

## Supplemental Material: Estimating Streamflow into Scott Valley

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The Scott Valley groundwater basin and its overlying streams are fed by runoff from the surrounding mountains. Tributaries to the Scott River, including the two forks of the Scott River itself, emanate from the mountains carrying significant runoff.

Understanding groundwater-surface water interactions in the Scott Valley requires knowledge of the streamflow amounts that enter the valley floor overlying the groundwater basin. Here, we construct a regression time series of streamflow in all major tributaries of the Scott River and for the South Fork and East Fork of the Scott River, which join at the upper end of the Scott Valley floor. The main purpose for developing these time series is to provide an approximation of surface flows into the Scott Valley at the (upgradient) margin of the groundwater basin.

The eight tributaries of interest here are Sugar, French, Etna, Patterson, Kidder, Mill (a tributary to Shackleford Creek), Shackleford, and Moffett Creeks. The Scott River itself is gauged near Callahan at both the East and South Forks (upstream of the confluence). An additional long-standing gauge (“Ft. Jones”) is located downstream of Scott Valley, west of Fort Jones on the Scott River.

Location of the flow gauges has been provided by the Siskiyou Resources Conservation District and is shown in Figure 1. The gauges at Sugar Creek, Moffet Creek, and Kidder Creek are located above irrigation diversions and do not reflect tributary inflows to the Scott River. Gauges at French Creek, South Fork, and East Fork are located at the margin, but within the Scott Valley.

Most of the tributaries have very limited records of streamflow gauging (Table 1), while the Ft. Jones gauge has a complete record for the past seventy years (Figure 2). To develop an appropriate groundwater-surface water model for the Scott Valley groundwater basin, it is therefore necessary to also develop a model of the main stem and tributary streamflows, at the upgradient boundary of the Scott Valley floor, for those time periods for which no streamflow data are available.

We determine missing tributary and main stem streamflow data at the upstream margins of the groundwater basin by statistical regression analysis. A number of independent predictor variables are considered for the regression analysis: streamflow of the Scott River at the downstream Fort Jones gauging station, streamflow at the East Fork and South Fork gauging stations in Callahan, streamflows on the tributaries when measured (Table 1), precipitation data, and snowpack data. The program R<sup>®</sup> was used to create linear regression models.

Snow water content stations are located throughout the Scott Valley. The measurements considered here are those taken in the month of April. The stations at Box Camp (BXC) and Marble Valley (MBV) were not used since the snowmelt from these stations enters the Scott River downstream (north) of the Scott Valley. For the model, the yearly average of the measured snow water content at Middle Boulder 1 (MBL), Etna Mountain (ETN), Dynamite Meadow (DYM), Swampy John (SWJ), and Log Lake (LOG) were used to aggregate across intra-watershed variabilities and to obtain a representative dataset of the snow water content for the regression analysis.

Daily mean precipitation were used to compute the following additional independent variables in the regression:

“MoPrecip”: sum of the average daily precipitation during the current month t

“PrevMoPrecip”: sum of the average daily precipitation during the prior month, t -1

“WYPrecip2Date”: sum of the average daily precipitation between the beginning of the current water year (starting on October 1) and the beginning of the current month, t

“WYPrecip”: sum of the average daily precipitation for the entire water year, of which the current month, t, is part (a model with “perfect foresight” because it includes information that represents events in the future relative to the date of the estimated streamflow).

Daily mean discharge has been recorded at Scott River immediately downstream of Scott Valley near Fort Jones CA (USGS 11519500) since October 1, 1941 (Figure 2, <http://waterdata.usgs.gov/nwis>). Table 1 lists the dates of available tributary streamflow data used for the regression analysis, including the east and south fork of the main stem Scott River. Daily tributary flow was downloaded from the California Water Data Library (<http://www.water.ca.gov/waterdatalibrary/>). The following list includes the code for each tributary: Shackleford Creek near Mugginsville (F25484); Mill Creek near Mugginsville (F25480); French Creek at Highway 3 near Callahan (F25650); Sugar Creek near Callahan (F25890); Scott River, East Fork, at Callahan (F26050); and Scott River, South Fork, near Callahan (F28100).

Monthly averages of reported daily streamflow data for the Scott River gauge at Fort Jones and at the two gauges in Callahan are log-normally distributed. For the regression analysis, all existing monthly average streamflow data,  $x_{i,t}$ , at gauging station  $i$  and month (time)  $t$  were therefore log-transformed and normalized to obtain a normally distributed data series of monthly flows,  $Norm(x_{i,t})$ , for each gauging station  $i$ :

$$Norm(x_{i,t}) = \frac{\log(x_{i,t}) - M[\log(x_i)]}{STD[\log(x_i)]}$$

where M is the arithmetic mean (of the log-transformed data series  $x_i$ ) and STD is the standard deviation.

Four transformed data series computed from known data sets were alternately used as independent variables to build regression models of normalized log-transformed tributary flows using linear regression:

- “Norm(Scott)”: Norm(Scott River Flow at Fort Jones)
- “ProductWeightedNorm(Scott)”:  

$$\sqrt[3]{\text{Norm(Scott River Flow at Fort Jones)} \times \text{WYPrecip} \times \text{AvgSnowWC}}$$
- “RatioWeightedNorm(Scott)”: 
$$\frac{\text{Norm(Scott River Flow at Fort Jones)}}{\sqrt{\text{Total WYPrecip} \times \text{AvgSnowWC}}}$$
- “SumWeightedNorm(Scott)”: [Norm(Scott River Flow at Fort Jones) + WYPrecip + WYPrecip2Date + MoPrecip + PrevMoPrecip + AvgSnowWC]

The following dependent variable time series were separately used against each of the above four independent variables to build a number of regression models for comparison:

- “Norm(Streamname)”: each individual normalized tributary flow gauge time series, all times
- “Norm(EastTrib)”: the combined record of all normalized tributary flow time series of tributaries along the east side of Scott Valley, all times
- “Norm(WestTrib)”: the combined record of all normalized tributary flow time series of tributaries along the west side of Scott Valley, all times
- “Norm(Trib)”: the combined record of all normalized tributary flow time series, all times

Over the period of record, the normalized flow data for the Scott River show a significant shift that occurs sometime during the long drought-free period between the 1955 drought and the 1977 drought. Beginning with the 1977 drought, summer month low flows (but not winter month high flows) are significantly lower than in the 1955 drought and earlier. We therefore created another set of regressions using a split “Norm(Trib)” dataset:

- Norm(Trib)-Pre-WY1972, which includes WY 1943 to WY 1972, and
- Norm(Trib)-Post-WY1972, which includes WY 1973 to WY 2011 data.

Note that “tributary flow” and “tribs” include the South and East Fork of the Scott River. For all of the above regressions, subsets of each log-transformed, normalized data series were used for the time period of interest.

Fitting each tributary separately against the Scott River data, or fitting the combined west side tributaries separately from the combined east side tributary data does not produce significantly higher correlation coefficients (Table 2). It therefore appears that a single regression for the combined dataset of normalized, log-transformed tributary flows is adequate and also takes advantage of the information that may be collected on some tributaries but not at others, given that tributary flows are highly correlated among each other.

When weighting the regressions by additional information, two models emerge with correlation coefficients similar to (and not much higher than) the unweighted regressions: the product-

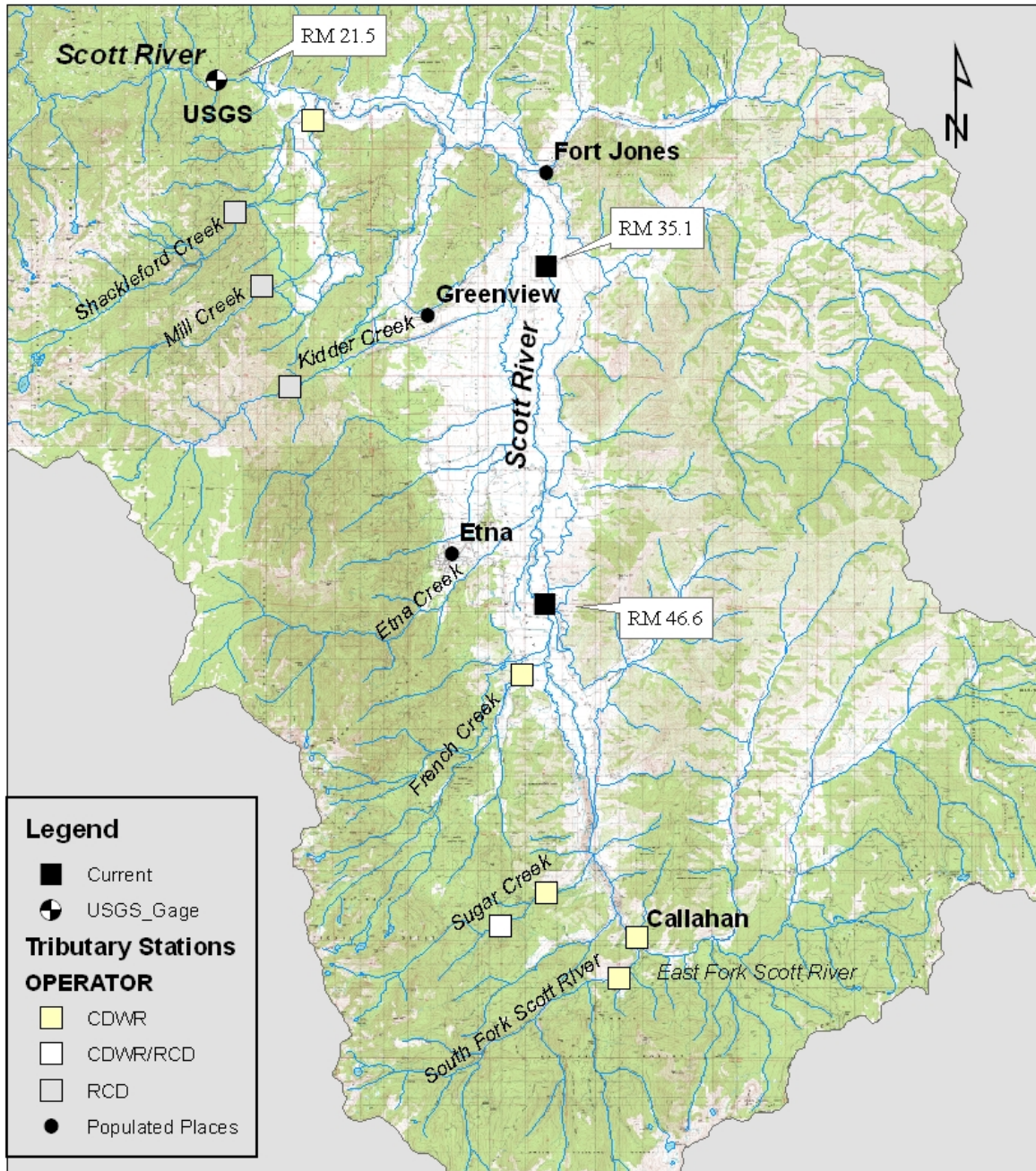
weighted regression and the sum-weighted regression. The ratio-weighted regression, on the other hand, performed very poorly.

The product-weighted regression provides large weights when high flow events coincide with wet years and large snow pack, and low weights when low flow events coincide with dry years and small snow packs. The product-weighted regression implies that tributary flows are relatively smaller (compared to Scott River flows) in dry years with low snow pack than in average or wet years or in years with higher snowpacks.

The sum-weighted regression provides the best correlation coefficient, if only slightly better than the unweighted correlations. The sum-weighted correlation assigns additional weights to several precipitation and snow-pack related data. For many regressions against Norm(Scott) and SumWeightedNorm(Scott), the correlation coefficient,  $r^2$ , is larger than 80% (2) indicating an overall strong, but not perfect, goodness of fit.

The best fit was obtained by the split time period regressions, Norm(Tribs)Pre-WY1972 and Norm(Tribs)Post-WY1972 vs. SumWeightedNorm(Scott), particularly in the critical summer months. Splitting the regression gave slightly better results ( $r^2$  values of 84.7% and 82.4%) than the fully combined regression Norm(Tribs) vs. SumWeightedNorm(Scott) ( $r^2=81.2\%$ ). The split Norm(Tribs)Pre-WY1972 and Norm(Tribs)Post-WY1972 vs. Norm(Scott) also provided an excellent fit with less explanatory factors.

# Map 1 - Scott River Water Supply Stream Discharge Monitoring Locations



0 1.5 3 6 Miles

Cartography by E. Yokel - Siskiyou RCD  
February, 2011

Figure 1. Streamflow measurements in Scott Valley (E. Yokel, Siskiyou RCD, 2011).

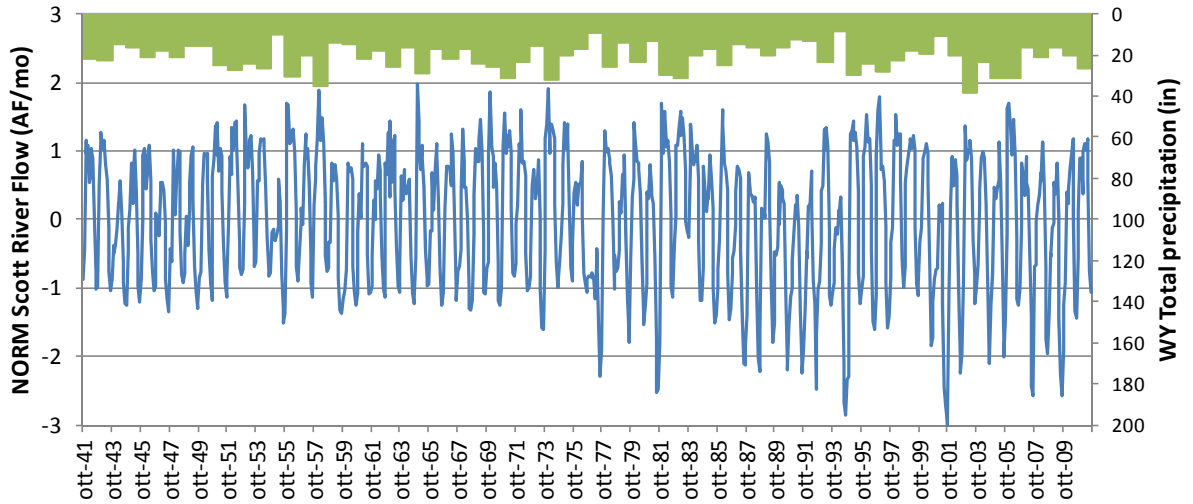


Figure 2. Log-transformed, normalized monthly average Scott River streamflow at Fort Jones, October 1941 through September 2011, computed from reported daily discharge (blue line) with corresponding water year total precipitation (green bars).

Table 1. Dates of available tributary streamflow data used for the regression analysis, including the east and south fork of the main stem Scott River.

	Pre-WY1972 Data Range	Post-WY1972 Data Range
<b>Kidder</b>	4/72-9/72	10/02-9/11
<b>Mill</b>	-	12/04-9/05
<b>Shackleford</b>	10/56-9/60	10/04-9/11
<b>Sugar</b>	9/57-9/60, 5/72-9/72	10/09-9/11
<b>Moffett</b>	10/58-9/67, 4/72-9/72	-
<b>East Fork</b>	10/59-9/72	10/72-9/74, 7/02-9/11
<b>South Fork</b>	10/58-9/60, 4/72-9/72	7/02-9/11
<b>French</b>	-	10/04-9/11
<b>Etna</b>	4/72-9/72	-
<b>Patterson</b>	4/72-9/72	-

Table 2. Key regression slopes, intercepts, and regression coefficients. Availability of data from individual streams is listed in Appendix (also see Table 5).

Dependent Variable	Independent Variable	Regression Slope [-]	Regression Intersect [-]	r <sup>2</sup> [%]
Norm(Tribs)	Norm(Scott)	0.903	0.122	81.2
Norm(Tribs)-Pre-WY1972	Norm(Scott)	1.053	-0.000405	84.7
Norm(Tribs)-Post-WY1972	Norm(Scott)	0.840	0.218	82.4
Norm(WestTribs)	Norm(Scott)	0.881	0.205	81.4
Norm(EastTribs)	Norm(Scott)	0.964	0.00975	83.7
Norm(Kidder)	Norm(Scott)	0.804	0.129	76.7
Norm(Shackleford)	Norm(Scott)	0.952	0.243	89.9
Norm(Sugar)	Norm(Scott)	0.979	0.0406	83.0
Norm(Moffett)	Norm(Scott)	1.044	-0.0567	78.0
Norm(EastFork)	Norm(Scott)	0.941	0.0364	87.4
Norm(SouthFork)	Norm(Scott)	0.900	0.317	82.1
Norm(French)	Norm(Scott)	0.879	0.350	82.2
Norm(Tribs-Summer)	Norm(Scott)	0.758	-0.123	50.1
Norm(Tribs)	RatioWeighted-Norm(Scott)	18.66	0.14	37.0
Norm(Tribs)	ProductWeighted-Norm(Scott)	0.1118	0.006066	76.3
Norm(Tribs)	SumWeighted-Norm(Scott)	0.930	0.370	82.3
Norm(Tribs)	SumWeighted-Norm(Scott) – Pre-WY1972	1.111	0.240	85.6
Norm(Tribs)	SumWeighted-Norm(Scott) – Post-WY1972	0.876	0.682	83.7