Estimation of 50-and 100-Year Tributary Accretion Floods
Lewiston Dam to Treadwell Bridge, Trinity River, California

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1. INTRODUCTION

The Trinity River, located in the northwest portion of California (Figure 1), has been the focus of study over the past 30 years in an effort to restore salmon populations. This effort culminated in 2001 with the signing of the Secretarial Record of Decision for the Trinity River Restoration Program. An important component of this Record of Decision is to increase instream flow releases from Lewiston Dam up to 11,000 cfs during Extremely Wet water years. However, these higher flow releases from Lewiston Dam is only one of several sources of high flows downstream of Lewiston Dam. In the winter months during large storm events, tributaries between Lewiston Dam (RM 112) and Treadwell Bridge (RM 97.4) can cumulatively cause mainstem Trinity River flows to approach or exceed 11,000 cfs on top of releases from Trinity and Lewiston Dams (McBain and Trush, in press). Additionally, Safety of Dam releases have historically exceeded 11,000 cfs twice since Trinity and Lewiston dams were completed in 1964, and while changed reservoir operations have certainly reduced the magnitude and frequency of Safety of Dams releases, this scale of release could potentially occur again. There are four bridges downstream of Lewiston Dam that are vulnerable to higher flows (Figure 2), with at least one that is impacted by flows as low as 6,000 cfs to 8,500 cfs. All four bridges downstream of Lewiston Dam currently do not have the capacity to convey flows up to 11,000 cfs, and observations during the 1997 flood showed that many of these bridges were overtopped. In response to these new higher flow recommendations up to 11,000 cfs mandated by the 2001 Record of Decision, the Bureau of Reclamation is developing designs to raise or reconstruct these four bridges to safely convey higher flows. The design flow for these bridges will consider several factors, including the Record of Decision flows, Safety of Dams releases, expected tributary accretion on top of dam releases, and desired flood magnitude and frequency that the bridges should safely pass (e.g., 50 or 100 year flood). Several studies have been conducted to estimate downstream flood magnitude due to tributary accretion (e.g., DWR, 1996; ACOE, 1976; McBain and Trush, 1997) using varying techniques. The purpose of this memorandum is to estimate 50 and 100-year tributary flood magnitude at the four bridge sites under the winter flood season (November-March) and the snowmelt runoff season (May-June). These flood magnitude estimates will help develop bridge design criteria.

2. OBJECTIVE

There are three populations of floods that need to be considered in the bridge designs: 1) future Safety of Dams releases, 2) Record of Decision releases, and 3) tributary flow

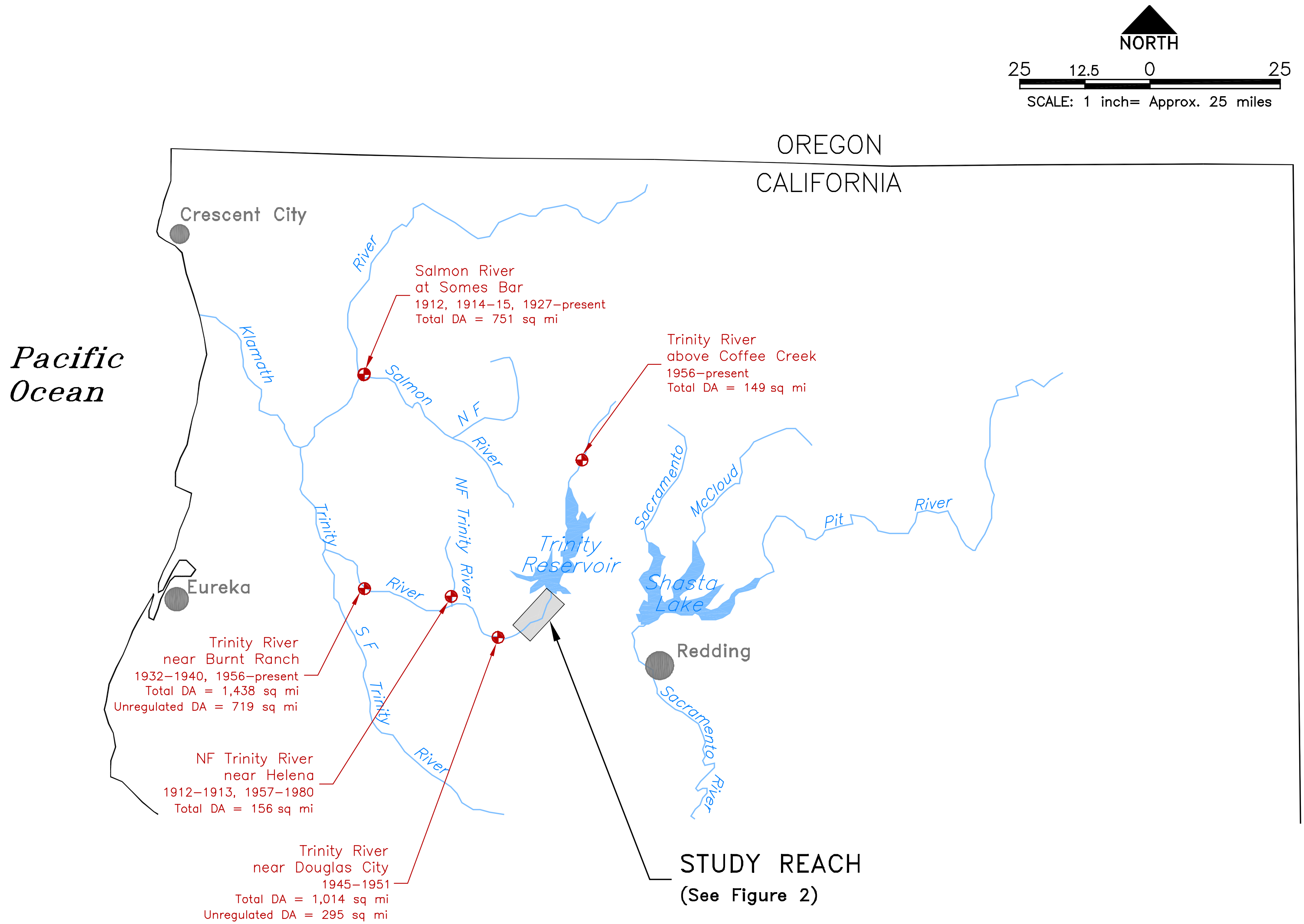

FIGURE 1. LOCATION OF REGIONAL GAGING STATIONS NEAR THE TRINITY RIVER

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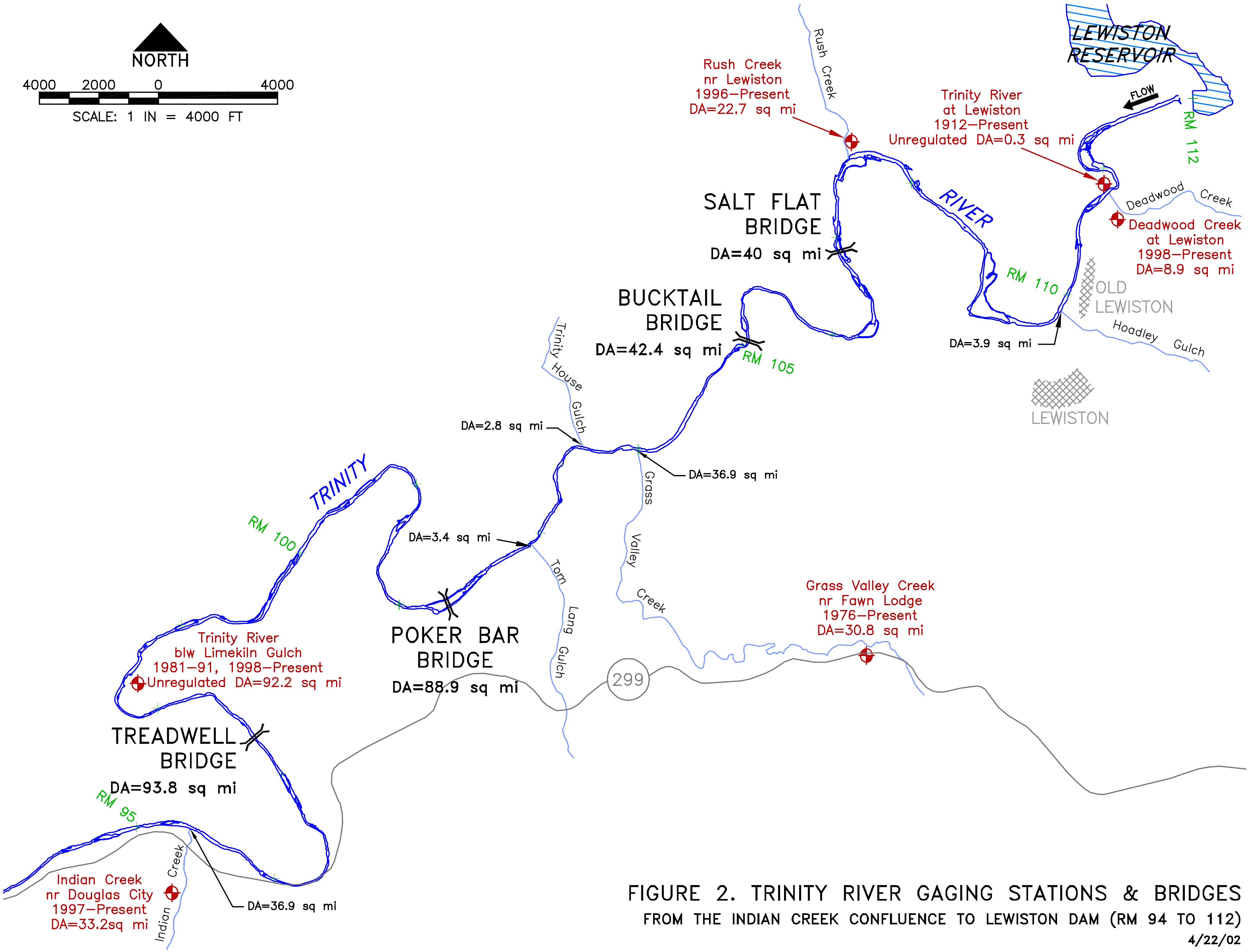

FIGURE 2. TRINITY RIVER GAGING STATIONS & BRIDGES

FROM THE INDIAN CREEK CONFLUENCE TO LEWISTON DAM (RM 94 TO 112)

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accretion on top of 1 and 2. The magnitude of tributary accretion depends on the time of year (winter flood period from November-March, or snowmelt runoff period in May-June) and the longitudinal location on the mainstem (tributary accretion increases with distance downstream. The objective of this paper is to facilitate bridge design flow estimates under the following design scenarios:

WINTER FLOOD SEASON (NOVEMBER-MARCH)

A. 300 cfs Record of Decision baseflow release from Lewiston Dam plus 50 and 100-year flood flow accretion from tributaries. The 300 cfs baseflow release would occur between October 15 and the beginning of high flow releases in May.
B. 6,000 cfs Safety of Dams release from Lewiston Dam plus 50 and 100-year flood flow accretion from tributaries. 6,000 cfs is the present-day maximum Safety of Dams release, and can occur between November 1 and March 31 when cumulative storms and/or snowmelt runoff encroaches into the Safety of Dams storage.

SPRING SNOWMELT RUNOFF SEASON (MAY-JUNE)

C. 11,000 cfs Record of Decision release for Extremely Wet water year from Lewiston Dam plus 50 and 100 year May-June snowmelt runoff flow accretion from tributaries.
D. 13,750 cfs Safety of Dams release from Lewiston Dam plus 50 and 100 year May-June snowmelt runoff flow accretion from tributaries.

We need to develop these estimates longitudinally along the river from Lewiston Dam to Treadwell Bridge by estimating tributary flood accretion for the 50 and 100-year flood recurrences during the winter flood season (November-March) and during the snowmelt runoff season (May-June). Concurrently, Reclamation is evaluating whether anticipated future Safety of Dam releases from Lewiston Dam are larger than 50 and 100-year tributary floods.

3. DATA SOURCES

Estimating flood frequency at the bridges required an analysis that estimated flood magnitudes from tributaries between Lewiston Dam and Treadwell Bridge during the two seasons listed above. Flood frequency analyses for these two seasons used two different data sources. Floods generated during the winter season are generated from high intensity rainfall or rain-on-snow events, and are almost always the largest flood peaks of the year; therefore, annual instantaneous peak flows were used for the 50 and 100-year winter flood season analysis. Higher flows generated during the May-June period are primarily snowmelt runoff events, which are usually more gradual and much smaller than the winter floods. Therefore, we used the maximum daily average flow during the May-June period, and adjusted the daily average flow to an estimated instantaneous peak flow to estimate the 50 and 100-year peak spring snowmelt runoff season flow magnitude. The pertinent gaging stations providing data used in various analyses in this report are listed in Table 1. Regional gaging stations are shown on Figure 1, and the study reach with local gages, tributaries, and the four bridges are shown in Figure 2.

Table 1. Gaging stations used in various analyses contained in this report.

Gaging Station	Gage #	Trinity River Mile	Drainage Area	Operator	Period of Record	Years of Record [total] (regulated)
Trinity River at Lewiston	11-525500	110.9	719 mi^2	USGS[a]	1911-present	[89] (36)
Deadwood Creek near Lewiston	N/A	N/A	8.9 mi^2	HVT[b]	1998-present	[4]
Rush Creek near Lewiston [d]	N/A	N/A	22.7 mi^2	HVT[b]	1997-present	[5]
Grass Valley Creek near Fawn Lodge	11-525600	N/A	30.8 mi^2	USGS[a]	1976-present	[26]
Trinity River near Limekiln Gulch [d]	11-525650	98.3	810 mi^2	USGS[a]/HVT[b]	1981-1991, 1998-present	[15] (15)
Indian Creek near Douglas City [d]	N/A	N/A	33.2 mi^2	HVT[b]	1997-present	[5]
Weaver Creek near Douglas City	11-525800	N/A	48.4 mi^2	DWR[c]	1959-1969	[11]
Browns Creek near Douglas City	11-525900	N/A	71.6 mi^2	DWR[c]	1957-1967	[11]
Trinity River near Douglas City	11-526000	87.7	1,014[d] mi^2	USGS[a]	1945-1951	[7]
Trinity River near Burnt Ranch	11-527000	48.6	1,438[e] mi^2	USGS[a]	1932-1940, 1956-present	[55] (36)
Trinity River above Coffee Creek	11-523200	146	149 mi^2	USGS[a]	1956-present	[45]
North Fork Trinity River near Helena	11-526500	N/A	156 mi^2	DWR[c]	1912-1913, 1957-1980	[26]
Salmon River at Somes Bar	11-522500	N/A	751 mi^2	USGS[a]	1912, 1914-15, 1927-present	[77]

[a] U.S. Geological Survey
[b] Hoopa Valley Tribe Fisheries Department
[c] State of California Department of Water Resources
[d] 295 mi^2 unregulated
[e] 719 mi^2 unregulated

4. WINTER FLOOD SEASON

The following four methods were used to estimate tributary flood magnitude for the 50 and 100-year floods at the four bridges:

1) Regional Regression Equation method
2) Additive Tributary model
3) Unit Runoff method
4) Regional Flood Frequency Analysis method

The four methods are used to develop a range of estimates; benefits and drawbacks for each method are discussed and considered when making a final recommendation on best flood magnitude to use at the bridge locations. Many of the methods below use the Log Pearson III flood frequency distribution to compute flood magnitudes on gaged streams. Previous work has estimated generalized skew factors of -0.1 from the map in Bulletin 17B (USGS, 1982); however, Reclamation compiled regional skew factors from nearby gaging stations and weighted them by the period of record. This analysis suggested that a generalized skew factor of -0.3 is more appropriate for the Trinity River basin, thus is used the following analyses.

4.1. Regional Regression Equation method

The regional regression equation method is based on the multivariate statistical analysis of North Coast California gaging stations performed by Waananen and Crippen (1977), and is used in Jennings, et al. (1994). For the North Coast of California, the regional regression equations for the 50- and 100-year floods are as follows:

$$Q_{50} = 8.57\,(A)^{0.87}\,(P)^{0.96}\,(E)^{-0.08}$$
$$Q_{100} = 9.23\,(A)^{0.87}\,(P)^{0.97}\,(E)^{0.00}$$

where A= drainage area, P= average annual precipitation, and E = elevation index. To compute the 50- and 100-year flood estimates at the Salt Flat Bridge and Bucktail Bridge, we added the computed 50- and 100-year flood estimates for Rush Creek and the Trinity River between Lewiston Dam and the bridge of interest. To compute the 50- and 100-year flood estimates at the Poker Bar Bridge and Treadwell Bridge, we added the computed 50- and 100-year flood estimates for Rush Creek, Grass Valley Creek, and the Trinity River between Lewiston Dam and the bridge of interest. We used the regional regression equations to compute the 50- and 100-year flood magnitude for Rush Creek and the mainstem Trinity River, and used the Log-Pearson III flood frequency prediction for Grass Valley Creek at Fawn Lodge ($A=30.8\ mi^2$). The 50-year and 100-year flood prediction at the Grass Valley Creek at Fawn Lodge is 4,802 cfs and 6,022 cfs, respectively (Figure 3).

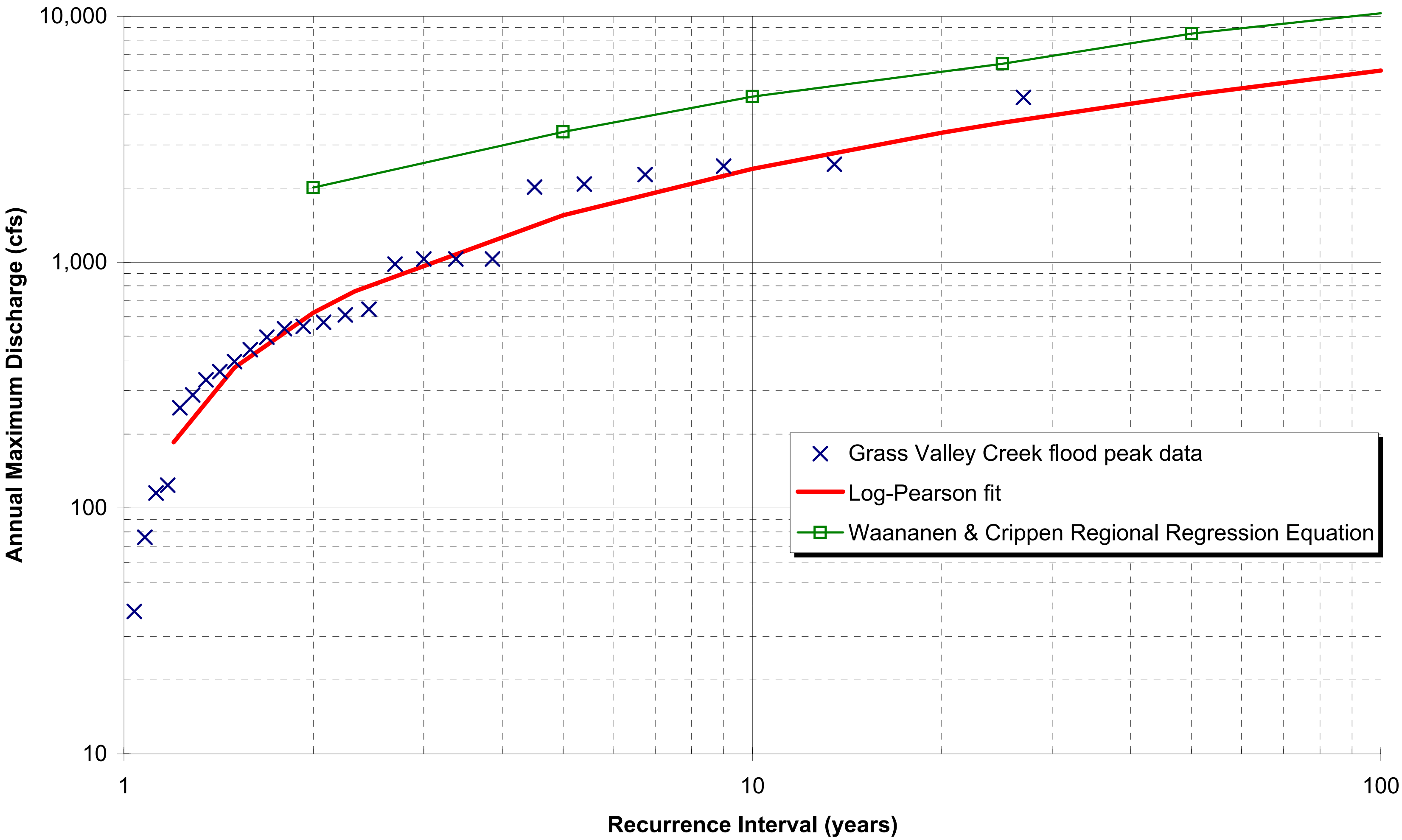
For comparison, we compared the Log-Pearson III 50 and 100-yr flood magnitude estimates from the Grass Valley Creek gaging station to that predicted by the regional regression equations using $A = 30.8\ mi^2$, P = 64 inches, E = 2.54 (Table 2, Figure 3).

Table 2. Comparison of 50- and 100-year flood magnitude predictions at Grass Valley Creek using the Waananen and Crippen (1977) regional regression equations and the Log-Pearson III predictions.

Flood frequency	**Regional Regression Equation Prediction**	**Log-Pearson III prediction from gaging data**	**Percent over-prediction**
50-year flood	8,503 cfs	4,802 cfs	77 %
100-year flood	10,286 cfs	6,022 cfs	71 %

The Grass Valley Creek gaging station is upstream from the confluence with the Trinity River, so we adjusted the flood magnitude predictions to account for the additional drainage area at the mouth ($Q_{mouth}=Q_{gage}*(A_{mouth}/A_{gage})^{0.87}$, where the exponent was taken

Figure 3. Grass Valley Creek at Fawn Lodge (USGS gage #11-5256; 1976-2001) flood frequency curve



from the regional regression equations. Using A_{mouth}=37.0 mi^2, A_{gage}=30.8 mi^2, and Q_{gage}= 4,802 cfs and 6,022 cfs for the 50 and 100-year flood, the resulting flood magnitude predictions that incorporate the additional drainage area between the Grass Valley Creek gaging station and the Trinity River confluence results in a 50-year flood estimate of 5,633 cfs and a 100-year flood estimate of 7,063 cfs. Results of applying the Waananen and Crippen (1977) regional regression equations to Rush Creek and the cumulative small tributaries along the mainstem Trinity River are shown in Table 3, as are the resulting estimates of 50- and 100-year flood magnitudes at the four bridges using this method.

Table 3. Summary of 50- and 100-year flood magnitude predictions at the four bridges using the Waananen and Crippen (1977) regional regression equations.

SALT FLAT BRIDGE		**Area**	**Precipitation**	**Elev. index**	**Q_{50}**	**Q_{100}**
	Rush Creek	22.7 mi^2	43 inches[1]	3.230	4,366 cfs	5,363 cfs
	Trinity R. & minor tribs	16 mi^2	45 inches [2]	1.803	3,773 cfs	4,425 cfs
	Sum at bridge location	**38.7 mi^2**			**8,139 cfs**	**9,788 cfs**
BUCKTAIL BRIDGE		**Area**	**Precipitation**	**Elev. index**	**Q_{50}**	**Q_{100}**
	Rush Creek	22.7 mi^2	43 inches[1]	3.230	4,366 cfs	5,363 cfs
	Trinity R. & minor tribs	18.4 mi^2	45 inches [2]	1.784	4,228 cfs	4,955 cfs
	Sum at bridge location	**41.1 mi^2**			**8,594 cfs**	**10,318 cfs**
POKER BAR BRIDGE		**Area**	**Precipitation**	**Elev. index**	**Q_{50}**	**Q_{100}**
	Rush Creek	22.7 mi^2	43 inches[1]	3.23	4,366 cfs	5,363 cfs
	Grass Valley Creek	37.0 mi^2		N/A	5,633 cfs	7,063 cfs
	Trinity R. & minor tribs	27.9 mi^2	45 inches [2]	1.765	5,960 cfs	6,978 cfs
	Sum at bridge location	**87.6 mi^2**			**15,959 cfs**	**19,404 cfs**
TREADWELL BRIDGE		**Area**	**Precipitation**	**Elev. index**	**Q_{50}**	**Q_{100}**
	Rush Creek	22.7 mi^2	43 inches[1]	3.23	4,366 cfs	5,363 cfs
	Grass Valley Creek	37.0 mi^2		N/A	5,633 cfs	7,063 cfs
	Trinity R. & minor tribs	32.8 mi^2	45 inches [2]	1.738	6,829 cfs	7,986 cfs
	Sum at bridge location	**92.5 mi^2**			**16,828 cfs**	**20,412 cfs**
DOUGLAS CITY GAGE		**Area**	**Precipitation**	**Elev. index**	**Q_{50}**	**Q_{100}**
	Rush Creek	22.7 mi^2	43 inches[1]	3.23	4,366 cfs	5,363 cfs
	Grass Valley Creek	37.0 mi^2		N/A	5,633 cfs	7,063 cfs
	Indian Creek	33.2 mi^2	61 inches[1]	2.76	8,610 cfs	10,480 cfs
	Weaver Creek	49.1 mi^2		N/A	4,930cfs	5,386 cfs
	Reading Creek	30.4 mi^2	63 inches[1]	2.90	8,193 cfs	10,015 cfs
	Browns Creek	74.1 mi^2		N/A	5,098 cfs	5,804 cfs
	Trinity R. & minor tribs	47.2 mi^2	45 inches [2]	1.674	9,307 cfs	10,850 cfs
	Sum at Douglas City	**293.7 mi^2**			**46,137 cfs**	**54,961 cfs**
	FEMA 1996 Estimate at Douglas City					**38,500 cfs**

[1] Based on average precipitation map in Rantz (1969)

[2]Based on Tom Lang Gulch gage precipitation in Waananen and Crippen (1977)

4.2. Additive Model for Tributary 50 and 100-year flood

Our objective with the Additive Model was to predict mainstem streamflow as a function of distance downstream from Lewiston Dam, using a simple additive model for flood magnitude at common recurrence intervals (Figure 4). This additive model uses the Trinity River near Burnt Ranch gaging station as a calibration point, so we analyzed tributaries larger than 10 mi^2. Flood frequency curves were developed for tributaries larger than 10 mi^2 between Lewiston Dam and the North Fork Trinity River. The 50 and 100 year flood magnitude for each tributary was computed by a combination of Log-Pearson III flood frequency analyses for the gaged streams, and regional flood frequency regression equations for the ungaged streams (Table 4). For those gaging stations that were not at the mouths of the tributaries, the flood magnitudes were adjusted by the additional drainage area at the mouth as done at the bottom of page 6.

Figure 4. Simple additive model for estimating longitudinal 50 and 100-yr annual peak flood magnitudes on the mainstem Trinity River downstream of Lewiston Dam.

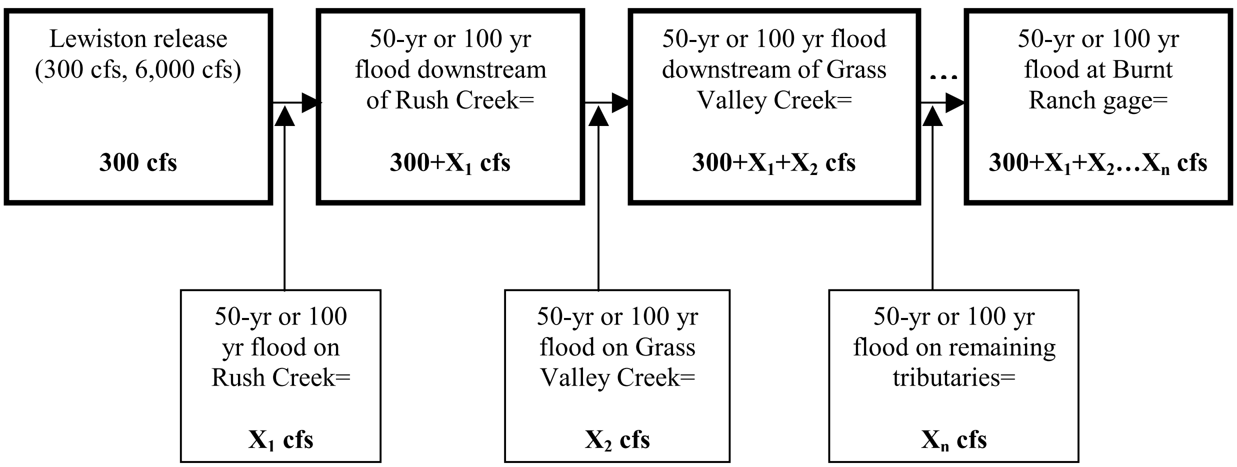


Table 4. Summary of methods used to estimate 50 and 100-year tributary flood magnitude for additive model.

Tributary	Flood Frequency Method
Rush Creek	Waananen and Crippen (1977) regional regression equation adjusted to the NF Trinity River
Grass Valley Creek	Log Pearson III flood frequency analysis
Indian Creek	Waananen and Crippen (1977) regional regression equation adjusted to the NF Trinity River
Weaver Creek	Log Pearson III flood frequency analysis
Reading Creek	Waananen and Crippen (1977) regional regression equation adjusted to the NF Trinity River
Browns Creek	Log Pearson III flood frequency analysis
Canyon Creek	Waananen and Crippen (1977) regional regression equation adjusted to the NF Trinity River
North Fork Trinity River	Log Pearson III flood frequency analysis

Tributaries with drainage areas less than 10 mi^2 were not analyzed. The flow contribution of each tributary to the mainstem Trinity River greater than 10 mi^2 was added for a given flood frequency (Figure 4). This additive model was continued downstream to the Trinity River near Burnt Ranch gaging station (Figure 1), where predicted flood magnitudes from the model were compared to that measured at the gaging station. This gaging station was chosen because it is the first station downstream of the study reach with a sufficiently long post-dam period of record (36 years) adequate to calibrate the model. The deviation of model predictions to that measured at the Trinity River near Burnt Ranch gaging station was then used as a correction factor to all the tributary contributions upstream such that the predicted results at the Burnt Ranch gaging station matched measured values. This simple additive model has many assumptions, including:

(1) flood routing is not considered (no lag or attenuation between gaging nodes).
(2) a flood of a given recurrence occurs on all watersheds during the same storm event (no regional differences).
(3) tributaries <10 mi^2 are ignored (not allowed to contribute to flood peaks in model).
(4) the gaging stations accurately measure discharge.
(5) the period of record used typifies the long-term average.
(6) The cumulative drainage area between the North Fork Trinity River and the Burnt Ranch gage is ignored because the individual streams are less than 10 mi^2 each.

Error inherent to assumptions (1), (3), and (6) are offsetting to a degree. The above methods were used to develop an overall longitudinal flood magnitude prediction along the mainstem Trinity River from Lewiston Dam (RM 112) to the Burnt Ranch gaging station (RM 48.6). From this longitudinal perspective assessing many tributaries, we focus most of our results on the 50 and 100-year flood flows on Rush Creek and Grass Valley Creek (X_1 and X_2 in Figure 4), since they are the primary tributaries affecting the four bridges (Table 4).

For Grass Valley Creek, a Log Pearson III flood frequency analysis using the 26 years of annual peak flow data was performed (Figure 3), which predicted a 50-year flood magnitude of approximately 4,802 cfs and 100-year flood magnitude of approximately 6,022 cfs at the gaging station (drainage area = 30.8 mi^2). These flood magnitudes were adjusted for watershed area at the mouth (37 mi^2) as done at the bottom of page 6, resulting in 50- and 100-year flood magnitude predictions of 5,633 cfs and 7,063 cfs.

Table 4. Summary of bridge location and tributaries contributing to flood hydrology at each bridge.

Bridge	River Mile	Contributing tributaries
Salt Flat Bridge	106.9	Rush Creek
Browns Mtn Bridge	105.0	Rush Creek
Poker Bar Bridge	102.2	Rush Creek and Grass Valley Creek
Treadwell Bridge	97.4	Rush Creek and Grass Valley Creek

Predictions from Rush Creek required a different approach due to limited flood peak data at that station. Therefore, we first used regional regression equations from Waananen and

Crippen (1977) for streams in north coastal California. These regional regression equations predicted the following 50- and 100-year flood magnitudes for Rush Creek:

$Q_{50RUSH} = 8.57\,(A_{RUSH})^{0.87}\,(P_{RUSH})^{0.96}\,(E_{RUSH})^{-0.08} = 4{,}366$ cfs
$Q_{100RUSH} = 9.23\,(A_{RUSH})^{0.87}\,(P_{RUSH})^{0.97}\,(E_{RUSH})^{0.0} = 5{,}363$ cfs

where A_{RUSH}= Rush Creek drainage area (22.7 mi^2), P_{RUSH}= Rush Creek average annual precipitation (43 inches), and E_{RUSH} is a Rush Creek elevation index (3.23). We then attempted to improve these regression equations by using a unit-area, unit-precipitation, unit-elevation adjustment with measured flood frequencies at the North Fork Trinity River gaging station (as shown in Waananen and Crippen, 1977). The North Fork Trinity River was used because it is unregulated, drains a similar portion of the Trinity Alps, and drains a similar elevation of the Trinity Alps. The adjustment was done as follows:

$Q_{50RUSH} = Q_{50NF}\,(A_{RUSH}/A_{NF})^{0.87}\,(P_{RUSH}/P_{NF})^{0.96}\,(E_{RUSH}/E_{NF})^{-0.08}$
$Q_{100RUSH} = Q_{100NF}\,(A_{RUSH}/A_{NF})^{0.87}\,(P_{RUSH}/P_{NF})^{0.97}$

Where A_{RUSH}= 22.7 mi^2, P_{RUSH}=43 inches, E_{RUSH}=3.23, A_{NF}=156 mi^2, P_{NF}=66 inches, E_{NF}=2.51, Q_{50NF}= 26,766 cfs Q_{100NF}= 31,141 cfs, such that the new equations and predicted flood magnitudes for Rush Creek are (Figure 5):

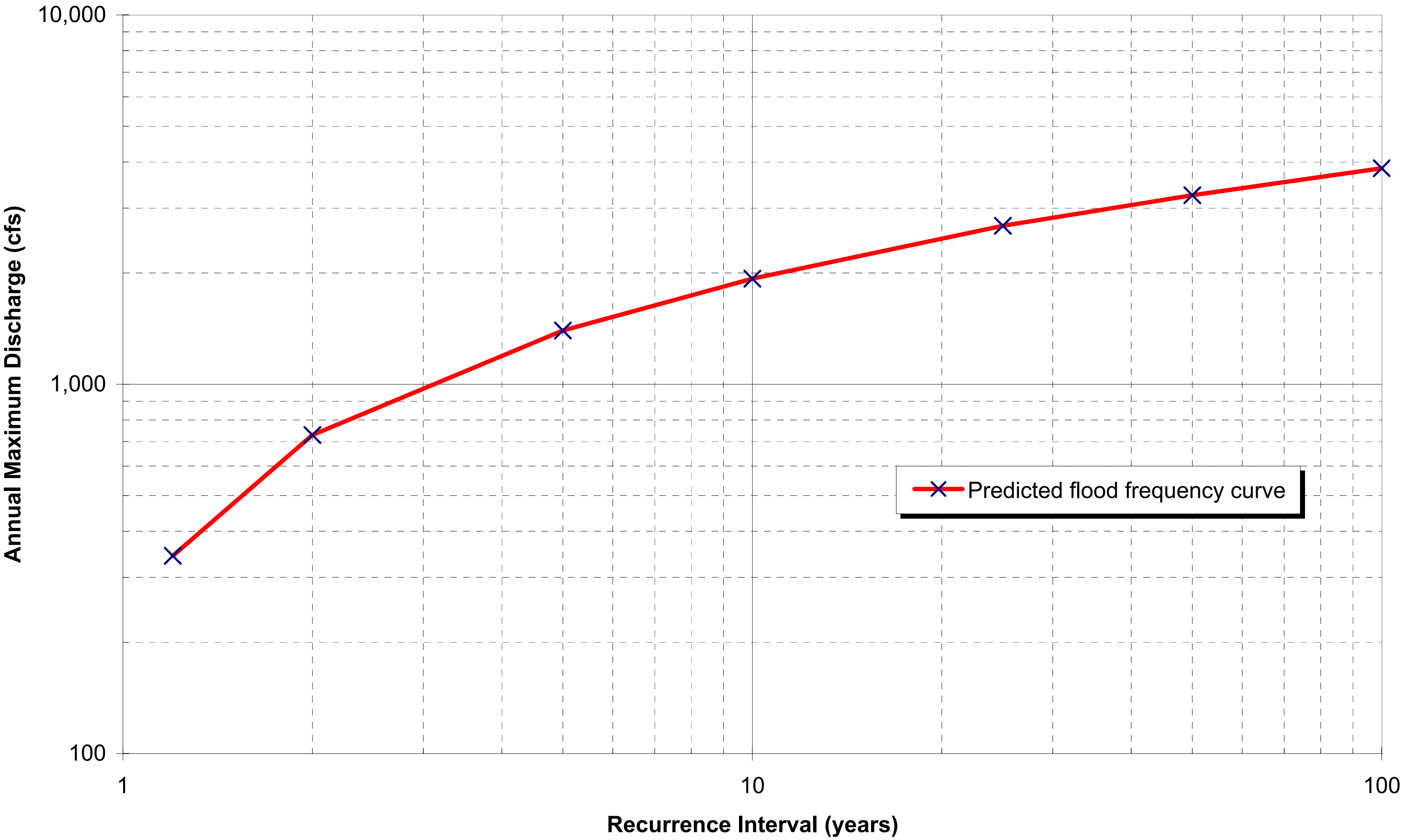
$Q_{50RUSH} = 26{,}766\,(22.4/156)^{0.87}\,(43/66P)^{0.96}\,(3.24/2.51)^{-0.08} = 3{,}249$ cfs
$Q_{100RUSH} = 31{,}141\,(22.4/156)^{0.87}\,(43/66)^{0.97} = 3{,}842$ cfs

Flood magnitudes were computed using Log Pearson III distribution for Weaver Creek and Browns Creek (11 years of data each), as well as the North Fork Trinity River (26 years of data). The unit-adjusted regional regression equations were used to predict the remaining flood magnitudes for Reading Creek (30.2 mi^2) and Canyon Creek (64.5 mi^2). Post-dam flood magnitudes were then computed at the Trinity River near Burnt Ranch gaging station to compare with the additive flood magnitudes downstream of the North Fork Trinity River (Table 5). Comparing the predictions from this simple model with predicted flood frequency estimates at the USGS Burnt Ranch gaging station showed that model predictions did a reasonable job at predicting flood magnitudes at the gaging station at larger recurrence interval floods (Table 5). Our simple model predicted discharges for each recurrence interval at the Burnt Ranch gaging station slightly smaller than “measured” at the Burnt Ranch gaging station, so a correction factor was applied to the flood magnitudes of each tributary at each recurrence interval to satisfy the constraint that predicted flood magnitude at the Burnt Ranch gage must equal the modeled flood frequency curve.

Table 5. Comparison of predicted versus “measured” flood magnitudes at the Burnt Ranch gaging station.

Flood Recurrence	Model prediction at Burnt Ranch gage	“Measured” value at Burnt Ranch gage	Correction Factor
50-yr	69,942 cfs	71,929 cfs	1.028
100-yr	81,831 cfs	86,710 cfs	1.060

Figure 5. Rush Creek near Lewiston flood frequency curve derived from Unit-correction of Waananen and Crippen (1977) regional regression equations.



The predicted 50- and 100-year flood magnitudes on Rush Creek (3,249 cfs and 3,842 cfs, respectively) were multiplied by the Table 5 correction factors (1.028 and 1.060, respectively) to result in predicted 50- and 100-year flood magnitudes of 3,342 cfs and 4,071 cfs. The Log-Pearson III predictions for the 50 and 100-year flood magnitudes at the mouth of Grass Valley Creek (5,633 cfs and 7,063 cfs, respectively) were also multiplied by the same correction factors to resulting predicted 50 and 100-year flood magnitudes of 5,793 cfs and 7,485 cfs. This correction factor adjustment based on the Burnt Ranch gaging station attempts to accommodate sources of error associated with the assumptions listed on page 10.

The flood magnitudes for Grass Valley Creek and Rush Creek 50- and 100-year flood magnitudes were then added to evaluate cumulative tributary contribution at the four bridge sites (Table 6).

Table 6. Summary of predicted 50- and 100-year tributary derived flows at pertinent bridges using the Additive Tributary Model.

Location	Predicted 50-yr flood magnitude: Additive Tributary Model	Predicted 100-yr flood magnitude: Additive Tributary Model
Salt Flat Bridge	3,342 cfs*	4,071 cfs*
Bucktail Bridge	3,342 cfs*	4,071 cfs*
Poker Bar Bridge	9,135 cfs*	11,556 cfs*
Treadwell Bridge	9,135 cfs*	11,556 cfs*

*Assumes 0 cfs release from Lewiston Dam

4.3. Unit Runoff method

The unit runoff method computes the flood magnitude at an ungaged location (e.g., tributary or mainstem Trinity River location) by multiplying a unit runoff magnitude (cfs/mi^2) developed from a nearby gaged stream to the unregulated drainage area at that ungaged location. Unregulated is defined as the drainage area downstream of Lewiston Dam, thus not subject to flow regulation from the Trinity River Division. In our application, we would multiply the unit runoff value for the 50- and 100-year flood with the unregulated drainage area at each bridge (Table 7).

Table 7. Unregulated drainage areas at each of the four bridges.

Location	Unregulated drainage area
Salt Flat Bridge	40.0 mi^2
Bucktail Bridge	42.4 mi^2
Poker Bar Bridge	88.9 mi^2
Treadwell Bridge	93.8 mi^2

Gaging stations used for this analysis should have a long period of record in order to accurately estimate the magnitude of the 50- and 100-year flood magnitudes. Because the unit runoff of a stream is a function of the drainage area (e.g., smaller watersheds have a higher unit runoff than comparable larger watersheds), as well as elevation and geography, gaging stations of similar watershed area, elevation, precipitation, and runoff patterns are preferable. The unit runoff method was done for two groups of gaging stations: 1) three very local gaging stations with drainage areas less than 160 mi^2 and period of record longer than 25 years, and 2) five local gaging stations with drainage areas less than 751 mi^2 and period of record longer than 25 years. For each gaging station, we computed the 50 and 100-year flood magnitude from Log-Pearson III distribution. One outlier occurred at the Salmon River at Somes Bar gaging station in WY 1965, where a landslide-induced dam break caused a much larger unit-runoff peak flow than that experienced on other nearby streams (133,000 cfs, or 177 cfs/mi^2). To estimate the flood peak at this gaging station, we plotted the unit runoff value for the December 22, 1964 flood at regional gaging stations against drainage area (Figure 6). The data suggest that a more reasonable unit runoff value of 100 cfs/mi^2 for the Salmon River at Somes Bar, resulting in a non-dam break peak flow estimate of 75,100 cfs. This value was substituted into the annual peak flow data and analyzed in the Log Pearson III flood magnitude predictions. The unit runoff values for these gages are summarized in Table 8, and linear regression equations were fitted to the data for each of these two groups of gaging stations (Figure 7).

Table 8. Summary of unit runoff values for the five gaging stations used in the Unit Runoff method.

Gaging Station	**Drainage Area**	**Years of Record**	**50-year flood**	**Unit 50-year flood**	**100-year flood**	**Unit 100-year flood**
Grass Valley Creek near Fawn Lodge	30.8 mi^2	26	4,802 cfs	156 cfs/mi^2	6,022 cfs	195 cfs/mi^2
Trinity River above Coffee Creek	149 mi^2	44	24,022 cfs	161 cfs/mi^2	28,798 cfs	193 cfs/mi^2
North Fork Trinity River near Helena	156 mi^2	26	26,766 cfs	172 cfs/mi^2	31,141 cfs	200 cfs/mi^2
Trinity River at Lewiston	719 mi^2	49	61,521 cfs	86 cfs/mi^2	73,792 cfs	103 cfs/mi^2
Salmon River at Somes Bar	751 mi^2	76	73,200 cfs	97 cfs/mi^2	84,770 cfs	113 cfs/mi^2

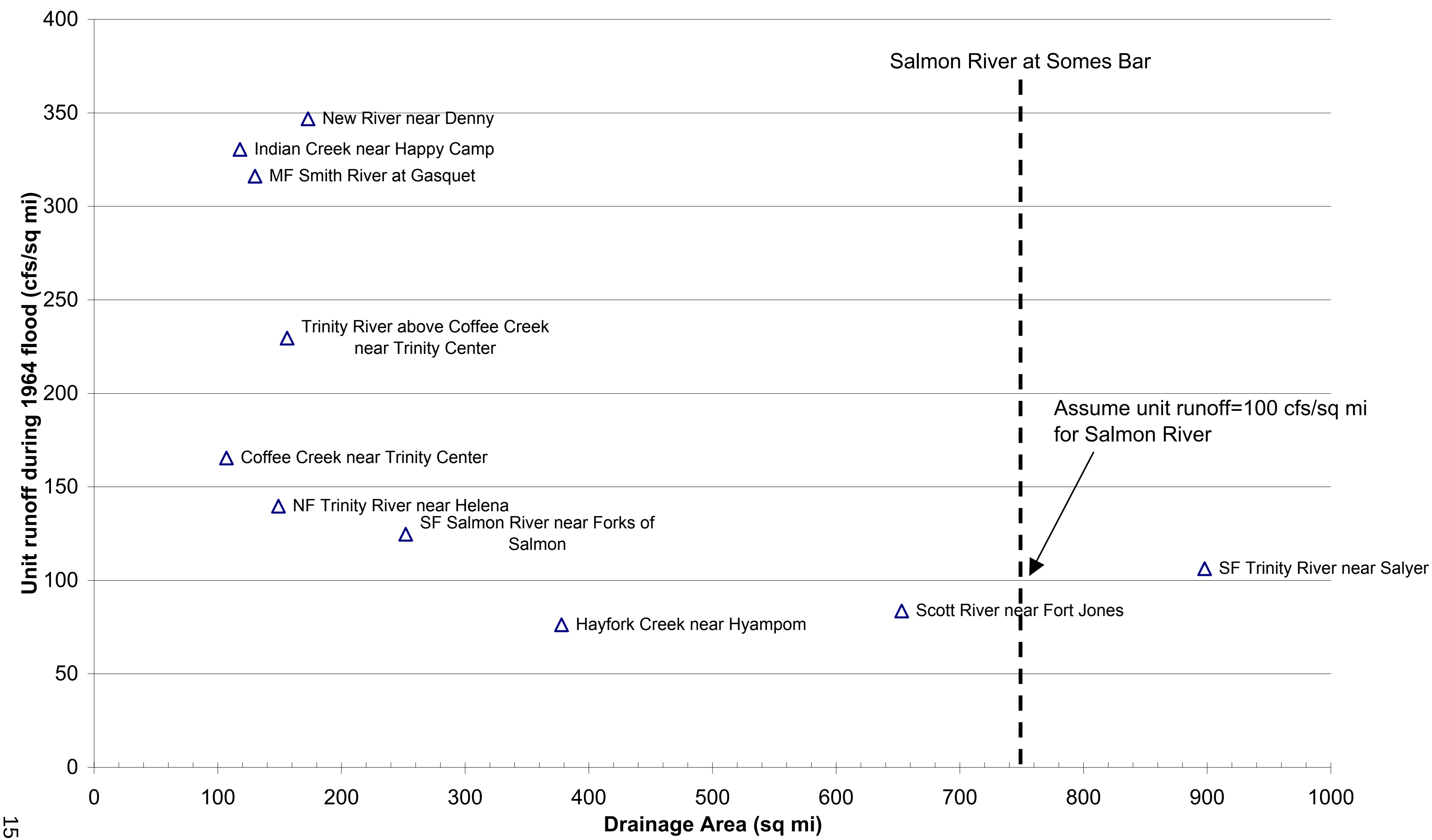
The regression equations enabled a prediction of the unit runoff value at each bridge based on the unregulated drainage area at each bridge. The unregulated drainage area, along with the 50- and 100-yr flood magnitude predictions at each bridge is listed in Table 9.

Table 9. Summary of 50- and 100-year flood magnitude predictions at the four bridges using regression based unit-runoff values from: a) three small local gaging stations with drainage areas < 156 mi^2, and b) five local gaging stations with drainage areas < 751 mi^2. Regression equations are shown in Figure 7.

		Using three small local gages < 156 mi^2		Using five local gages < 751 mi^2	
Location	Unregulated drainage	Predicted 50-yr flood	Predicted 100-yr flood	Predicted 50-yr flood	Predicted 100-yr flood
Salt Flat Br	40.0 mi^2	6,258 cfs	7,817 cfs	6,785 cfs	8,207 cfs
Bucktail Br	42.4 mi^2	6,643 cfs	8,287 cfs	7,180 cfs	8,685 cfs
Poker Bar Br	88.9 mi^2	14,299 cfs	17,416 cfs	14,601 cfs	17,639 cfs
Treadwell Br	93.8 mi^2	15,128 cfs	18,381 cfs	15,356 cfs	18,547 cfs
Douglas City	295 mi^2	52,895 cfs	58,399 cfs	41,777 cfs	50,129 cfs

Assumes 0 cfs release from Lewiston Dam

Figure 6. Comparison of regional estimates for unit-runoff during Dec 22, 1964 flood to estimate peak flow on Salmon River at Somes Bar gaging station



Theoretically, applying the unit runoff method avoids the flood routing assumption and incorporates all the smaller tributaries, providing a better estimator of local flood magnitude for the 50- and 100-year flood than the Additive Tributary Model. Within the unit runoff method, the prediction using the three gages are probably better estimates for the four bridges than predictions using the 5 gages because the drainage area for all four bridges is under 94 mi^2, which is very close to the three gages. Douglas City is included as a means to compare to the FEMA 100-year flood estimates. The estimates using the five gages is probably a better estimate for the Douglas City location, as the Douglas City location is midway between the three small gages and the remaining two larger gages (Figure 7).

4.4. Regional Flood Frequency Analysis

This analysis was performed by Reclamation's Technical Service Center, Denver CO. This method originally analyzed four groups of gages of varying locality, drainage area, and period of record. Ultimately we used the following three groups of regional gages because they were most appropriate for use at the Trinity River bridge sites:

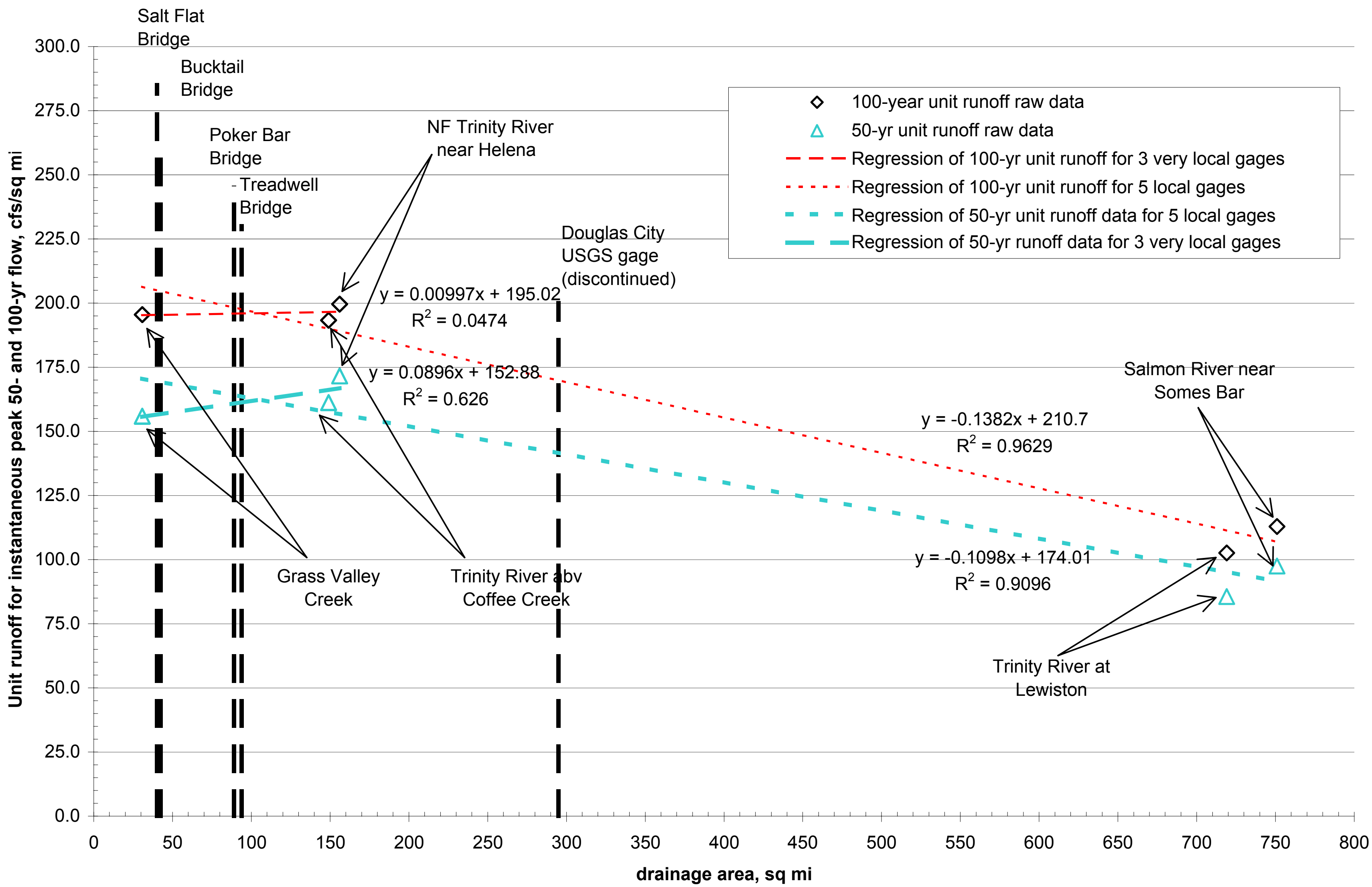
- Three small local gages < 156 mi^2 (Grass Valley Creek, Trinity River above Coffee Creek, NF Trinity River)
- Five local gages < 751 mi^2 (above three streams plus pre-dam Trinity River at Lewiston and Salmon River near Somes Bar)
- Nine regional gages < 764 mi^2 (above five plus SF Trinity River, Clear Creek near French Gulch, Sacramento River at Delta, SF Salmon River)

For each of the three groups of gages, the analysis was done in the following steps:

1. the annual instantaneous peak values were compiled and log-transformed, with the mean, standard deviation, and skew computed for each gage;
2. The mean for each gage ($X_{meanlog}$) was plotted as a function of drainage area, and based on the unregulated drainage area computed at each bridge, the mean log was estimated at each of the four individual bridge sites ($X_{meanlogbridge\text{-}i}$). This was also done for the Douglas City gage location in order to compare results to the 100-year flood magnitude predicted by FEMA (1996).
3. The standard deviation (SD) and skew of the log transformed peak flow values were weighted by the period of record for each gage to develop a weighted mean skew value for that group of gaging stations. The effective period of record was also computed as the sum of years of record for all gages divided by the number of gages.
4. Based on the weighted skew obtained in 3), the Pearson Type III deviate (K) was obtained for the 50- and 100-year flood (p=0.02 and p=0.01) from Bulletin 17B (USGS 1982). We used 2 significant figures on the skew values, therefore, we linearly interpolated between values in the Bulletin 17B K-value table.
5. The estimate of the 50-and 100-year flood magnitude for each bridge was computed from the following equation (USGS 1982):

$$Q_{50}=10^{(Xmeanlogbridge\text{-}i\ +(SDmean*K_{0.02})}$$
$$Q_{100}=10^{(Xmeanlogbridge\text{-}i\ +(SDmean*K_{0.01})}$$

Figure 7. Unit Runoff value regressions for local Trinity River gaging stations



The parameters generated from this approach are shown in Table 10, and the predicted flood magnitudes at each bridge (and Douglas City) are summarized in Table 11.

Table 10. Summary of parameters used in Regional Flood Frequency method.

	Effective period of record	**Weighted mean log SD**	**Weighted mean Skew**	**(50 yr) $K_{0.02}$**	**(100 yr) $K_{0.01}$**
Three gages	42	0.347	-0.65	1.867	2.074
Five gages	44	0.35	-0.31	1.884	2.096
Nine gages	32	0.38	-0.34	1.689	1.839

Table 11. Summary of 50- and 100-year flood magnitude predictions at the four bridges using Regional Flood Frequency method.

	Three gages		Five gages		Nine gages	
Location	Predicted 50-yr flood	Predicted 100-yr flood	Predicted 50-yr flood	Predicted 100-yr flood	Predicted 50-yr flood	Predicted 100-yr flood
Salt Flat Br	4,311 cfs	5,178 cfs	4,864 cfs	5,776 cfs	4,147 cfs	4,678 cfs
Bucktail Br	4,700 cfs	5,645 cfs	5,159 cfs	6,125 cfs	4,405 cfs	4,969 cfs
Poker Bar Br	14,085 cfs	16,918 cfs	10,877 cfs	12,915 cfs	9,465 cfs	10,677 cfs
Treadwell Br	15,251 cfs	18,319 cfs	11,481 cfs	13,633 cfs	10,005 cfs	11,286 cfs
Douglas City	83,374 cfs	100,141 cfs	36,424 cfs	43,250 cfs	32,685 cfs	36,870 cfs

Assumes 0 cfs release from Lewiston Dam

5. DISCUSSION OF WINTER FLOOD RESULTS (NOV 1 – MAR 31)

The compiled prediction of 50- and 100-year flood magnitude due to tributary accretion using all methods above are summarized in Table 12. Table 12 assumes zero release from Lewiston Dam. The two Winter Flood options described on page 4 were then evaluated by adding in Lewiston Dam releases of 300 cfs (winter baseflow) and 6,000 cfs (Safety of Dams). Results are shown in Tables 13-14.

5.1. Discussion and comparison with previous studies

A short description and assessment of each of the four methods summarized in Tables 12-14 follow below. Each method is given a qualitative ranking (low, moderate, high) based on the expected accuracy of the flood magnitude prediction. The ranking is based on the quality of data, length of data, applicability of data, and applicability of analysis.

5.1.1. Method 1: Regional Regression Equations

The predictions using the Waananen and Crippen (1977) regional regression equations should be ranked low because: 1) the were developed using data only through 1973, such that the 27 years of additional data up to the present-day is not used in the equation development, and 2) the equations were developed over a broad "North Coast" area, rather than specifically to the Trinity River basin. Flashy rainfall-dominated coastal streams are lumped together with less flashy snowmelt dominated streams, such that this aggregate effect reduces the precision of the estimated flood magnitude at a specific

Table 12. Summary of 50- and 100-year flood magnitudes at Trinity River bridges using a variety of methods
Assumes Lewiston Dam release of 0 cfs

WINTER FLOOD SEASON

Method 1: Regional Regression Equations to predict 50- and 100-year flood magnitude during Winter Flood season

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	8,139 cfs	8,594 cfs	15,959 cfs	16,828 cfs	46,137 cfs
100 yr	9,788 cfs	10,318 cfs	19,404 cfs	20,412 cfs	54,961 cfs

Method 2: Additive Tributary Model method to predict 50- and 100-year flood magnitude during Winter Flood season

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	3,342 cfs	3,342 cfs	9,135 cfs	9,135 cfs	32,313 cfs
100 yr	4,071 cfs	4,071 cfs	11,556 cfs	11,556 cfs	38,971 cfs

Method 3a: Unit Runoff method to predict 50- and 100-year flood magnitude during Winter Flood season - 3 LOCAL SMALL GAGES

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	6,258 cfs	6,643 cfs	14,299 cfs	15,128 cfs	52,895 cfs
100 yr	7,817 cfs	8,287 cfs	17,416 cfs	18,381 cfs	58,399 cfs

Method 3b: Unit Runoff method to predict 50- and 100-year flood magnitude during Winter Flood season - 5 LOCAL GAGES

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	6,785 cfs	7,180 cfs	14,601 cfs	15,356 cfs	41,777 cfs
100 yr	8,207 cfs	8,685 cfs	17,639 cfs	18,547 cfs	50,129 cfs

Method 4a: Regional Flood Frequency method to predict 50- and 100-year flood magnitude during Winter Flood season - 3 LOCAL SMALL GAGES

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	4,311 cfs	4,700 cfs	14,085 cfs	15,251 cfs	83,374 cfs
100 yr	5,178 cfs	5,645 cfs	16,918 cfs	18,319 cfs	100,141 cfs

Method 4b: Regional Flood Frequency method to predict 50- and 100-year flood magnitude during Winter Flood season - 5 LOCAL GAGES

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	4,864 cfs	5,159 cfs	10,877 cfs	11,481 cfs	36,424 cfs
100 yr	5,776 cfs	6,125 cfs	12,915 cfs	13,633 cfs	43,250 cfs

Table 13. Summary of OPTION A: 50- and 100-year flood magnitudes at Trinity River bridges assuming 300 cfs release from Lewiston Dam

WINTER FLOOD SEASON

Method 1: Regional Regression Equations to predict 50- and 100-year flood magnitude during Winter Flood season

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	8,439 cfs	8,894 cfs	16,259 cfs	17,128 cfs	46,437 cfs
100 yr	10,088 cfs	10,618 cfs	19,704 cfs	20,712 cfs	55,261 cfs

Method 2: Additive Tributary Model method to predict 50- and 100-year flood magnitude during Winter Flood season

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	3,642 cfs	3,942 cfs	9,435 cfs	9,735 cfs	32,613 cfs
100 yr	4,371 cfs	4,671 cfs	11,856 cfs	12,156 cfs	39,271 cfs

Method 3a: Unit Runoff method to predict 50- and 100-year flood magnitude during Winter Flood season - 3 LOCAL SMALL GAGES

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	6,558 cfs	6,943 cfs	14,599 cfs	15,428 cfs	53,195 cfs
100 yr	8,117 cfs	8,587 cfs	17,716 cfs	18,681 cfs	58,699 cfs

Method 3b: Unit Runoff method to predict 50- and 100-year flood magnitude during Winter Flood season - 5 LOCAL GAGES

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	7,085 cfs	7,480 cfs	14,901 cfs	15,656 cfs	42,077 cfs
100 yr	8,507 cfs	8,985 cfs	17,939 cfs	18,847 cfs	50,429 cfs

Method 4a: Regional Flood Frequency method to predict 50- and 100-year flood magnitude during Winter Flood season - 3 LOCAL SMALL GAGES

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	4,611 cfs	5,000 cfs	14,385 cfs	15,551 cfs	83,674 cfs
100 yr	5,478 cfs	5,945 cfs	17,218 cfs	18,619 cfs	100,441 cfs

Method 4b: Regional Flood Frequency method to predict 50- and 100-year flood magnitude during Winter Flood season - 5 LOCAL GAGES

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	5,164 cfs	5,459 cfs	11,177 cfs	11,781 cfs	36,724 cfs
100 yr	6,076 cfs	6,425 cfs	13,215 cfs	13,933 cfs	43,550 cfs

Table 14. Summary of OPTION B: 50- and 100-year flood magnitudes at Trinity River bridges assuming 6000 cfs SOD release from Lewiston Dam

WINTER FLOOD SEASON

Method 1: Regional Regression Equations to predict 50- and 100-year flood magnitude during Winter Flood season

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	14,139 cfs	14,594 cfs	21,959 cfs	22,828 cfs	52,137 cfs
100 yr	15,788 cfs	16,318 cfs	25,404 cfs	26,412 cfs	60,961 cfs

Method 2: Additive Tributary Model method to predict 50- and 100-year flood magnitude during Winter Flood season

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	9,342 cfs	15,342 cfs	15,135 cfs	21,135 cfs	38,313 cfs
100 yr	10,071 cfs	16,071 cfs	17,556 cfs	23,556 cfs	44,971 cfs

Method 3a: Unit Runoff method to predict 50- and 100-year flood magnitude during Winter Flood season - 3 LOCAL SMALL GAGES

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	12,258 cfs	12,643 cfs	20,299 cfs	21,128 cfs	58,895 cfs
100 yr	13,817 cfs	14,287 cfs	23,416 cfs	24,381 cfs	64,399 cfs

Method 3b: Unit Runoff method to predict 50- and 100-year flood magnitude during Winter Flood season - 5 LOCAL GAGES

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	12,785 cfs	13,180 cfs	20,601 cfs	21,356 cfs	47,777 cfs
100 yr	14,207 cfs	14,685 cfs	23,639 cfs	24,547 cfs	56,129 cfs

Method 4a: Regional Flood Frequency method to predict 50- and 100-year flood magnitude during Winter Flood season - 3 LOCAL SMALL GAGES

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	10,311 cfs	10,700 cfs	20,085 cfs	21,251 cfs	89,374 cfs
100 yr	11,178 cfs	11,645 cfs	22,918 cfs	24,319 cfs	106,141 cfs

Method 4b: Regional Flood Frequency method to predict 50- and 100-year flood magnitude during Winter Flood season - 5 LOCAL GAGES

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	10,864 cfs	11,159 cfs	16,877 cfs	17,481 cfs	42,424 cfs
100 yr	11,776 cfs	12,125 cfs	18,915 cfs	19,633 cfs	49,250 cfs

location. As a means to evaluate the predictive accuracy of the regional regression equations to local streams, we applied the regional regression equations for the North Coast to the Grass Valley Creek near Fawn Lodge flood frequency curve (Figure 3) and the Trinity River above Coffee Creek flood frequency curve (Figure 8). This comparison suggests that the regional regression equations over predict flood magnitude at all flood recurrence intervals at these two "measured" locations, particularly at the Grass Valley Creek gaging station. Additionally, the method gives very large flood magnitude predictions at the Salt Flat and Bucktail bridges compared to the other methods, suggesting the bias described above is the source of these overly large predictions. Therefore, we give the flood magnitude predictions from this method a low ranking.

5.1.2. Method 2: Additive Tributary Model

The Additive Tributary Model method is not a standard approach, and the substantial list of simplifying assumptions reduces the confidence in the flood magnitude predictions. Ignoring flood routing, small tributary contributions, and alignment of flood peaks are the primary sources of uncertainty. Using the Trinity River near Burnt Ranch gaging station as a calibration point is useful in concept, but is so far downstream from our reach that the value of the calibration is dubious. Therefore, we give the flood magnitude predictions from this method a low-moderate ranking.

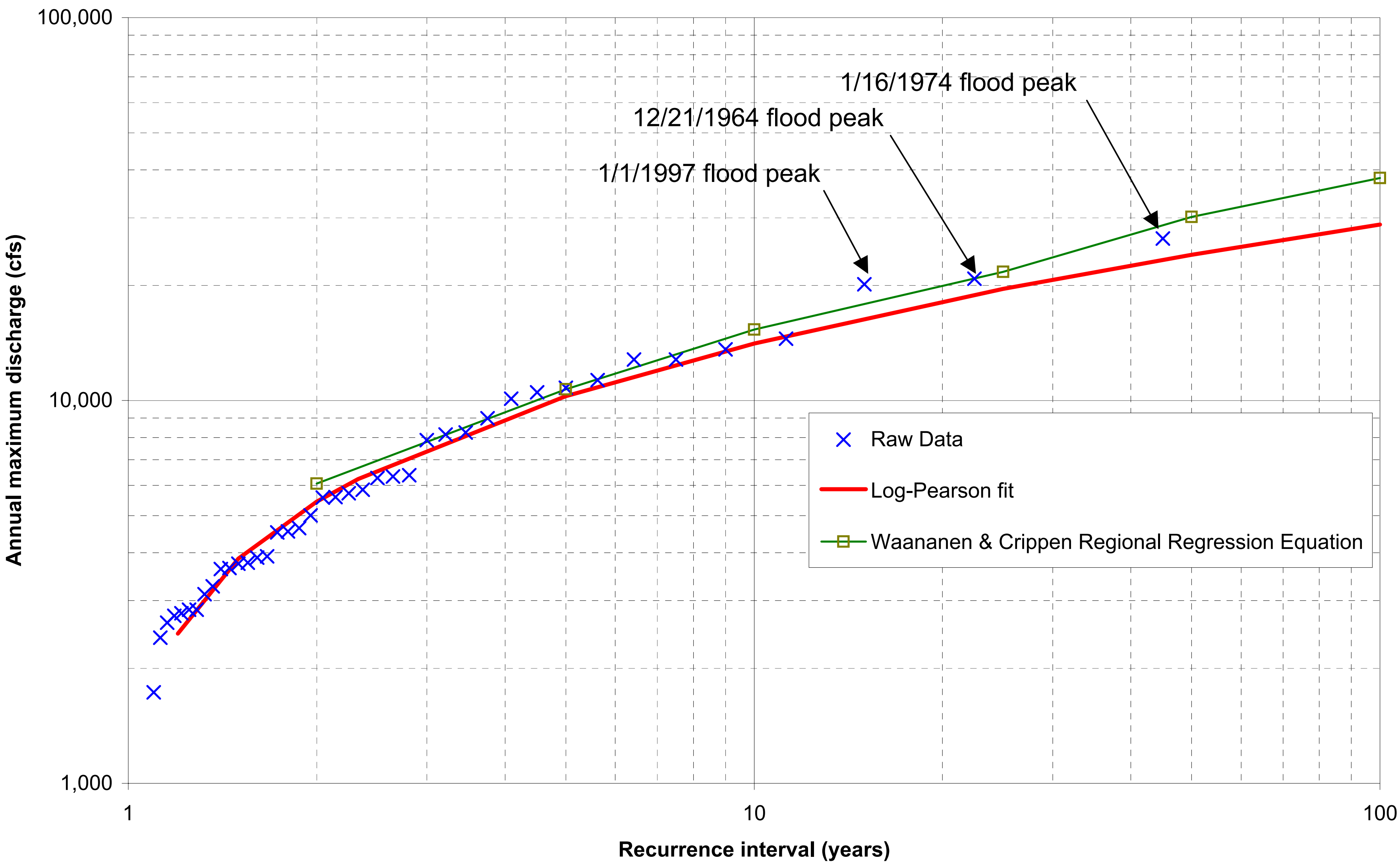
5.1.3. Method 3: Unit Runoff Method

The Unit Runoff method using the three smaller gaging stations provides good flood magnitude predictions because the gages are nearby, have long periods of record, have similar precipitation and runoff patterns, and have similar drainage areas as the four bridge locations. Adding the two additional gages provide additional period of record, but they are much larger watersheds and are not as local as the three smaller gages. These two additional gages cause the regression equation to predict a higher unit-runoff value than just using the three smaller gages alone. A weakness in the Unit Runoff method is that watershed elevation and precipitation is not an explicit variable, and must be accounted for in choosing appropriate local gages with similar elevation and precipitation. The choice of Grass Valley Creek, Trinity River above Coffee Creek, and the North Fork Trinity River near Helena bracket the drainage areas at the bridges, and provide consistent unit runoff values for the 50- and 100-year flood. The Unit Runoff method accounts for all watershed area at the bridge locations, and routing mechanisms are accounted for in the unit-runoff predictions. Therefore, we prefer the three-gage approach, and give the flood magnitude predictions from this method a high ranking.

5.1.4. Method 4: Regional Flood Frequency Method

The Regional Flood Frequency method uses regional drainage area-to-mean flood peak magnitude relationships to modify variables in the Log Pearson III flood frequency computation. As with the Unit Runoff method, groups of local and regional gages are used to develop the drainage area-to-mean flood peak magnitude relationships, so there are tradeoffs between low numbers of very local gages to expanding to larger numbers of more regional gages. The effective period of record shown in Table 10, combined with the "localness" of the gages used, can guide which group provides a better flood

Figure 8. Trinity River above Coffee Creek (USGS Gage #11-523200) flood frequency analysis



magnitude estimate. Based on this possible criterion, the three gage and five gage groups are preferable. Going beyond this delineation is more difficult because we do not have extensive experience using this method. In comparing with the Unit Runoff method, the deviation in predicted log mean values as a function of drainage area appears to be much larger (factor of 2) than the deviation in predicted unit runoff as a function of drainage area (appx 6% maximum), which would add uncertainty to flood magnitude predictions. The predicted 100-year flood magnitude predictions using the three gages (Table 12) are 33% smaller than the Unit Runoff Method predictions for the two upstream bridges; however, for the two downstream bridges, the 100-year predictions are functionally exactly the same as those predicted by the Unit Runoff Method predictions. Therefore, we give the flood magnitude predictions from this method a moderate to high ranking.

5.2. Comparison of 3-gage unit runoff prediction with ACOE (1976) study

The predicted 100-year flood magnitudes from this report are compared with those predicted in FEMA (1996). The FEMA 100-year flood magnitudes on Grass Valley Creek and along the Trinity River are listed in Table 14. The FEMA 100-year flood due to tributary accretion is estimated by subtracting 8,200 cfs as shown in Table 15, and can be compared to the varying modeling predictions summarized in Table 13. Using the Unit Runoff method with 3-gages as a preliminary preferred method, we compared the results with that predicted by the Corp of Engineers (Table 15). The longitudinal flood frequency estimates are quite different, and deserve some attention. Unfortunately, the FEMA flood estimate computations are unavailable and cannot be duplicated. A primary limitation in their analysis, assuming that they used regional gaging stations in their flood magnitude estimates, is the short period of record available (only up through 1973 if they used the regional regression equations) and the absence of the 26 years of record at the Grass Valley Creek gaging station (1976-2001).

Table 15. 100-year flood magnitude estimates based on FEMA (1996).

Location	FEMA 100-yr Flood Flow Estimate	FEMA 100-yr Flood Flow Estimate assuming Lewiston Release=300 cfs	Predicted 100-yr Flood Flow Estimate using 3-gage Unit Runoff method
Lewiston Dam	8,500 cfs	300 cfs	300 cfs
Salt Flat/Bucktail Bridges	20,500 cfs	12,300 cfs	8,587 cfs @ Bucktail
Grass Valley Creek	12,000 cfs	N/A	N/A
Poker Bar/Treadwell Bridge	32,500 cfs	24,300 cfs	18,681 cfs @ Treadwell
Douglas City (downstream of Browns Creek)	38,500 cfs	30,300 cfs	58,699 cfs

Our 100-year flood magnitude estimates are substantially lower than the FEMA numbers at the bridge locations, then larger at the discontinued USGS Douglas City gaging station. First observe the longitudinal trend of the FEMA estimates. The only sizable tributaries contributing flow to the Salt Flat and Bucktail bridges are Deadwood Creek (DA=8.9 mi^2), Hoadley Gulch (DA= 3.8 mi^2), and Rush Creek (DA=22.7 mi^2). The total unregulated drainage area from Lewiston Dam to the Salt Flat Bridge is 40 mi^2 (including minor tributaries), such that the FEMA 100-year flood contribution would be 300 cfs/mi^2. By comparison, the 100-yr flood estimate for the Trinity River above Coffee Creek

(DA=149 mi^2, n=44 years) is 28,800 cfs, for a unit-runoff of only 193 cfs/mi^2, and Grass Valley Creek only has a unit runoff of 195 cfs/mi^2 for the 100-year flood. It seems unlikely that Rush Creek and smaller tributaries could contribute 300 cfs/mi^2 during a 100-yr flood due to their small drainage areas. If the FEMA flood magnitudes at Salt Flat and Bucktail bridges are conservatively large, then they would also be conservatively large at the Poker Bar and Treadwell bridges. The 12,000 cfs accumulation between these two locations from Grass Valley Creek is also large for the drainage area. The drainage area between the Salt Flat Bridge and the Poker Treadwell Bridge is 53 mi^2, such that the FEMA 100-year flood contribution is 226 cfs/mi^2. While this unit-runoff value is more reasonable, it still seems too high. The largest increase in drainage area occurs between the Treadwell Bridge location and Douglas City gage as Indian Creek, Weaver Creek, Reading Creek, and Browns Creek all contribute to mainstem Trinity River flood flows. The 100-year flood magnitude contributed by the watershed between Treadwell Bridge and the Douglas City site (6,000 cfs) seems very small compared to the substantial increase in drainage area (201 mi^2 for a unit runoff of only 30 cfs/mi^2). Therefore, the FEMA flood magnitude estimates probably need revisiting to incorporate the additional gaging period of record, availability of the Grass Valley Creek gage, and the distribution of drainage area contribution to the mainstem Trinity River.

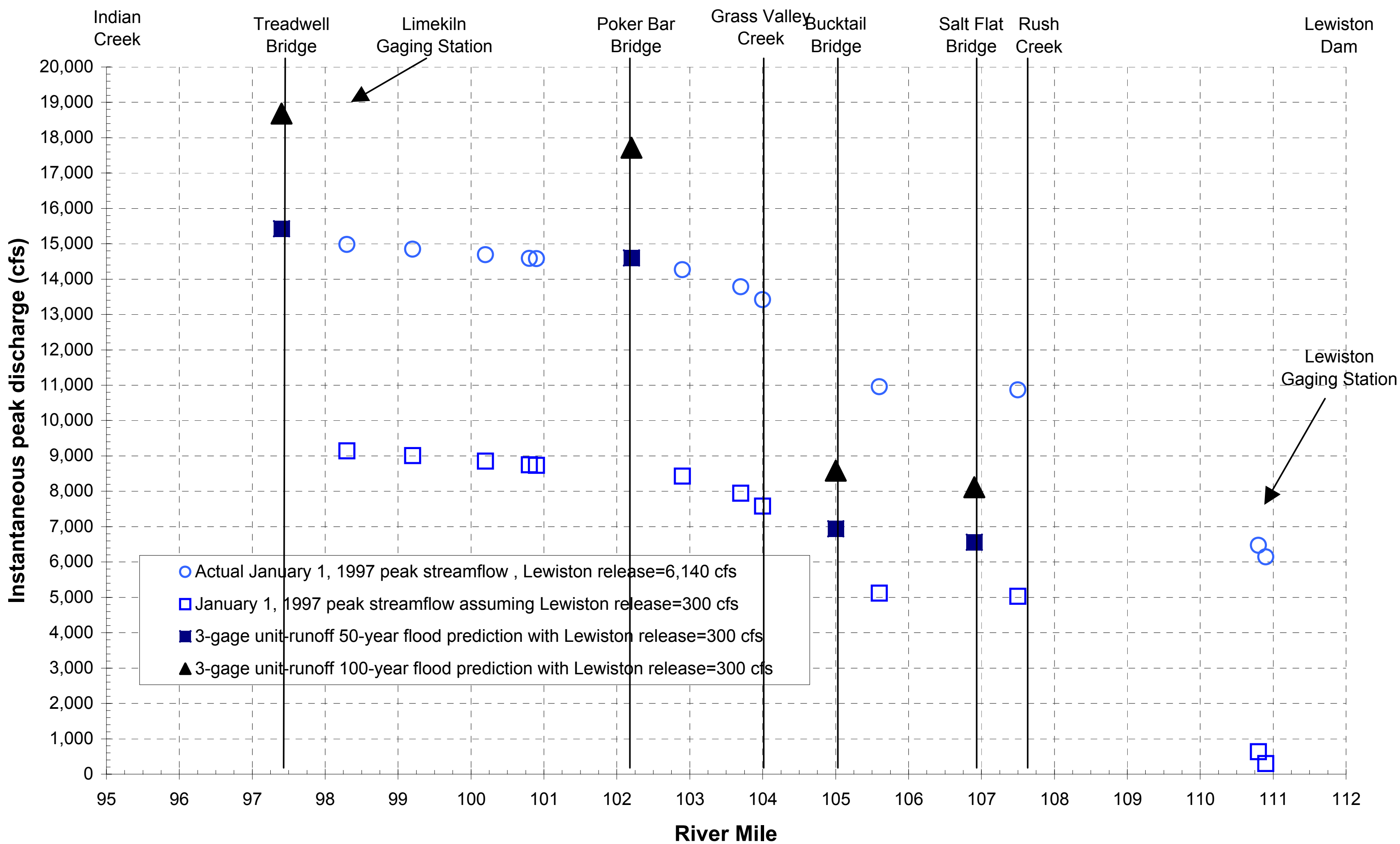
5.3. Comparison of 3-gage unit runoff prediction with the January 1997 flood

The January 1997 flood was a moderate intensity, warm, rain-on-snow flood that caused large flows on the higher elevation watersheds and moderate floods on the lower elevation rainfall dominated watersheds. The peak of the flood on Rush Creek occurred almost exactly on midnight of January 1, 1997, and the peak on Grass Valley Creek occurred at approximately the same time. The corresponding mainstem release at Lewiston Dam was approximately 6,140 cfs. We evaluated the longitudinal magnitude of the 1997 flood using a series of gaging stations and site-specific hydraulic estimates (Figure 9), resulting in estimated flood peak of approximately 11,000 cfs at the Salt Flat Bridge and Bucktail Bridge, and approximately 15,000 cfs at the Poker Bar Bridge and Treadwell Bridge.

In order to estimate the magnitude of the 1997 flow at the bridges if flow releaes were 300 cfs instead of the actual 6,140 cfs release from Lewiston Dam, we subtract 5,840 cfs from each longitudinal node (subtract 6,140 cfs Safety of Dam release and add 300 cfs typical baseflow release). Resulting flows due to tributary contributions only would be approximately 5,100 cfs at the Salt Flat Bridge and Bucktail Bridge and 9,000 cfs at the Poker Bar Bridge and Treadwell Bridge (Figure 9). Comparing these 1997 tributary derived flood magnitudes with the Unit Runoff method predictions suggests that the 1997 flood was approximately 65% of the 100-year flood prediction at the Salt Flat Bridge, 62% at the Bucktail Bridge, 52% at the Poker Bar Bridge, and 49% at the Treadwell Bridge. The percentages likely decrease in the downstream direction because the 1997 flood on Grass Valley Creek was only a 10-year recurrence event, causing the deviation between the 1997 flood and predicted 100-year event magnitude to increase.

To put the 1997 flood into perspective, we evaluated the magnitude of the flood at nearby regional gaging stations. Regional flood frequency estimates of the 1997 flood vary with

Figure 9. Predicted Trinity River 50-year and 100-year annual maximum flood magnitude assuming Lewiston Dam 300 cfs release and 3-Gage Unit-Runoff method.



the watershed. Using a re-constructed 145-year period of record of 1-day volume based on mean daily flows (pre-dam values from USGS gaging station, post-dam values from USBR inflow computations), the 1997 flood was greater than a 100-year flood (Reclamation, in press). However, using the shorter 26-year period of record at the rainfall runoff dominated Grass Valley Creek, the 1997 flood was only a 10-year flood using the annual instantaneous maximum values. The same flood frequency analysis of was performed on two snowmelt-dominated streams that drain the Trinity Alps. At the Trinity River above Coffee Creek (gage elev. = 2,537 ft, n = 44 years), the predicted frequency of the 1997 flood was approximately a 27-year flood (Figure 8), while at the Salmon River at Somes Bar (gage elev. = 483 ft, n = 76 years), the predicted frequency of the 1997 flood was approximately a 40-year flood (Figure 10). The predicted recurrence intervals of the 1997 flood (10 to 40-year recurrence) are all much less than that predicted by the flood frequency analysis of daily average inflows at Lewiston (> 100 years, Reclamation, in press), although the period of record at the Lewiston measurement point is longer (84 years) than any of the tributary stations (Table 16). Therefore, designing the bridges to accommodate cumulative predicted 100-year tributary flood magnitudes from Rush Creek and Grass Valley Creek should provide protection well above that observed during the 1997 flood.

Table 16. Comparison of 1997 flood on regional streams with 50 and 100-year flood magnitudes.

Tributary	1997 peak	Estimated 1997 flood recurrence	50-yr flood	100-yr flood
Grass Valley Creek	2,460 cfs	10 year[a]	4,800 cfs[a]	6,022 cfs[a]
Trinity River abv Coffee Creek	20,100 cfs	27 year	24,000 cfs[a]	28,800 cfs[a]
Salmon River at Somes Bar	70,800 cfs	40 year	73,200 cfs[b]	84,800 cfs[b]
Rush Creek	4,400 cfs	>100 year[c]	3,200 cfs[c]	3,800 cfs[c]
Trinity River at Lewiston	75,765 cfs	143 year	56,800 cfs[d]	68,000 cfs[d]

[a] from Log-Pearson III fit of USGS annual instantaneous peak discharge values
[b] from Log-Pearson III fit of USGS annual instantaneous peak discharge values, Dec 1964 flood adjusted
[c] from Unit-conversion of regional regression equations; a 100-yr event if using Unit-Runoff method
[d] from USBR (in press) Log-Pearson III fit of USGS and USBR annual maximum daily average discharge values

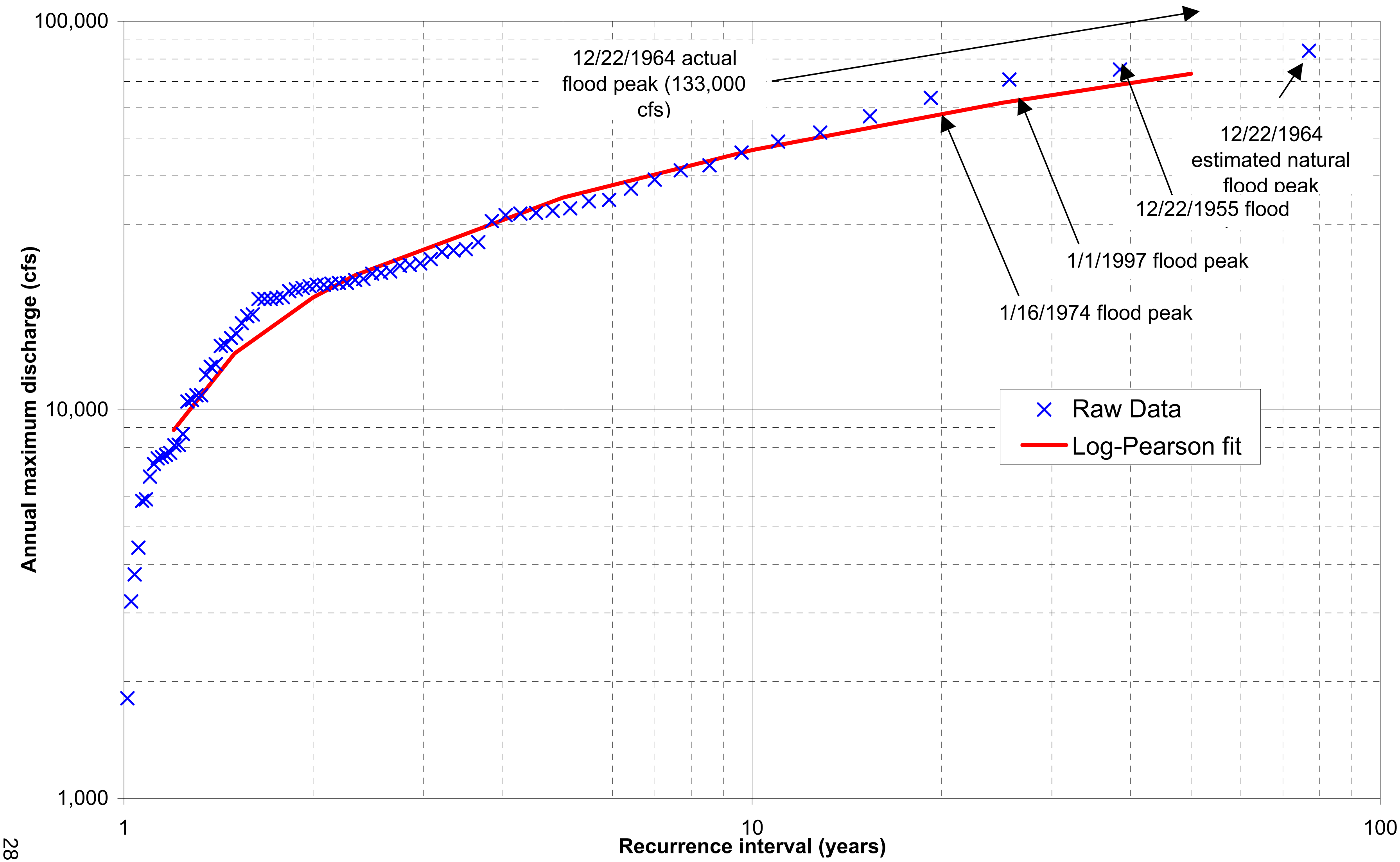
5.3.1. Summary

We recommend using the 50 and 100-year flood magnitude results predicted by the three-gage Unit-Area Method. These results are summarized in Table 17.

Table 17. Recommended 50 and 100-year flood magnitude estimates at the four bridges using the three-gage Unit Area Method (results have been rounded from Table 13 and Table 14).

Location	50-yr flood, Lewiston release=300 cfs	100-yr flood, Lewiston release=300 cfs	50-yr flood, Lewiston release=6,000 cfs	100-yr flood, Lewiston release=6,000 cfs
Salt Flat Bridge	6,550 cfs	8,120 cfs	12,250 cfs	13,820 cfs
Bucktail Bridge	6,950 cfs	8,590 cfs	12,650 cfs	14,290 cfs
Poker Bar Bridge	14,600 cfs	17,700 cfs	20,300 cfs	23,400 cfs
Treadwell Bridge	15,400 cfs	18,700 cfs	21,100 cfs	24,400 cfs

Figure 10. Salmon River at Somes Bar (USGS Gage #11-522500) flood frequency analysis



6. SNOWMELT RUNOFF SEASON

As done for the winter flood season, we applied the Unit Runoff of 50- and 100-year tributary accretion at each of the bridges, but only for the May-June snowmelt runoff season. USGS does not publish peak values during the snowmelt runoff season, so we initially used maximum daily average value for the May-June period for each year, then adjusted this daily value to represent a peak value for that day. Kamman (1999) evaluated differences between daily averages and daily peak values on Grass Valley Creek during the snowmelt season, and suggests using an average conversion value of 1.33. We computed the 50- and 100-year flood magnitude for Rush Creek, Grass Valley Creek, and the remaining drainage area between Lewiston Dam and the bridge of interest using the Unit Runoff method, and then add the three flow magnitudes together to get an estimate at each bridge. This assumes that peak snowmelt flows occur at the same time, are additive, and there is no flood peak attenuation. However, comparing recent annual hydrographs between Rush Creek and Grass Valley Creek shows that there are still significant deviations in the timing of the maximum daily flow during this period due to regional differences (Figure 11 and 12).

While Rush Creek has been gaged since 1996, the period of record is too short to extrapolate to the 50- and 100-year flood magnitude estimates. The period of record at Grass Valley Creek is longer (26 years), but still short enough to make it difficult to predict a 50 or 100-year flood with a high level of confidence. Regardless, Grass Valley Creek is our best data source, and was used. We first tabulated the maximum daily average flow for the May-June period, multiplied by 1.33 to convert to daily peak value, and fit the data to the Log Pearson III distribution to predict the 50- and 100-year flood magnitude. We were concerned about applying the generalized skew value used in the annual peak flow analysis to the distribution of snowmelt high flow events, so we investigated the May-June maximum daily average value skew of nearby gages. The skew at the pre-dam Trinity River at Lewiston station was –1.05, at Grass Valley Creek near Fawn Lodge was +0.99, and at the NF Trinity River near Helena was +0.13. This large range provided no trend in appropriate generalized skew to use in the Log Pearson III computations, so we chose to apply the same generalized skew as used in the annual maximum flood frequency computations (-0.30). Applying this method results in a 50-year May-June flow magnitude of 499 cfs, and a 100-year May-June flow magnitude of 637 cfs (Table 18).

To test the sensitivity of the generalized skew value to predictions, we computed the 50 and 100-year May-June flow predictions assuming the measured skew at the Grass Valley Creek gage (+0.99) is a more appropriate skew estimate for the population of data. This increased predicted 50 and 100-year May-June flow to 636 cfs and 902 cfs, respectively. Carrying this through to the downstream tributaries results in a 50- and 100-year flow prediction of 1,613 cfs and 2,219 cfs at the Treadwell Bridge, which can be compared to corresponding predictions of 1,370 cfs and 1,746 cfs using a generalized skew of -0.30 (Table 18). These flood magnitudes could be used as a conservative estimate; however, a substantial safety factor is already built into the computations of flow magnitude at the bridges because we assume that the maximum peak flow occurs at the same time for all tributaries, and occurs at the same time as a Record of Decision flow

Figure 11. Rush Creek Annual Hydrograph for Water Year 1998 (Extremely Wet).

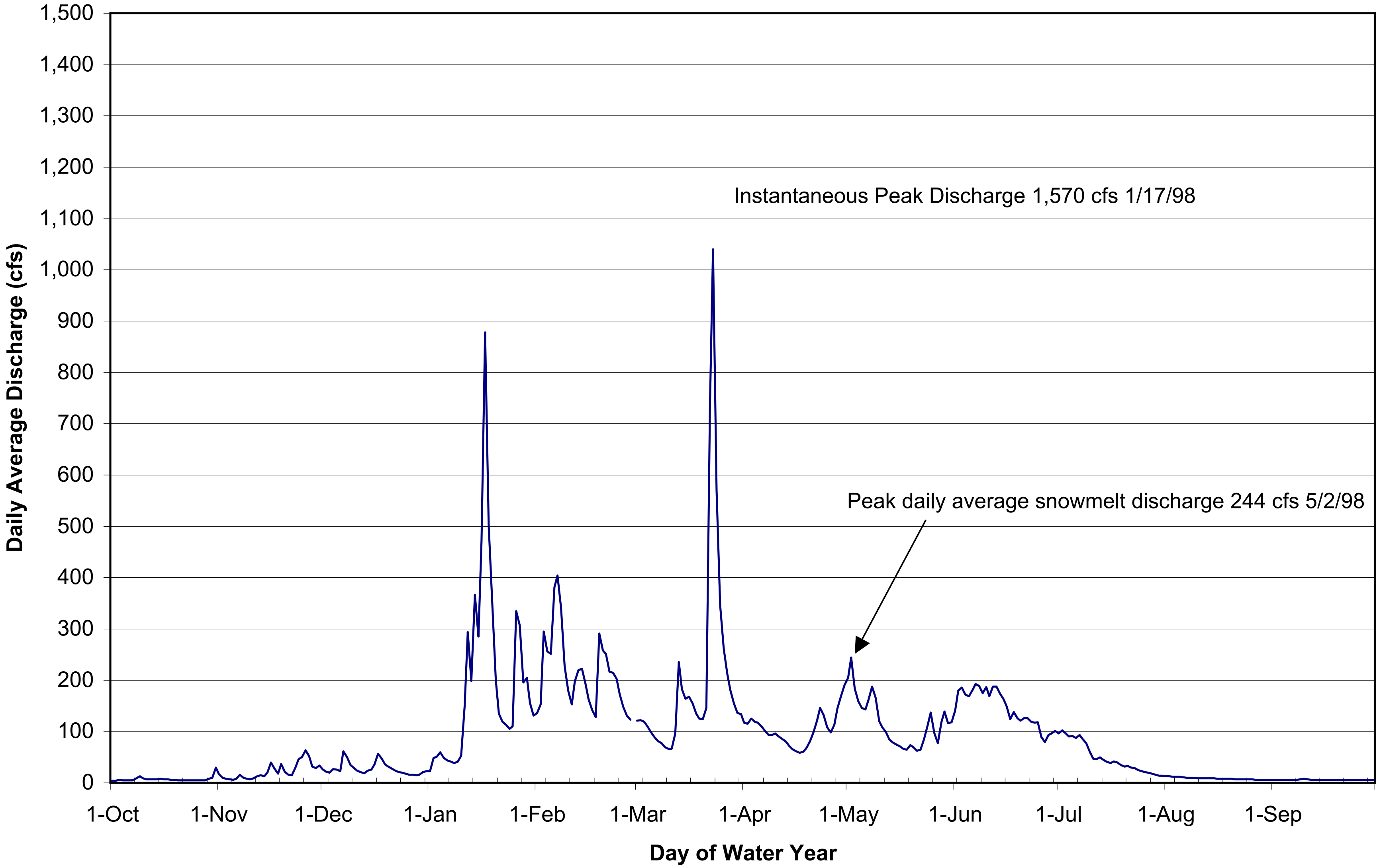
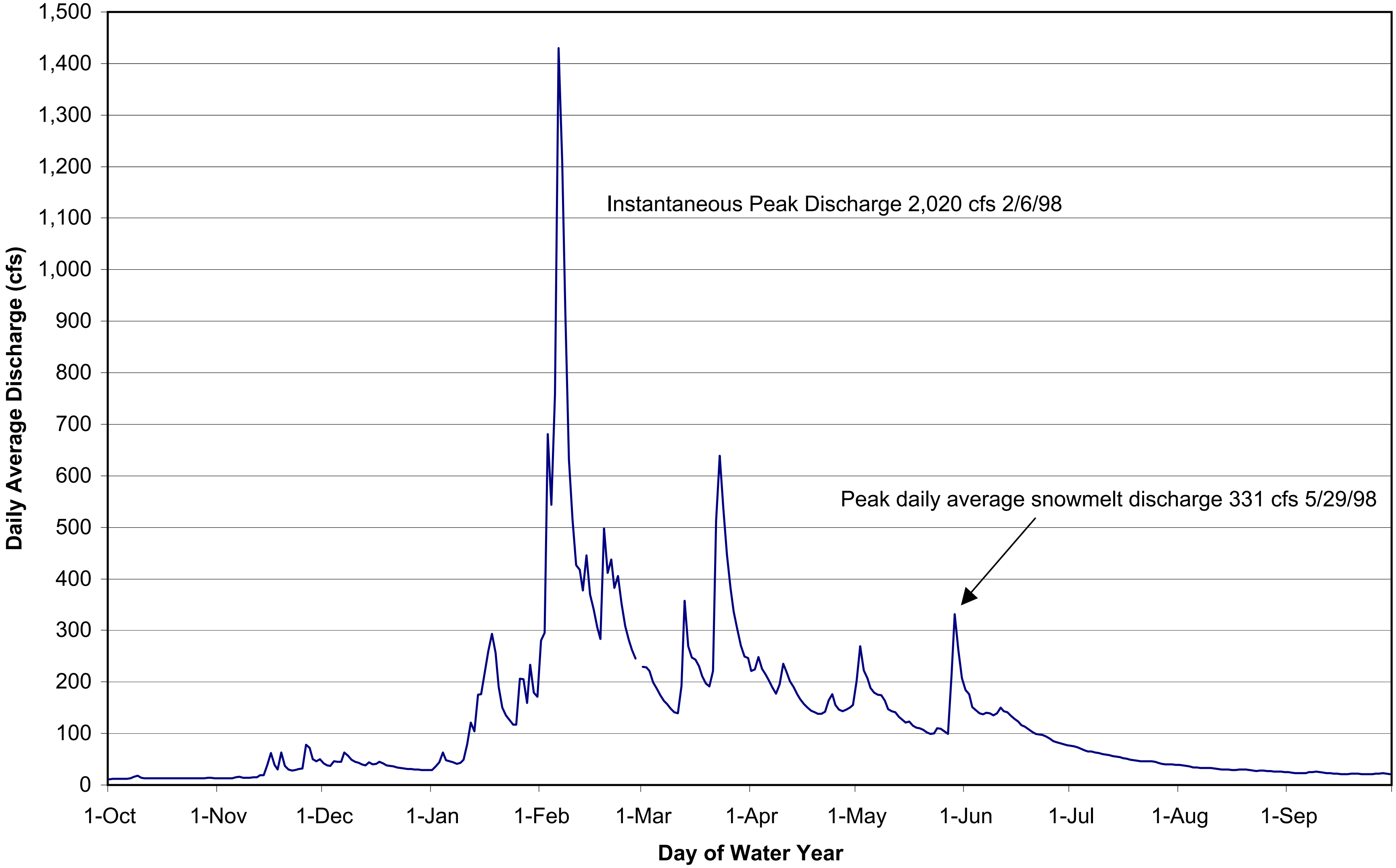


Figure 12. Grass Valley Creek at Fawn Lodge (USGS Station # 11525600)
Annual Hydrograph for Water Year 1998 (Extremely Wet)



release. As shown in the 1998 hydrographs in Figures 11 and 12 (Extremely Wet year, largest May-June peak flow over 27 years of record at the Grass Valley Creek gage), the peaks were approximately four weeks apart. Therefore, we used the predicted May-June flow values as shown in Table 18.

Table 18. Predicted maximum peak flow values for bridges during the May-June snowmelt runoff season using -0.30 generalized skew (assumes Lewiston Dam release = 0 cfs).

		50-year May-June peak flow magnitude	100-year May-June peak flow magnitude
SALT FLAT BRIDGE			
	Rush Creek	336 cfs	428 cfs
	Cumulative smaller tributaries	256 cfs	326 cfs
	TOTAL AT SALT FLAT BRIDGE:	**592 cfs**	**754 cfs**
BUCKTAIL BRIDGE			
	Rush Creek	336 cfs	428 cfs
	Cumulative smaller tributaries	291 cfs	464 cfs
	TOTAL AT BUCKTAIL BRIDGE:	**627 cfs**	**800 cfs**
POKER BAR BRIDGE			
	Rush Creek	336 cfs	428 cfs
	Grass Valley Creek	547 cfs	698 cfs
	Cumulative smaller tributaries	432 cfs	551 cfs
	TOTAL AT POKER BAR BRIDGE:	**1,315 cfs**	**1,676 cfs**
TREADWELL BRIDGE			
	Rush Creek	336 cfs	428 cfs
	Grass Valley Creek	547 cfs	698 cfs
	Cumulative smaller tributaries	504 cfs	643 cfs
	TOTAL AT TREADWELL BRIDGE:	**1,387 cfs**	**1,769 cfs**

Rather than using regional regression curves to Rush Creek (a mis-application since we are assessing May-June flows rather than annual instantaneous peak flows), we simply performed a unit area drainage area adjustment from the Grass Valley Creek 50 and 100-year flood magnitudes to estimate 50 and 100-year flood magnitudes on Rush Creek:

$$Q_{50rushmayjune} = Q_{50gvcmayjune} *(A_{rush}/A_{gvc})^{1.0}$$
$$Q_{100rushmayjune} = Q_{100gvcmayjune} *(A_{rush}/A_{gvc})^{1.0}$$

Where $A_{rush} = 22.7\ mi^2$ and $A_{gvc} = 30.8\ mi^2$. An exponent of 1.0 is used instead of 0.87 (used for annual peak analysis) because we do not know if the 0.87 value is applicable for the snowmelt runoff flows. The drainage area at each bridge not accounted for in the Grass Valley Creek and Rush Creek watersheds were also multiplied by the unit runoff values:

$$Q_{50tribsmayjune} = Q_{50gvcmayjune} *(A_{tribs}/A_{gvc})^{1.0}$$
$$Q_{100tribsmayjune} = Q_{100gvcmayjune} *(A_{tribs}/A_{gvc})^{1.0}$$

The resulting 50- and 100-year May-June peak flow estimates for Rush Creek and the additional smaller tributaries are shown in Table 18, as are the resulting flow estimates at each bridge location.

These flow magnitudes were added to the two May-June Lewiston Dam release scenarios, and results are shown in Table 19. If Lewiston Dam is releasing 11,000 cfs for an Extremely Wet year at a time when a 100-year snowmelt runoff is peaking (a conservative assumption), the corresponding mainstem flows would be 11,754 cfs at the Salt Flat Bridge, 11,800 cfs at the Bucktail Bridge, 12,676 cfs at the Poker Bar Bridge, and 12,769 cfs at the Treadwell Bridge. If Lewiston Dam is releasing 13,750 cfs for a Safety of Dams release at a time when a 100-year snowmelt runoff is peaking (again, a conservative assumption), the corresponding mainstem flows would be 14,504 cfs at the Salt Flat Bridge, 14,550 cfs at the Bucktail Bridge, 15,426 cfs at the Poker Bar Bridge, and 15,519 cfs at the Treadwell Bridge.

6.1. Comparing the 1998 snowmelt runoff with flood frequency analysis results

We again used a recent high flow year to ground truth our 50 and 100-year flood estimates. For the snowmelt runoff period, we used 1998 because it was the second largest water year in record for the Trinity River (n=88 years, 1912-1999), and we had daily average discharge records for both Grass Valley Creek and Rush Creek for 1998. The maximum daily average discharge in 1998 for Rush Creek was 244 cfs on May 2 (Figure 11), and was 331 cfs for Grass Valley Creek May 29 (Figure 12). Multiplying these daily average values by 1.33 results in estimated peak values of 325 cfs for Rush Creek, and 441 cfs for Grass Valley Creek. These estimates are much smaller than the 50-year flood prediction shown in Table 18.

To further evaluate the predicted 50 and 100 year flood magnitudes shown in Table 18, we evaluated additional 1998 indices of Trinity Reservoir inflows (period of record = 88 years): Maximum daily average, Maximum volume over the May-June period, and Maximum yearly inflow. Results of the 1998 inflows were as follows: 1) the maximum May-June daily average flow for WY 1998 was the fifth largest (15,400 cfs), with an approximate flood recurrence of 17 years, 2) the runoff volume over the May-June period for WY 1998 was the second largest (922,300 acre-ft), with an approximate 50 year recurrence interval, and 3) the total water yield for WY 1998 was also the second largest (2,701,000 acre ft), with an approximate 50 year recurrence interval. These results suggest that our estimates of the 50- and 100-year May-June snowmelt runoff magnitudes on Rush Creek and Grass Valley Creek are conservatively large; designing the bridges to convey the predicted 50- and 100-year May-June flow peaks will most likely provide a moderate safety factor.

Table 19. Summary of OPTION C and D: 50- and 100-year flood magnitudes at Trinity River bridges assuming an 11,000 cfs and 13,750 cfs ROD release from Lewiston Dam

MAY/JUNE SNOWMELT RUNOFF SEASON

Option C: Release 11,000 cfs ROD flow on top of 50- and 100-year flood magnitude during May-June snowmelt runoff season

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	11,592 cfs	11,627 cfs	12,315 cfs	12,387 cfs	Not Computed
100 yr	11,754 cfs	11,800 cfs	12,676 cfs	12,769 cfs	Not Computed

Option D: Release 13,750 cfs SOD or ROD flow on top of 50- and 100-year flood magnitude during May-June snowmelt runoff season

Recurrence Interval	Flow at Salt Flat Bridge	Flow at Bucktail Bridge	Flow at Poker Bar Bridge	Flow at Treadwell Bridge	Flow at Douglas City
50 yr	14,342 cfs	14,377 cfs	15,065 cfs	15,137 cfs	Not Computed
100 yr	14,504 cfs	14,550 cfs	15,426 cfs	15,519 cfs	Not Computed

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