Hydrology of Deer Creek and its Tributaries

A Contribution to Planning a Restoration Project

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Abstract

The Natural Heritage Institute, in collaboration with Friends of Deer Creek, is preparing a stream restoration proposal for Deer Creek in Nevada County, California. The restoration plan focuses on the mainstem of Deer Creek between Scotts Flat Reservoir and Lake Wildwood. Establishing a clear picture of the hydrology of the creek and its tributaries is essential for drafting a restoration plan.

For the mainstem of Deer Creek, I developed a flood frequency curve from USGS gauge data on Deer Creek itself and on the nearby Oregon Creek. Oregon Creek's topography, elevation, orientation, and size are similar to that of Deer Creek, so Oregon Creek is an appropriate instrument for Deer Creek. I use Oregon Creek gauge data to estimate 'natural' flows on Deer Creek, because Oregon Creek is a free flowing stream. I use the gauge data on Deer Creek itself to calculate current flows.

Deer Creek's tributaries are ungauged, so there are no flow records that can be analyzed to estimate flows and to develop flood frequency curves. I collected and analyzed survey data to estimate bankfull flows on the tributaries to Deer Creek, and used two methods to calculate flows with return intervals of 2, 5, 10, 25, 50 and 100 years. The first method is Waananen and Crippen's regional flood frequency relation, requiring inputs of drainage area, mean annual precipitation, and an altitude index. The second method of estimating flows, developed by Hedman and Osterkamp, relies on channel geometry and on classifying a stream according to its vegetation and climate. Comparing the total discharge from the tributaries with the discharge from the mainstem of Deer Creek for each return interval of interest shows that my estimates are reasonable: for both methods, the combined flows from the tributaries are less than the flow on Deer Creek.

NHI will use the results of this analysis, along with information on the geomorphology, riparian and stream habitats, benthic macroinvertebrates, and water quality, in formulating the Deer Creek restoration plan.

Introduction:

The Natural Heritage Institute (NHI), a non-profit environmental organization focusing on natural resources management, with help from Friends of Deer Creek (FDC), a community stewardship organization, is preparing a restoration plan for Deer Creek in Nevada County, California.

Deer Creek and its watershed do not appear blighted compared with some urban creeks or heavily managed rivers; nevertheless, dams, water diversions and import, urbanization, and the legacy of gold mining have affected the health of Deer Creek. Dams and water diversions and import alter the hydrology and water chemistry of Deer Creek, and disrupt sediment transport. There are three dams on Deer Creek. The dams that form Deer Creek Reservoir and Scotts Flat reservoir were both built in 1949, and the dam that forms Lake Wildwood was built in 1970. There are two hydroelectric power plants on Deer Creek. Nevada Irrigation District (NID) operates a 0.875 megawatt plant on Scotts Flat Reservoir, and Pacific Gas and Electric Company (PG&E) runs a power plant near Smartville, where the US Geological Survey (USGS) has a stream flow gauge. There are three water diversion canals that convey water away from the mainstem of Deer Creek, as well as one water import canal from the South Yuba River into Deer Creek. (Figure 1: USGS schematic, Diversions and storage in South Yuba River Basin).

Development in the foothills of the Sierra Nevada is a direct result of the 130 percent population increase in the region from 1970 to 1990 (Duane p.176). Urbanization alters the hydrology of a watershed, affecting the infiltration and runoff rates, and also changes the sediment and pollution inputs. Like many rivers and streams in California's Gold Country, Deer Creek has a legacy of hydraulic mining, which includes altered geomorphology and sediment transport, and changes in water chemistry from toxics such as arsenic and mercury (NHI, 2005).

NHI's proposed restoration plan focuses on the mainstem of Deer Creek between Scotts Flat Reservoir and Lake Wildwood. In addition to hydrology, NHI has identified the following areas for data and information collection: geomorphic form and function, riparian habitat, stream habitat, benthic macroinvertebrates, and water quality. My contribution to the process of planning a restoration project was assisting NHI with the surveying of the tributaries of Deer Creek, and analyzing the collected data to form some conclusions about the hydrology of Deer Creek. I also analyzed USGS stream flow data for the mainstem of Deer Creek.

There are six tributaries to the mainstem of Deer Creek near Nevada City, along the reach that will be restored. (Figure 2: Study Area.) The tributaries to Deer Creek are ungauged. The mainstem has two USGS gauges, though neither is on the stretch that will be included in the restoration project. Estimating flows on the tributaries is necessary to get a clear picture of the flows on Deer Creek itself. My fieldwork consisted of surveying four tributaries to Deer Creek: Willow Valley Creek, Little Deer, Eagle Ravine Creek, and Woods Ravine Creek. NHI has already surveyed the other two tributaries, Mosquito Creek and Gold Run, and I obtained this data from them.

The objective of my study was to apply estimation techniques to develop flow duration and flood frequency curves, and to estimate bankfull discharge—hydrologic metrics for use in restoration planning. The estimates represent naturally occurring flows on Deer Creek, flows in absence of water diversions or import, and I compare these with current flows on Deer Creek.

Methods:

My fieldwork consisted of longitudinal and cross section surveys, measuring flows, and documenting channel and water conditions on four tributaries to Deer Creek. From the longitudinal profile I obtained water surface slope, which I used in calculating discharge. To survey each long profile I walked in or along the channel, and observed and recorded channel characteristics. For each tributary, I surveyed cross sections (three for Willow Valley Creek, two on the other tributaries), and at each cross section recorded the water depth and velocity measured with a flow meter. Although primarily intended to provide information on the hydrology of Deer Creek, the level surveys also provide information useful for determining the geomorphology of the creek.

In addition to the fieldwork, I analyzed stream flow data available from the USGS to estimate natural and current flows on the mainstem of Deer Creek.

Flood Frequency:

Mainstem of Deer Creek:

Deer Creek has two USGS gauges on it, one next to the PG&E powerhouse near the town of Washington (USGS Gauge #11414205), and one on the mainstem near Smartville (USGS Gauge #11418500). The first gauge data is not useful in developing a flood frequency curve for Deer Creek because the gauge records discharge from the powerhouse. (Figure 3: Hydrograph of discharge from the Powerhouse on Deer Creek). This hydrograph is a classic illustration of a managed flow.

Although the hydrograph of the data collected at the Smartville gauge illustrates a more naturally flowing stream, each peak flow recorded at this site is "affected by regulation or diversion" (USGS) (Figure 4: Hydrograph of discharge at Smartville).

Therefore, I do not use this gauge's records to approximate naturally occurring flows upstream, on the reach of Deer Creek that is being considered for restoration. However, the flows recorded at the Smartville gauge *are* useful for comparing natural flows to current flows on Deer Creek.

I developed two flood frequency curves using the USGS stream flow data: one approximating 'natural' flows on Deer Creek, and the other illustrating current conditions. To approximate natural flows, instead of the USGS gauges on Deer Creek itself, I use the USGS gauge data from nearby Oregon Creek. There are three gauges on Oregon Creek, USGS gauges #11409300, #11409400 and #11409500. The hydrology of both creeks is similar, with the water coming from a mix of rain and snowmelt. Oregon Creek is a free flowing creek that flows into the Middle Yuba River. Oregon Creek is an appropriate instrument for Deer Creek because the creeks' elevation, orientation, and size are similar. Also, the topography of their drainage areas is very similar. Essentially, because the two creeks originate at about the same longitude and elevation and are only 15 miles apart, Oregon Creek data is a good representation of what natural conditions would be like on Deer Creek.

Table 1: Summary of gauges and periods of record, Oregon Creek

Gauge #	Period of Record
11409300	1968-02-19 to 2000-02-14
11409400	1969-01-20 to 2004-02-18
11409500	1911-04-03 to 1969-01-20

To obtain a continuous record of flows from 1911 to 2004, I combined the data for gauges 400 and 500 by scaling the flows from gauge 400 by a factor equal to the ratio of the drainage area at gauge 500 to the drainage area at gauge 400 (34.3/29.1 square miles). Next, to approximate the flows on Deer Creek, I scaled the Oregon Creek data by a factor of 84/34.3, the ratio of the creeks' respective drainage areas. Using the chronology of peak flows, I calculated the discharge for various return periods. (Table 2: Deer Creek – Chronology of Peak Flows, Rankings, and Return Periods, extrapolated from Oregon Creek data). I plotted a flood frequency curve on probability paper, to be able to extrapolate the 100-year return flood. (Figure 8: Flood Frequency Curve, Deer Creek, extrapolated from USGS data for Oregon Creek).

I also developed a flood frequency curve from the flow data from the USGS gauge at Smartville. (Figure 9: Flood Frequency Curve for Deer Creek, using USGS gauge at Smartville).

Tributaries:

There are no flow records for the tributaries of Deer Creek. Instead, I relied on two estimation methods to calculate the peak runoff at two, five, ten, 25, 50 and 100 year return intervals. The two methods I used are the flood frequency relation developed for California by Waananen and Crippen, and the estimation method developed by Hedman and Osterkamp.

For the Sierra Region, Waananen and Crippen obtained the following equations from their regression analysis:

$$Q_2 = 0.24\ A^{0.88}\ P^{1.58}\ H^{-0.80}$$
$$Q_5 = 1.20\ A^{0.82}\ P^{1.37}\ H^{-0.64}$$
$$Q_{10} = 2.63\ A^{0.80}\ P^{1.25}\ H^{-0.58}$$
$$Q_{25} = 6.55\ A^{0.79}\ P^{1.12}\ H^{-0.52}$$
$$Q_{50} = 10.4\ A^{0.78}\ P^{06}\ H^{-0.48}$$
$$Q_{100} = 15.7\ A^{0.77}\ P^{1.02}\ H^{-0.43}$$

This method of calculating regional flood frequencies requires inputs of drainage area (A), mean annual precipitation on the drainage area (P), and altitude index (H). I obtained the drainage area data from NHI (Figure 2: Map of Study Area). The altitude index is the average of the altitude at 85 % and 10 % along the channel above the gauge of interest, in thousands of feet. I estimated the altitude index from a USGS 7.5 minute topographical map.

The second method for estimating flows on ungauged streams relies on channel geometry. A study by E.R. Hedman and W.R. Osterkamp (1982) presents equations for calculating return flows for streams in the Western United States. Classifying Deer Creek and its tributaries as alpine pine-forested streams, I used the equations

$$Q_2 = 1.3\ W_{AC}^{\ 1.65}$$
$$Q_5 = 2.8\ W_{AC}^{\ 1.60}$$
$$Q_{10} = 4.4\ W_{AC}^{\ 1.55}$$
$$Q_{25} = 7.0\ W_{AC}^{\ 1.50}$$
$$Q_{50} = 9.6\ W_{AC}^{\ 1.45}$$
$$Q_{100} = 13\ W_{AC}^{\ 1.40}$$

where W_{AC} is the width of the active channel. I present the results from the Waananen and Crippen method and the Hedman and Osterkamp method together, for comparison, in Table 3: Flow Estimates on Deer Creek and its Tributaries.

Bankfull Discharge:

Bankfull discharge is an important hydrologic metric, corresponding to return flows of one-and-a-half to three years. Bankfull flow shapes the stream channel, mobilizes sediment, scours holes, creates gravel bars, and performs other valuable geomorphologic and hydrologic functions. The cross-section surveys provide data for calculating flow at bankfull. To facilitate calculations, we selected the locations for our cross-sections where the channel was relatively straight and with relatively uniform slope.

I calculated bankfull discharge at each cross section using the Manning equation, $V = (1.49\ S^{0.5}\ R^{0.67}) / n$, where V = velocity, S = water surface slope near the cross section (obtained from the longitudinal profile), R = hydraulic radius (wetted perimeter divided by cross-sectional area), and n = coefficient of roughness. Manning equation yields velocity, which is then multiplied by the cross-section area to obtain discharge.

Using the Manning equation requires an estimate for the value of n, the roughness coefficient. I used Chow's additive method for estimating n (Chow, 1959). (Figure 5: Estimating Manning's n using Chow's Additive Method). The resulting n is a composite of material, the degree of irregularity, the variation in channel, the effect of obstructions, vegetation, and the degree of meandering. I averaged the bankfull discharge for each tributary from the two or three values obtained for each cross section (Table 3).

Table 4: Summary of Roughness Coefficient Values

Creek	*Estimated n*
Little Deer	0.0405
Willow Valley	0.070
Woods Ravine	0.054
Eagle Ravine	0.058
Gold Run[a]	0.020
Mosquito[a]	0.020

[a] data from NHI

Discussion of Results:

My work contributed to NHI's efforts to understand the past and present hydrology of Deer Creek. These results will be used in developing a plan for restoring the creek and its watershed. NHI is interested both in natural and current flows on Deer Creek, in the reach to be restored. Information about natural flows, or what the flows would be without any dams, reservoirs, or canals, facilitate evaluating whether Deer Creek now gets enough flows to maintain its hydrologic health. However, in the absence of historical flow records, what exactly ‘natural flows’ are on Deer Creek is difficult to determine.

Mainstem:

To assess the difference in the magnitude the flows on Deer Creek between those measured at Smartville and those extrapolated from Oregon Creek data, I constructed hydrographs for 1983 and 1990, a wet and dry year, respectively. Each hydrograph plots discharge for both current flows (Smartville data) and ‘natural’ flows (extrapolated from Oregon Creek data). The hydrographs, for both the wet and the dry year, suggest that current flows on Deer Creek are fairly similar to natural flows in both magnitude and pattern. (Figures 10-13). The disparity between the natural and current flows is greater in the dry year, and in the dry season (from April to September) of both years. To highlight this greater difference at lower flows, I ‘zoomed in’ on the hydrographs, adjusting the vertical scale. (Figure 11, Figure 13).

From the flood frequency curve I constructed, I obtained the values for natural and current flows with return intervals of two, five, ten, 25, 50 and 100 years. (Table 5).

Table 5: Summary of Natural and Current Flows on Deer Creek

Return Interval	Deer Creek Natural Flows (cfs) – extrapolated from Oregon Creek data	Deer Creek Current Flows (cfs) - Smartville gauge
2	4000	5500
5	6300	8250
10	9800	9750
25	16300	12000
50	21000	13750
100	26000	15500

Again, estimated natural flows are similar to the current flows on Deer Creek. The flood frequency curve for natural flows is steeper than the curve for current flows, suggesting that water storage facilities on Deer Creek mitigate the magnitude of the larger, less frequent flows.

Tributaries:

Estimating flows on Deer Creek's ungauged tributaries is as fraught with uncertainty as estimating past natural flows on the mainstem of Deer Creek. I check the reasonableness of my estimates in three ways. First, applying two methods—Waananen and Crippen's method and Hedman and Osterkamp's method—to estimate Q2, Q5, Q10, Q25, Q50, and Q100 for the tributaries is a way to check how reasonable is each estimate. The methods input distinct variables with no overlap. The two methods yield results that are within an order of magnitude of each other, suggesting that the estimates are reasonable. (Table 3).

Another way to evaluate the quality of the estimates is to compare the value for Q2 with the estimate of bankfull discharge, since bankfull usually occurs every one-and-a-half to three years. The estimated bankfull discharge and Q2 are within an order of magnitude of each other for all tributaries except Eagle Ravine. (Table 5). Using order of magnitude comparisons, while it may seem imprecise, is appropriate here because the estimation methods are themselves imprecise.

Comparing the total discharge from the tributaries with the discharge on the mainstem of Deer Creek is a final, admittedly crude, way to evaluate my estimates. (Table 3). The sum of the flows on the tributaries logically should not exceed the flow on the mainstem. My results, by this criterion, are reasonable.

Concluding Remarks

My fieldwork and data analysis contribute to the assessment of the hydrology of Deer Creek that NHI is performing to formulate a stream and watershed restoration project. Uncertainty in my estimates and conclusions results from errors in the collection of data in the field, from applying estimation methods based on regression analysis and channel geometry, and from appropriating flow data from one creek to represent conditions on another, however similar, creek. Further, uncertainty and errors get compounded as the analysis proceeds. In spite of the inevitable uncertainty, my results seem reasonable as far as I am able to evaluate them against each other and against other sources.

Walking along the tributaries of Deer Creek, my impression was that the creek is in relatively good hydrologic health. The hydrologic analysis I performed affirms this impression, as current flows do not seem to deviate drastically from estimated historical, or 'natural,' flows. While Deer Creek's hydrology may not be severely impacted, NHI's preliminary assessments of water quality indicate that mercury bioaccumulation levels in the Deer Creek watershed, caused by mercury contamination from hydraulic mining, are among the highest in the northwestern Sierra Nevada (NHI 2005). Similarly, although current flows are not significantly different from the past natural flows, the amounts of sediment they need to move are much greater than occur naturally—another legacy of hydraulic mining. So, while the picture that emerges of the hydrology of Deer Creek is far from bleak, it does not detract from the need for restoration. Rather, a hydrologic assessment is a necessary step along the path to restoring the total health of the watershed.

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Figure Captions:

Table Captions: