisms. Large floods are also important in forming key habitats including floodplains and wetlands. The IHA tutorial lists influences that small and large floods can have on aquatic ecosystems. These are provided above in the Small Floods section.

The results of the IHA EFC large floods analysis indicate that the hydrologic regime has potentially been altered, but definitive conclusions are difficult to make due to the small population of large flood events in both the PreSF and PostSF periods.

Indicators of Hydrologic Alteration – Low Flows

The IHA software was used to conduct a variety of analyses aimed at characterizing alterations to the low flow regime. Annual minima flow analysis was used to analyze changes to the magnitude and duration of annual extreme water conditions. Low pulse analysis was employed to determine the frequency and duration of low pulse events and how these have been altered by reservoir development. The Julian date of the annual minimum flow was calculated to determine the timing of annual extreme water conditions and how water management has shifted the timing. Monthly low flow analysis was used to investigate changes to the magnitude of monthly water conditions. Extreme low flow analysis was used to investigate how most critical low flows have been altered.

The IHA software calculated a variety of parameters that are applicable to the low flow analysis. This included analysis of annual minimum flows, low flow pulses, Julian date of annual minimum flows, monthly low flows, and extreme low flow conditions. Two-period analysis was conducted for each of these parameters, for 1935-1964 and 1965-2009, to investigate alterations to the hydrologic regime through reservoir development and water management. Annual minimum flows, low flow pulses, and the Julian date of annual minimum flows were evaluated using the Range of Variability Approach (RVA), to assess the degree of hydrologic alteration to each parameter. The monthly low flows and extreme low flows are part of the Environmental Flow Components (EFC) analysis and therefore do not allow for the RVA to assessing hydrologic alteration. For these methods hydrologic alteration was assessed through changes to the 25th, 50th (median), and 75th percentiles from the PreSF to PostSF period.

Method 1. Annual Minima Flow Analysis

The IHA software calculates the magnitude and duration of annual extreme water conditions using the 1, 3, 7, 30, and 90-day means. Comparing these hydrologic parameters for two time periods allows for analysis of how the Scotts Flat reservoir upgrade has altered the magnitude and duration of the annual minima *d*-day flows. The magnitude and duration of annual minimum flows can have the following ecosystem influences:

· Balance of competitive, ruderal, and stress- tolerant organisms
· Structuring of aquatic ecosystems by abiotic vs. biotic factors
· Soil moisture stress in plants
· Dehydration in animals
· Anaerobic stress in plants
· Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments
· Distribution of plant communities in lakes, ponds, floodplains

Results of the IHA annual *d*-day minima analysis indicate that the magnitude and duration of annual minimum flows have been altered from PreSF to PostSF. For each of the 1, 3, 7, 30, and 90 day averages, the PostSF *d*-day minimum median flow is slightly greater than in the PreSF period. **Table 1.15** summarizes the degree of Hydrologic Alteration (HA), with a plot of the 1-day annual minimum provided in **Figure 1.26**. An in depth description of the RVA analysis and methods for calculating the degree of Hydrologic Alteration can be found at the beginning of the IHA section, as well as in TNC (2009).

Annual Minima	Low HA	Middle HA	High HA
1 day	-0.5704	0.8162	-0.4272
3 day	-0.5704	0.7576	-0.3556
7 day	-0.4988	0.5818	-0.2123
30 day	-0.3556	0.2889	0.002469
90 day	-0.1407	0.05455	0.07407

Table 1.15: Annual d-day minima, Hydrologic Alterations (HA) summary.

Table 1.15 indicates that there have been changes to the annual flow minima, for each of the *d*-days analyzed. For each *d*-day analysis in the PostSF period there is a decrease in low RVA category flows, indicating that in the PostSF period there is a lower probability of experiencing flows in the PreSF low range. For each *d*-day analysis in the PostSF period there is an increase in the Middle RVA category, indicating that in the PostSF period there is a greater chance of experiencing flows in the PreSF middle range than historically was observed. For the 1 (**Figure 1.26**), 3, and 7 day average annual flow minima in the PostSF period there is a decrease in the High RVA category, indicating that in the PostSF period there is less chance of experiencing flows in the High RVA category than historically was observed. For the 30 and 90-day analysis hydrologic alteration is not significant in the High RVA category.

The changes observed to the hydrologic regime in the PostSF period have important implications for aquatic and riparian organisms. Annual *d*-day minimum flows in the PostSF period tend to fall within the PreSF RVA boundaries, with fewer points falling above and below the high and low RVA. The decrease in low and high RVA category *d*-day flows combined with the increase in middle RVA category flows in the PostSF period points to less variability in each annual *d*-day minimum. In addition to experiencing less variability, annual minimum flows have a tendency to be higher in the PostSF period, which confirms the results of the previous two-period low flow frequency analysis. This slight increase could be attributed to discharges from the Lake Wildwood reservoir WWTP in the PostSF period, contributing constant flow to lower Deer Creek and influencing the low flow record. In addition, it is possible that NID system losses are greater in the PostSF period than the PreSF period. System losses could be attributed to leaking infrastructure (canals, diversion points) or over-estimating system demand and subsequent water deliveries. A third potential source of water could be return flows from agricultural and ranching properties that are downstream of NID canals and diversion points, as NID has no ability to reclaim the water.

In general the alterations to the annual flow minima are minor, with the median annual flow in the PostSF period less than 0.5 cfs greater than in the PreSF period for each *d*-day analysis. This is a much different result from the annual flow maximum analysis, where the peak flow regime has been drastically altered. Although the alterations to the annual flow minimum have been minor, this analysis suggests that the 5.0 cfs or natural in-stream flow water rights requirement is not being achieved at the USGS gauge, with only the 90-d minimum resulting in flows near the 5.0 cfs level. This results in low flow conditions, often concentrated with wastewater effluent, leading to unnatural high temperatures, excessive algae blooms, and pH swings, all of which impact aquatic organisms that inhabit lower Deer Creek including macroinvertebrates and threatened and endangered fish species such as Chinook salmon and steelhead trout. Efforts should be undertaken to work with NID, Lake Wildwood Association, and the State Division of Water Rights to ensure that the 5.0 cfs or natural flow allotment is achieved downstream of Lake Wildwood reservoir.

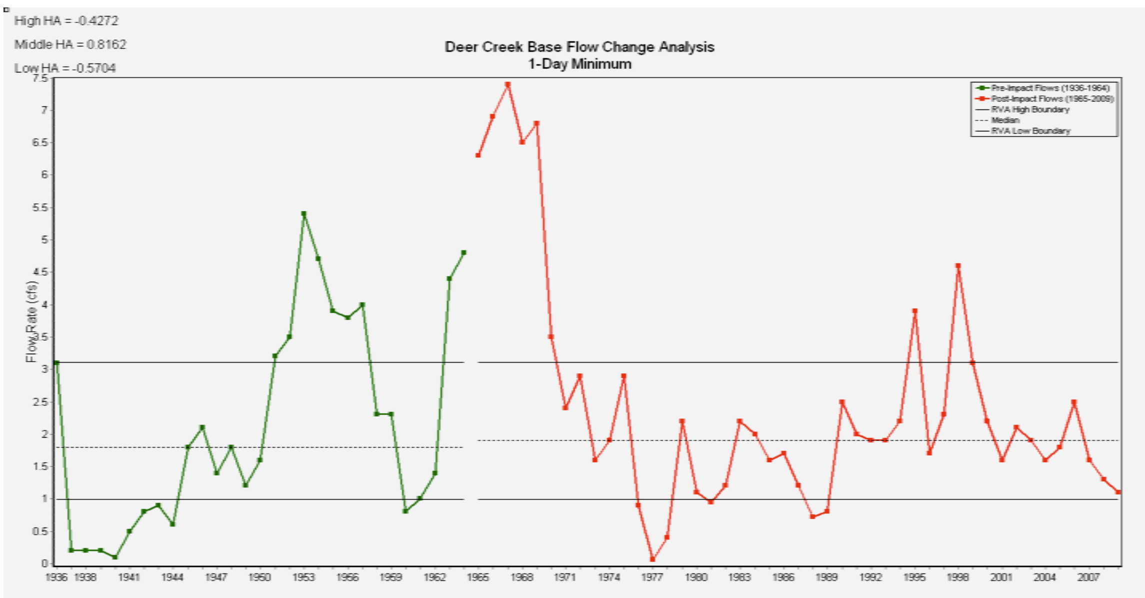


Figure 1.26: IHA software minimum flow analysis, annual 1-day minima plot.

Method 2. Low Pulses: Frequency and Duration

The IHA software calculates the frequency and duration of low pulses during each water year. Low pulses are classified as flows below the 25th percentile of flows for the entire period of record, with the frequency being the number (count) of low flow pulses in each water year, and low flow pulse duration being the median length of low flow pulses in days. The low pulse analysis allows investigation into the changes in base flow and whether this has impacted the frequency and duration of low flow pulses in Deer Creek. The duration and frequency can influence many factors that are important to aquatic ecosystem function and health, including (TNC 2009):

· Frequency and magnitude of soil moisture stress for plants
· Frequency and duration of anaerobic stress for plants
· Soil mineral availability
· Access for water birds to feeding, resting, reproduction sites

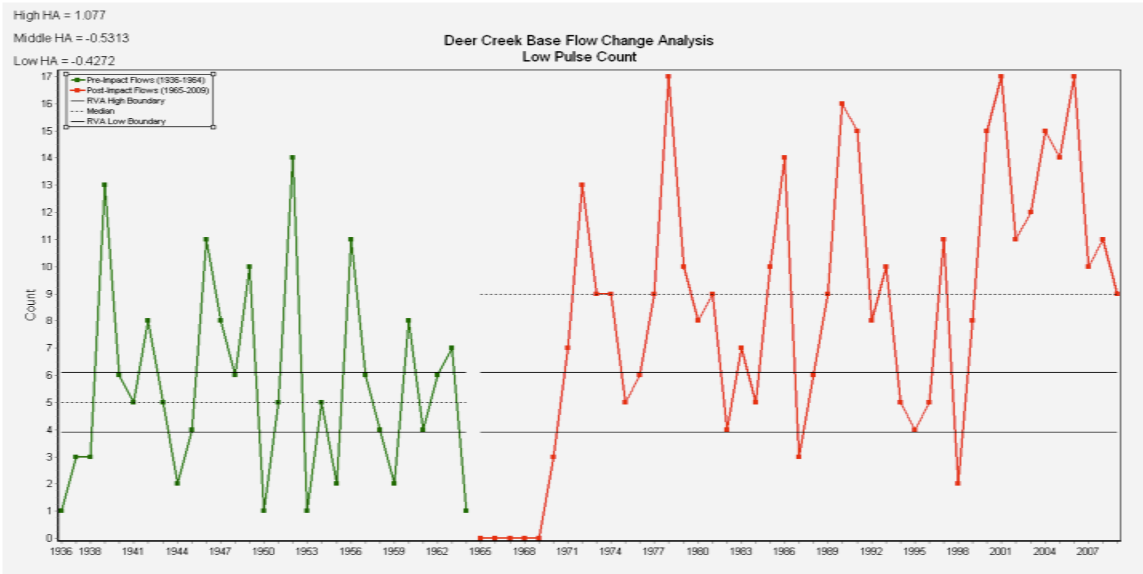


Figure 1.27: IHA software low flow pulse analysis, low pulse count (frequency) plot.

The results of the low pulse analysis (**Figure 1.27**) indicate that the change in base flow associated with the upgrade of Scotts Flat reservoir has altered the frequency and duration of low flow pulses in Deer Creek downstream of Lake Wildwood reservoir. There is considerable variability in both low pulse count datasets, likely influenced by changes in weather and climate. The frequency of low pulses increases from the PreSF to PostSF period, with the PostSF median falling above and outside the PreSF RVA boundaries. There were five years of no low flow pulses after upgrading Scotts Flat reservoir, from 1965 to 1969, with low flow pulses increasing in frequency after the completion of Lake Wildwood reservoir in 1970. The median in the PreSF period is five with RVA boundaries at four and six, with the median in the PostSF period at nine. There is an increase in the High Hydrologic Alteration category (+1.077) and decreases in the Middle and Low categories. This indicates that the frequency with which low pulses have occurred in Deer Creek has increased since the upgrade of Scotts Flat, with low pulses being more frequent after 1964 and particularly 1970. This has important implications for aquatic organisms as an increase in low flow pulses could lead to a decrease in the frequency that aquatic habitat is available, reduce surface water availability for aquatic and terrestrial organisms, and cause increased stress on aquatic organisms through increased frequency of low flows that concentrate pollutants and increase water temperature. Further analysis should be conducted, particularly using 15-minute stream flow data, to investigate low flow pulses as the mean daily flow smoothes out and eliminates many of the low flow pulses that occur over short periods of time.

The low pulse duration analysis (**Figure 1.28**) also indicates differences between the PreSF and PostSF periods. The PreSF and PostSF medians are the same, with the PostSF median falling within the PreSF RVA boundaries. In the PreSF period there were many years with low flow pulses of extended duration (>20 days) and no years without a low flow pulse, which was not the case in the PostSF period. In the PostSF period the longest duration low flow pulse was seventeen days and there were five years with no low flow pulses, which is further evidenced by the decrease in the High Hydrologic Alteration category (-.7852) and slight increase in the Middle and Low categories. The duration of low flow pulses in the PostSF period was highly clustered around the median, generally within the RVA boundaries, or just above the high or below the low RVA boundaries. The decrease in extended duration low flow pulses can have numerous implications for aquatic organisms and ecosystems as there is a reduced duration of stressful aquatic conditions. However, this could be partially mitigated by the increased frequency of low flow pulses in the PostSF period.

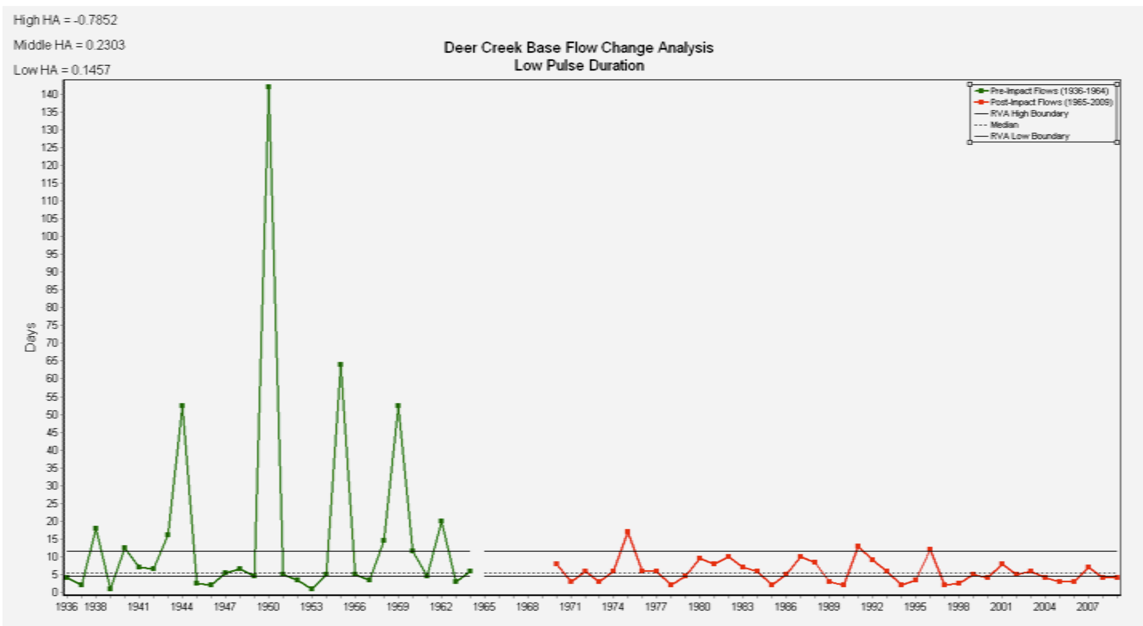


Figure 1.28: IHA software low flow pulse analysis, low pulse duration plot.

<u>Method 3. Julian Date of Annual Minimum Flow</u>

The IHA software analyzes the mean daily flow record to determine the Julian day of the annual minimum flow. The Julian day is used because this method simplifies calculating statistics for timing variables. Julian dates represent calendar dates by integer values, with 1 corresponding to January 1 and 366 to December 31. There are always 366 Julian days in a year, regardless of whether it is a leap year or not, with February 29 corresponding to Julian day 60 in leap years. This ensures that each calendar date is represented by the same Julian date in each year. The timing of annual extreme water conditions can influence many factors important to aquatic organisms. The IHA tutorial lists the following ecosystem influences that can be influenced by the timing of annual extreme water conditions, with results of the date of minimum flow analysis provided in **Figure 1.29**:

· Compatibility with life cycles of organisms
· Predictability/avoidability of stress for organisms
· Access to special habitats during reproduction or to avoid predation
· Evolution of life history strategies, behavioral mechanisms

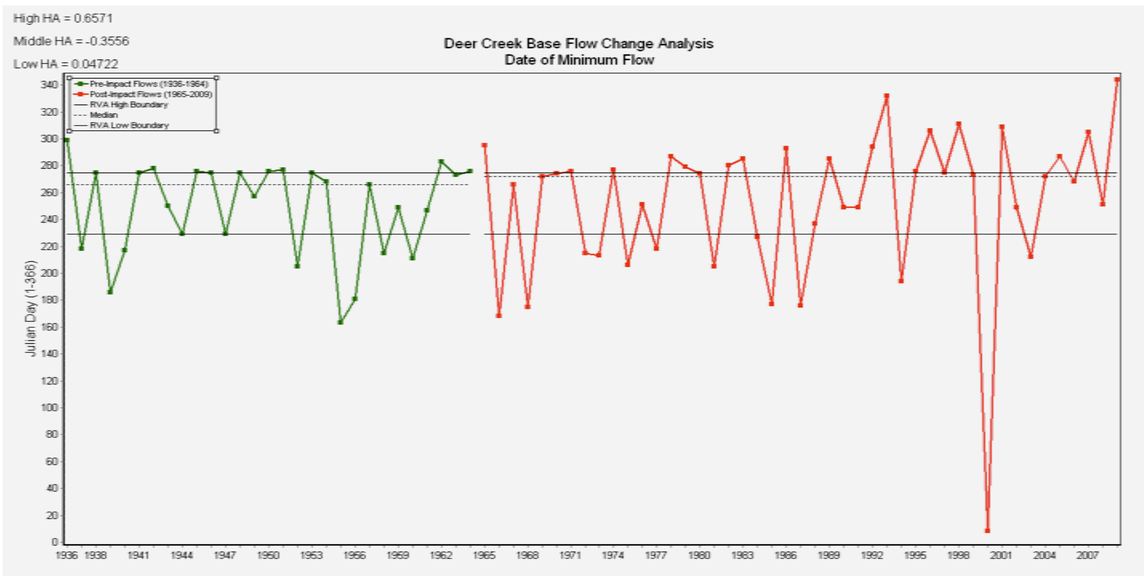


Figure 1.29: IHA software Julian date analysis, plot of the date of annual minimum flow.

The results of the Julian date analysis in **Figure 1.29** indicate that the timing of the annual minimum flow has been altered since the upgrade of Scotts Flat Reservoir and subsequent base flow change. In the PreSF period the Julian date of annual minimum flow falls between day 160-300 (June 8-October 26), with a median of 265 (September 21) and low and high RVA boundaries of 230 (August 17) and 275 (October 1) respectively. In the PostSF period the median (day 273, September 29) is shifted later in the year by eight days. There is greater variability in the PostSF period with an increase in the High RVA category (0.6571) compared to historical observations. In the PostSF period there is a slight increase in the low RVA category (0.04722), with a decrease in the middle RVA category (-0.3556). In the PostSF period there is one instance (water year 2000) in which the annual minimum flow occurs prior to Julian date 160 (day 5), which does not occur elsewhere in the entire period of record.

The results indicate that there is a greater chance of the annual minimum flow occurring later in the calendar year and on a date that is outside of the PreSF range of variability. The median shift in the timing of the annual flow minimum to eight days later in the year is potentially significant, although both the PreSF and PostSF period annual minimum flows occur near the beginning of the water year (October 1, day 275), which is to be expected for the Deer Creek watershed. It is possible that the occurrence of the low flow minimum later in the year in the PostSF period is related to the end of the irrigation season, with NID serving more users in the PostSF period and thus delivering more water using Deer Creek. In addition irrigation flows are often not reduced until on or after October 15, which could shift the annual minimum flow later in the water year. When the irrigation flows are reduced system losses from delivery and runoff from properties decrease, potentially leading to less water in the creek after October 15.

Method 4. Environmental Flow Components – Monthly Low Flows Analysis

The IHA software EFC analysis determines the magnitude of monthly water conditions by calculating the median low flow value for each month during the calendar year for each period of record. The user determines how low flows are classified with the default for low flows beginning at the 25th percentile of the median daily flow value for the period of record. After calibrating the software it was determined that flows less than the 25th percentile should be classified as low flows, as is the IHA software default. The magnitude of monthly water conditions can have the following influences on the ecosystem (TNC 2009):

- Provide adequate habitat for aquatic organisms
- Maintain suitable water temperatures, dissolved oxygen, and water chemistry
- Maintain water table levels in floodplain, soil moisture for plants
- Provide drinking water for terrestrial animals
- Keep fish and amphibian eggs suspended
- Enable fish to move to feeding and spawning areas
- Support hyporheic organisms (living in saturated sediments)

Month	PostSF Median	PostSF Interquartile Range
October	Lower median low flow.	Smaller interquartile range, shifted down on plot.
November	Lower median, shifted below 25th percentile.	Smaller interquartile range, PostSF 75th percentile at PreSF median.
December	Lower median-near PreSF 25th percentile.	Similar interquartile range, shifted down on plot.
January	Lower median.	Smaller interquartile range, shifted down on plot.
February	Lower median.	Larger interquartile range.
March	Lower median – near PreSF 25th percentile.	Smaller interquartile range, shifted down on plot.
April	Lower median – near PreSF 25th percentile.	Similar interquartile range, shifted down on plot. PostSF 75th percentile near PreSF median.
May	Lower median – near PreSF 25th percentile.	Similar interquartile range size, shifted down on plot.
June	Lower median – near the 25th percentile.	Smaller interquartile range, PostSF 75th percentile below PreSF median.
July	Slightly lower median.	Smaller interquartile range.
August	Slightly lower median.	Similar interquartile range, slight shift up on plot.
September	Slightly higher median.	Similar interquartile range, shifted up on plot.

Table 1.16: Summary of the IHA software EFC monthly low flows analysis, using the non-parametric method.

Table 1.16 summarizes the results of the IHA EFC monthly low flow analysis, with an example plot provided in **Figure 1.30**. The results of the monthly low flow analysis indicate that the Scotts Flat reservoir upgrade and base flow change have potentially resulted in alterations to the monthly low flow regime. In the PostSF period, every month except for September results in a lower median monthly low flow than the PreSF period. This indicates that the hydrologic regime has been altered and lower monthly median flows are the result, which means less water available in the creek near the watershed outlet during peak flow months in the winter and spring as well as during summer low flow months. The median monthly flow decreases are larger for the wet season months than during the dry season, which can be attributed to Scotts Flat reservoir capturing large volumes of stream flow during winter and spring months, and water management of flows during irrigation season months. In general the PostSF period interquartile ranges tend to be similar or smaller, except for February, than the PreSF period interquartile ranges. The trend in the smaller interquartile ranges suggests less variability in monthly low flows in the PostSF period when compared to PreSF, which is often the case in a managed watershed.

The EFC monthly low flow analysis indicated that for the majority of months, low flows were greater in the PreSF period compared to the PostSF period, which highlights the impacts of reservoirs and water management on the flow regime and the need for augmenting the existing flow regime. The reduction in monthly low flows in Deer Creek results in reduced habitat availability for aquatic organisms, water availability for terrestrial animals, water table levels in the floodplain, and soil moisture for plants. In addition, particularly during the natural low-flow months of summer and early fall, a decrease in the magnitude of monthly low flows could result in increased water temperatures, increased concentrations of wastewater effluent and decreased water quality, and stranding of fish or amphibian eggs. These attributes are important to consider because there are threatened and endangered species of fish that inhabit lower Deer Creek, with flow alterations potentially decreasing the overall habitat suitability for these organisms.

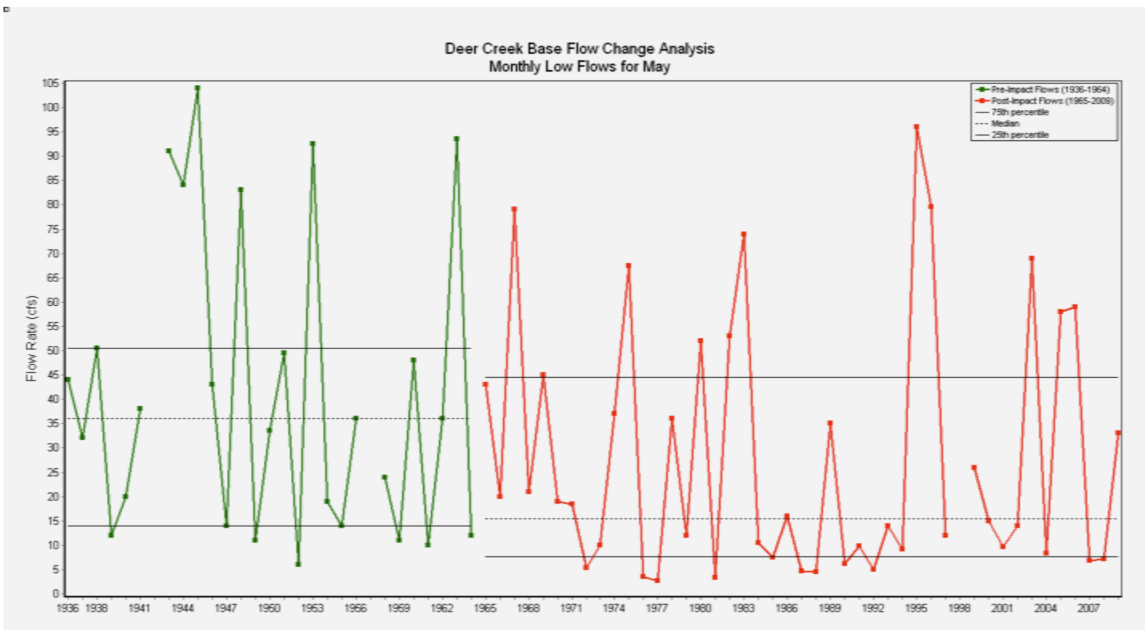


Figure 1.30: Summary plot of the IHA software EFC monthly low flows analysis, using the non-parametric method, and plotting alterations to low flows in the month of May.

<u>Method 5: Environmental Flow Components – Extreme Low Flows Analysis</u>

During droughts or certain times of the year (summer, early fall) flows drop to very low levels, which can be stressful for many aquatic organisms while providing necessary conditions for others (Richter et al. 1996; TNC 2009). Water chemistry, water temperature, and dissolved oxygen levels can become highly stressful to many organisms during extreme low flow conditions, often to the point that these conditions cause considerable mortality. Extreme low flows can also concentrate aquatic prey for some species and may be necessary to dry out low-lying floodplain areas, enabling certain species of plants to regenerate (TNC 2009). The IHA Tutorial lists the following influences that extreme low flows can have on aquatic ecosystems (TNC 2009):

· Enable recruitment of certain floodplain plant species

· Purge invasive, introduced species from aquatic and riparian communities
· Concentrate prey into limited areas to benefit predators

The IHA software EFC analysis classifies flows into multiple categories including extreme low flows, low flows, high flow pulses, small floods, and large floods. The user determines how each is classified with the default for extreme low flows set to the 10th percentile of daily flows for the entire period. After calibrating the software for Deer Creek the 5th percentile was determined to better represent extreme low flow conditions, with 1.4 cfs as the threshold for extreme low flows. This percentile is commonly used to represent low flow conditions (Hauer and Lamberti 1996; Richter et al. 1996; Pyrce 2004; TNC 2009). The analysis computes the median of extreme low flows for each water year. Using this setting 13 extreme low flows occurred in the PreSF period and 11 in the PostSF period. Four outputs are available for extreme low flow analysis including peak, duration, frequency, and timing of extreme low flows.

Results indicate that the Scotts Flat reservoir upgrade and subsequent base flow change in water year 1965 had a minimal impact on extreme low flows. The median for peak extreme low flows has not changed significantly from the PreSF to PostSF period, although the interquartile range is smaller in the PostSF period and shifted up on the plot, indicating less variability within the extreme low flow classification and higher extreme low flows. The lack of variability could be due to increased water management in the Deer Creek watershed, with more surface storage and water deliveries reducing the magnitude of extreme low flow fluctuations, and water deliveries and system losses leading to increased stream flows during conditions that would naturally promote extreme low flows. The median duration of extreme low flows decreased in the PostSF period, but the variability increased with more 1-day extreme low flows as well as extended duration extreme low flows ($d \geq 7$ days). This is evidenced by the increase in the interquartile range, with the 75th percentile up from 4 to 11 cfs in the PostSF period. The frequency results should be interpreted with caution, as the majority of years do not have extreme low flows. This largely skews the frequency data results. The results indicate that in the PostSF period there is less variability in the frequency of annual extreme low flows, as evidenced by the 75th percentile shift down on the graph from 3 to 0.5. This is largely attributed to the years with no extreme low flows, as the frequency plot clearly exhibits similar variability in the PreSF and PostSF periods. The timing of annual extreme low flows has minimally been impacted by the base flow change, with a slight shift in the PostSF median and interquartile range to later in the year, coupled with a larger interquartile range. This matches the annual minimum flow analysis, with similar medians PreSF and PostSF, and a shift in the annual flow minimum to later in the year during the PostSF period annual minimum flow analysis. Overall, the analysis indicates minor impacts to extreme low flows from the PreSF to PostSF period, with the frequency, duration, and timing of extreme low flows altered most in the PostSF period.

Indicators of Hydrologic Alteration – Flow Duration Curves

Method 1. Annual Flow Duration Curves

The IHA software uses daily mean flow data to calculate period of record FDCs for multiple time scales, including annually and monthly. Annual FDCs were generated for two periods, PreSF and PostSF, to investigate the impacts to the hydrologic regime associated with the upgrade of Scotts Flat reservoir. **Figure 1.31** plots the annual FDCs for the PreSF and PostSF periods.

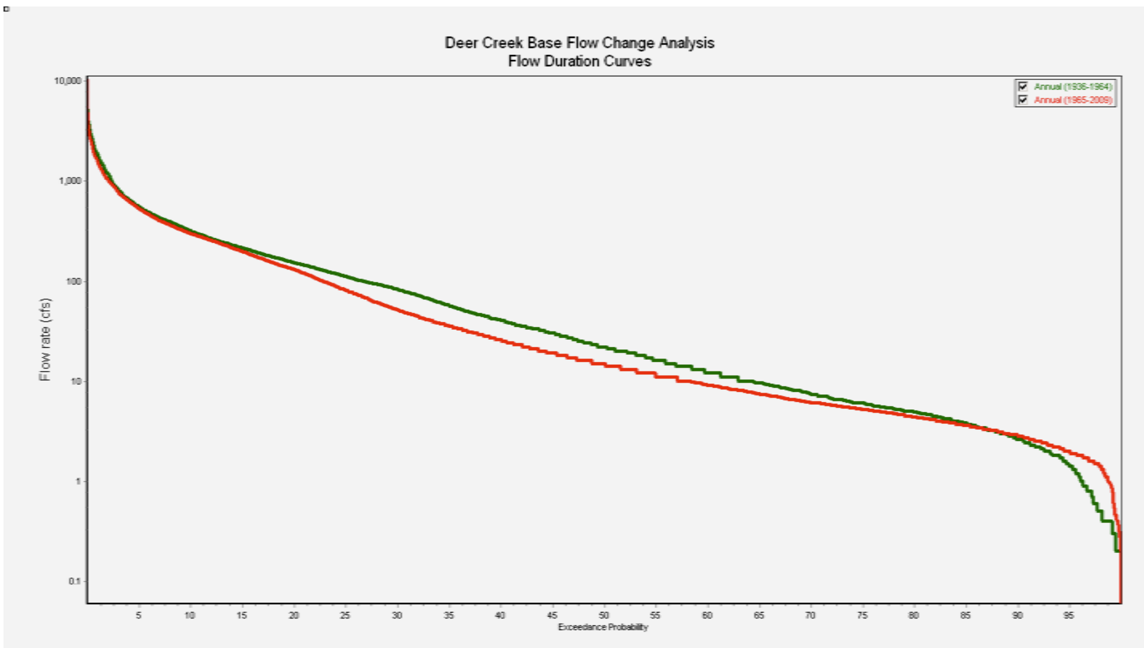


Figure 1.31: IHA software Annual Flow Duration Curves for PreSF and PostSF, with the PreSF period plotted green and the PostSF period red.

The plot in **Figure 1.31** indicates that the annual FDC has changed since water year 1965, coinciding with the upgrade of Scotts Flat reservoir. The PreSF period has a greater probability of lower discharge flows ($q_{.90}$ – $q_{.98}$), with the exception $q_{.99}$ – $q_{.100}$, due to critical water years and the lowest mean daily flow on record occurring PostSF. There is a greater probability of higher base and high pulse discharge flows ($q_{.15}$ – $q_{.90}$) PreSF, with the annual curves coinciding above $q_{.15}$. These results are the same as the results of the previous FDC analysis (**Figure 1.21**), and confirm that the hydrologic regime has been altered from the PreSF to PostSF period. The results suggest a greater probability of high and base flows PreSF above $q_{.75}$, which indicates that there is less water flowing in Deer Creek during the PostSF period than the PreSF period, at the USGS gauge near the watershed outlet. In addition, there is a greater probability of low discharge flows PreSF, with the slight increase in flow (< 1.0 cfs) potentially attributed to the Lake Wildwood reservoir WWTP, NID system losses, and runoff from ranches and farms. The WWTP began discharging into Deer

Creek during the PostSF period, with NID system losses and runoff from farms and ranches increasing as more water is delivered and applied to the landscape.

Method 2. Monthly Flow Duration Curves

The IHA software generates FDCs for each month of the year, using the same algorithm as in the annual FDC analysis. Monthly FDCs are important for determining the magnitude and frequency of monthly flows, with the two period analysis providing an opportunity to investigate alterations to the hydrologic regime. Results of the monthly FDC analysis are provided in **Table 1.17**, with an example monthly FDC plot provided in **Figure 1.32**.

Month	Flow Duration Curve-Low Flows	Flow Duration Curve-Base/High Pulse Flows	Flow Duration Curve-Flood Flows
September	PreSF lower extreme/low flows (0-99 EP).	PreSF lower base/high pulse flows (0-99 EP).	PreSF lower flood flows, monthly peaks (0-99 EP).
October	Similar extreme/low flows (83-99 EP).	Slightly greater PreSF base flows (57-83 EP), similar base/high pulse flows (35-57 EP).	High pulse/flood flows lower in PreSF (1-35 EP), PreSF highest flow on record (0-1 EP, Oct 1962: 11,600 cfs).
November	PreSF lower extreme low flows (96-99 EP); greater PreSF low flows (10-96 EP).	PreSF greater base/high pulse/flood flows (10-96 EP).	PreSF slightly lower large flood flows (2-10 EP), similar monthly peaks (0-2 EP).
December	PreSF lowest point overall, greater extreme/low flows (23-99 EP).	PreSF greater base/high pulse flows (23-99 EP).	PreSF/PostSF similar high pulse/small flood flows (10-23 EP), PreSF greater large flood flows (2-10 EP), PreSF/PostSF similar monthly peaks (0-2 EP).
January	PreSF greater extreme/low flows (35-99 EP).	PreSF greater base/high pulse flows (35-99 EP).	PreSF/PostSF similar small/large flood flows (7-35 EP), PreSF slightly lower (4-7 EP) flows, PreSF/PostSF similar monthly peaks (0-4 EP).
February	PreSF greater extreme/low flows (1-99 EP).	PreSF greater base/high pulse flows (1-99 EP).	PreSF greater high pulse/small flood/large flood flows (1-99 EP), PostSF greatest monthly peak.
March	PreSF greater extreme/low flows (41-99 EP).	PreSF greater base/high pulse flows (41-99 EP).	PreSF/PostSF similar small/large flood flows (5-41 EP), PreSF slightly greater monthly peaks (0-5 EP).
April	PreSF greater extreme/low flows (7-99 EP).	PreSF greater base/high pulse flows (7-99 EP).	PreSF greater small/large flood flows (7-99 EP), similar monthly peaks (0-7 EP).
May	PreSF greater extreme/low flows (12-99 EP).	PreSF greater base/high pulse flows (12-99 EP).	PreSF greater small flood flows (12-99 EP), PreSF slightly lower large flood flows (2-12 EP), PreSF/PostSF similar monthly peaks (0-2 EP).
June	PreSF slightly greater extreme low flows (97-99 EP), PreSF slightly lower low flows (95-97 EP), PreSF greater low flows (2-95 EP).	PreSF greater base/high pulse flows (2-95 EP).	PreSF greater small/large flood flows (2-95 EP), PreSF/PostSF similar monthly peaks (0-2 EP).
July	PreSF lower extreme/low flows (80-99 EP).	PreSF slightly lower base/high pulse flows (47-80 EP), PreSF/PostSF similar high pulse flows (0-47 EP).	PreSF/PostSF similar small flood/large flood/monthly peaks (0-47 EP).
August	PreSF lower extreme/low flows (40-99 EP).	PreSF lower base/high pulse flows (40-99 EP), PreSF/PostSF similar high pulse flows (27-40 EP).	PreSF lower flood flows, monthly peaks (0-27 EP).

Table 1.17: Summary of IHA monthly flow duration curve analysis, comparing extreme and low flows, base and high pulse flows, and small and large flood flows.

The results of the IHA monthly FDC analysis indicate that there have been significant alterations to the majority of the monthly FDCs. Starting with the beginning of the water year in October, there is not much alteration to the FDC up to the 35th exceedance probability ($EP_{.35}$). From $EP_{.35}$ (~10 cfs) to $EP_{.01}$ (~500 cfs) the PostSF period exhibits greater flows than the PreSF period, with the highest flows above $EP_{.01}$ greater in the PreSF period. Flows are higher in the PostSF period from $EP_{.35}$ – $EP_{.01}$ due to the Lake Wildwood reservoir drawdown release in the PostSF period, which has altered the October flow duration curve by increasing the frequency, magnitude, and duration of stream flows in October. Lake Wildwood reservoir drawdown releases have ranged from 100 – 450 cfs in the past, with durations varying from less than 3 days to over one week, occurring with a frequency of every one in four years. The highest flow on record occurs in the PreSF period, in October 1962, which results in greater flows for the PreSF period. The most significant alteration to the October FDC is the increased frequency of high pulse and small flood flows as a result of the Lake Wildwood reservoir drawdown release. Opportunities to re-create a natural storm hydrograph, modeling flows after the magnitude, duration, frequency, and rise and fall rates of a natural October storm flow during the Lake Wildwood reservoir drawdown release should be undertaken during the 2011 drawdown. For a more detailed analysis and discussion of Lake Wildwood drawdown releases, please refer to the section at the end of the Hydrology chapter that focuses on the Lake Wildwood Drawdown Release.

For the November monthly FDC, flows were generally greater in the PreSF period than the PostSF period, except for the tail ends of the curve. The lowest stream flows occur in the PreSF period, indicating low and extreme low flows were more common during November in the PreSF period. From $EP_{.96}$ – $EP_{.10}$ the PreSF period experiences a greater probability of higher stream flows than the PostSF period, possibly because Scotts Flat reservoir captures runoff from early season stream flows, and Lake Wildwood reservoir re-fills the reservoir that has been drawn down approximately 10ft. Both of these would lead to a reduction in low flow, base, and high pulse stream flows downstream of the reservoirs at the gauging station. Above $EP_{.10}$ PreSF and PostSF flows are generally similar, with slightly lower flows observed in the PreSF period from $EP_{.10}$ – $EP_{.02}$, and overlapping curves through the peak end of the FDC. This indicates that minimal alterations have occurred to the peak flows that occur in November.

The December monthly FDC indicates that flows were greater in the PreSF period from $EP_{.99}$ – $EP_{.23}$, which suggests that December low, base, and high flow pulses were greater in the PreSF period. Above $EP_{.23}$ the PreSF and PostSF FDCs are relatively similar, with a slightly greater PreSF FDC from $EP_{.23}$ – $EP_{.02}$, and a greater peak flow in the PostSF period. The higher peak flow in the PostSF period of record is a result of the highest stream flow in the period of record occurring December 31, 2005. In general, small and large flood flows are quite similar in December, but alterations have occurred to low, base, and high pulse flows with a reduction in stream flows in the PostSF period. This can be attributed to Scotts

Flat reservoir capturing early wet season runoff for storage and potentially indicates the need for augmenting low and base flows during this time of year.

As with the December monthly FDC, the January monthly FDC indicates that low and base flows were greater in the PreSF period, with the PreSF curve plotting greater flows from $EP_{.99}$ – $EP_{.35}$. Above $EP_{.35}$ flows are similar in the PreSF and PostSF periods, indicating minimal alterations to the January high flow pulses, small floods, and large floods. The most significant alteration evident in the January FDC is that flows with exceedance probabilities between $EP_{.99}$ – $EP_{.35}$ were greater in the PreSF period. This indicates that there is less water moving through the Deer Creek system in the PostSF period, which could be attributed to Scotts Flat reservoir capturing runoff for storage. As with the December analysis, this indicates the need for augmenting flows during this time of year, to increase low and base flows to better represent natural flow conditions.

The February monthly FDCs indicate that there was more water moving through Deer Creek in the PreSF period. The PreSF FDC remains above the PostSF FDC, except above $EP_{.01}$ as a result of the peak February flow occurring in the PostSF period of record. This indicates that there have been significant alterations to the flow regime during this month, with less water flowing through the watershed and available for aquatic and riparian organisms. As with previous months, this could be attributed to Scotts Flat reservoir storing runoff until the reservoir spills, reducing the amount of water moving through the watershed outlet. The severity of the alteration to the February monthly FDC is further evidence that winter flows have been altered, and combined with the December and January analysis points to the need for augmented flows in the watershed.

The March monthly FDC shows that in the PreSF period there was a greater probability of higher stream flows from $EP_{.99}$ – $EP_{.41}$ when compared to the PostSF period. As with the previous three months this suggests there is less water in the creek during March in the PostSF period, with a reduction in monthly low and base flow magnitudes. From $EP_{.41}$ – $EP_{.05}$ the PreSF and PostSF FDCs are similar, with overlapping curves, indicating that there has been minimal alteration to the March high flow pulses and small floods. Above $EP_{.05}$ the PreSF period exhibits greater magnitude large flood and peak flows than the PostSF period, but these differences are minor. This indicates that there has been minimal alteration to the high flow regime, with the primary alterations to the March FDC occurring from $EP_{.99}$ – $EP_{.41}$. The analysis again points to the need for augmentation of low, base, and high flow pulses during winter and early spring months.

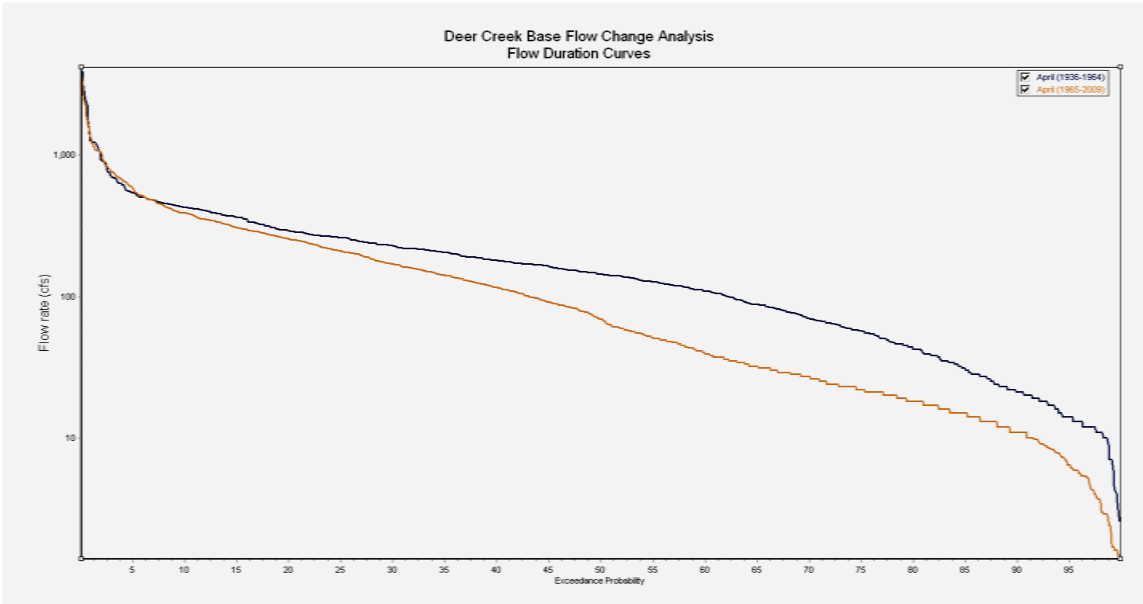


Figure 1.32*:* IHA software monthly flow duration curves for the month of April, with the PreSF period plotted dark blue and the PostSF period orange.

The April monthly FDCs (**Figure 1.32**) indicate that there was a greater probability of stream flows being higher in the PreSF period than the PostSF for the majority of exceedance probabilities during the month of April. PreSF stream flows were greater from $EP_{.99}$ – $EP_{.07}$, indicating that the magnitude of flow associated with these exceedance probabilities has been reduced in the PostSF period. This reduction could be associated with water management, with April 15th the start of the primary irrigation season for NID, but those relationships are difficult to establish using this analysis. Above $EP_{.07}$ the PreSF and PostSF FDCs are similar, overlapping through the peak of the curve. This indicates that the probability of the highest stream flows has not been altered for the month of April, with large flood flows occurring with a similar magnitude, frequency, and duration. Again, this analysis indicates the need for restoration of the flow regime.

The May monthly FDCs are similar to the April plots in **Figure 1.32**, with a greater probability of higher stream flows in the PreSF period than the PostSF period for the majority of exceedance probabilities. PreSF stream flows were greater from $EP_{.99}$ – $EP_{.12}$, indicating the magnitude of stream flows associated with these exceedance probabilities has decreased from the PreSF to PostSF period. The timing of the reduction in May suggests that NID water management could be responsible for the altered FDC in the PostSF period, as NID captures late spring rainfall and early summer runoff that would typically flow through the watershed and diverts it for urban and agricultural water users, leaving less water flowing through the watershed outlet than would have historically occurred. Above $EP_{.12}$ the PreSF and PostSF FDCs are very similar, with the PostSF curve plotting slightly greater magnitudes for $EP_{.12}$ – $EP_{.02}$, and overlapping curves from $EP_{.02}$ to the peak of the curve, indicating there have been minor alterations to the high flow end of the May FDC.

The June monthly FDCs are similar to those for April and May, with a greater probability of higher stream flows in the PreSF period than the PostSF period, except from $EP_{.99}$ – $EP_{.97}$. Above $EP_{.97}$ the PreSF FDC remains above the PostSF FDC until $EP_{.02}$, upon which the two FDCs are similar through the peak of the curve. The magnitude shift of the FDC down on the plot indicates there is less water moving through the Deer Creek watershed outlet during the month of June in the PostSF period, which can probably be attributed to water management reducing the volume of stream flows at the watershed outlet because these are considered system losses. In the Deer Creek watershed the hydrograph during the months of May and June would be influenced by snowmelt, to keep stream flows high through early summer. Scotts Flat reservoir now allows for management of the snowmelt flows, which ultimately leads to a reduction in stream flows at the watershed outlet, as stream flows are diverted out of Deer Creek into canals, diversions, and other reservoirs.

The July monthly FDCs show the least alteration out of all of the monthly FDCs, with a greater probability of higher stream flows in the PostSF period than the PreSF period from $EP_{.99}$ – $EP_{.80}$, but this difference is minor, on the order of 1.0 cfs or less. Above $EP_{.80}$ the FDCs coincide through the top of the plot, indicating there has been minimal alteration to the July FDC from the PreSF to PostSF period.

The August monthly FDCs indicate that there is a greater probability of higher stream flows in the PostSF period than the PreSF period, for every exceedance probability. This is the first month in the water year where this is the case. Although PreSF and PostSF period FDCs are close from $EP_{.40}$ – $EP_{.27}$, there is still a greater probability of higher flows in the PostSF period for this exceedance probability range. As with the July monthly FDCs, the order of magnitude of alteration is approximately 1.0 cfs or less across the entire range of exceedance probabilities, indicating that while the alterations persist throughout the FDC, they constitute minor flow volumes.

The September monthly FDCs, like the August monthly FDCs, indicate that there is a greater probability of higher stream flows in the PostSF period than the PreSF period, for every exceedance probability. This is the second straight month where this is the case, with both months located near the low flow end of the water year. The order of magnitude of alteration is approximately between 1.0 and 5.0 cfs and varies with exceedance probability. This indicates there is a greater probability of more water in the creek at this time of year near the watershed outlet in the PostSF period, which could be a result of the Lake Wildwood reservoir WWTP effluent discharges, NID system losses, and runoff associated with agricultural and grazing properties. The increase in water quantity at this time of year does not necessarily equate to better habitat conditions in lower Deer Creek, due to the altered constitution of the water.

During the wet season (November – June) in general there is a greater probability of less water flowing through the watershed outlet in the PostSF period compared to the PreSF period, indicating that reservoir development and water management have altered the magnitude, duration, timing, and frequency of stream flows in the watershed. In dry months (July – September) alterations are less severe, with a probability of a slightly greater amount of water flowing through the watershed outlet in the PostSF period compared to the PreSF period. This could indicate that reservoir development and water management, including increased water deliveries and system losses in the watershed, runoff from working landscapes, and effluent discharges from the Lake Wildwood reservoir WWTP, have slightly increased summer flows at the watershed outlet in August and September. The analysis points to the need for augmenting flows from November through June, although this may be difficult to achieve because this is when NID stores water for delivery during irrigation season months. Wet and above normal water years might provide an opportunity for augmenting flows during these months through water releases from Scotts Flat reservoir, as the likelihood of additional water is greatest during these years and losses to NID would be minimal when compared to the cost of providing additional water during critical, dry, and below normal water years. Opportunities for additional water releases should be explored through NID, although additional study is needed to justify and prioritize the needs throughout the water year so that NID can make informed management decisions.

Other Indicators of Hydrologic Alteration Analysis

<u>Method 1. IHA Monthly Flows</u>

The IHA software allows for analysis of the magnitude of monthly water conditions through mean or median daily flow analysis. This produces an average flow value for each month based on the period of record. A two period non-parametric analysis was employed to determine median monthly flow values for the periods before (PreSF) and after (PostSF) the upgrade of Scotts Flat Reservoir in 1964, the year base flow changed in Deer Creek. The magnitude of monthly water conditions is important to analyze because they can have the following influences on the aquatic ecosystem:

· Habitat availability for aquatic organisms
· Soil moisture availability for plants
· Availability of water for terrestrial animals
· Availability of food/cover for furbearing mammals
· Reliability of water supplies for terrestrial animals
· Access by predators to nesting sites
· Water temperature, oxygen levels, photosynthesis in water column

Table 1.18 provides a summary of the results of the median monthly flow analysis, with a description of how the PostSF median flow has been impacted, and hydrologic alteration values from the RVA analysis. An example plot is shown for the month of April in **Figure 1.33**.

Month	PostSF Median	Low HA	Middle HA	High HA
October	Similar median.	-0.1407	0.2352	-0.1944
November	Median falls below Low RVA boundary (~10 cfs decrease).	0.8617	-0.297	-0.4988
December	Median falls below Low RVA boundary (~10 cfs decrease).	0.6469	-0.2384	-0.3556
January	Median decrease to near Low RVA boundary (~20 cfs decrease).	0.4321	-0.3556	0.002469
February	Slight median decrease (~15 cfs decrease).	0.3605	-0.06263	-0.284
March	Slight median decrease (~20 cfs decrease).	0.3605	-0.4727	0.2173
April	Median falls below Low RVA boundary (~70 cfs decrease)	0.7901	-0.5313	-0.1407
May	Median falls below Low RVA boundary (~30 cfs decrease).	1.077	-0.5313	-0.4272
June	Median decrease to near Low RVA boundary (~10 cfs decrease).	0.1457	0.3475	-0.5704
July	Slight median increase (~1 cfs increase).	-0.1407	0.1717	-0.06914
August	Similar median.	-0.3556	0.07407	0.2889
September	Median increase (~1.5 cfs increase).	-0.642	0.2303	0.3605

Table 1.18: Summary of the IHA monthly flow magnitude analysis.

The results of the IHA software median monthly flow analysis indicate that changes to the magnitude of monthly water conditions have occurred since the upgrade of Scotts Flat reservoir in 1964. Certain trends appear when analyzing the results, many of which were also evident from the results of the flow duration curve analysis. The median monthly flow value decreases in 8/12 months, exhibits no change in 2/12 months, and increases slightly in 2/12 months. The median monthly flow decreases are all during the wet season, November – June, indicating that reservoir development has potentially impacted the magnitude of monthly flows during these months, possibly impacting high flow pulses, and small and large floods. These alterations could have important implications for aquatic and terrestrial organisms.

The months with no median change (August, October) and months with a slight median increase (July, September) occur during the summer and NID's primary irrigation season when flows throughout the majority of the watershed are being managed by NID. This indicates that reservoir development and management has had a minimal impact on the magnitude of monthly flows at the watershed outlet during the base and low flow periods of the water year, with approximately 1.5 cfs or less of additional water available during July and

September. Some of the alterations during these months are likely caused by effluent discharges from the Lake Wildwood reservoir WWTP, as the plant has operated in the PostSF period since the early 1970's, discharging effluent into Deer Creek downstream of Lake Wildwood reservoir where NID is unable to re-capture the water. The WWTP signal is difficult to detect during the wet season but in the summer months, when flows are often less than 10.0 cfs, these effluent flows become significant and could be offsetting flow decreases associated with reservoir development and management. This is purely from a physical quantity perspective, not water quality, as the water consists of wastewater effluent.

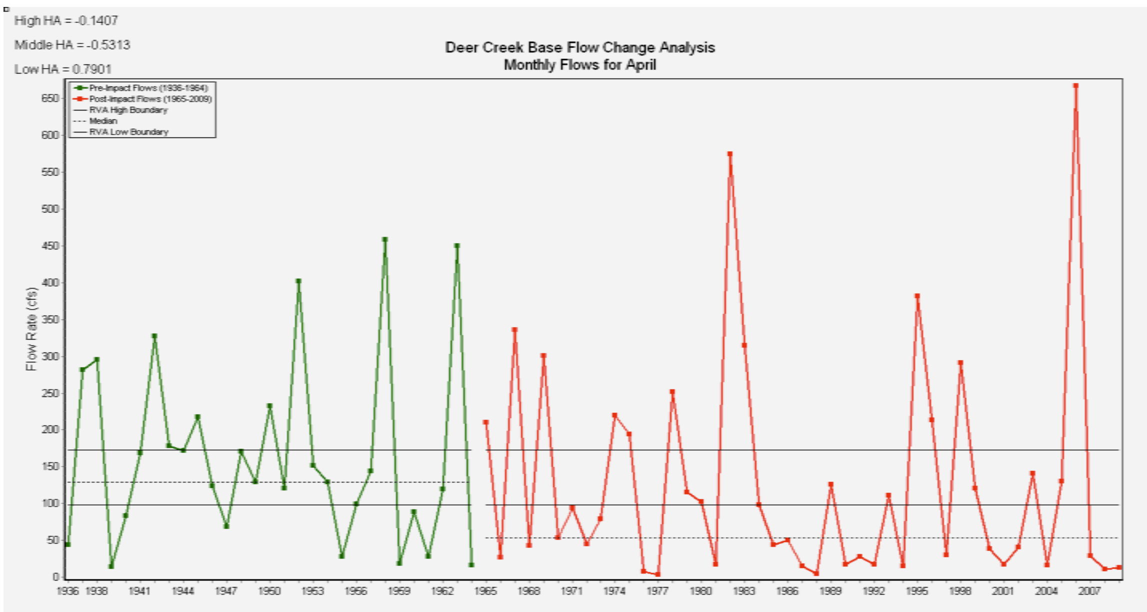


Figure 1.33: Results of the IHA median monthly flow analysis for the month of April.

Hydrologic Alteration values were greatest for November, December, April, and May, with an increase in Low RVA category flows in the PostSF period compared to PreSF. This corresponds to decreases in the Middle and High RVA category flows and a median flow decrease. This indicates the hydrologic regime has been altered, with a lower median monthly flow value in 8/12 months of the year after the 1964 Scotts Flat reservoir upgrade, resulting in less water flowing through the watershed outlet during these months and the majority of the year. As with the monthly flow duration curve analysis, the median monthly flow analysis results indicates periods of the water year during which flow augmentation could potentially help restore a more natural flow regime.

Figure 1.34 is a graphical summary of the results from the monthly flow alteration analysis and confirms the results already presented. Visualizing the results illustrates the magnitude of monthly flow alteration. Months with the greatest hydrologic alteration are evident by the lack of overlap between the PreSF RVA boundaries and the PostSF median monthly flow values. As previously discussed this includes November, December, April, and May.

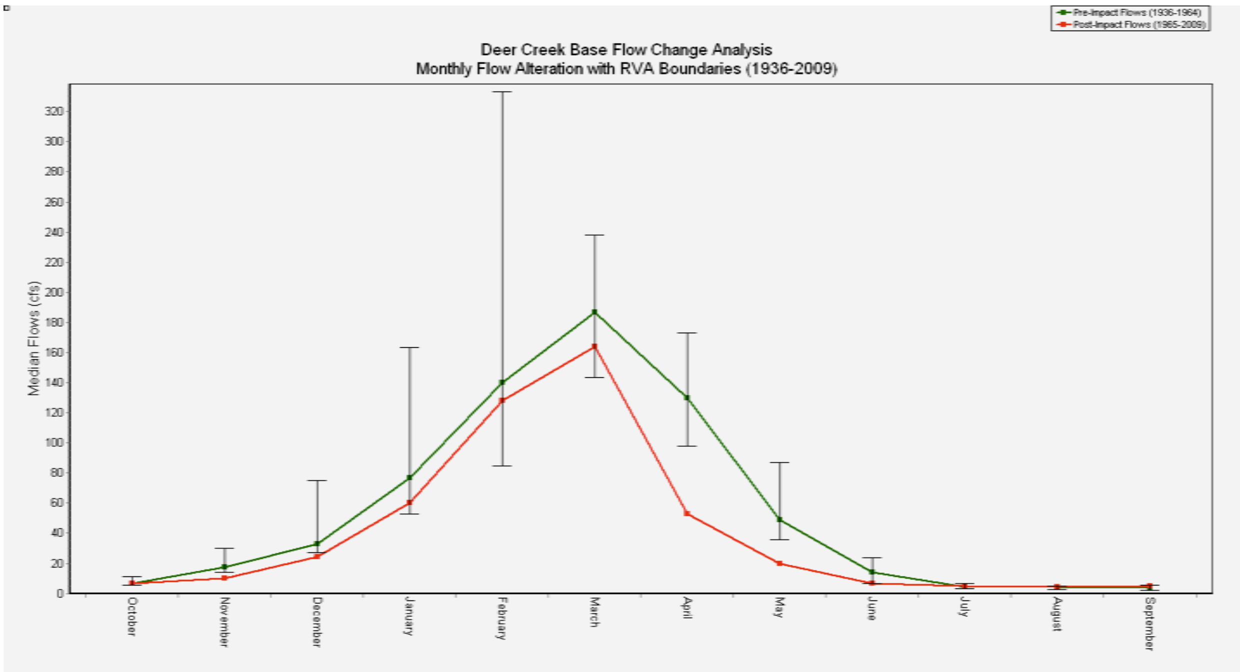


Figure 1.34: IHA monthly flow alteration with RVA boundaries.

Reductions in the magnitude of median monthly flow values can have important implications for the ecosystem. The decrease in median monthly flows during April and May is of particular concern, due to the magnitude of the alteration. Fortunately there have not been significant alterations to median monthly flow values during the driest months of the year. For 8/12 months there is a reduction in the median monthly flow value and thus less water available for aquatic and riparian organisms in the lower reaches of Deer Creek. This means fewer habitats available for aquatic organisms, less water for terrestrial animals, and less water for riparian plants (TNC 2009). Further analysis should be conducted to determine flow augmentation needs during these months. Although there is a lack of long-term data, additional analysis focusing on the upper Deer Creek watershed would be beneficial, as the current analysis is most applicable to reaches in the lower most portion of the watershed near the outlet. NID uses much of upper Deer Creek as a canal during irrigation season and these alterations would be important to quantify, if possible.

<u>Method 2. Rate and Frequency of Changes in Stream flow</u>

The IHA software calculates the frequency of stream flow reversals by dividing the hydrologic record into rising and falling periods, corresponding to daily changes in flows that are positive or negative. The number of reversals corresponds to the number of times that flow switches from one type of period to another (Richter et al. 1996). Rates of change were calculated for each rise and fall period with the median of all positive or negative differences between consecutive daily values representing the average annual rate of change (Richter et al. 1996). RVA analysis was used in the rate and frequency analysis and allows for assessment of the degree of hydrologic alteration from the PreSF to PostSF period. Rates of change are important to assess because they influence the ability of aquatic and riparian organisms to take refuge or otherwise respond to changing flows, the amount of habitat availability, and the potential for stranding of organisms (Cassin et al. 2005). Flow reversals can constitute a disturbance for organisms sensitive to changes in water depths, velocities or amount of habitat available (Cassin et al. 2005). Frequent flow reversals could require greater energy expenditure, interfere with feeding behavior or efficiency, and reduce the availability of refugia (Cassin et al. 2005). The frequency of reversals and the rates of flow change parameters characterize the degree of flashiness exhibited by a given river system. The IHA Tutorial provides the following ecosystem influences that can be impacted by the rate and frequency of annual water condition changes (TNC 2009):

· Drought stress on plants (falling levels)
· Entrapment of organisms on islands, floodplains (rising levels)
· Desiccation stress on low-mobility stream edge (varial zone) organisms

Parameter	Low HA	Middle HA	High HA	Median Change
Rise Rate	0.09333	-0.5569	0.1278	-1.2 cfs
Fall Rate	-0.1944	-0.1573	0.45	1 cfs
Reversals	0.04722	0.1278	-0.2123	1

Table 1.19: Summary of the IHA software rate and frequency of change analysis, with each parameter, the hydrologic alteration factors, and change to the median value. A decrease in median rise rate corresponds to a slower rise rate while the increase in fall rate median corresponds to a slower fall rate.

Method 2a. Rise Rate

Table 1.19 summarizes the results of the rise rate of change analysis, with the degree of hydrologic alteration to each RVA category and median change from the PreSF to PostSF period. The results indicate that the rise rate of change has been altered. There is a negligible increase in low RVA category flows (0.09333), appreciable decrease in middle RVA category flows (-0.5569), and slight increase in high RVA category flows (0.1278). The median rate of change decreases 1.2 cfs day^{-1} and falls below the PreSF low RVA boundary, with the highest and lowest annual rise rates occurring in the PostSF period. The decrease in middle RVA category flows combined with an increase in low and high RVA category flows, indicate that there is an increase in values outside of the historic range of variability. This is confirmed by the rates of change in the PostSF period, with values greater than and less than any value observed in the PreSF record, although this could be influenced by the types of water years and observed flow events in each period. The PostSF period has the highest annual peak flows observed on record and thus this may help explain why the greatest rates of change occur during the PostSF period. The results indicate greater dispersion of flows and an increase in rise rates that are outside the historic range of variation. The changes observed to the rise rates could have implications for aquatic and riparian organisms, although more investigation is needed to make definitive conclusions. Further investigation should incorporate analysis of the 15-minute or hourly USGS stream flow datasets, as the current analysis utilized mean daily flow data, which does not permit analysis of rise rates that occur over periods of less than one day. While the daily analysis may be appropriate for larger river systems, analysis of rise rates over shorter time periods would be more appropriate for Deer Creek. The 15-minute data is available from the USGS for 10/1/1987-present, with hourly data available prior to 1987 dating back to 1935.

Method 2b. Fall Rate

Table 1.19 summarizes the results of the fall rate of change analysis, with the degree of hydrologic alteration to each RVA category and median change from the PreSF to PostSF period. The results indicate that the change in fall rate has been altered from the PreSF to PostSF period. There is a decrease in low (-0.1944) and middle (-0.1573) RVA category flows, and an increase in high RVA category flows (0.45). The median increases by 1.0 cfs from the PreSF to PostSF period and plots at the high RVA boundary, which represents a decrease in the flow fall rate. As with the rise rate analysis, the slowest and greatest rates of change occur in the PostSF period. This combined with the decrease in low and middle RVA flows and increase in high RVA flows indicates that there is an increase in values outside of the historic range of variability. This is confirmed by the rates of change in the PostSF period, with values greater than and less than any value observed in the PreSF period. This points to greater dispersion of flows and an increase in extreme fall rates that are outside the historic range of variation, with the changes observed to the fall rates potentially having implications for aquatic and riparian organisms. This could also be a product of varied water years and flow events in the PostSF period, as the PostSF period had more critical water years as well as larger magnitude annual peak flow events that were outside of the PreSF range of variability but does not necessarily indicate an alteration to the watershed through a management activity. As with the rise rate analysis the fall rate data should be explored using the 15-minute and hourly datasets available from the USGS, to investigate fall rates that occur over periods of less than one day. The recession limb of many storm hydrographs recedes rapidly over short periods of time and thus this analysis would be beneficial to further characterize alterations to fall rates through time as a result of reservoir upgrades and water management.

Method 2c. Flow Reversals

Table 1.19 summarizes the results of the flow reversals analysis, with the degree of hydrologic alteration to each RVA category and median change from the PreSF to PostSF period. The results indicate that the frequency with which hydrologic reversals occur has been altered from the PreSF to PostSF period. There is an insignificant increase in low RVA category flows (0.04722), increase in middle RVA category flows (0.1278), and a decrease in high RVA category flows (-0.2123). The median increases by one reversal from the PreSF to

PostSF period and plots within the PreSF RVA boundaries, indicating minimal alterations to flow reversals. As with the rise and fall rate analysis the most extreme values occur in the PostSF period, with the greatest and least number of annual reversals occurring in the PostSF period. In general this points to the potential for greater variability in annual flow reversals in the PostSF period.

Further investigation would be beneficial to quantifying rise and fall rates and flow reversals, through the use of the 15-minute and hourly USGS data, versus the current analysis that employs the use of mean daily flow data. This will allow for better quantification of rise and fall rates during storm events as well as natural and managed flow reversals. The mean daily flow set does not allow for investigation into daily flow reversals and rise or fall rates over time periods less than a day. The averaging of daily flows smoothes the hydrograph and thus analyzing the 15-minute and hourly datasets would provide further insight into these parameters. The IHA software does not allow for this type of data to be analyzed, so other software or methods should be explored.

Indicators of Hydrologic Alteration Summary

The IHA software allows for creation of a plot that summarizes the extent of alteration to each IHA parameter, so that the greatest alterations can be identified. **Figure 1.35** provides a plot of the IHA parameters and the greatest hydrologic alterations. The larger the hydrologic alteration value is (the larger the bar), the greater the alteration from the PreSF to PostSF period. Details for each parameter are provided in the previous sections, with this plot only providing a visual summary of the results for every IHA parameter analyzed.

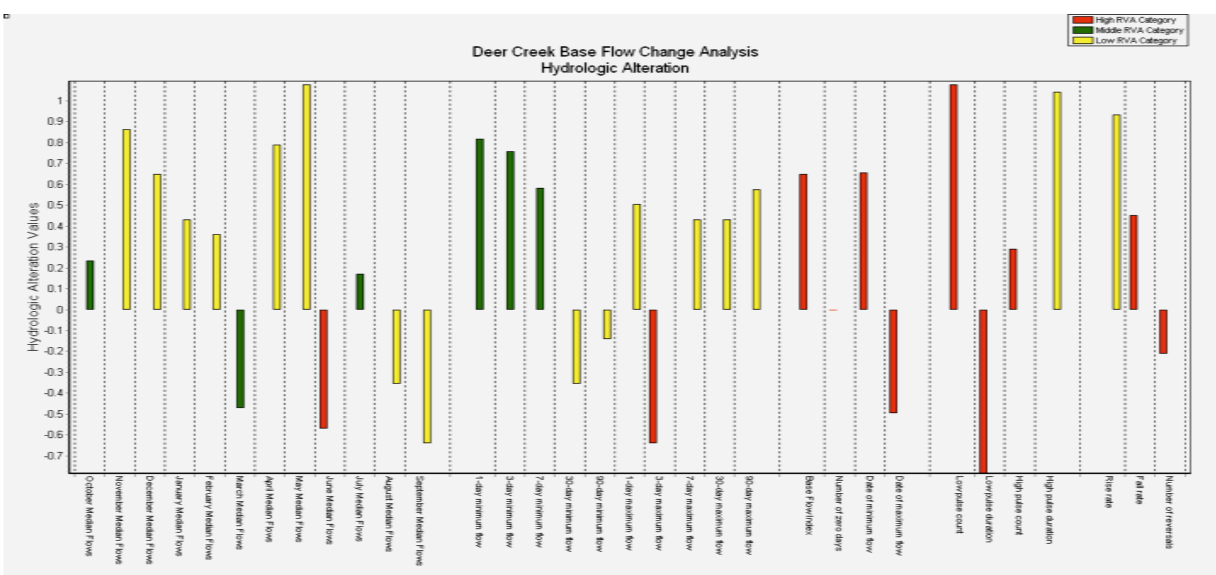


Figure 1.35: Graph showing results of the IHA analysis, displaying the areas of greatest hydrologic alteration for each IHA parameter analyzed.

Lake Wildwood Drawdown Release Stream Flow Data Analysis

Methods

Lake Wildwood reservoir must periodically drawdown their reservoir in October to dredge out sediments that have accumulated, in order to maintain reservoir levels. This involves lowering the reservoir by approximately ten to twelve feet by releasing water into Deer Creek downstream of the reservoir. Releases began in 1979 and have occurred 25 times in 32 years, about three times out of every four years, but there is considerable variability to when releases occur, primarily based on how much sediment enters the reservoir during the previous storm season. Releases have occurred every year starting in 1979 except 1981, 1982, 1988, 1991, 2005, 2006, 2009, and 2010. The thirty-one year dataset since releases began provides an adequate time period to investigate alterations to the hydrologic regime as a result of the drawdown. Several methods were used to evaluate alterations to the hydrologic regime caused by the periodic Lake Wildwood reservoir drawdown release. The analyses were aimed at:

- Using the entire period of record to compare flows during October drawdown release and non-release years to look for alterations to the hydrologic regime.
- Comparing flows for natural storm events in October against flows caused by drawdown releases in an attempt to mimic a natural storm event with the drawdown release.

The stream flow data record was primarily separated into two parts for this analysis, consisting of release and non-release years. A flood flow frequency analysis was performed using the same methods as the other flood frequency analyses in this chapter (IACWD 1982). The USACE HEC-Statistical Software Package (HEC-SSP) was used to perform the flood frequency analysis as well as a duration analysis, comparing release and non-release years. Comparisons were made of hydrographs for October natural storm events and past drawdown events, in order to look for natural storm events upon which to model the drawdown release. Mean daily flow (cfs) values were used for the flood frequency and duration analysis, as instantaneous peak flow data for the month of October were not available prior to 1987. Instantaneous, 15-minute data were used for the rise and fall rate analysis and comparison of storm events. These results can be compared against the IHA analysis that focused on the month of October, including the October flow duration curves and October monthly median flow.

Results and Discussion

The flow regime of lower Deer Creek for the month of October has been fundamentally changed by the Lake Wildwood reservoir annual drawdown events since they began in 1979. A histogram of the annual October peak flow illustrates how the flow regime has been altered (**Figure 1.36**).

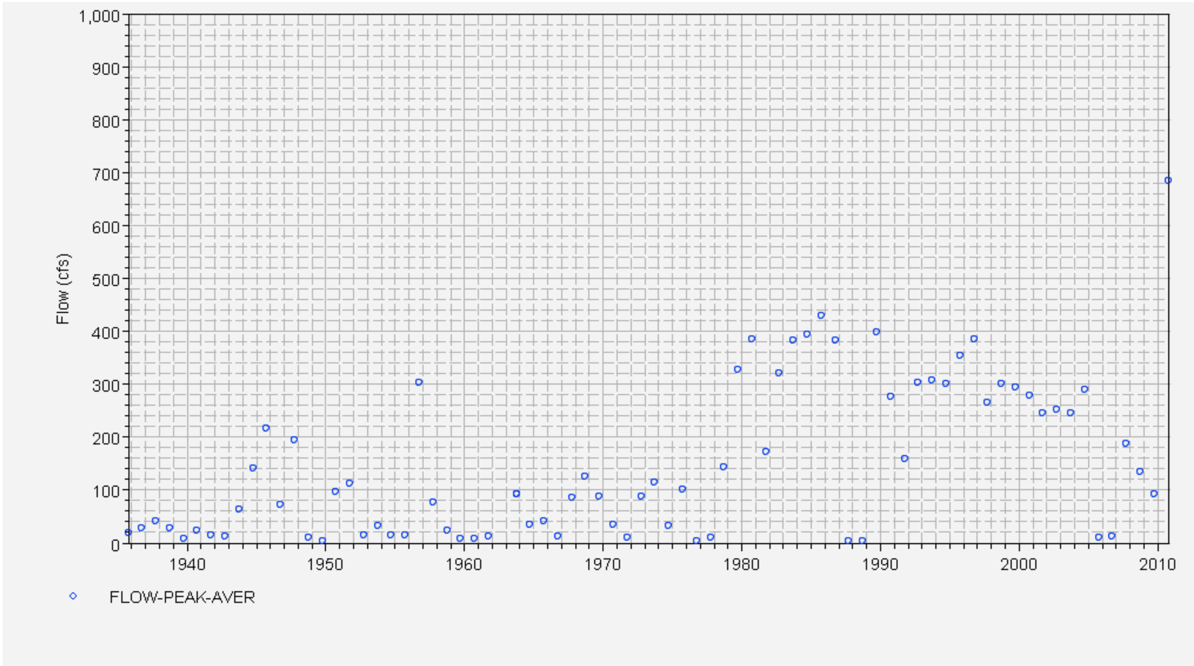


Figure 1.36: Histogram plotting annual peak flow events for the month of October, using mean daily flow data from 1935-2010. Drawdown releases began in 1979. The highest peak flow on record (7370 cfs, October 1962, statistically a high outlier) was omitted from the plot to make it easier to visualize how the peak flow regime has been altered.

A list of the exceedance probabilities and recurrence intervals for annual peak flow events during October for the 1.01, 2, 5, 10, 20, 50, and 100-year flow events for non-release and drawdown release years can be found in **Table 1.20**, with graphs of the results provided in **Figure 1.37** and **1.38.** The flood frequency analysis is useful for evaluating the probability of a certain magnitude flow event occurring annually, in this case each October in either release or non-release years.

Exceedance Probability (%)	Return Interval (yrs)	Release Years (cfs)	Non-Release Years (cfs)
99	1.01	119 – (94.3, 154)	2 – (1.3, 4)
50	2	316 – (289, 350)	33 – (23.5, 47)
20	5	376 – (341, 426)	132 – (90.3, 201)
10	10	400 – (360, 459)	302 – (191, 500)
5	20	417 – (373, 481)	632 – (366, 1,145)
2	50	431 – (384, 502)	1,563 – (793, 3,149)
1	100	438 – (389, 512)	2,989 – (1,362, 6,467)

Table 1.20: Return intervals for the month of October, for the 2, 5, 10, 20, 50, and 100-year flows for non-release and release years. Confidence intervals (0.95, 0.05) are provided next to the flow value for each return interval.

The results of the flood frequency analysis for peak flow events during the month of October indicate that the peak flow regime has been altered as a result of Lake Wildwood reservoir conducting drawdown releases. The frequency and magnitude of October peak flow events have been altered as a result of the drawdown release, with greater annual peak flows occurring more frequently for small flood events. In release years peak flows are greater for return intervals Q1.01, Q2, Q5, and Q10, while flows during non-release years are greater for the Q20, Q50, and Q100 flow events. The lack of variability in the release years dataset, with no low annual peak flows and a dataset of flows consistently between 100-400 cfs, results in greater values for return intervals Q1.10-Q10. The opposite is true of the non-release years dataset, where a substantial amount of variability is found, with both the highest and lowest annual peak flow events on record. This results in lower values for small flood events (Q1.01-Q10) and greater values for large flood events (Q20-Q100) when compared to the release years dataset. The October 1962 storm event during a non-release year, with a peak flow of 7370 cfs, influences the analysis to produce higher flow values for the large flood events (Q20-Q100) in non-release years when compared to release years. Furthermore, peak flows during release years level out near 400 cfs, as this is the maximum discharge rate at which Lake Wildwood reservoir has conducted releases, reducing the magnitude of flows for return intervals Q20-Q100. This leads to the curve reaching an asymptote, leveling off, and resulting in lower values for the large flood events. The lack of variability in the release years dataset leads to greater confidence in the results, despite the small period of record (n=23). When looking at the plots in **Figures 1.37** and **1.38** it is evident the shape of the curves are very different for non-release (**1.37**) and release (**1.38**) years.

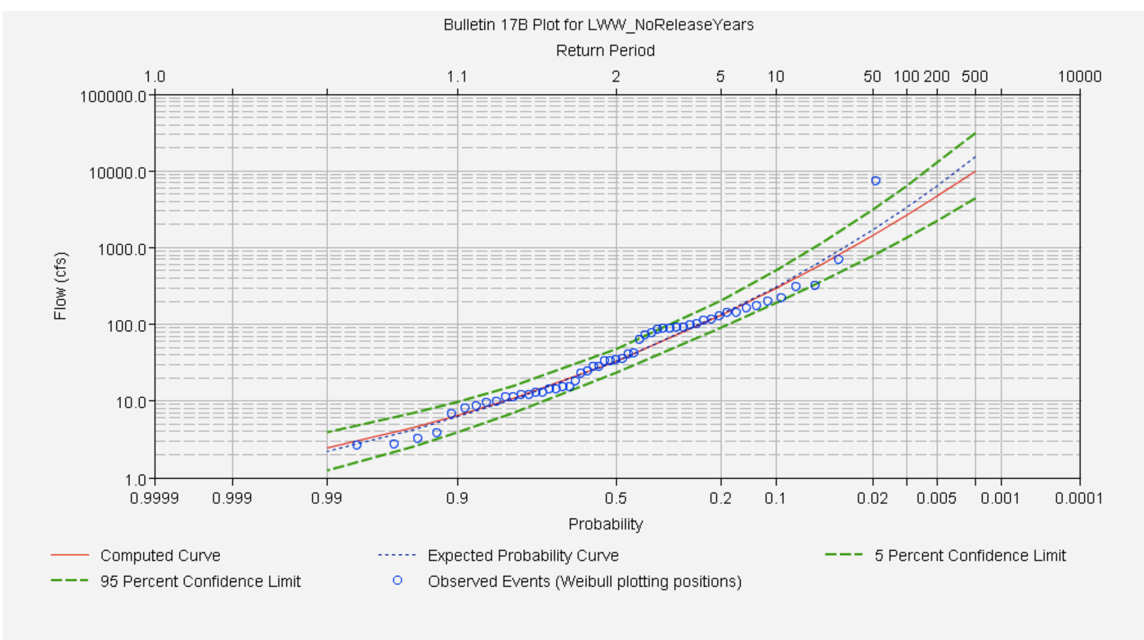


Figure 1.37: Results of the HEC-SSP flood frequency analysis for years in which no drawdown release occurred (n=52).

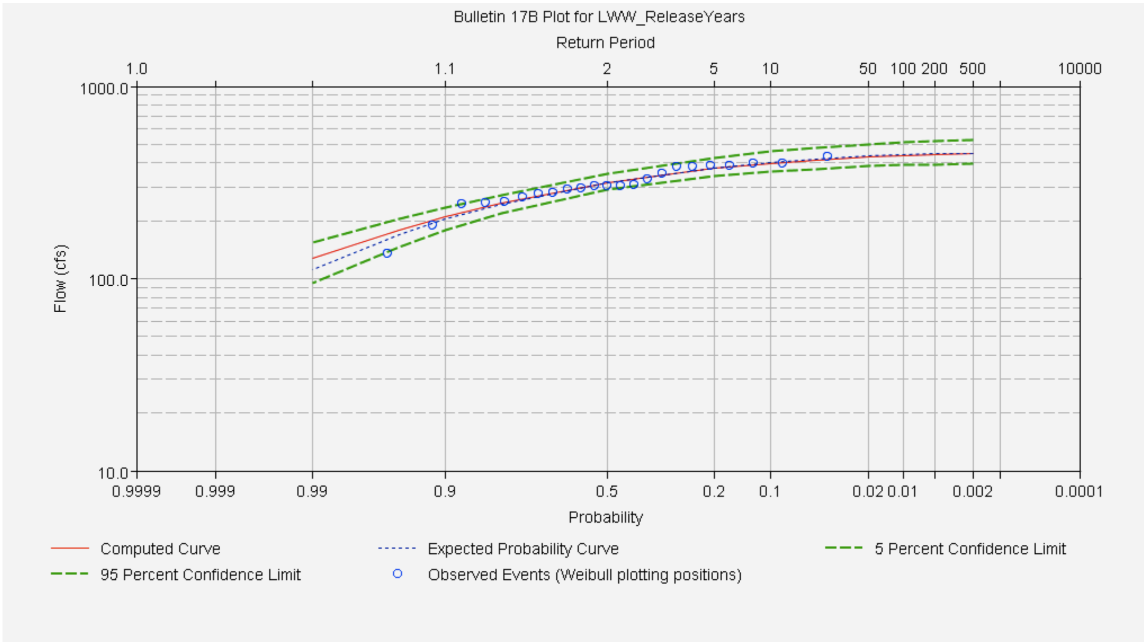


Figure 1.38: Results of the HEC-SSP flood frequency analysis for years in which drawdown releases occurred (n=23).

The alterations to the peak flow regime during October likely have influenced the aquatic community downstream of the reservoir. The frequency with which high flow events occur during October is outside the natural range of variability, as evidenced by comparing the Q1.01-Q10 flow magnitude for release and non-release years. This indicates the need to work with Lake Wildwood reservoir to reduce peak flows during the drawdown release. To further investigate alterations to the October flow regime, a duration analysis was performed on mean daily flow data for non-release and release years.

As with the flood frequency analysis the duration analysis indicates alterations to the hydrologic regime as a result of Lake Wildwood reservoir drawdown releases during the month of October. The duration analysis is useful for showing the percent of time that discharge is likely to equal or exceed a specific discharge value for any given day in October. **Table 1.21** provides a comparison of exceedance probabilities and return intervals for non-release years and drawdown release years. Exceedance probabilities can be thought of as the percent of time a certain flow volume is expected to be exceeded, with return intervals corresponding to how frequently the flows are expected to occur in years.

Exceedance Probability (%)	Return Interval (yrs)	Non-Release Years (cfs)	Release Years (cfs)
99	1.01	0.5	1.25
50	2	6.9	8
25	4	15	35
15	6.67	19	131
10	10	24	202
5	20	41	257
2	50	99.7	353
1	100	158	384
0.1	1,000	2833	430

Table 1.21: Results of the duration analysis, including exceedance probabilities and return intervals for and non-release and drawdown release years.

The results indicate that there is a difference in the duration of flows between non-release and release years. When compared against drawdown release years, lower discharges are expected to occur a greater percent or duration of the time during non-release years, as evidenced by the lower discharge values for every return interval except for the 1,000 year return flow. The 1,000-year return interval flow volume is greater for non-release years because the highest flow on record (7370 cfs), a high outlier as determined by the HEC-SSP software, occurred during a non-release year. In release years from the Q1.01 through Q100 a greater volume of flow is expected a greater percentage of the time when compared to non-release years, indicating that higher flows are expected to occur for longer durations in years that drawdown releases occur and that there is more water moving through the system in October during release years. The small period of record for drawdown release years (n=23) likely influences and skews the results of the duration analysis, particularly for return intervals greater than 25 years, and thus incorporating more data into this analysis as it becomes available over time would be beneficial. That said, the flow values during release years tend to level off between 350-450 cfs, unless a natural storm event occurs separate from the drawdown release, so a longer period of record might not result in great differences for the Q25-Q100 because values have already reached an asymptote. Differences between release and non-release years are also evident when visualizing the results. **Figures 1.39 and 1.40** plot the results of the duration analysis, with **Figure 1.39** representing non-release years and **Figure 1.40** drawdown release years.

The graphs in **Figures 1.39** and **1.40** help with interpreting the results of the duration analysis and allow for visual investigation of differences between drawdown release and non-release years. One apparent difference between the two figures is that the scale is shifted from **Figure 1.39** to **1.40**, with **Figure 1.39** containing a larger range of values, from 0.1 to 10,000 cfs. This is representative of the highest and lowest streamflows occurring during non-release years, and the variability in streamflows observed when water management is not occurring by Lake Wildwood reservoir. In **Figure 1.40** (release years) half of the points on the interpolated curve (6.67 to 1,000-yr return intervals) are concentrated above 100.0 cfs, a shift in the percent of time certain discharges are expected to occur when compared with non-release years (**Figure 1.39**), where half of the points reside over 10.0 cfs and only two are above 100.0 cfs (100-yr and 1000-yr return intervals). Again these plots indicate that the drawdown release has altered the percentage of time certain flow volumes would be expected during the month of October by increasing flow volumes associated with return intervals from 1 – 100-years, and eliminating the streamflow variability observed during non-release years. This has resulted in more water moving through the system in drawdown release years and a managed hydrograph that lacks variability in streamflows that would be observed during non-release years.

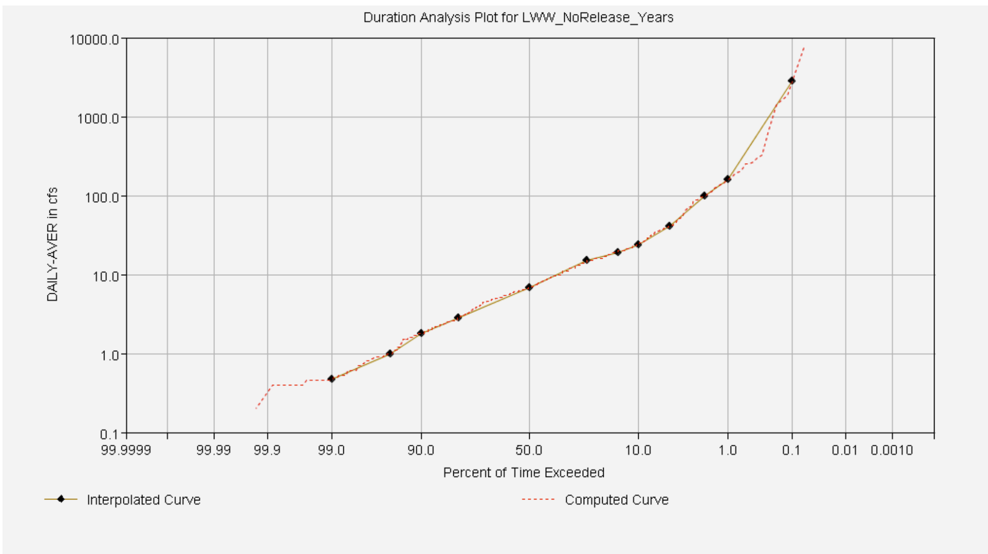


Figure 1.39: Graph showing the results of the duration analysis for years in which no drawdown release occurred (n=52).

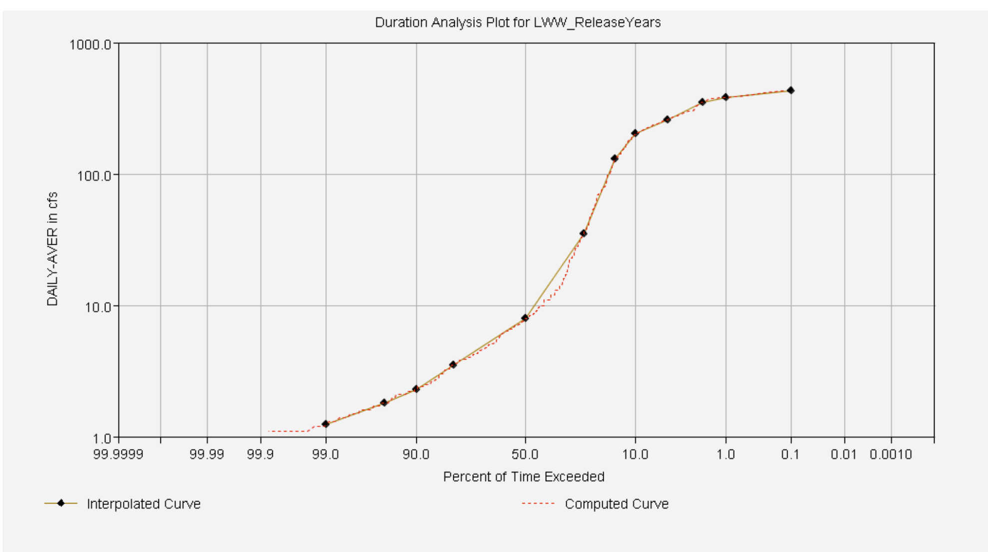


Figure 1.40: Graph showing the results of the duration analysis for years in which drawdown releases occurred (n=23).

Although the duration analysis indicates there have been alterations to the October hydrograph, there is not much that can be done about the volume of water in the system and the percent of time certain flow volumes are exceeded during October drawdown release years, as Lake Wildwood must conduct releases in order to maintain their reservoir. In order to successfully lower the reservoir level Lake Wildwood must release at a certain flow magnitude for a duration of at least 3 days, depending on release volume. It is possible that greater variability in streamflow magnitudes and durations could be produced during drawdown releases, in an attempt to mimic flows in non-release years by providing greater variability in streamflows, but it is unlikely that this will significantly alter the drawdown release flow regime. This is because of limitations in minimum and maximum flow release volumes from the reservoir and the limited time period available to Lake Wildwood for completing the release. Further analysis was conducted into natural storm flows that occurred in October, in an attempt to look for natural storm events that could serve as guides for conducting the drawdown release.

Investigation was conducted into natural storm events that occurred during the month of October to check for the prevalence of storm events that could be used as a model for conducting Lake Wildwood reservoir drawdown releases. Data from 1987-2010 were used in this analysis, as this was the period of record most readily available from the USGS in 15-minute resolution. Suitable storm events were identified in 1989, 1991, and 2010, which could be used as models for conducting the drawdown releases, and it is likely that others exist prior to the beginning of the 1987 dataset. The graphs in **Figures 1.41, 1.42, 1.43** illustrate these flows, with the graph in **Figure 1.44** comparing the 1989, 1991, and 2010 natural storm flow events against drawdown releases that occurred in 1989 and 2008. A drawdown release occurred in 1989 and was followed by a natural storm event.

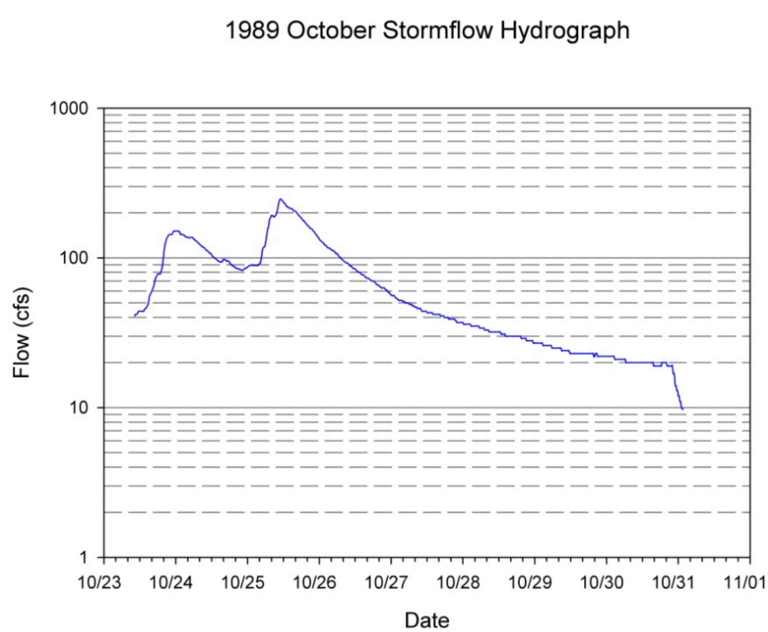


Figure 1.41: A natural storm hydrograph that occurred during October 1989.

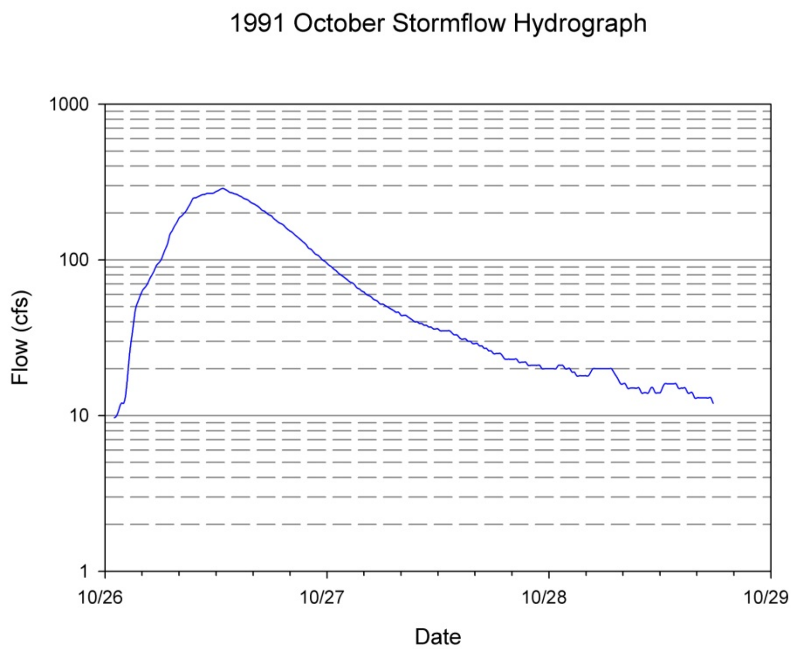


Figure 1.42: A natural storm hydrograph that occurred during October 1991.

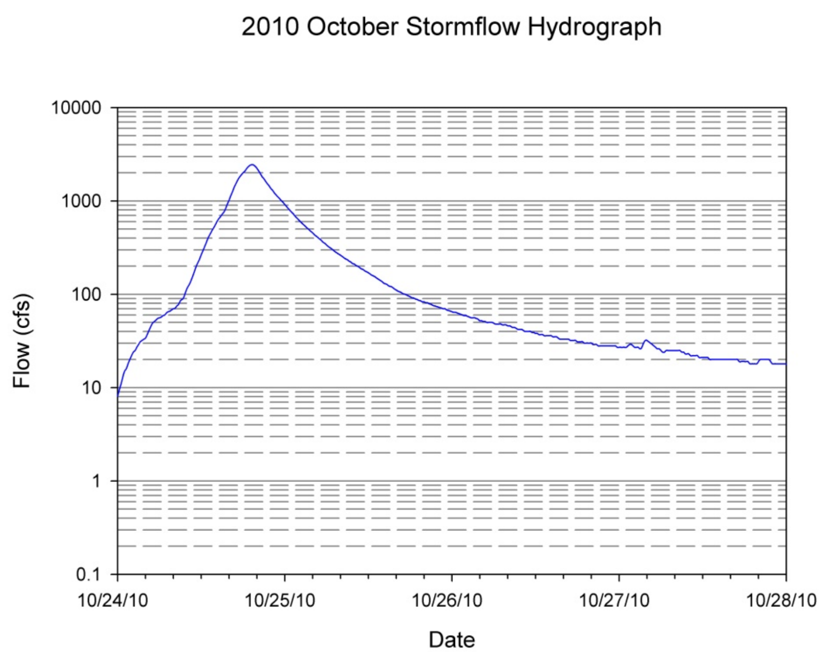


Figure 1.43: A natural storm hydrograph that occurred during October 2010.

The graphs in **Figures 1.41**, **1.42**, and **1.43** illustrate natural storm events that have occurred in October since 1987. There are notable differences between the storm events, with the storm event in **Figure 1.43** resulting in flows greater than 2,000 cfs, much greater than Lake Wildwood reservoir's release capacity, and subjecting aquatic organisms to rapid rise and fall rates. The storm events in **Figures 1.41** and **1.42** represent flow magnitudes that are within Lake Wildwood's release capacity and rise and fall rates that are less stressful for aquatic organisms. After discussion with the Lake Wildwood Lake Committee and Lake Wildwood Public Works Department, it was determined that the graph in **Figure 1.41** represents the most ideal model flow event, as a sufficient volume of water could be released from the reservoir, the duration of the release could be less than one week, rise rates are moderate when compared to **Figure 1.43**, aquatic organisms could adjust to increasing flows before the second and maximum peak flow is reached, and there is a slow recession limb to allow for aquatic organisms to adjust to streamflow decreases. Flow magnitudes could be shifted up or down on the plot, in order to achieve the necessary release volume required by Lake Wildwood reservoir in the desired period of time. In addition, after the first peak is reached flow volumes could be held steady, to reduce any turbidity increases that could be caused by lowering and subsequently increasing stream flows. The overall flow volume that is necessary to be released is dependent upon whether the reservoir is being lowered ten or twelve feet. A twelve foot lowering of the reservoir is planned for 2011, whereas the majority of years the reservoir is only lowered by ten feet.

One potential limiting factor to mimicking a natural storm event during the drawdown release is the ability of Lake Wildwood's Public Works Department to make frequent adjustments to release volumes, in order to increase or decrease the amount of water being released from the reservoir. In order to follow the model streamflow, slight adjustments would need to be made every half-hour or less, to mimic natural rise and fall rates associated with the model storm event. After discussions with Lake Wildwood it was determined that during the normal workday the Public Works Department could make adjustments as needed, with adjustments in past releases occurring as early as 7:15AM and as late as 5:00PM. This would mean there would be a constant release volume overnight, as there would be no one from Public Works available to make flow adjustments, which does not occur in the model flow event but is unavoidable due to logistical constraints. Because of this limitation, it would be desirable to re-create the first rising limb of the hydrograph on the first day, with a leveling off of flows overnight before a second rise in flows on day 2. From the peak on day 2 the recession limb could be adjusted as needed to ensure the required volume of water is released and the reservoir lowered to the right levels so that dredging operations could commence.

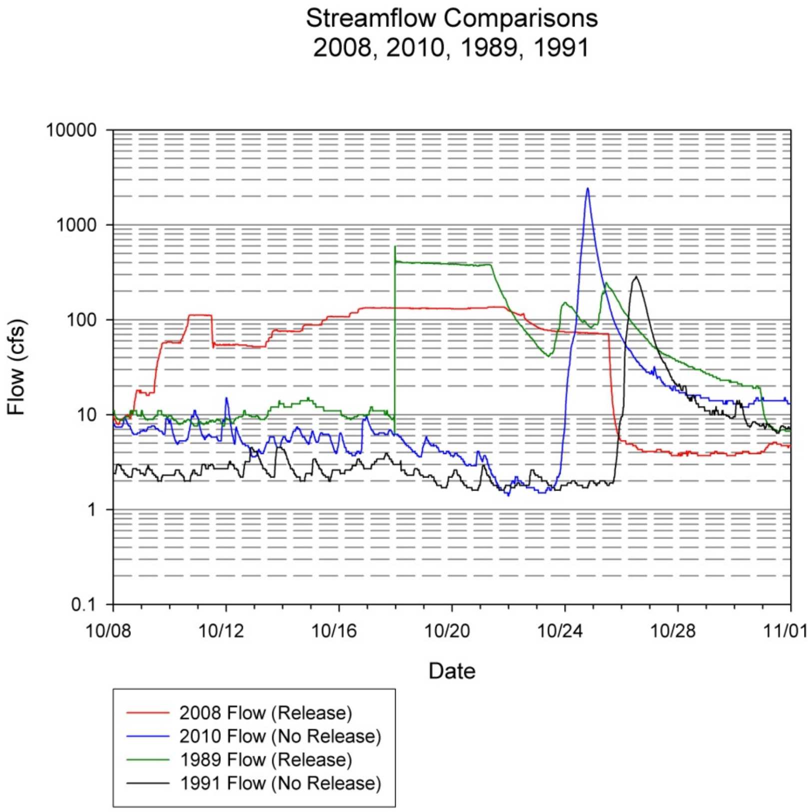


Figure 1.44: Comparison of natural streamflow hydrographs against two drawdown releases. Both a drawdown release and natural storm flow are present in the 1989 graph.

It is difficult to quantify the impact that drawdown release flows have had on aquatic and terrestrial wildlife. It is known that fish, macroinvertebrates, and vegetation rely on life cycle triggers that include flow magnitude, duration, timing, as well as water temperature (Poff et al. 1997). Large releases of water in October can potentially have negative impacts on stream biota because flows of these magnitudes and durations would be outside the natural range of variability. A study by Novotney (1985) on a flood control dam in Kentucky compares macroinvertebrate populations upstream and downstream of a reservoir. The study attributes major decreases in sensitive Ephemeroptera, Trichoptera, and Plecoptera organisms downstream of the dam to changes in the natural flow patterns (Novotney 1985). Because the drawdown has occurred periodically for the past 30 years, communities of fish and macroinvertebrates have possibly shifted to accommodate the highly unseasonal October flows. By mimicking the flow patterns of natural storm events that have occurred during the month of October it may be possible to restore hydrologic function to the October hydrograph and improve the conditions and habitat for macroinvertebrates and fish, such as Chinook salmon and steelhead trout, in lower Deer Creek. Further investigation is needed into the impacts associated with the drawdown release, as well as methods for remediating impacts to the flow regime and aquatic ecosystem.

D. Recommendations

Justin Wood

- **Compare the timing, both seasonally and between years, of peak flows occurring in Oregon Creek and Deer Creek to better understand the impact of Scotts Flat reservoir on peak flows in Deer Creek.**
  Investigations into Oregon Creek low flows should be conducted by water year type, to determine natural flow volumes in each type of water year for potential application to Deer Creek. In addition, better methods for estimating unimpaired, natural stream flows in the Deer Creek watershed should be explored, possibly through GIS-based modeling and desktop analysis and through additional streamflow gauging infrastructure on unimpaired perennial tributaries to Deer Creek.

- **Install rain gauges at locations near gauging stations, to better understand rainfall-runoff relationships, and to understand the full range of natural flow variability within Deer Creek.**
  Two rain gauges are being installed in the watershed in 2011; one in Nevada City and one in Rough and Ready, to supplement the existing USGS, NID, and Sierra Water Trust stream flow gauging infrastructure. Additional rain gauges and precipitation loggers should be installed in areas upstream of Scotts Flat reservoir, and in the Squirrel Creek watershed, to inform rainfall-runoff relationships throughout the watershed.

- **Restore the natural peak flood flow regime in the Deer Creek watershed and further investigate peak flows in the watershed.**

  Current peak flood flow magnitudes and return intervals near Scotts Flat reservoir and downstream of Lake Wildwood reservoir are outside the predicted natural range due to reservoir development and water management. In addition, the Scotts Flat reservoir upgrade and base flow change in 1964 has resulted in alterations to the flood regime, with potential reductions in the magnitude and frequency of peak flood flows in the period after the reservoir upgrade, which further indicates there have been alterations to the annual peak flow regime. When compared to the predicted natural flows, current peak flows at Scotts Flat reservoir in the upper Deer Creek watershed have been reduced from the Q2 – Q10 range, possibly due to the dam capturing runoff from one-quarter of the watershed. Peak flows downstream of Lake Wildwood reservoir in the lower Deer Creek watershed have been reduced from the Q25 – Q100 range, due to reservoirs capturing runoff and reducing the magnitude and frequency of large flood flows. Restoration would involve releases from Scotts Flat reservoir during storm events, to ensure that natural peak flows are achieved throughout the watershed. In addition, restoring the flood regime would also lead to more natural annual and monthly FDCs, increased duration of high flow pulses, increased monthly median flows, and an increase in monthly low flows. The FDCs indicated there is much less water in the creek annually and during the wet season months specifically (November – June), with high flow pulse durations, monthly median, and monthly low flows reduced during wet months after Scotts Flat reservoir upgraded in 1964. Efforts to allow more natural runoff patterns, such as snowmelt and upper tributary flow through Scotts Flat reservoir, should be explored during April, May, and June, with large reductions to the median monthly flow volumes in these months, due to water management and diversions of water away from the main stem of Deer Creek.

- **Restore a more natural hydrograph to the October flow regime downstream of Lake Wildwood reservoir and investigate changes to the aquatic ecosystem as a result of the drawdown releases.**

  The periodic Lake Wildwood reservoir drawdown release alters the flow regime during the month of October. Large releases of water in October can potentially have negative impacts on stream biota because flows of these magnitudes and durations would not occur naturally. By modeling drawdown releases after natural storm flows that occurred in October it may be possible to restore hydrologic function to the October hydrograph and improve the conditions and habitat for macroinvertebrates and fish, such as Chinook salmon and steelhead trout, in lower Deer Creek. Anadromous fish enter Deer Creek during the months of September or October and could be affected by the drawdown release. Further investigation should be made into impacts to these threatened and endangered fish species, as well as on macroinvertebrates and other aquatic species that inhabit lower Deer Creek.

- **Work with Lake Wildwood Association, Nevada Irrigation District, and the State Division of Water Rights to ensure that in-stream flow requirements outlined in water rights documents are achieved downstream of Lake Wildwood reservoir.**

  Currently water rights state that 5 cfs or the natural flow volume must be passed through Lake Wildwood reservoir. Efforts to quantify natural flows indicate that in a natural system during summer and early fall low flow months there would be 5.0 cfs in Deer Creek downstream of Lake Wildwood reservoir during most water years, except for dry and critical water years. Low flow frequency analysis indicates that at present, mean daily low flows drop below 7.9 cfs every year, with flows dropping below 2.0 cfs every other year, which suggests the in-stream flow requirements are not being achieved. Overall the results indicate that the 5.0 cfs or the natural flow volume requirement is not being achieved downstream of Lake Wildwood reservoir all the time, and efforts should be undertaken to ensure the required in-stream flow allotment is received. It is important to ensure these flow volumes are achieved because they improve water quality by reducing the impact of Lake Wildwood reservoir WWTP effluent discharges on lower Deer Creek through reduced nutrient concentrations and water temperatures, and increased dissolved oxygen levels. It is of particular importance that the 5.0 cfs or natural flow requirement is achieved during September, October, and November, as these are the months in which Chinook salmon begin to enter Deer Creek to spawn. This could possibly be achieved through effective management of the Lake Wildwood reservoir drawdown release, and through increased flows upstream of Lake Wildwood reservoir. If NID were to increase the "natural" flow volume being delivered into Lake Wildwood reservoir to 5.0 cfs, Lake Wildwood would have to pass the extra water through to lower Deer Creek because 5.0 cfs would be the natural flow entering the reservoir. These are two possible solutions to increased in-stream flows during October and November, a critical time for anadromous fish in Deer Creek.

Geomorphology of the Deer Creek Watershed

FODC/SSI

A. Introduction to the Geomorphology of Deer Creek

Understanding geomorphic processes and how they vary along Deer Creek is critical because geomorphic processes drive the form of the creek channel and floodplains, which in turn influence in-stream and floodplain habitat, riparian vegetation, water quality, biota and many other important stream qualities (National Research Council 1992). To restore and maintain healthy aquatic and riparian ecosystems successfully, restoration efforts must recreate the physical conditions necessary to support natural biotic communities (Gore 1985). Assessing the geomorphic conditions of Deer Creek can help inform areas where flow augmentation is needed to restore geomorphic health and function.

Deer Creek exhibits reaches typical of a classic Sierra Nevada bedrock river, (McBain and Trush 2004) and reaches characteristic of an alluvial river (Trush et. Al. 2000). Steep, bedrock reaches are often followed by more gradually sloped reaches where significant alluvial features can be found for great distances. A common misperception of bedrock rivers is that the channel morphology is static, and thus unaffected by changes to flow and sediment supply. However, bedrock rivers are often dynamic depositional environments too.

Deposition occurs within a confining, rigid bedrock framework that exhibits a bedrock template of pools and riffles.

This bedrock framework provides complex hydraulic controls that create diverse nested depositional features ranging from formations of large boulders to fine sand deposits. These depositional areas are important because the richness of biological communities in Sierra Nevada river ecosystems depends in part on the complexity created by these depositional features and processes. Sierra bedrock rivers have the following attributes of properly functioning bedrock river reaches (McBain and Trush 2004):

1. Bedrock rivers exhibit nested depositional features;
2. Bedrock river ecosystems require variable annual hydrographs;
3. Episodic sediment delivery enhances spatial complexity;
4. Bedrock channel maintenance requires multiple flow thresholds;
5. Maintenance of depositional features is partially independent of bedload transport capacity;
6. Biological hotspots occur at highly depositional reaches;
7. Hydraulic pathways in the river corridor fluctuate seasonally and annually.

Several attributes of properly functioning alluvial river reaches have been identified that can help identify desired processes and develop management actions to restore or maintain healthy functions for Deer Creek. Trush et al. (2000) identified 10 such attributes, the following seven of which are most relevant to Deer Creek:

1. Each annual hydrograph component accomplishes specific geomorphic and ecological functions.
2. The channel bed surface is frequently mobilized.
3. Alternate bars must be periodically scoured deeper than their coarse surface layers.
4. Alluvial channels are free to migrate.
5. Floodplains are frequently inundated.
6. Large floods create and sustain a complex main stem and floodplain morphology.
7. Diverse riparian plant communities are sustained by the natural occurrence of annual hydrograph components.

Each of these attributes is a function of the relationship between the hydrologic and geomorphic conditions of the river. The hydrologic patterns necessary to understand this relationship in Deer Creek have been described above in the Hydrology section. The geomorphic assessment approach and results are described below.

B. Approach

Justin Wood

The general approach taken to begin to understand the geomorphic aspects of Deer Creek involves the following steps:

- Reach classification: using aerial video footage and analysis of topographic data, the distinct reaches of Deer Creek were identified and mapped based on longitudinal slope and valley width parameters.
- Channel Morphology typing: within each reach, the channel morphology and major habitat types were identified and mapped.
- Detailed surveys: within key reaches, locations that can serve as indicators of hydro-geomorphologic function and health were identified and surveyed in detail.
- Analysis of data collected in the previous three steps.

C. Reach Classification

The purpose of classifying Deer Creek into distinct geomorphic reaches is to "permit rapid inventory of large regions, provide a stratified geomorphological framework within which more detailed observations can be organized, and provide an initial basis for selecting restoration strategies" (Kondolf 1995).

By analyzing aerial photos, topographic maps, and aerial video footage of the entire length of Deer Creek, eleven distinct reaches were identified. **Figure 2.1** shows the reach divisions in upper Deer Creek. Reach divisions correspond with significant slope breaks, adjusted slightly to allow easy identification in the field. For this chapter Scotts Flat reservoir refers to both upper and lower Scotts Flat (Scotts Flat dam and Deer Creek Diversion Dam).

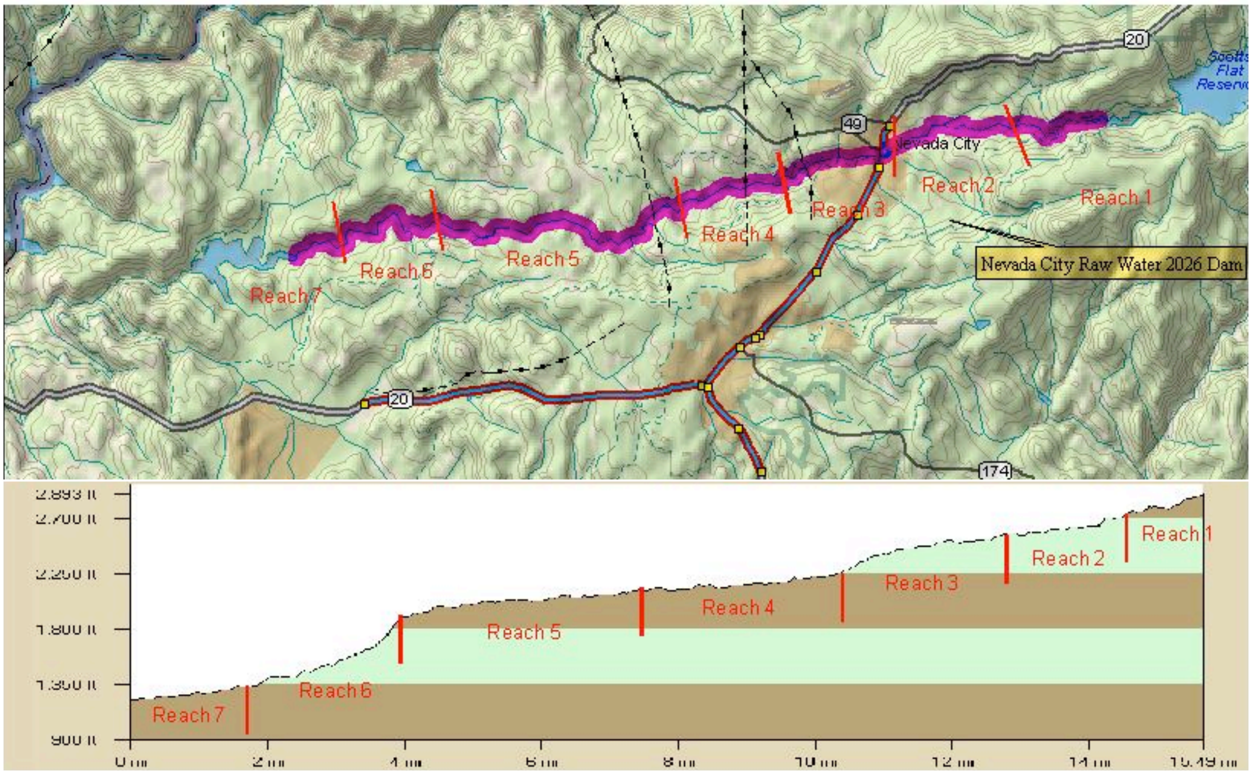


Figure 2.1: Plan View of Reach Divisions along the Main stem of Deer Creek, from lower Scotts Flat Reservoir downstream to Lake Wildwood Reservoir

Seven reaches were identified in upper Deer Creek (Scotts Flat to Lake Wildwood):

Reach 1: Lower Scotts Flat Reservoir to Willow Valley Creek

- Upstream Elevation: 2884 ft
- Downstream Elevation: 2624 ft
- Change in Elevation: 260 ft
- Linear Distance: 9030 ft
- Average Slope: 0.028

Reach 2: Willow Valley Creek to Little Deer Creek

- Upstream Elevation: 2624 ft
- Downstream Elevation: 2475 ft
- Change in Elevation: 149 ft
- Linear Distance: 11460 ft
- Average Slope: 0.013

Reach 3: Little Deer Creek to Providence Mine Road

- Upstream Elevation: 2475 ft
- Downstream Elevation: 2182 ft
- Change in Elevation: 293 ft
- Linear Distance: 11040 ft
- Average Slope: 0.027

Reach 4: Providence Mine Road to Little Deer Creek Lane

- Upstream Elevation: 2182 ft
- Downstream Elevation: 2108 ft
- Change in Elevation: 74 ft
- Linear Distance: 10670 ft
- Average Slope: 0.0069

Reach 5: Little Deer Creek Lane to Tunnel Ditch

- Upstream Elevation: 2108 ft
- Downstream Elevation: 1940 ft
- Change in Elevation: 168 ft
- Linear Distance: 16740 ft
- Average Slope: 0.010

Reach 6: Tunnel Ditch to Paddy Flats

- Upstream Elevation: 1940 ft
- Downstream Elevation: 1330 ft
- Change in Elevation: 610 ft
- Linear Distance: 14100 ft
- Average Slope: 0.043

Reach 7: Paddy Flats to Wildwood Reservoir

- Upstream Elevation: 1330 ft
- Downstream Elevation: 1216 ft
- Change in Elevation: 114 ft
- Linear Distance: 8450 ft
- Average Slope: 0.013

Four reaches were identified in lower Deer Creek (Lake Wildwood to the Yuba River):

Reach 8: Lake Wildwood Reservoir Spillway to one mile downstream of Lake Wildwood Wastewater Treatment Plant (WWTP)

- Upstream Elevation: 1130 ft
- Downstream Elevation: 945 ft
- Change in Elevation: 185 ft
- Linear Distance: 2,799 ft
- Average Slope: 0.066

Reach 9: Downstream of Lake Wildwood WWTP to Squirrel Creek

- Upstream Elevation: 945 ft
- Downstream Elevation: 802 ft
- Change in Elevation: 143 ft
- Linear Distance: 6,515 ft
- Average Slope: 0.0219

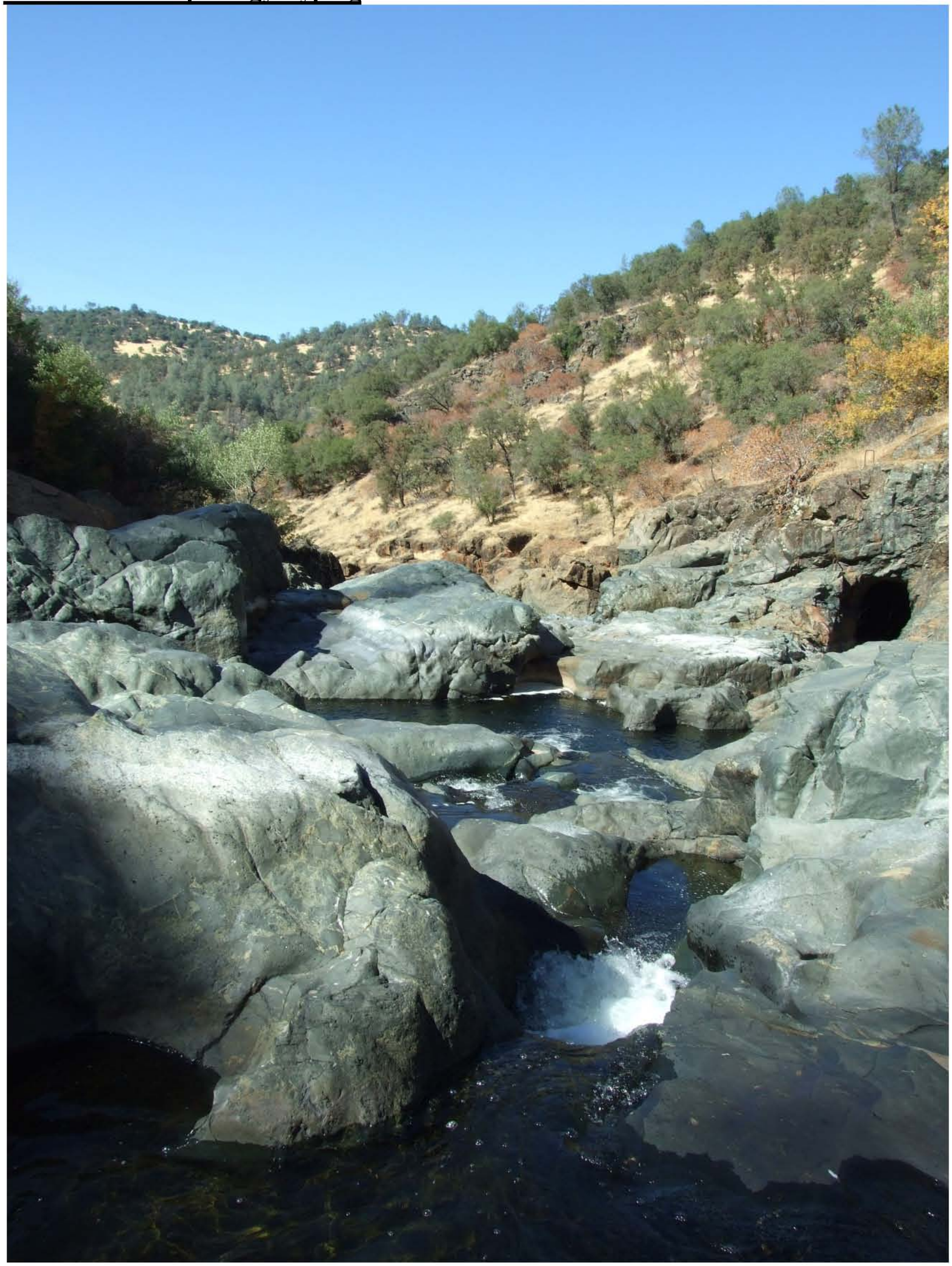
Reach 10: Squirrel Creek to Mooney Flat Rd bridge

- Upstream Elevation: 802 ft
- Downstream Elevation: 625 ft
- Change in Elevation: 177 ft
- Linear Distance: 8,905 ft
- Average Slope: 0.0199

Reach 11: Mooney Flat Rd bridge to Yuba River

- Upstream Elevation: 625 ft
- Downstream Elevation: 280 ft
- Change in Elevation: 345 ft
- Linear Distance: 4,774 ft
- Average Slope: 0.0723

D. Channel Morphology Typing



Justin Wood

Within each of the reaches described above, the channel morphology type was determined as part of the field assessment. The most appropriate classification system for channel type morphology for Deer Creek is the Montgomery-Buffington classification of channel-reach geomorphology in mountain drainage basins (Montgomery and Buffington 1997), which offers a "process-based framework within which to assess channel condition and response potential." Mountain drainages exhibit seven channel morphologies: colluvial, bedrock, cascade, step pool, plane bed, pool riffle, and dune riffle. Five classifications are represented in **Figure 2.2**.

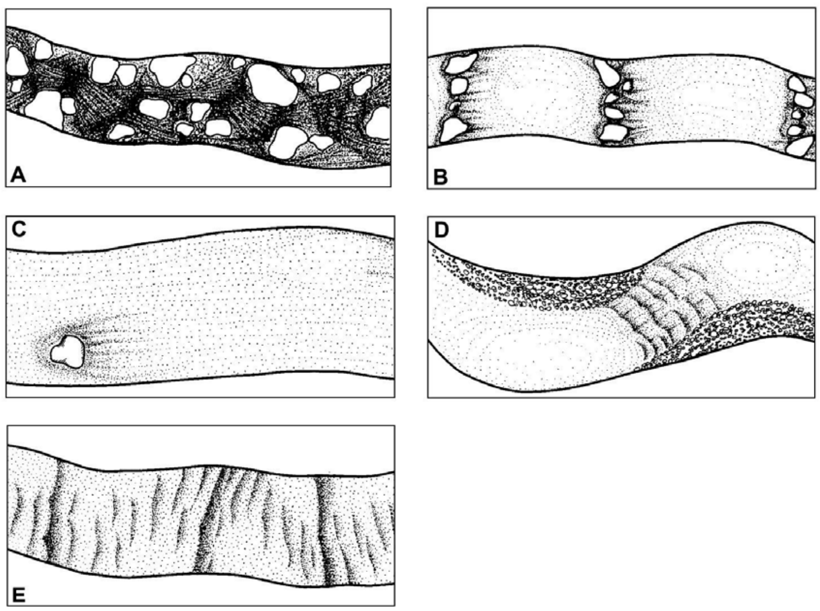


Figure 2.2: Schematic Plan Form of Mountain Stream Channel Classifications: **A)** Cascade; **B)** Step Pool; **C)** Plane Bed; **D)** Pool Riffle; **E)** Dune Riffle (Reprinted from Montgomery and Buffington 1997).

Examples of these channel types on Deer Creek are shown in **Figures 2.3, 2.4, 2.5, 2.6,** and **2.7**. Note that Deer Creek does not feature Dune Riffle habitat, Type E.

Figure 2.3: Example of a cascade reach **(Type A)**, one mile downstream of Scotts Flat

Figure 2.4: Example of a step pool reach **(Type B)**, ¼ mile downstream of Scotts Flat

Figure 2.5: Example of plane bed reach, **(Type C)**, ¼ mile upstream of Bitney Springs Road

Figure 2.6: Example of a riffle pool reach **(Type D)**, ½ mile upstream of Bitney Springs Road

Figure 2.7: Bedrock reach, ¾ mile downstream of Scotts Flat

E. Sediment Transport

Kyle Leach

Introduction

As mentioned above, several attributes of healthy rivers are a function of sediment transport and deposition dynamics, including in bedrock reaches. These attributes are as follows:

- Bedrock rivers exhibit nested depositional features.
- Episodic sediment delivery enhances spatial complexity.
- Biological hotspots occur in reaches with significant deposits, gravel bars and floodplain habitat.

And in depositional reaches:

- The channel bed surface is frequently mobilized.
- Alternate bars must be periodically scoured deeper than their coarse surface layers.
- Alluvial channels are free to migrate.
- Diverse riparian plant communities are sustained by the geomorphic effect of natural annual hydrograph components.

It is important therefore to understand the sediment transport and deposition dynamics of Deer Creek to determine whether the attributes of a healthy creek are being sustained and where augmentation is needed to restore function. Low flows, which occur most of the time, transport relatively minor amounts of bedload sediment because the bedload transport rate is near zero. Very large flood flows, although having the highest transport rates, account for relatively minor amounts of bedload sediment because high flows occur infrequently and are generally of short duration. Consequently, the largest proportion of the total bedload is transported by flows around the peak of the total bedload transport curve (i.e., the effective discharge). In many rivers, bankfull discharge approximates effective discharge.

Conceptually, the required maintenance flow regime begins at a discharge at which gravels making up the bed of the channel begin to move and includes all flows up to and including the 100-year flow. This range of flows should sustain the attributes of healthy functions listed above, including: mobilize the channel bed sediment, scour alternate bars deeper than their coarse surface layers, scour vegetation from the channel, partially inundate the floodplain, and provide high flow functions needed to sustain streamside vegetation (Schmidt and Potyondy 2004).

Methods

For the purpose of evaluating whether current flows are of sufficient magnitude to sustain healthy river attributes, it was assumed that mobilization of the median sized sediment (D_{50}) would represent mobilization of some portion of the bed. It was assumed that the mobilization of the D_{84} sized sediment would represent mobilization of the channel bed as a whole.

Sediment supply thresholds were evaluated using a combination of field observations and calculations. Field data were collected at six sites on the main stem of upper Deer Creek, at four sites on lower Deer Creek, and one site on Squirrel Creek. Data were collected at each site generally according to the methods described in Harrelson *et al.* (1994) and included channel cross sections, longitudinal profile, channel substrate size, high-water marks and water surface elevations. Channel substrate size was determined by pebble counts (Wolman 1954). The sediment transport estimates are based on the investigations of Sagan and Bagnold (1975) and Leopold, Wolman and Miller (1964). The approach is based on observations of the mobilization of channel substrate as a function of water depth and channel slope.

In addition to the field data and observations, dredged material data from Lake Wildwood reservoir was analyzed to investigate the annual amount of sediment transported into Lake Wildwood reservoir. Examining records of sediment excavated from Lake Wildwood during reservoir maintenance and dredging operations can provide estimates of the amount of sediment currently transported by Deer Creek.

Results

Upper Deer Creek

Table 2.1 indicates that at the majority of sites, three of the key attributes of good geomorphic function (*i.e.,* D_{50} is mobilized every 1-2 yrs, D_{84} is mobilized every 5-10 years and the floodplain is inundated every 1-2 years) are accomplished much less often than is considered necessary for a properly functioning river. With the exception of the Nevada City Wastewater Treatment Plant, where D_{50} and D_{84} material would be expected to be mobilized at the ideal frequency, and the Upper Stocking Flat location, where D_{50} sediments are mobilized at a good frequency, none of the other sites achieve the desired frequency for any of the three attributes. Only at FODC/SSI site 5 does the floodplain get inundated at relatively close to the ideal frequency. This indicates that overall, upper Deer Creek is not healthy and functioning from a geomorphic perspective, and that flow augmentation could serve as a way to restore health and function to the creek.

Site No.	Site name	Frequency D_{50} mobilized (yrs) (1 – 2 yrs is ideal)	Frequency D_{84} mobilized (yrs) (5 – 10 yrs is ideal)	Frequency floodplain is inundated (yrs) (1 – 2 years ideal)
1	Scotts Flat	2 – 5	25 – 50	no floodplain
2	FDC #2	10	50 – 100	10
3	NC WWTP	1	5 – 10	no floodplain
4	Providence	2 – 5	100	10 – 25
5	Upper Stocking	1 – 2	50 – 100	10 – 25
6	Lower Stocking	5 – 25	50 – 100	5 – 10
7	FDC #5	2 – 5	10 – 25	2 – 5
8	FDC #6	10 – 25	50 – 100	no floodplain

Table 2.1: Summary of substrate mobilization and floodplain inundation frequencies in upper Deer Creek.

Lower Deer Creek and Squirrel Creek

Three cross sections were surveyed at site 8, site 16, site 9, and site 10, with two cross sections surveyed at the LWW Weir. The data in **Table 2.2** summarize the results from all cross sections at each site, which explains why there is a large frequency range for some of the attributes. **Table 2.2** indicates that at the majority of sites surveyed in lower Deer Creek and Squirrel Creek, key attributes of good geomorphic function are accomplished within the necessary frequency for a properly functioning river.

Site (Reach)	Frequency D_{50} mobilized (1 – 2 years ideal)	Frequency D_{84} mobilized (5 – 10 yrs is ideal)	Frequency floodplain is inundated (1 – 2 yrs is ideal)
LWW Weir (Reach 8)	1 – 2	5 – 10	5 – 10
Site 8 (Reach 9)	2 – 5	5 – 25	2 – 10
Site 16	1 – 2	5 – 10	2 – 5
Site 9 (Reach 10)	1 – 5	10 – 25	2 – 5
Site 10 (Reach 10)	1 – 2	2 – 10	2 – 5

Table 2.2: Summary of substrate mobilization and floodplain inundation frequencies in lower Deer Creek and Squirrel Creek.

The data indicate that the Lake Wildwood Weir site, immediately downstream of Lake Wildwood Reservoir, is accomplishing two of the three geomorphic functions: The D_{50} and D_{84} are mobilized at an ideal frequency. However, the floodplain is inundated every five to ten years, instead of at the ideal frequency of one to two years, indicating that floodplain connectivity in this reach could be improved. This may be in part due to the road and developments that exist downstream of the spillway, with the road having been built up over time and armored with large rocks, which prevents access to the floodplain in some locations.

At site 8 the frequency at which the D_{50} and D_{84} are mobilized is within the ideal range at some cross sections, as indicated by the overlap between the expected and ideal years, but not at every cross section. This indicates that the D_{50} and D_{84} are being mobilized at the ideal frequency. The same situation occurs with regards to floodplain inundation, as there is an overlap between the ideal and expected frequencies. This suggests that the floodplain at site 8 could be inundated at the ideal frequency in some locations.

The data for site 16 on Squirrel Creek suggest that all three geomorphic attributes are being accomplished at the ideal frequency. Mobilization of the D_{50} and D_{84} is expected within the ideal frequency at each of the cross sections. Inundation of the floodplain is predicted at a frequency of two to five years, which suggests that the floodplain may or may not be inundated at the ideal frequency. Overall the data point to good geomorphic health and function in this section of Squirrel Creek, a tributary with no major dams.

The data for site 9 indicate that all three geomorphic attributes are being accomplished at the ideal frequency, with expected frequencies that overlap the ideal frequency for each attribute. Mobilization of the D_{50} is predicted to occur every one to five years, which suggests that the D_{50} could be mobilized at the ideal frequency. Mobilization of the D_{84} is expected to occur every ten to twenty-five years, which is just outside the ideal frequency and suggests that the D_{84} is not mobilized at an ideal frequency. The floodplain at site 9 could be inundated at the ideal frequency in some locations, indicating there is adequate floodplain connectivity in this section of Deer Creek.

At site 10 the data suggest that all three geomorphic attributes are accomplished within the ideal frequency, with the D_{50} and D_{84} mobilized at the ideal frequency. Inundation of the floodplain at site 10 is expected every two to ten years, which indicates there is potential for the floodplain to be inundated within the ideal frequency, but it is likely that floodplain connectivity is less than ideal based on the expected range.

Lake Wildwood Reservoir Sediment Transport Estimates

Figure 2.8 shows the volume of annual sediment excavated from Lake Wildwood reservoir since 1986. The average volume excavated per year is 12,300 yd^3, and consists of a combination of suspended and bedload sediment. It is important to note that the Lake Wildwood managers do not completely remove all of the sediment that is transported into the reservoir, with the area of excavation typically focused on the upstream end of the reservoir, and the finest material transported beyond this zone of excavation, particularly during the extreme flood events. 2008 was the first year that other portions of the reservoir were dredged for sediment, all of which consisted of very fine material. Thus, the excavation data likely underestimate the amount of sediment transported by Deer Creek into Lake Wildwood.

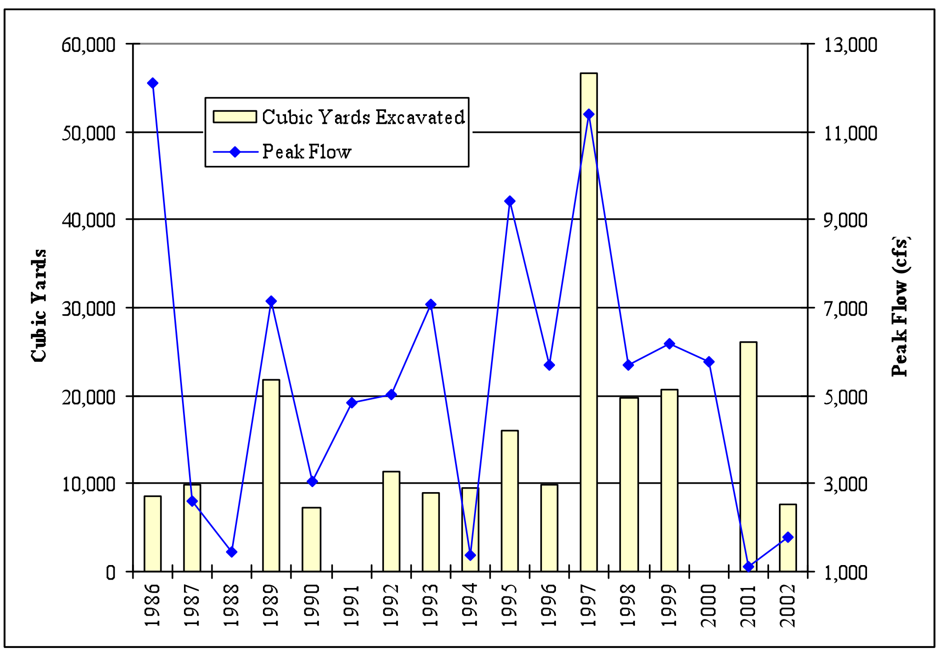


Figure 2.8: *Amount of sediment excavated from Lake Wildwood compared to annual peak flows on Deer Creek at the Smartsville Gage (USGS #11418500)*

Lake Wildwood is approximately 15.5 miles downstream of the Scotts Flat reservoir complex, and the watershed area between the two dams is approximately 36 mi^2. Based on the Lake Wildwood excavation data, the average sediment yield therefore is 342yd^3/mi^2 each year, or approximately 764 tons/mi^2/yr. The maximum amount of sediment transported in one year occurred in 1997 when Deer Creek transported 56,000 yd^3, or 1555 tons/mi^2, enough sediment to cover the 36 mi^2 portion of the watershed to a depth of 0.6 in. By contrast, during the 19th century hydraulic mining era, the Deer Creek drainage produced enough sediment to cover the entire watershed in 4.7 inches of sediment (Heur 1891; Gilbert 1917 in Allan 1999). The average sediment yield rate of 764 tons/mi^2 is less than the average yield rate estimated for California of 1,300 tons/mi^2 (Dunne and Leopold 1978). The USGS estimated that the Yuba River sediment yield is approximately 970 tons/mi^2/yr (Snyder et. Al. 2004). Residual stores of sediment generated during the mining era also affect transport in the Yuba River drainage. The climate, unstable bedrock, rate of geologic uplift, and land use within California's watersheds produce the highest yields of sediment in the country and some of the highest in the world (Mount 1995).

Discussion

The sediment transport estimates indicate that most of the sites on upper Deer Creek are not exhibiting the geomorphic attributes of a healthy and functioning creek, while sites on lower Deer Creek and Squirrel Creek generally are functioning and healthy from a geomorphic perspective. This is evident by the number of sites on upper Deer Creek that do not meet the ideal frequency for D_{50} or D_{84} mobilization and floodplain inundation, with only two sites mobilizing the D_{50} at the ideal frequency, one site mobilizing the D_{84} at the ideal frequency, and no sites that inundate the floodplain at the ideal frequency. Only the Nevada City WWTP site accomplishes the mobilization attributes, and there is no floodplain present at this location to evaluate floodplain inundation. The low frequency with which substrates are mobilized and floodplains are inundated in upper Deer Creek reduces the health and productivity of the Deer Creek watershed overall and indicates the need for restoration of the natural flow regime to restore the geomorphic attributes of the creek. The low frequency of these events is primarily caused by three factors:

1. Scotts Flat reservoir reduces the magnitude of flows for floods in the 2 – 10 year frequencies.
2. Scotts Flat eliminates the supply of sediment from the watershed upstream of the reservoir, resulting in the coarsening of sediment downstream of the dam. This results in higher flows being required to mobilize the dominant substrate in the channel.
3. Residual debris from the mining era remains at many locations in terraces above the stream channel, from Scotts Flat downstream to Lake Wildwood reservoir, which limits the capacity for floodplain inundation.

The sites on lower Deer Creek do not appear to be as impacted by Scotts Flat as sites on upper Deer Creek, likely due to increasing watershed area and contributions of sediment and stream flow from numerous perennial tributaries. In lower Deer Creek several sites accomplish the mobilization attributes and inundate the floodplain at an ideal frequency, with three sites mobilizing the D_{50} at the ideal frequency, three sites mobilizing the D_{84} at the ideal frequency, and two sites inundating the floodplain at within the ideal frequency. Squirrel Creek is unaffected by Scotts Flat reservoir, with minimal impacts to sediment transport capacity in Squirrel Creek near the Deer Creek confluence.

The data indicate there is a fundamental difference in geomorphic attributes when comparing upper Deer Creek with lower Deer Creek and Squirrel Creek. Squirrel Creek is an undammed tributary and thus is able to flow freely from its headwaters to the confluence with Deer Creek, which allows for natural sediment transport and deposition processes to occur. On Deer Creek downstream of Lake Wildwood reservoir there is a sufficient volume of flow to mobilize the creek bed and inundate the floodplain at an ideal frequency, likely due to increased distance from Scotts Flat reservoir. The farther downstream from Scotts Flat reservoir, the larger the watershed area that is contributing flow to Deer Creek, with numerous additional tributaries contributing flow that helps mobilize sediments and inundate the floodplain. The bed downstream of Lake Wildwood has not coarsened to the same extent as the reach downstream of Scotts Flat and is still capable of being mobilized at desired frequencies. This could possibly be attributed to the type or purpose of each dam and the duration each dam has been in existence. Scotts Flat reservoir was constructed before Lake Wildwood reservoir and serves to capture water, which reduces flows directly downstream of Scotts Flat when the reservoir is not at full capacity, and leads to bed coarsening. The tall, steep spillway at Scotts Flat promotes scour of Deer Creek, whereas the spillway at Lake Wildwood is not as tall or steep and has a large pool at its base, which leads to less bed scour than downstream of Scotts Flat. Lower Deer Creek and Squirrel Creek do not have as much evidence of remnant mining debris as does upper Deer Creek in the form of tailings and debris piles, and therefore have the capacity for floodplains to be inundated at an ideal frequency. This could be due to the steep, bedrock nature of much of lower Deer Creek, leading to transport reaches that have blasted the mining sediment downstream and into the Yuba, without leaving any terraces in the more gradual depositional stretches of creek.

F. Floodplain Connectivity

Introduction

As described above in the sediment transport section, one of the attributes of a healthy river is that the floodplains are frequently inundated (Trush et al. 2000). Floodplains are the engines of biological activity in river systems. Flooding of riparian areas delivers much needed sediment and nutrients to the floodplain, scours and prepares the floodplain surface for pioneer species, provides rearing habitat for key fish species, and delivers nutrients back into the main channel. The frequency, timing, and magnitude of flooding have profound impacts on the type of vegetation and habitat that exist in the riparian areas. Ideally, alluvial rivers in California would experience overbank flooding every 1-2 years. Whether or not this occurs is a function of the shape, size, and roughness of the channel, and the stream hydrograph, all of which have been altered in Deer Creek. Hydraulic mining contributed massive amounts of sediment to Deer Creek, some of which is still stored in its channel and floodplains in locations such as Providence Mine and Stocking Flat (**Figure 2.9**).

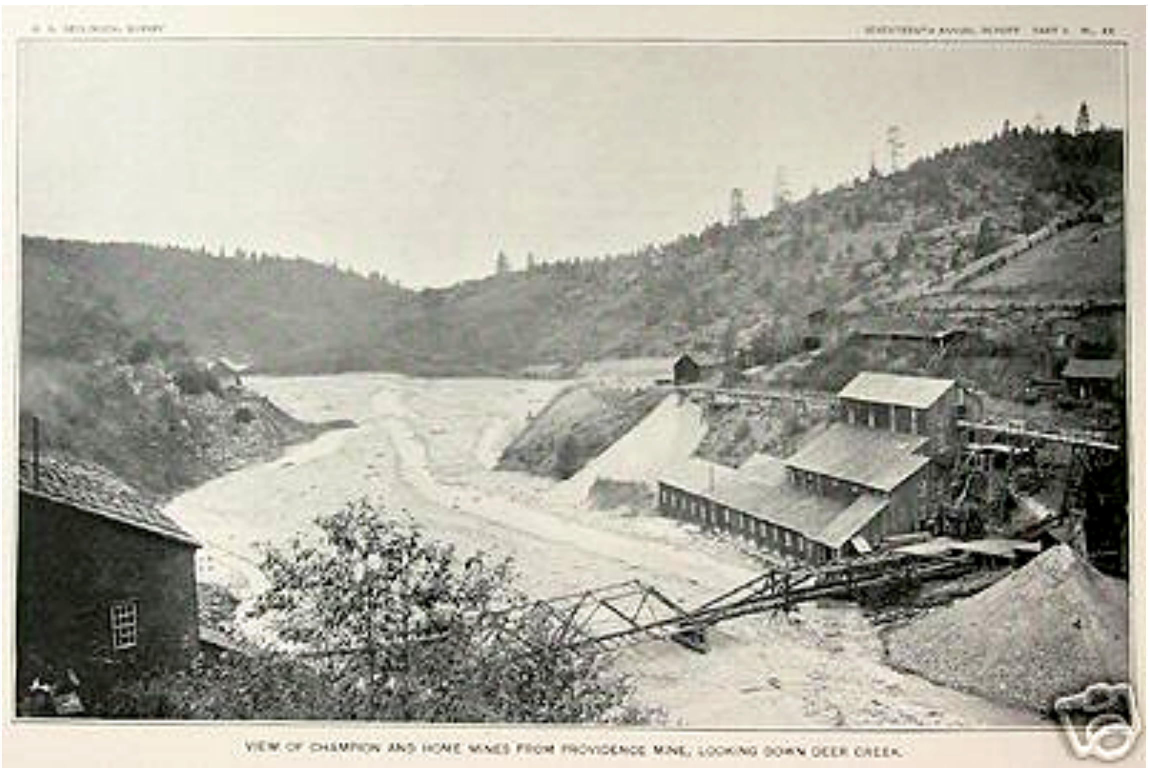


Figure 2.9: Massive amounts of sediment in the Deer Creek channel at the height of the mining era. This photo is of Deer Creek at Champion Mine, 1.5 miles West of Nevada City, circa 1880.

Methods and Results

Analysis was conducted on the frequency of floodplain inundation in the Deer Creek watershed. This was accomplished by surveying several cross sections along Deer Creek and Squirrel Creek and comparing that with the high flow events of varying return intervals. By examining aerial photographs and surveying the creek from the over flight, most of the likely floodplains in the study area were identified. Cross sections were selected to provide a reasonable representation of the floodplain types in the Deer Creek watershed. The results of this analysis are provided in **Table 2.3.**

The results indicate that in many sections of upper Deer Creek between Scotts Flat and Lake Wildwood reservoirs, the floodplain is not inundated as frequently as it should be. The data indicate that the floodplains are inundated more frequently on lower Deer Creek downstream of Lake Wildwood and on the undammed Squirrel Creek. On upper Deer Creek the impacts of water management and mining are quite apparent, with abandoned floodplain terraces that are not appropriately scoured, seeded, and inundated by frequent small floods. This is evident at the Providence Mine and Stocking Flat locations. Only two of the nine survey locations on upper Deer Creek have a floodplain that is inundated at the ideal frequency. Terraces of mining rock and debris have been abandoned due to channel incision and post-mining degradation, with NID flow management compounding the problem by reducing small floods with a return interval of 2 – 10 years. In lower Deer Creek and Squirrel Creek impacts are not as severe, with four of five surveyed floodplains inundated within the ideal frequency.

Floodplains in lower Deer Creek are inundated more frequently than those in upper Deer Creek. There is minimal evidence of mining rock and debris in lower Deer Creek and Squirrel Creek, with no large areas of hydraulic mining deposits or tailing piles that have led to abandoned floodplain terraces. Additionally Squirrel Creek is an undammed tributary and lower Deer Creek benefits from a large watershed area downstream of Scotts Flat reservoir, thus allowing small floods to occur in these reaches of creek more frequently than in upper Deer Creek. The LWW Weir site is the only location on lower Deer Creek at which floodplain inundation does not occur at the ideal frequency. This could be attributed to road and other infrastructure developments in the floodplain at the LWW Weir site, with the road built up above the floodplain and thus preventing access to the historic floodplain. Additionally the creek has been forced to adjust to the construction of the Lake Wildwood dam and spillway, which likely altered floodplain connectivity in this reach of Deer Creek.

Location	Flow to Inundate Floodplain (cfs)	Return Interval (yrs)	Adequate Return Interval?
Site 2	2100	50	No
Providence XS #1	3600	50	No
Providence XS #2	5800	100	No
Upper Stocking XS#1	1976	2	Yes
Upper Stocking XS#2	3250	50	No
Lower Stocking #1	4026	50	No
Lower Stocking #2	2525	20	No
Lower Stocking #3	3250	35	No
Site 5	1200	2	Yes
Lake Wildwood Weir	2808	5 – 10	No
Site 8	2048	2 – 10	Maybe
Site 16	1012	2 – 5	Yes
Site 9	2086	2 – 5	Yes
Site 10	3070	2 – 5	Yes

Table 2.3: Frequency of floodplain inundation on Deer and Squirrel creeks.

Discussion

Impacts from mining and water management have altered floodplain connectivity in the Deer Creek watershed, with numerous floodplains no longer inundated at the ideal frequency for maintaining the health and function of the creek. Floodplains are most impacted in and around Nevada City for many reasons including mining and water management. At site 2 a major road prevents Deer Creek from accessing its historic floodplain on river right. At Providence Mine and Stocking Flat, excess mining debris has choked the channel and caused floodplain terraces to become abandoned, with NID flow management preventing small floods that would help maintain floodplain connectivity. Flow management has promoted creek incision into the mining deposits, which has resulted in abandoned floodplain terraces high above the creek channel. Stocking Flat is the largest depositional floodplain in the Deer Creek watershed. In mountain streams, where so much of the biotic activity occurs in depositional reaches and occasional large floodplains, it is critical that the floodplains function properly, which is clearly not the case in the majority of upper Deer Creek.

In lower Deer Creek there is no evidence of hydraulic mine tailing piles, as are found in upper Deer Creek, to limit access to the floodplain. There are also no large depositional areas such as Stocking Flat located on lower Deer Creek, with much of the habitat consisting of bedrock dominated transport reaches. Lower Deer Creek is also farther downstream from Scotts Flat, and in some sections has the flow contribution from the undammed Squirrel Creek, thus alleviating impacts associated with flow management to some degree, as small floods occur closer to the historic frequency. The Lake Wildwood Weir is the only site where the floodplain is not inundated at the ideal frequency, as development of a road on river left has limited floodplain connectivity.

G. Recommendations

Michael O'Connor

❖ **Expand hydrological and geomorphological monitoring in the Deer Creek watershed.**
In order to better understand the geomorphic and hydrologic function of Deer Creek, it is essential to collect additional hydrologic and geomorphic data. Recording stream gauges should be installed throughout the watershed, with attempts to gauge major tributaries and sections of creek near reservoirs, cities, and NID diversion points. Geomorphological monitoring should focus on expanding to major tributaries and sections of Deer Creek that were not surveyed as part of this project. This includes the north and south forks of Deer Creek upstream of Scotts Flat reservoir, Squirrel Creek, Clear Creek, Grub Creek, Gold Run Creek, and Slate Creek.

❖ **Monitor Stocking Flat for overbank flooding (timing, frequency, extent, duration), and changes in geomorphology and vegetation.**
The reach is easily accessible and has several documented cross-sections that can be used to monitor changes to geomorphology over time. In addition to monitoring the floodplain at Stocking Flat, an automatic stream gauge should be installed to collect hydrological data in this reach.

- **Further investigate the extent of floodplain problems, such as connectivity and disturbance, in the Deer Creek watershed; address the problem associated with the infrequency of floodplain inundation.**

  To advance geomorphic restoration goals, more investigation is needed into the extent that floodplain problems are caused by historic mining practices or other factors, and the opportunities and constraints on removing hydraulic debris terraces to restore floodplain connectivity. To address the problem associated with the lack of frequent floodplain inundation, two approaches could be employed. First, during storm events, releases from Scotts Flat could be increased enough to inundate floodplains on an average frequency of once in two years. The level of flow increase required would range from 500 – 4,000 cfs depending on location. At locations requiring increases of more than 1,000 cfs, floodplains are likely artificially elevated as a result of residual mining debris. At these locations floodplains have essentially become terraces, abandoned as the river cut down through mining deposits. In these locations the second approach could be employed: reshaping the river channel using heavy equipment to create a channel that reflects the altered hydrology and sediment supply of today. This approach has been used on the Trinity River, which has a mining and dam building history not unlike Deer Creek. On the Trinity, managers re-graded significant areas of abandoned floodplain terraces down to elevations that are now flooded on a regular basis. Initial attempts to re-grade the floodplain at Stocking Flat began in 2009, but the project is currently on hold because the property owners, the Bureau of Land Management, found that there was mercury stored in the floodplain, which could potentially methylate with restored floodplain inundation. In addition to the floodplain at Stocking Flat a large floodplain exists on a downstream property near Lake Wildwood reservoir, where the landowners are open to restoration of their property and the creek. Opportunities to restore the health and function of Deer Creek at this location should be pursued, since the landowners have been very supportive of the work of FODC/SSI.

- **Implement gravel augmentation projects downstream of reservoirs in the watershed.**

  Downstream of both Scotts Flat and Lake Wildwood reservoirs a sediment supply deficit exists, due to the dams capturing the majority of sediment, which would have historically been transported to downstream reaches. While gravel supplies have been depleted in the bedrock section just downstream of lower Scotts Flat dam, the lack of channel downcutting and difficulty of access make gravel augmentation a low priority at this location. Reaches downstream of Lake Wildwood Reservoir, including at the spillway (Lake Wildwood Weir), site 8, and site 10, are a high priority for gravel augmentation and habitat restoration, based upon ease of access and permission from landowners, lack of adequate in-stream habitat, and importance of aquatic habitat to critical species such as Chinook salmon and steelhead. A pilot gravel augmentation project is scheduled for implementation during summer 2011 at site 10, and the results from this project will inform larger scale gravel augmentation work in the lower Deer Creek watershed.

- **Restore sediment transport capacity to the Deer Creek watershed.**
  To address the problem associated with mobilizing substrates in upper Deer Creek and at the Lake Wildwood weir site, two methods could be used. First, releases from Scotts Flat reservoirs could be increased during certain storm events to reach mobilization thresholds. During 2-year events, flows would need to be increased by at least 400 cfs, and for 10-year events flows should be increased by at least 1000cfs. Second, certain reaches with significant riffle habitat could be "mechanically mobilized," a strategy used in restoration efforts downstream of dams on streams that support anadromous fish such as salmon and steelhead. Mechanical mobilization involves using tractors pulling implements that rip up the top layer of gravel bars to facilitate mobilization when significant flow events occur. This, combined with supplementation of gravels through gravel augmentation, would reduce the dominant size of channel substrates, and would reduce the flows at which substrates would be mobilized.

- **Restore a natural hydrograph to main stem Deer Creek.**
  The absence of a natural hydrograph results in reduced winter flood flows, reduced spring flows, and increased summer low-flows. The reduction in winter flood flows and spring flows leads to a decrease in the frequency of floodplain inundation. This, combined with increased summer low-flows, results in a narrow band of riparian vegetation in many portions of upper Deer Creek. Restoring the natural hydrograph would promote floodplain inundation, disturbance of the floodplain surface, deposition of silt and sands, and deposition of seed sources, all of which would promote the health and function of the riparian zone.