Yuba River
New Bullards Bar to Colgate Powerhouse

Accretionary flow Analysis

Prepared for: Yuba County Water Agency

By

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Executive Summary

River discharge is a master variable influencing mountain river systems and is important in understanding their ability to support many environmental functions as well as societal values particularly the generation of electricity and in providing water supply and flood control. Understanding river discharge under different climatic conditions throughout the year is therefore essential in the quantification or qualification of a river's functions and in guiding management decisions for societal use. Ungaged, accretionary flows, within California has been found to be an extremely important water source in hydrodynamic modeling and in developing water balances for water resources management and planning. Diverse methods exist for estimating flow accretions to any given point ranging in complexity from the simplistic methods relating flow in proportion to drainage area to complex rainfall-runoff computer models.

The purpose of this study was to evaluate options for estimating flow accretions occurring in the Yuba River immediately upstream of Colgate Powerhouse. The calculation of accretionary flows at this specific location is necessary to co-locate discharge estimates with stage data obtained from a stage gage installed at the downstream boundary of the study area. The study area includes the North (N.) Yuba River below New Bullards Bar Dam and the portion of the Yuba River from the confluence of the N. Yuba River and Middle Yuba River to just upstream of Colgate Powerhouse. Stage data was recorded for the period between November 11, 2015 and February 2, 2016 including recordation of several large flow events.

Development of a rainfall-runoff or other catchment model was outside the scope of this effort, therefore accretion estimation was based on two general concepts; 1) Statistical regression using statistical methods to develop a relationship between a reference catchment of similar characteristics to the area of interest that has known flows and 2) Area-Weighting where accretion in the area of interest is computed in reference to a comparable catchment with known flows using an area-weighted scaling factor based on the ratios of area and distribution of precipitation.

Stream discharge data used in the analysis was obtained from the California Data exchange center (CDEC) and USGS national water information system; additional data was provided by Yuba County Water Agency. Precipitation information was obtained from the Northwest Alliance for Computational Science and Engineering Parameter-Elevation Regressions on Independent Slopes Model (PRISM).

A total of twelve methods were developed to estimate accretion within the study area. Due to similarity between certain methods and based on a preliminary analysis the six most promising methods were selected for further review. The methods selected for review were comprehensive in covering the range of different methods used to calculate flow accretion, removing duplicative estimates that had similar to nearly identical estimates or methods that resulted in unrealistic accretion values. Three distinct comparative analyses were conducted to determine the preferred accretion calculation method. This involved comparison of the calculated accretion with study area total gaged upstream discharge for the period of stage gage measurement, comparison of the calculated accretion with stage gage height measurements, and a historic comparison of calculated accretion with a small sub-basin within the study area (Sweetland Creek) where existing flow data was available.

Results of hydrologic analysis indicate that the area-weighting method using the CDEC LCB gage and Oregon Creek catchment as the index catchment, herein referred to as the AW-LCB method, represents the best analyzed accretion estimator for the study area. This method

will be used in subsequent analysis of the study area to evaluate geomorphology and habitat conditions within the Yuba River between New Bullards Bar Dam and Colgate Powerhouse. Specifically this method will allow generation of a stage-discharge relationship at the downstream study area boundary. This relationship is critical to defining boundary conditions for proposed discharge dependent hydrodynamic modeling of the study area. Furthermore, this method can be used in the creation of a historic flow record at the downstream study area boundary through application of the model using historic flow records that will allow for further hydrologic analysis of flow study area flow patterns.

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1. Introduction

Mountain river systems support many important environmental functions as well as societal value particularly in their ability to generate electricity and provide water supply and flood control. River discharge is a master variable influencing these systems capacity to support these functions and values. Understanding river discharge under different climatic conditions throughout the year is therefore essential in the quantification or qualification of a river's functions and in guiding management decisions for societal use.

Although it is common to find discharge gaging stations within mountain river systems at some locations, there are many management situations in which it is necessary to estimate flows at specific locations where no gages are present. Quantification of flow at such locations is often necessary due to increases in the amount of downstream flow resulting from (a) many small tributaries supplying water to a larger river and (b) groundwater discharging from surrounding hillsides. These ungagged sources of water are broadly defined as *accretionary flows* (aka *flow accretions*).

Accretionary flow within California has been found to be an extremely important water source in hydrodynamic modeling and in developing water balances for water resources management and planning (Pasternack and Senter 2011, Howitt et al. 2007, YCWA 2012). Diverse methods exist for estimating flow accretions to any given point. These methods vary greatly in complexity from the simplest methods relating flow in proportion to drainage area to complex rainfall-runoff computer models (Dayyani et al 2003). While the accuracy of prediction typically improves with model complexity the penalty lies in the considerable effort required to develop, calibrate, and validate these models. Simpler approaches involving proportionalities or regression analysis can be accomplished quickly and yield reasonable results (USGS 2007). In general, these simpler methods involve transferring observed flows to unobserved locations and/or using data climatic, watershed physiography, and/or contributing area characteristics in the ungagged area.

The purpose of this study was to evaluate options for estimating flow accretions occurring in the Yuba River immediately upstream of Colgate Powerhouse. The calculation of accretionary flows at this specific location is necessary to co-locate discharge estimates with stage data obtained from a stage gage installed at the downstream boundary of the study area. This information will be used to develop a stage-discharge relationship that will guide further analysis of the study area as part of a larger project being conducted to evaluate geomorphology and habitat conditions within the Yuba River between New Bullards Bar Dam and Colgate Powerhouse (see Section 2 for discussion of the study area). Stage data was recorded for the period between November 11, 2015 and February 2, 2016 including recordation of several large flow events.

2. Study Area

The study area includes the North (N.) Yuba River below New Bullards Bar Dam and the portion of the Yuba River from the confluence of the N. Yuba River and Middle Yuba River to just upstream of Colgate Powerhouse (Fig. 1 and Fig. 2). The present condition of the N. Yuba/Yuba River within the study area is a heavily regulated system used for flood protection, power generation, and water management.

Figure 1 - Vicinity Map

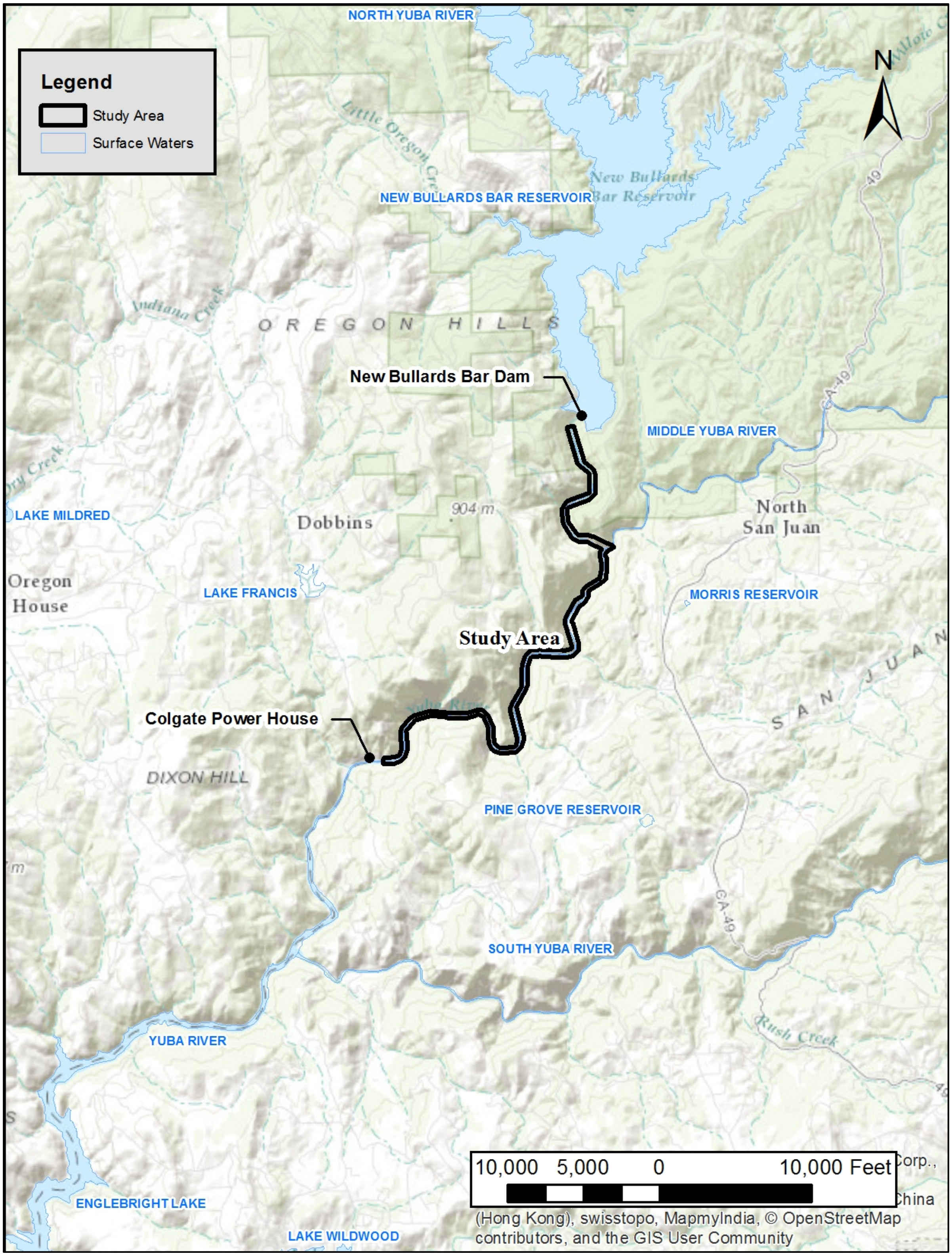

Figure 2 - Study Area Map

2.1. Water Facility Infrastructure

The portion of the N. Yuba River below New Bullards Bar Dam above the confluence of the Middle Yuba River receives minimal releases from New Bullards Bar Dam in accordance with the Federal Energy Regulatory Commission (FERC) minimum operational flow requirement of 5 cfs. Additional sources of water in the reach are seepage from the dam, other operational releases, flow over the emergency spillway, and accretionary flows. A stream gage located below the dam provides continuous flow data from 1966 to the present (present gage operated by Yuba County Water Agency [YCWA]).

The Middle Yuba River has a complex system of dams and diversion for water resources management. Extending eastward into the Sierra with the headwater near Jackson Meadows, Middle Yuba flows are captured in Jackson Meadows and Milton Reservoirs. Water from Milton Reservoir (Milton Diversion Dam) is diverted via the Yuba-Bear Project's Milton-Bowman Tunnel to Bowman Lake (South Yuba Basin). The Yuba-Bear Project has minimum instream flow requirements below the Milton Diversion Dam. Downstream of Milton Reservoir the Middle Yuba is confined within steep narrow canyons until Our House Dam. Our House Dam, ~ 13 miles upstream of the confluence with the N. Yuba is used to retain and transport water to New Bullards Bar Dam. Water is conveyed to Oregon Creek via the Lohman Ridge Tunnel where it is subsequently conveyed to New Bullards Bar Dam via the Camptonville Tunnel. Middle Yuba flows below Our House Dam to the confluence of Oregon Creek consist of releases from Our House Dam (note FERC minimum operational flow requirement of 30 cfs June 16 – April 14 and 50 cfs April 15 – June 15) as well as seepage from the dam, flow over the emergency spillway (when flows exceed the Lohman Ridge Tunnel Diversion capacity of 860 cfs), and accretionary flows.

Oregon Creek connects to the Middle Yuba River ~ 4.4 miles upstream of the confluence with the N. Yuba River. Log Cabin Dam located approximately 3.8 miles upstream of the Middle Fork confluence is used to retain and transport water to New Bullards Bar Dam as previously described. Flows above Log Cabin dam are unregulated, making this a good reference catchment for accretionary flow analysis to be discussed further in this summary. Oregon Creek flows below Log Cabin Dam to the confluence of Oregon Creek consist of releases from Log Cabin Dam (note FERC minimum operational flow requirement of 8 cfs June 16 – April 14 and 12 cfs April 15 – June 15) as well as seepage from the dam, flow over the emergency spillway (when flows exceed the Camptonville Tunnel diversion capacity of 1,100 cfs), and accretionary flows.

Diversions to and from the Middle fork and Oregon Creek increase the hydrologic complexity of these features and disrupt natural flow patterns. Natural flows attributed solely to Oregon Creek can be viewed as flow out of Log Cabin Dam plus flows out of Oregon Creek through Camptonville Tunnel less flows input to Oregon Creek from Lohman Ridge Tunnel.

Below the confluence of Oregon Creek and the Middle Fork of the Yuba to the confluence of the N. Yuba water consist of the previously described sources and any additional accretionary flow. Similarly, flows downstream of the Middle fork N. Yuba confluence to the downstream study area boundary comprise these upstream flows and any accretionary flow.

Several nominal tributaries discharge to the N. Yuba/Yuba River along the study area contributing appreciable surface flow only during storm events. Channelized flow in these drainages is ephemeral. The most significant drainage is Sweetland Creek located approximately

4.3 miles upriver of Colgate powerhouse. Despite the relatively large drainage area compared to other drainages Sweetwater flow is still ephemeral.

2.2. Basin Delineation

Several of the flow accretion methods evaluated involve relating drainage area or other parameters aggregated at a basin scale between gaged and ungagged basins. The CalWater 2.2.1 Watershed Boundary dataset was used as a starting point in delineating study area and relational drainage basins. CalWater 2.2.1 was developed in cooperation with the California Department of Water Resources (DWR), the California State Water Resources Control Board (SWRCB) and Regional Water Quality Control Boards (RWQCB), as well as U.S. Geological Survey (USGS) to standardize California watershed boundaries. The CalWater 2.2.1 boundaries were divided into sub-basins used in this analysis based on topographic information from USGS 7.5 minute topographic quadrangle maps and LiDAR data (September 2014) collected within the study area. Figure 3 depicts the sub-basin delineation results, aggregated basins used in accretion calculations, as well as the location of existing discharge gages used in the analysis. Table 1 provides area information and description of the aggregated basins used in accretion calculations.

Table 1 - Study Area Basin Areas

Name	**Description**	**Drainage Area (square miles)**
Oregon Creek abv Log Cabin Dam	Oregon Creek drainage area above USGS gage 11409400.	29.12
Oregon Creek abv Camptonville	Oregon Creek drainage area above USGS gage 11409300.	22.64
Oregon Creek: LCB-CAMP	Oregon Creek drainage area between USGS gage 11409400 and 11409300.	6.48
N Yuba: Slate - GYB	N Yuba drainage area between USGS gage 11413100 and 1141300.	100.21
Sweetland	Sweetland Creek drainage area above USGS gage 11413600.	2.87
Study Area	Yuba River drainage area between downstream boundary (Stage Gage Location) to USGS gages 11409400, 11413517, and 11408880, respectively.	52.20

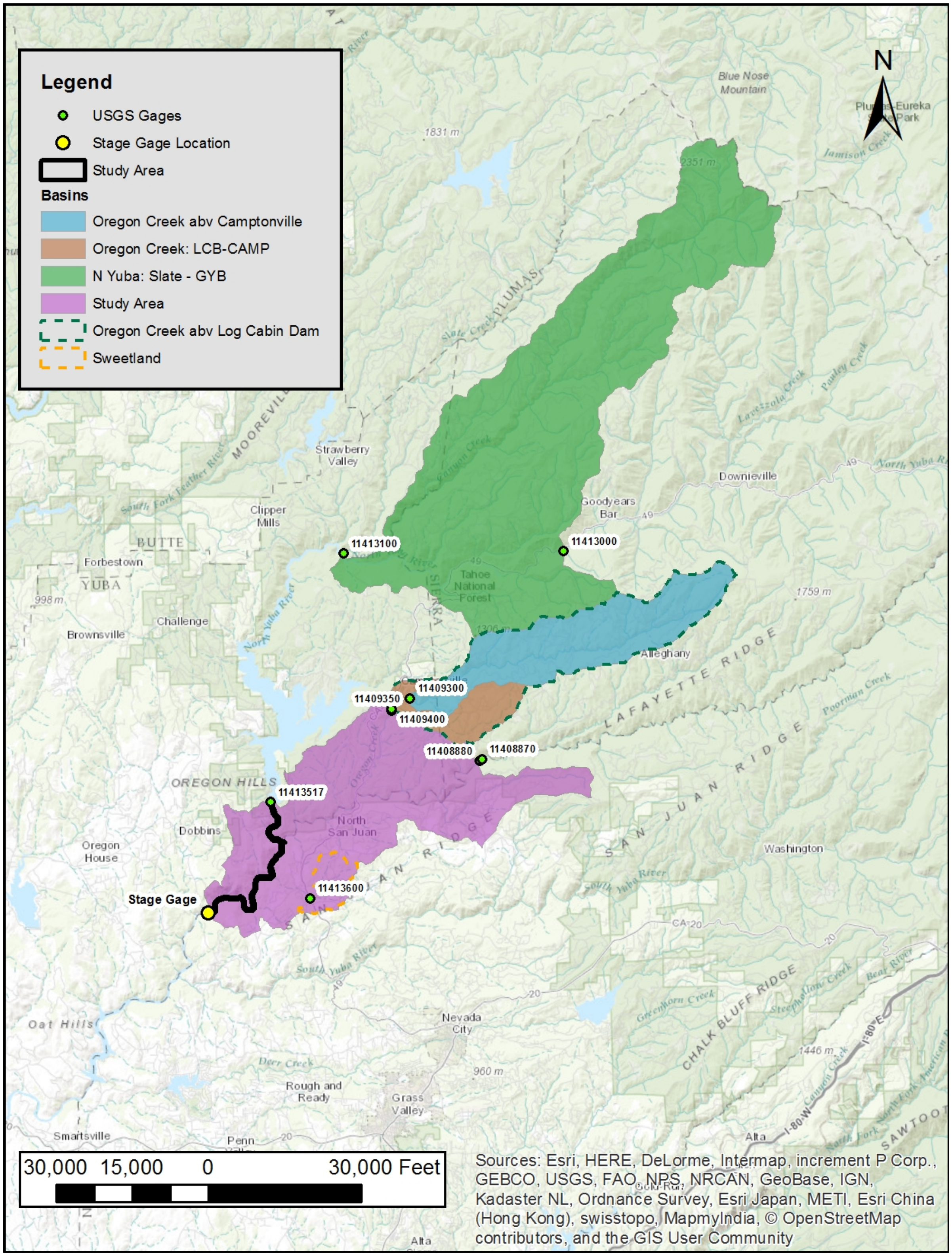

Figure 3 - Study Area Basins

3. Methods for Estimating Accretionary Flows

Innumerable methods for estimating accretionary flows are available and range substantially in complexity. Development of a rainfall-runoff or other catchment model was outside the scope of this work and was not considered. Other common approaches used to compute accretionary flows that were evaluated include:

- Mass Balance: Simple mass balance equations are used in conjunction with upstream and downstream gages to compute additional flow volumes.
- Statistical Regression: Statistical methods are used to develop a relationship between a reference catchment of similar characteristics to the area of interest that has known flows. This is often accomplished by developing a relationship between upstream and downstream gaged flows, normalizing the relationship for catchment area, and applying the normalized regression to the area of interest.
- Area-Weighting: Accretion in the area of interest is computed in reference to a comparable catchment with known flows using an area-weighted scaling factor based on the ratios of area and distribution of precipitation. The USGS proposes the following area-weighted relationship between ungaged and gaged flows (Q), drainage areas (A), and Precipitation (P) within a single catchment (USGS 2007):

$$Q_{ungaged} = \left(\frac{A_{ungaged}}{A_{gaged}}\right) \times \left(\frac{P_{ungaged}}{P_{gaged}}\right) \times Q_{gaged} \qquad \text{(Eq. 1)}$$

Due to limitation and uncertainty in available stream gage data, the mass balance method was quickly ruled out as infeasible/inaccurate. This determination was namely due to high variability observed in the potential downstream gage measuring inflows into Englebright Dam. Several different applications of the statistical regression and area weighting method were used as described in the following sections.

3.1. Data Sources

Unless otherwise specified in the following sections the following sources of data were used in all calculations.

3.1.1. Discharge Data

Stream discharge data was obtained from the California Data exchange center (CDEC) and USGS national water information system (NWIS). Additional data was provided by YCWA for flow immediately below New Bullards Bar Dam (gage YC7) and through the Lohman Ridge (gage YC4) and Camptonville (gage YC2) Tunnels, respectively. Flow below New Bullards Bar Dam was given in 15- minute intervals and converted to hourly or daily averages as needed. Tunnel data was given as hourly averages and similarly converted as needed. Data available from CDEC and NWIS are summarized in Tables 2 and 3. All data are in units of cubic feet per second (CFS) and were converted to hourly or daily average intervals as needed. Generally average daily flow intervals were used for regression based analysis (Sections 3.4, 3.5, and 3.6) and historic comparison (Sections 4.3 and 4.4). Hourly average flow intervals were used where possible (e.g. all necessary data was available at an hourly interval or finer) and typically in area-weighted accretions estimates (Sections 3.2. and 3.3).

Table 2 - CDEC Gage Data

Source	Gage ID	Name	Date Available	Parameter/Notes
CDEC	ORH	Middle Yuba River Below Our House Dam	06/18/1998 to present	Hourly Discharge (computed from Stage Curve)
CDEC	LCB	Oregon Creek Below Log Cabin	06/18/1998 to present	Hourly Discharge (Flow)
CDEC	NYS	N Yuba R. Abv Slate Ck Nr Strawberry	01/24/2007 to present	15-Min Event Discharge(computed)
CDEC	GYB	N Yuba R Blw Goodyears Bar	07/31/2008 to present	15-Min Event Discharge(computed)

*Coloring represents gages on same reach of the river and/or groups of gages used in accretion analysis

Table 3 - NWIS Gage Data

Site Number	Station Name	Start Date (yyymmdd)	End Date (yyymmdd)
11413100	N Yuba R Ab Slate C Nr Strawberry Ca	19680701	19870930
11413000	N Yuba R Bl Goodyears Bar Ca	19301001	Present
11413600	Sweetland C Nr North San Juan Ca	19681001	19730930
11413520	N Yuba R Bl New Bullards Bar Dam Nr N San Juan Ca	19660813	20040930
11413517	N Yuba R Low Flow Rls Bl New Bullards Bar Dam Ca	20031001	20150930
11409400	Oregon C Bl Log Cabin Dam Nr Camptonville Ca	19680901	20150930
11409350	Camptonville Tu A It Nr Camptonville Ca	19881001	20150930
11409300	Oregon C A Camptonville Ca	19671001	20010429
11408880	M Yuba R Bl Our House Dam Ca	19681001	20150930
11408870	Lohman Ridge Tu A It Nr Camptonville Ca	19881001	20150930

*Coloring represents gages on same reach of the river and/or groups of gages used in accretion analysis
** All data in units of CFS and interval of average daily discharge.

3.1.2. Precipitation Data

Precipitation information for each sub-basin was obtained from the Northwest Alliance for Computational Science and Engineering Parameter-Elevation Regressions on Independent Slopes Model (PRISM). PRISM data is available at several spatial scales and averaging periods. PRISM data used in the accretion analysis included:

- 30-year (1981-2010) normal average monthly condition for each month at 800 m scale.
- Total monthly precipitation for November 2015-February 2016 at a scale of 0.04166667 decimal degrees.

Generally long-term normal monthly average precipitation was used for accretion analysis involving long duration time-series discharge data (e.g. the entire period of record of a gage) as was the case in many of the regression based estimates. The monthly precipitation data for November 2015-February 2016 was used with the area-weighting methods in estimating accretion over the period when stage data was recorded (November 11, 2015 and February 2, 2016). Appendix A provides a summary of the monthly precipitation averages used in calculations.

3.1.3. Stage Data

Stage data was obtained using an In-Situ Level Troll 500 data logger. The logger was installed at the downstream study area boundary in a stable protected area to minimize fluctuations in stage measurement. Stage measurements were recorded from November 10, 2015 to February 2, 2016 in 15 minute intervals. The In-Situ Level Troll 500 has a range of 11.5 feet and a reported accuracy of ±0.05% of full scale (FS)[1] and ±0.1% of FS[2]. This equates to an uncertainty between 0.00575 feet (0.69 inches) and 0.0115 feet (0.138 inches). Measurements were converted to hourly averages for n=2009 measurements (discharge data is available in either 15-minute or hourly averages thus the largest interval, hourly, was used for consistency).

River discharge routing estimates were conducted to determine the most appropriate travel time between each upstream gage and the stage gage. This was accomplished by successively lagging each upstream gage reading by 1-hour and identifying the lag that had the best correlation to the stage gage measurements. Lag times of 4-hours for Oregon creek (LCB gage), 2-hours for the Middle fork (ORH gage), and 8-hours for the N. Yuba (YC7 gage) resulted in the highest correlation coefficients.

3.2. Area-Weighting Method: Oregon Creek Below Our House Dam – AW-LCB

Oregon Creek was used in the area-weighting based accretion calculations as an index gaged catchment. The catchment is predominately below 5,000 feet mean sea level (msl) and thus, similar to the study area, is a rainfall-runoff driven system. Above USGS gage 11409300 (e.g. Oregon Creek above Camptonville) the system is unregulated however the period of record for this gage is limited to 1967-2001. While this gage is optimal for area-weighting calculation purposes for these reasons, the cessation of recordation renders it unusable for current estimates of accretion within the study area via area-weighting analysis methods.

In lieu of this upstream gage, CDEC gage LCB, also located on Oregon Creek approximately 1.75 miles downstream was used for computational purposes. Due to the upstream presence of Camptonville Tunnel (YC2 gage) and Lohman Ridge Tunnel (YC4 gage), adjustment to this the LCB gage was necessary to procced with the accretion calculations (e.g. Adjusted Oregon Creek flow = Oregon Creek gage + Camptonville Tunnel – Lohman Ridge Tunnel). The inputs to the area-weighting equation (Eq. 1) are as follows:

- A_{gaged} = Area of the Oregon Creek catchment above Log Cabin Dam (Table 1);
- Q_{gaged} = Average daily discharge from LCB +YC2-YC4;
- P_{gaged} = Average monthly precipitation of the Oregon Creek catchment above Log Cabin Dam for the period concurrent with downstream stage measurements (Nov 2015 – Feb 2016).

[1] Across factory-calibrated pressure range.
[2] Across factory-calibrated temperature and pressure range.

- $A_{ungaged}$ = Area of study area catchment (Table 1); and
- $P_{ungaged}$ = Average monthly precipitation of the study area catchment for the period concurrent with downstream stage measurements.

P_{gaged} and $P_{ungaged}$ were calculated in ArcGIS using the zonal statistics as table tool to compute mean precipitation values with the gaged and ungagged catchments as the input boundaries and the PRISM raster data as the target for statistical analysis[3]. Weighing factors (See Appendix A) were calculated based on Eq. 1 and used to generate monthly accretionary flows at the downstream study area boundary.

3.3. Area-Weighting Method: N. Yuba Slate to Goodyear Bar – AW-NYS

The N. Yuba above New Bullards Bar Dam also represents a good index catchment in applying the area-weighting method and was used as an index gaged catchment for comparison to the Oregon Creek area-weighted accretion. Although the N. Yuba catchment extends well into the Sierras, a snowmelt dominated system, gages at Goodyear Bar (GYB) and above Slate creek (NYS) allow for isolation of a portion of this catchment that is predominately below 5,000 feet msl and is a rainfall-runoff driven system. Above the Slate creek gage the river is remarkably unregulated, a factor that may actually be a hindrance given the degree of management influencing flows within the study area. The inputs to the area-weighting equation for this catchment are as follows:

- A_{gaged} = Area of the N. Yuba catchment between NYS and GYB gages including Canyon Creek catchment;
- Q_{gaged} = Average daily discharge from NYS-GYB;
- P_{gaged} = Average monthly precipitation of A_{gaged} for the period concurrent with downstream stage measurements.
- $A_{ungaged}$ = Area of study area catchment (Table 1); and
- $P_{ungaged}$ = Average monthly precipitation of $A_{ungaged}$ for the period concurrent with stage measurement above Colgate Powerhouse.

P_{gaged} and $P_{ungaged}$ were the same as above, weighing factors (Appendix A) were calculated based on Eq. 1 and used to generate monthly accretionary flows at the downstream study area boundary.

3.4. Regression Method: N. Yuba Goodyear Bar to Slate – R-NYR

Statistical regression relating the relationship between upstream discharge to accretion was conducted similar to the approach used by Pasternack and Senter (2011). Accretionary flows were calculated as the difference between USGS gages 11413000 and 11413100 on the N. Yuba River (i.e. N. Yuba below Goodyears Bar and N. Yuba above Slate creek gages, respectively) for the period of overlapping measurement, August 1, 1968 to March 31, 1987[4]. Data was classified

[3] PRISM data is in GCS_North_American_1983 projection and NAD 83 Datum. Catchment data is in NAD_1983_2011_StatePlane_California_II_FIPS_0402_Ft_US projected coordinate system.

[4] Note these USGS gages are synonymous with current CDEC gages GYB and NYS, respectively. NYS and GYB have an overlap period from 2008-present that was not included in the regression analysis.

by season to account for different seasonal hydrologic processes, such as dry-season soil dryness and snowmelt vs rainfall accretion processes:

- Dry season (August 1 through November 30);
- Snowmelt season (April 1 through July 31); and
- Wet season (December 1 through March 31).

For each season a regression model (linear or second order polynomial) was generated for accretion (Y) as a function of upstream discharge (X = GYB discharge). Table 4 displays a summary of the resulting analysis including the regression equation, R^2, and number of samples.

Table 4 - R-NYR Season Regression Summary

Season	Equation[1]	R^2	n
Dry	$y = 1.534E\text{-}05x^2 + 0.5186x$	0.909	2379
Melt	$y = 2.176E\text{-}05x^2 + 0.2949x$	0.699	2349
Wet	$y = 0.6835x$	0.845	2303

[1] All coefficients had significant p-values less than 0.0001

In addition to separation by season, classifying each water year (WY) according to a Wet, Normal, or Dry index incorporated an additional layer of analysis. Water year indices were derived based on calculated unimpaired total annual flows in thousand acre feet (TAF) from the CDEC YRS gage. Results were ranked by flow volume and plotted (Flow vs. Rank). Natural breaks in the plot were used to define index classes. These breaks also coincided well with 33rd and 66th quantile values. Furthermore, index types correspond well with both Yuba River Index and Sacramento River Index Values (Appendix B). This additional level results in nine separate regressions each of which is summarized in Table 5.

Table 5 - R-NYR Season and Water Year Regression Summary

WY Type	Season	Equation[1]	R^2	n
Dry	Dry	$y = 4.58E\text{-}04x^2 + 0.240x$	0.884	610
Dry	Melt	$y = 4.76E\text{-}05x^2 + 0.3237x$	0.819	610
Dry	Wet	$y = 1.37E\text{-}04x^2 + 0.6102x$	0.894	606
Normal	Dry	$y = 4.30E\text{-}04x^2 + 0.1481x$	0.627	549
Normal	Melt	$y = 0.3946x$	0.681	519
Normal	Wet	$y = 7.24E\text{-}05x^2 + 0.6667x$	0.902	485
Wet	Dry	$y = 0.6163x$	0.913	1220
Wet	Melt	$y = 2.95E\text{-}05x^2 + 0.2552x$	0.669	1220
Wet	Wet	$y = 3.83E\text{-}06x^2 + 0.6351x$	0.846	1212

[1] Intercepts were set equal to zero, and this may require adjustment. All coefficients had significant p-values less than 0.0001

Stage gage measurements span the dry and wet seasons. The WY index for 2016 is still ongoing but to-date measurements suggest it will be either a normal or wet year. Using the appropriate regression relationship, accretions for the study area were calculated for the period of stage measurement. The translation of the accretionary regression from the N. Yuba catchment to the study area catchment requires some degree of adjustment. Two methods for adjustment were contemplated; both employ a weighted area adjustment factor to account for the difference in catchment size. The regression methodology relates measured upstream discharge to accretion, therefore the primary determinant of downstream accretion is the upstream discharge in the translation process. Realistically only two sources of upstream discharges are available to determine study area accretion; a) N. Yuba upstream discharge (Eq. 2) or b) the study area upstream discharge (Eq. 3):

Where $f(X) = regression\ equation$:

$$Q_{ungaged} = f(Q_{GYB}) * \left(\frac{A_{ungaged}}{A_{gaged}}\right) \quad \text{(Eq. 2)}$$

$$Q_{ungaged} = f(Q_{Study}) * \left(\frac{A_{ungaged}}{A_{gaged}}\right), \quad Q_{Study} = (Q_{Middle}) + (Q_{Oregon}) + (Q_{NBB}) \quad \text{(Eq. 3)}$$

The decision of upstream discharge and regression method selection results in six different possible accretion scenarios based on if water year is included, the discharge source (GYB gage or the total gaged study area flows), and if water year is included, the water year type. Each of these scenarios was assigned an arbitrary method code name and is summarized in Table 6.

Table 6 - R-NYR Regression Summary

Method Code	WY Included (yes/no) and WY Type	Upstream Discharge Source
R-NYR-V1	N	GYB
R-NYR-V2	N	Study
R-NYR-V1- Norm	Y - Normal Year	GYB
R-NYR-V2-Norm	Y - Normal Year	Study
R-NYR-V1-Wet	Y - Wet Year	GYB
R-NYR-V2-Wet	Y -Wet Year	Study

Substitution of GYB discharge for the upstream discharge source results in greater accretion than using the study area cumulative upstream discharge. Generally there is little change in accretion when upstream discharge is held constant with the exception of the dry season (November) accretions in the normal year regression. For example the mean signed differences between R-NYR-V1 and R-NYR-V1-Wet and between R-NYR-V2 and R-NYR-V2-Wet are 11.4 and 2.7, cfs respectively (there are also very strong correlation coefficients of ~1 between these methods). Larger differences occur when comparing both the no WY regression and the wet year regressions with the normal year regression. A comparison matrix showing cross comparison of mean signed difference and correlation coefficients is included in Appendix C. In order to reduce the number of accretion estimates used in comparison across methods only the R-NYR-V1 and R-NYR-V2 models were compared with other methods in determining the selected accretion estimator (Section 4).

3.5. Combined: Area-Weighting Regression Method Oregon Creek Camptonville – C-OR

As discussed in Section 3.2 above Oregon Creek is an optimal catchment to use as an index gaged catchment. It is a rainfall-runoff driven system and unregulated above USGS gage 11409300 (Oregon Creek above Camptonville). However the period of record for this gage is limited to 1967-2000, thus the lack of current measurement prohibits the use of this gage to compute study area accretion using the area-weighting method and therefore adjusted Oregon creek flows were estimated based on the Oregon Creek gage below log cabin dam and data from the two diversion tunnels (AW-LCB method).

For comparison purposes an additional accretion method that includes combination of the area-weighted method (to compute historic study area accretion) and regression method (to create a useable relationship with active gages) was used to calculate study area accretion based on discharge from the Oregon Creek above Camptonville gage[5]. This methodology is generally entails the following:

- Using the same area-weighted method as described in Sections 3.2 and 3.3, study area accretion was estimated for the period of record of gage 11409300 (October 1, 1967 - September 30, 2000). The only modification of the previous methodology was the use of 30-year monthly normal 800m grid precipitation data available from PRISM to generate monthly weighting factors for all months.
- Calculated accretion was added to gaged flows from Oregon Creek (below log cabin dam), the Middle Yuba, and below NBB (e.g. total flow at downstream study area boundary) for the period when data was available for all three gages and overlapping with the accretion calculations above (September 1, 1968 - September 30, 2000)[6]. Regression analysis was completed in the same manner as for the N. Yuba (Section 3.4) to develop a relationship between upstream discharge and accretion (i.e. the accretion calculated using the area-weighting method).
    - Unlike the regression analysis for the N. Yuba, relationships between upstream discharge and accretion were generally less obvious and the overall data was characterized by greater variance. Scatter plots of accretion vs. total discharge shows the weak indication of two distinct linear patterns but it is unclear of the process causing this result (e.g. analysis revealed that these patterns do not appear to be related to WY, season, or temporal change in reservoir management) (Fig. 4**)**.
    - Separation of the total upstream discharge by gage and subsequent comparison of each gage to accretion yields more promising results with a clear relationship between accretion and USGS gage 11409400 (Oregon Creek below log cabin)[7]. No clear trend was observed between accretion and gaged flows on the Middle Yuba or flows below NBB. These relationships are characterized by highly variable responses likely in part to operational and flow management decisions.
- Similar to the N. Yuba regression analysis, additional study was completed to review relationships based on seasonal variation and WY type.

[5] Notably this method could also be applied to the Oregon Creek below Log Cabin gage.
[6] No data for Oregon Creek below log cabin is available for October 1, 1995 – September 30, 1996.
[7] This relationship may be strong due to the use of Oregon Creek in the preliminary accretion calculations.

- Singularly, WY type shows little to no reduction in variance when comparing total gaged flows to accretion. Furthermore, the two distinct, divergent linear patterns in the data remain persistent.
- Inclusion of WY type and separation by season also do not produce significant relationships between accretion and total gaged flows (9x scenarios reviewed).
- Flows upstream of the study area are highly managed. To review if distinct management actions influence the observed variability in the data (e.g. changing management over time might display distinct patterns) upstream discharge was split into bins for a variety of time periods. The resulting plots of accretion vs. total upstream discharge did not indicate any noticeably different trends or patterns and data was consistently scattered (Fig. 5**)**.
- The most promising results occurred when looking at accretion as a function of season and WY-type in relation to Oregon creek, USGS gage 11409400, discharge individually. The best regression relationships occur for the following regression models (listed in order of highest R^2):
    - Wet Season, Wet year linear model;
    - All Data linear model; and
    - Wet Season linear model.
- Several of the regression models that include both season and WY effects between accretion and Oregon Creek flows display curves resembling power law relationship that can also be fairly well approximated by piecewise linear functions(Fig. 6 and Fig. 7). The diverging dual linear paths described above are also present in several of these models (Fig. 8**)**.

These combined area-weighted and regression method and associated model review yields three reasonable regression functions relating study area accretion to Oregon Creek gaged flows. Table 7 provides a summary of the selected regression models. There is very little variability between these methods (average difference in signed error ranges between 0.38 and 1.67 cfs); as such only the All Data method was used for further comparison with other methods (Section 4). A comparison matrix showing cross comparison of mean signed difference and correlation coefficients is included in Appendix C.

Table 7 - C-OR Regression Summary

Upstream Gage	Method	Equation	R^2	n
11409400	C-OR All Data (All Season and years)	y = 1.7509x	0.6359	11718
11409400	C-OR Wet Season All Years	y = 1.7663x	0.62	3758
11409400	C-OR Wet Season Wet Year	y = 1.6995x	0.6747	1575

This method and the resulting accretion estimates no doubt have high potential for uncertainty. A-priori calculated accretionary flows make up a primary component of the regression model for estimated flows. These a-priori flows are estimated based on the area-weighting method and errors in the estimates will propagate into the regression models. The use of Oregon Creek as an index catchment may also inherently bias the resulting regression as demonstrated by the only reasonable relationships between discharge and accretion was that associated with the Oregon Creek upstream gage.

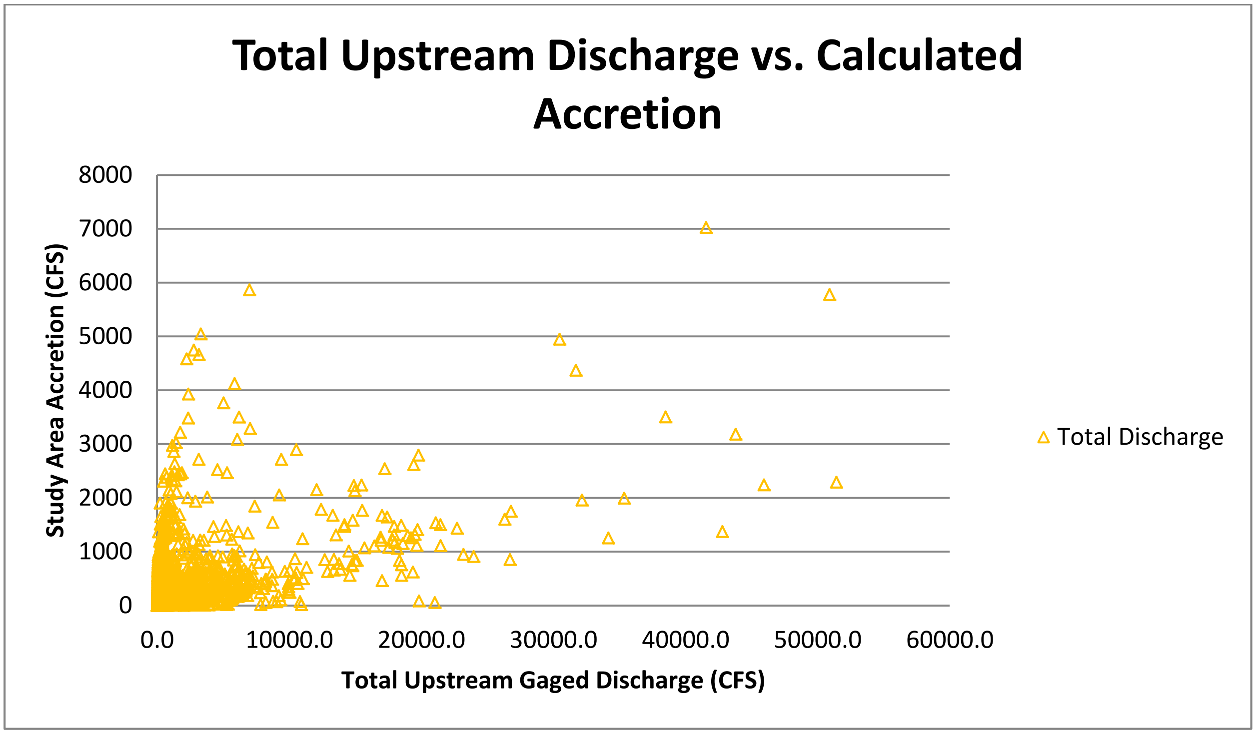

Figure 4 - Example of Divergent Linear Patter in Accretion vs. Gaged Flows

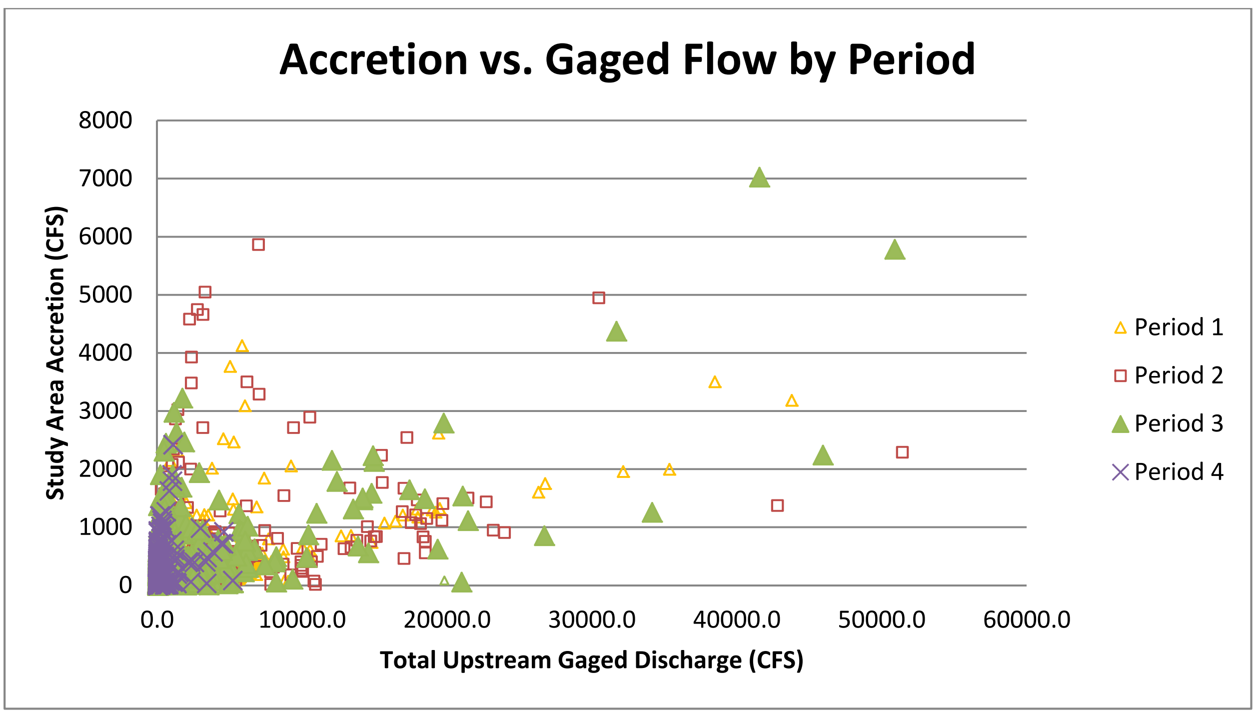

Figure 5 - Example time period separation of data (WY groupings: 1:1968-1978, 2:1978-1988, 3:1988-1998, 4:1998-2000)

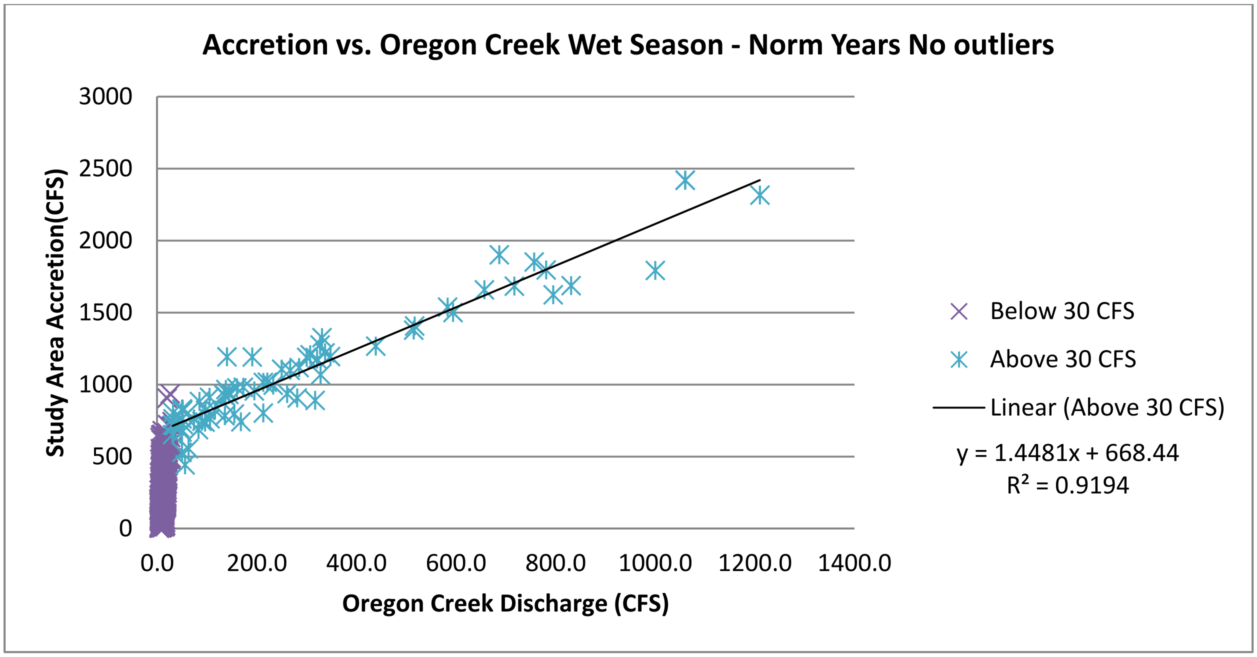

Figure 6 - Example of the piecewise linear pattern in Wet Season Normal Year accretion response

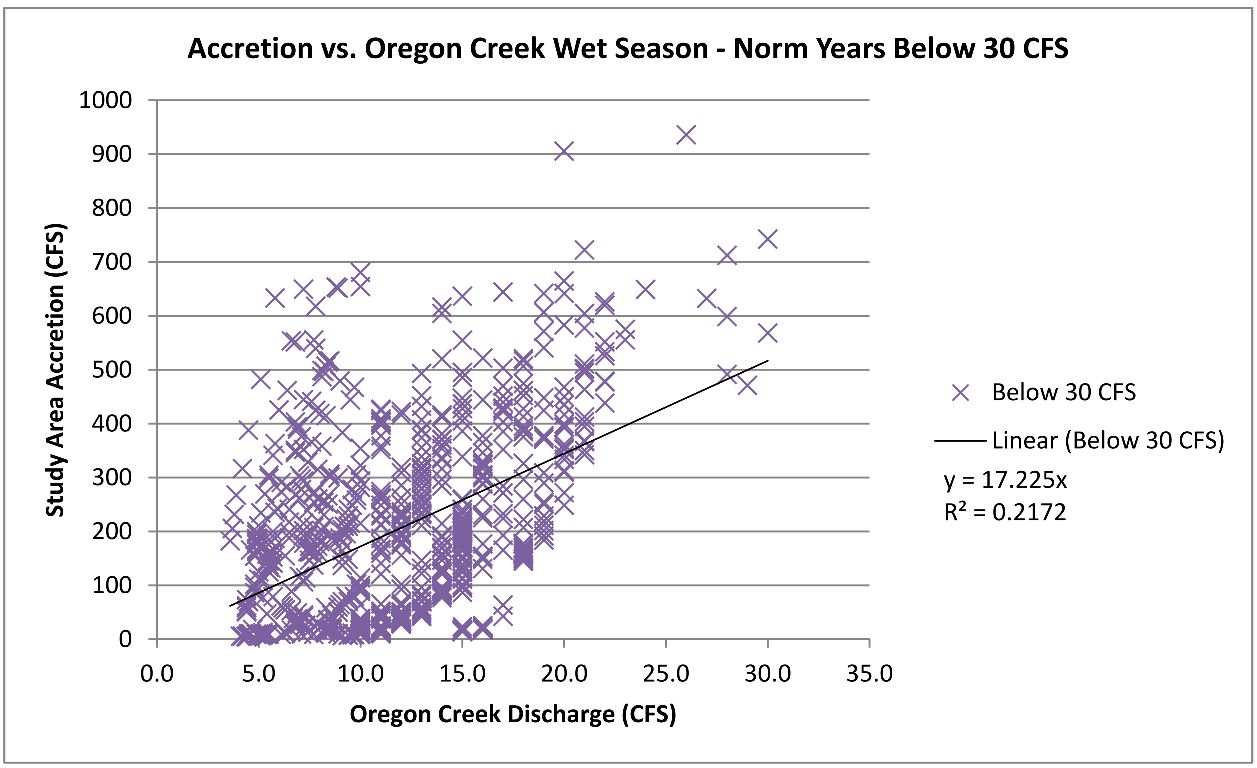

Figure 7 – Example of high variance in model for point with upstream discharge below 30 CFS

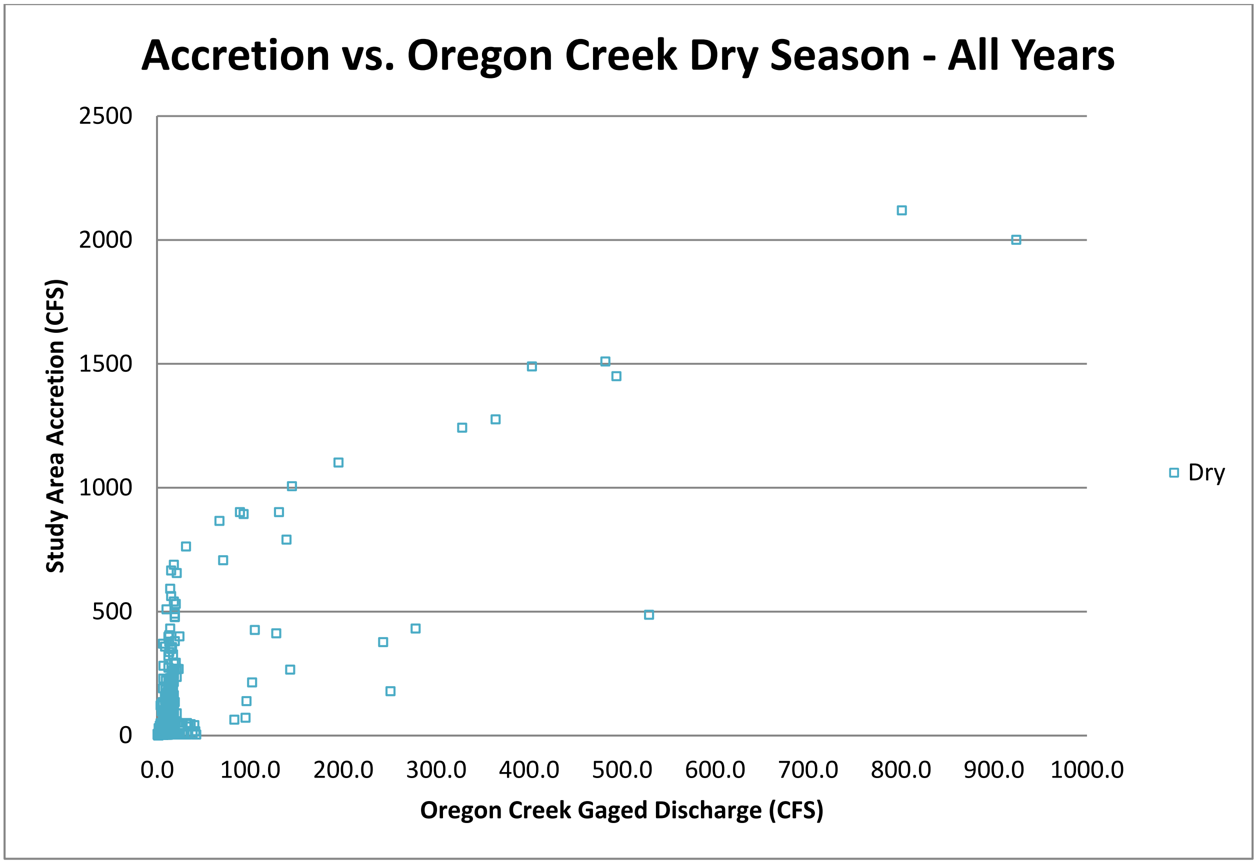

Figure 8 - Example of the slight dual linear pattern in accretion with season and WY effects.

3.6. Ratio Method: N. Yuba Goodyear Bar to Slate – RT-NYR

A thought experiment based on the previous methods described herein was used to generate one additional method for accretion estimation. This method is primary based on the area-weighting method but incorporates some of the theory in the regression analysis method. The though experiment is as follows: Consider two catchments that are similarly situated and have reasonably similar physiographic conditions and rainfall-runoff processes. Assume there is an upstream gage and an ungagged downstream location where flow data is desired. Simplistically, flow at the downstream location may be given by the following where P = precipitation within the area of desired accretion; A = area of accretion; and C = some coefficient that addresses the basins physiographic conditions and rainfall-runoff processes:

$$Q_{ungaged,downstream} = Q_{gaged,upstream} + C(P_{basin} * A_{basin}) \qquad \text{(Eq. 4)}$$

Now assume that we have a reference basin with a similar or identical value of C that is fully gaged (e.g. an upstream and downstream gage). Relating Eq. 4 between the two basins assuming each element is proportional leads to the following which can be easily solved for the flow at the location of interest.

$$\frac{Q_{Known,downstream}}{Q_{ungaged,downstream}} = \frac{Q_{Known,upstream,}}{Q_{Unknown,gaged,upstream}} + \frac{C(P_{Known,basin}*A_{Known,basin})}{C(P_{Unknown,basin}*A_{Unknown,basin})} \quad \text{(Eq. 5)}$$

$$Q_{ungaged,downstream} = \frac{Q_{Known,downstream}}{\left[\frac{Q_{Known,upstream,}}{Q_{Unknown,gaged,upstream}} + \frac{(P_{Known,basin}*A_{Known,basin})}{(P_{Unknown,basin}*A_{Unknown,basin})}\right]} \quad \text{(Eq. 6)}$$

Noticeably this equation requires a reference area that has upstream and downstream gaged flows as well as similar physiographic conditions and rainfall-runoff processes. In the absence of an unknown upstream gage, such as the case of a headwater catchment, the first term in the denominator also drops out. The only area meeting these conditions was the N. Yuba River catchment using the gages above Slate Creek (downstream) and Goodyears Bar (upstream). The remaining values and calculations necessary to estimate study area accretion for the period of stage measurement are the same as the N. Yuba Area-weighting method (Section 3.3).

4. Results, Comparison, and Validation

The methods outlined in Section 3 yield considerably different accretion estimates for the period of stage gage measurement. Several analyses comparing accretion results to existing discharge and stage measurements were conducted to determine the most appropriate estimate for use in further investigation of the study area. In order to simplify analysis a reduced number of the potential accretion estimation methods described in Section 3 were selected for further review. This list is comprehensive in covering the range of different methods used to calculate flow accretion, removing duplicative estimates that had similar to nearly identical estimates or methods that resulted in unrealistic accretion values. The comparison methods and associated results are discussed in the remainder of this section. Table 8 summarizes the accretion methods considered for further evaluation including a coding nomenclature consistent with Section 3 and used throughout the remainder of this report.

Table 8 – Selected Accretion Methods

Description	Code
Area-Weighting Method – Oregon Creek Below Our House Dam	AW-LCB
Area-Weighting Method – N. Yuba Goodyear Bar to Slate	AW-NYS
Regression - N. Yuba Goodyear Bar to Slate (V1)	R-NYR-V1
Regression - N. Yuba Goodyear Bar to Slate (V1)	R-NYR-V2
Combined: Area-Weighting Regression Method Oregon Creek Camptonville (All data)	C-OR
Ratio Method – N. Yuba Goodyear Bar to Slate	RT-NYR

4.1. Comparison with Upstream Discharge

Comparison of study area accretion with study area total gaged upstream discharge was conducted for the selected accretion methods. All methods display a general fit with the trends of the discharge data (Fig. 9). Correlation coefficients between study area accretion and upstream discharge, the average ratio of the accretion to upstream flow, and the Nash-Sutcliffe efficiency are given in Table 9 below[8], n=2009 for all computations.

Table 9 – Accretion Comparison to Upstream Discharge Summary Statistics

Code	Correlation with upstream discharge (r)	Average ratio of accretion to upstream discharge	Nash-Sutcliffe Coefficient
AW-LCB	0.74	1.86	0.30
AW-NYS	0.59	1.83	0.21
R-NYR-V1	0.86	2.71	0.58
R-NYR-V2	1.00	0.34	0.57
C-OR	0.95	0.40	0.27
RT-NYR	0.96	1.04	0.62

It is not be surprising that the regression methods (R-NYR-V1, R-NYR-V2, and C-OR) have high correlation values. These methods calculate accretion as a direct function of upstream discharge, the R-NYR-V2 method specifically using the study area upstream discharge as the input. The area-weighting methods also use upstream discharge as an input but instead apply a weighting factor based on monthly precipitation values. More interesting is the relationship between the magnitude of accretion and upstream discharge. The ratio of accretion to upstream flow shows that for several methods (AW-LCB, AW-NYS, R-NYR-V1, and RT-NYR), accretion, on average, accounts for more water than upstream gaged flows into the project area. This is consistent with the findings of Pasternack and Senter (2011) who found accretion to range between 3.16 to 10.27 times upstream flow (depending on season) within a study area along the nearby South Fork of the Yuba River. Closer inspection confirms that this excess is not due to a small number of high leveraging events but that for each of these methods approximately 50% (~ 69 % for R-NYR-V1) of accretionary flows are greater than total gaged flows. Median values near 1 also indicate the distribution of accretionary flows is scattered about being even with incoming flow. There is a stark contrast for C-OF and R-NYR-V1 where accretion is never greater than total upstream flow.

[8] These metrics were not considered the primary indicator of the best accretion estimate but were reviewed none-the-less. The Nash-Sutcliffe efficiency is given for comparison only and is not considered a relevant measure of fit.

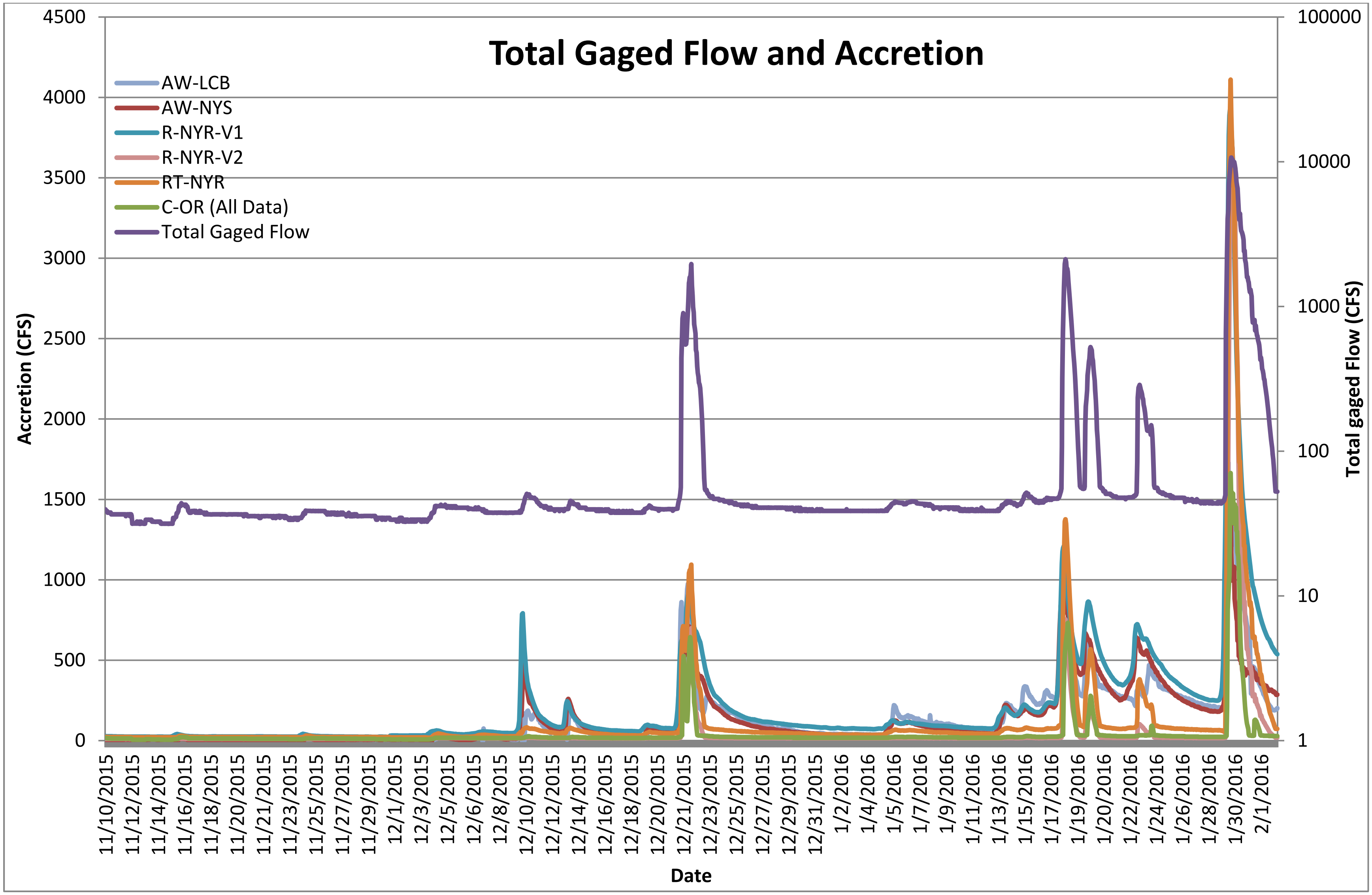

Figure 9 - Comparison with Gaged Flows

4.2. Comparison with Stage Data

Comparison of study area accretion against the stream gage height measurements obtained at the downstream study area boundary was conducted for the selected accretion methods. This comparison is considered a more valuable estimator in determining the most appropriate method. Total upstream gaged flows are constant across all methods therefore accretion is the only variant, and furthermore should coincide well with changes in stage. All methods display a general fit with the larger trends of the stage data (Fig. 10). Correlation coefficients between study area accretion and stage height, root mean squared error (RMSE), and mean squared error (MSE) of the log transform of accretion, are given in Table 9 below, n=2009 for all computations:

Table 10 – Accretion Comparison to Stage Height Summary Statistics

Code	Correlation with stage gage height (r)	RMSE	MSE of Log Transformed Data
AW-LCB	0.94	250.87	0.77
AW-NYS	0.89	230.38	0.84
R-NYR-V1	0.92	450.08	0.61
R-NYR-V2	0.80	315.81	1.03
C-OR	0.83	152.96	1.08
RT-NYR	0.90	378.56	0.60

The good correlation of the AW-LCB method to the stage gage heights in conjunction with the comparatively low RMSE value are considered good indications that this method may represent a promising accretion estimator within the study area (See additional support in Section 4.3).

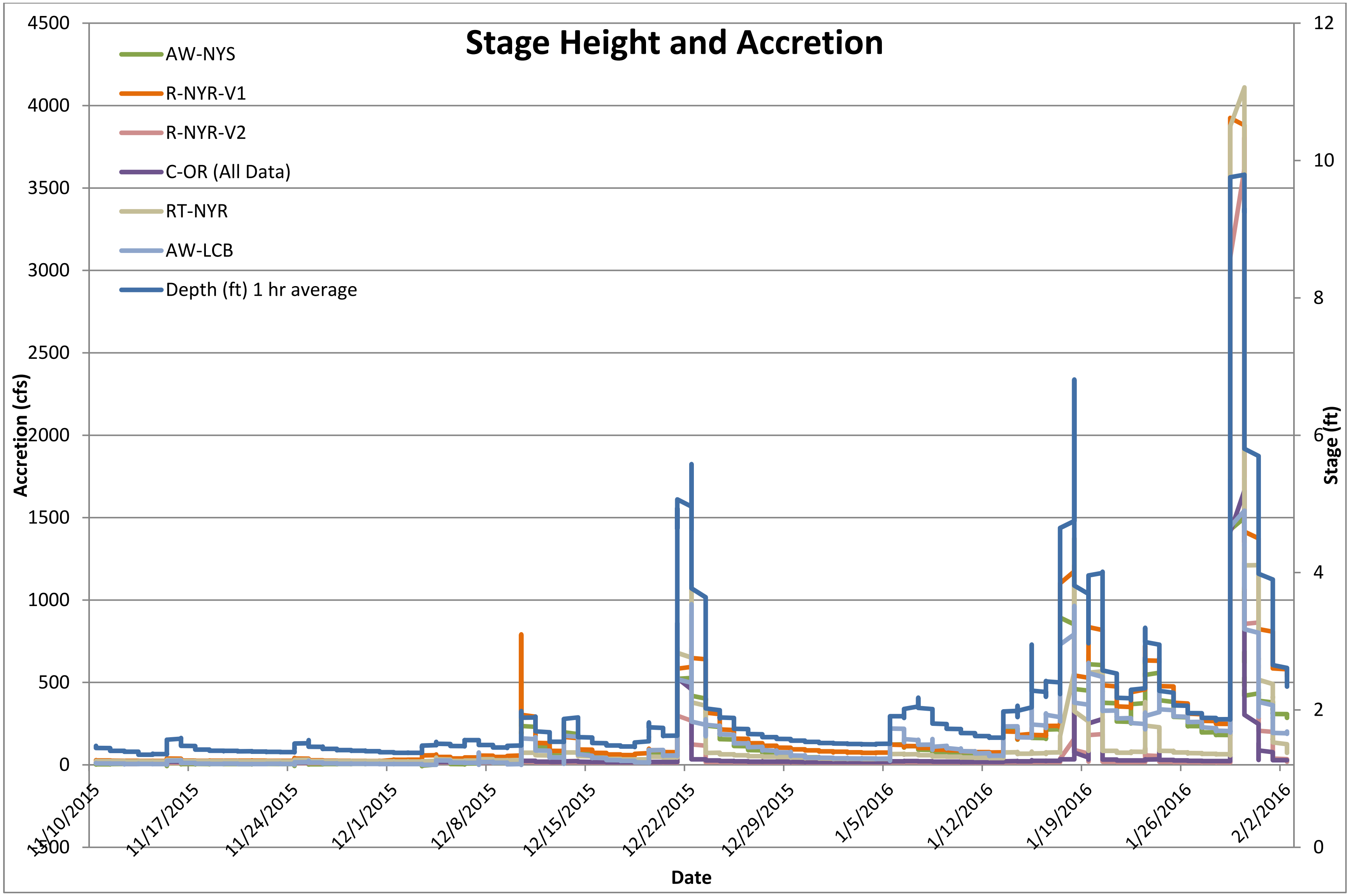

Figure 10 - Comparison with Stage Height

4.3. Sweetland Creek Historic Flow Comparison

Sweetland Creek is a small tributary contributing to the study area below the middle fork confluence. USGS gage 11413600 located approximately half-way upstream from the creeks confluence with the Yuba River was operational for a limited period between 1968 and 1973. This gaged sub-basin of the study area catchment represents a good opportunity to review area-weighted accretion calculations and other methods against these gaged flows. In order to compare the calculated vs. measured flows, new area-weighted accretion calculation were completed similar to the methods discussed above with the Sweetland Creek catchment as the ungauged target catchment. Adjustments to other methods were made accordingly to allow comparison. Calculations requiring the input of precipitation data leveraged the PRISM 30-Year (1981-2010) normalized monthly averages.

The primary limiting factor determining applicability for comparison with Sweetland Creek was overlap between a method's ability to estimate accretion and gage 11413600's period of record. Based on this limitation the following methods allowed comparison:

- AW-NYS: Area-weighting method using the N. Yuba between Slate Creek and Goodyears Bar as the index catchment (similar to Section 3.3);
- AW-CAMP: Area-weighting method using Oregon Creek above Camptonville as the index catchment with flow data from USGS gage 11409300. This method is considered a surrogate for the previously discussed AW-LCB model (Section 3.2). Use of the AW-LCB for comparison with Sweetland Creek was not possible due to limitation on the period of availability of discharge data for the two diversion tunnels that are required to generate flow estimates using this model. A separate analysis validating the use of the AW-CAMP model as a surrogate for the AW-LCB model is provided in Section 4.4.;
- R-NYR-V1: Regression model similar to Section 3.4 with an adjusted area coefficient and separate regression functions for each season.
- R-NYR-V1 with WY's: Regression model similar to Section 3.4 with an adjusted area coefficient and separate regression functions for each season and water year type.
- C-OR: Regression model similar to Section 3.5 with an adjusted area-weighting factor to apply this method to the Sweetland catchment; and
- RT-NYR: Ratio method with N. Yuba above Slate creek as the downstream gage. Since there is no upstream gage on Sweetwater creek the first term in the denominator of Eq. 6 drops out and only the downstream gage is considered. This results in the calculation being similar to the area-weighting method. Updates were made to use the appropriate precipitation and area coefficients.

Summary statistics between Sweetland Creek and estimated accretion are provided in the table overleaf and include Correlation, RMSE, and Nash-Sutcliffe efficiency, n = 1826 for all computations:

Table 11 - Accretion Comparison with Sweetland Creek

Code	Correlation (r)	RMSE	Nash-Sutcliffe Coefficient
AW-CAMP	0.82	9.77	0.45
AW-NYS	0.70	11.58	0.23
R-NYR-V1	0.73	28.75	-3.74
R-NYR-V1 with WY/s	0.71	29.87	-4.12
C-OR	0.77	33.94	-5.61
RT-NYR	0.66	34.33	-5.76

The AW–CAMP estimates result in the best metrics and fit to the flow data (Fig. 11). This further supports that this method provides the best accretion estimate within the study area. This method represents a surrogate for AW-LCB, further confirming that the AW-LCB accretion method represents the best accretion estimate for the study area.

4.4. Area-weighted Comparison (LCB vs CAMP)

Section 4.3 provides evidence that the AW–CAMP method represents a good accretion estimate within the study area. However, as noted several time in this document, the gage used in this estimate (Oregon Creek above Camptonville) stopped recording in 2001 and thus current accretion estimates from this gage are not possible. Section 4.2 of this report indicates that the AW-LCB method also represents a good study area accretion estimator. Comparison of study area accretion generated using the AW–CAMP and AW-LCB methods were completed for the period between October 1, 1988 and September 30, 2000 (e.g. the period when all data for both methods is available). Results from the comparison indicate a high level of correlation between calculated accretions. This high correlation supports the use of AW-CAMP as a surrogate measure of AW-LCB in the method comparison with Sweetland Creek gaged flows where AW-CAMP performed best of all methods. Summary statistics of the comparison between these two methods are provided in Table 12 below, n = 3897 for all computations:

Table 12 - AW-LCB vs. AW-CAMP

Summary Statistic	Value
LCB-CAMP: Minimum (CFS)	-1009.98
LCB-CAMP: Maximum (CFS)	833.435
LCB-CAMP: Average unsigned error (CFS)	-15.1778
LCB-CAMP: Average signed error (CFS)	36.56812
Correlation	0.963757
Nash-Sutcliffe Efficiency	0.912659
RMSE (CFS)	1.141756

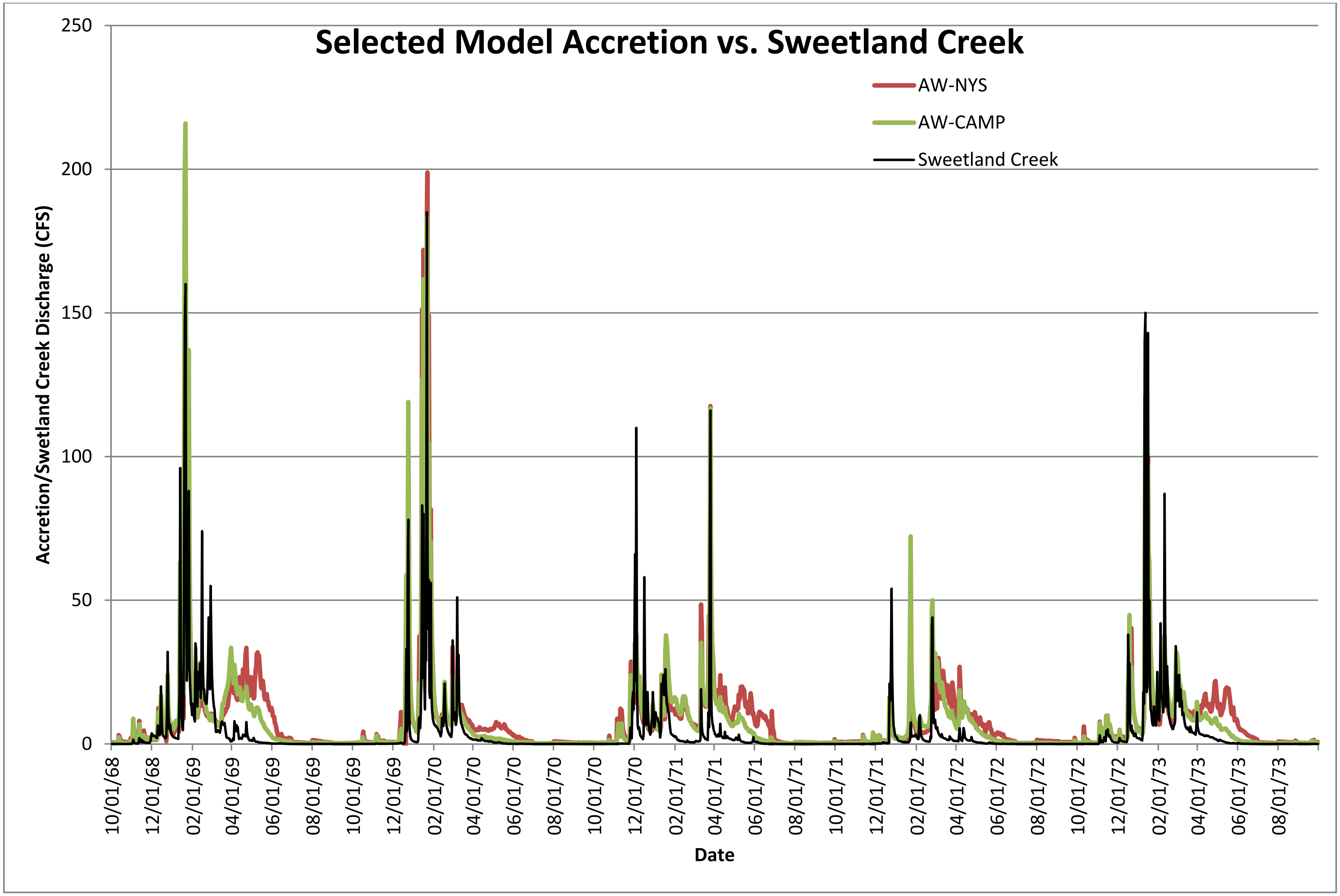

Figure 11- Selected Models and Sweetland Creek Flows

5. Conclusion

Results of hydrologic analysis indicate that accretionary flow is an important component of total flow within the study area, often accounting for a greater magnitude than gaged inputs. Review of several methods to estimate accretionary flow demonstrate the variability in resulting flow values. Strong correlation and low root mean square error when compared to onsite stage gage measurements as well as good correlation with historic gaged flows within the study area (Sweetland Creek) indicate that the AW-LCB method represents the best available accretion estimator for the study area. This method will be used in subsequent analysis of the study area to evaluate geomorphology and habitat conditions within the Yuba River between New Bullards Bar Dam and Colgate Powerhouse. Specifically this method will allow facilitation of the following:

- Generation of a stage-discharge relationship at the downstream study area boundary. This relationship is critical to defining boundary conditions for proposed discharge dependent hydrodynamic modeling of the study area.
- Creation of a historic flow record at the downstream study area boundary through application of the model using historic flow records that will allow for further hydrologic analysis of flow study area flow patterns.

6. References

Dayyani S, Mohammadi K, Najib H.R. 2003. River flow estimation for ungaged stations using GIS model. Seventh International Water Technology Conference Egypt 1-3 April 2003.

Howitt, R.E., Lund J.R., Kirby K.W., Jenkins M.W., Draper A.J., Grimes P.M, Ward K.B., Davis M.D., Newlin B.D., Van Lienden B.J., Cordua J.L., and Msangi S.M,, 1999. Integrated Economic-Engineering analysis of California's Future Water Supply Online: http://cee.engr.ucdavis.edu/faculty/lund/CALVIN. (Accessed May 2016).

Pasternack, G. B. and Senter, A.E. 2011. 21st Century instream flow assessment framework for mountain streams. California Energy Commission, PIER. CEC-500-2013-059.

Prism Climate Group, Oregon State University, http://www.prism.oregonstate.edu/, Accessed March-April 2016.

United States Geological Survey (USGS). 2007. The National Streamflow Statistics Program: A Computer Program for Estimating Streamflow Statistics for Ungaged Sites. Chapter 6 of Book 4, Hydrologic Analysis and Interpretation, Section A, Statistical Analysis, Estimating Techniques for Rural Areas. Reston, Virginia, 2007

________. 2016. National Water Information System: Web Interface. Online: http://waterdata.usgs.gov/ca/nwis/inventory. (Accessed March-April 2016).

Yuba County Water Agency (YCWA). 2012. Yuba River Development Project FERC Project No. 2246. Model Report Appendix A. Hydrology Report. June 2012.

Appendix A - PRISM Data

A.1 – Catchment Area Ratios

Name	Area Ratio (Study Area/Catchment Area)
Oregon Creek abv Log Cabin Dam	1.79
Oregon Creek abv Camptonville	2.31
Oregon Creek: LCB-CAMP	8.06
N Yuba: Slate - GYB	0.52
Sweetland	18.19
Study Area	1

A.2 – Mean Catchment monthly PRISM precipitation for November 2015-February 2016

Name	Mean Catchment Monthly Precipitation in mm November 2015-February 2016			
	Nov-15	Dec-15	Jan-16	Feb-16
Oregon Creek abv Log Cabin Dam	138.14	350.24	473.07	69.88
Oregon Creek abv Camptonville	138.78	374.04	500.24	73.44
N Yuba: Slate - GYB	148.00	399.02	533.37	86.39
Study Area	121.91	286.21	372.02	52.05

A.3 – Area-Weighting Factor based on November 2015-February 2016 PRISM Data

Name	Area-Weighting Factor			
	Nov-15	Dec-15	Jan-16	Feb-16
Oregon Creek abv Log Cabin Dam	1.58	1.46	1.41	1.34
Oregon Creek abv Camptonville	2.03	1.76	1.71	1.63
N Yuba: Slate - GYB	0.43	0.37	0.36	0.31

A.4 – Mean Catchment monthly Normalized 30-Year (1981-2010) PRISM precipitation

Name	Mean Catchment 30-Year (1981-2010) Monthly Normalized Precipitation in mm											
	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Oregon Creek abv Log Cabin Dam	263.72	252.61	229.15	128.66	87.38	26.95	3.39	5.71	24.11	88.30	197.72	291.43
Oregon Creek abv Camptonville	266.87	253.99	229.49	129.98	89.90	27.97	3.82	5.56	24.09	87.74	195.34	293.78
Oregon Creek: LCB-CAMP	257.73	248.28	226.31	124.82	79.63	24.00	2.20	6.01	24.22	89.89	199.00	288.37
N Yuba: Slate - GYB	287.00	299.39	249.61	145.12	99.02	28.76	4.66	6.34	30.86	96.19	227.58	331.12
Sweetland	207.61	180.60	169.09	85.93	54.82	15.00	0.92	5.71	18.14	58.14	149.44	215.46
Study Area	218.01	201.97	194.74	98.65	61.67	16.92	1.10	5.34	18.21	70.33	167.86	245.51

A.5 – Area-Weighting Factor based on 30-Year PRISM Data

Name	Area-Weighting Factor											
	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Oregon Creek abv Log Cabin Dam	1.48	1.43	1.52	1.37	1.27	1.13	0.58	1.68	1.35	1.43	1.52	1.51
Oregon Creek abv Camptonville	1.88	1.83	1.96	1.75	1.58	1.39	0.67	2.22	1.74	1.85	1.98	1.93
N Yuba: Slate - GYB	0.40	0.35	0.41	0.35	0.32	0.31	0.12	0.44	0.31	0.38	0.38	0.39

Appendix B – Water Year Indices

B.1 – Water Year Indices

Year	WY Type	YUBA Index	Sacramento River Index
1968	Normal	Below Normal	Below Normal
1969	Wet	Wet	Wet
1970	Wet	Wet	Wet
1971	Wet	Wet	Wet
1972	Normal	Below Normal	Below Normal
1973	Normal	Above Normal	Above Normal
1974	Wet	Wet	Wet
1975	Wet	Wet	Wet
1976	Dry	Critical	Critical
1977	Dry	Critical	Critical
1978	Normal	Above Normal	Above Normal
1979	Normal	Below Normal	Below Normal
1980	Wet	Wet	Above Normal
1981	Dry	Dry	Dry
1982	Wet	Wet	Wet
1983	Wet	Wet	Wet
1984	Wet	Wet	Wet
1985	Dry	Below Normal	Dry
1986	Wet	Wet	Wet
1987	Dry	Critical	Dry
1988	Dry	Critical	Critical
1989	Normal	Below Normal	Dry
1990	Dry	Dry	Critical
1991	Dry	Critical	Critical
1992	Dry	Critical	Critical
1993	Normal	Above Normal	Above Normal
1994	Dry	Critical	Critical
1995	Wet	Wet	Wet
1996	Wet	Wet	Wet
1997	Wet	Wet	Wet
1998	Wet	Wet	Wet
1999	Normal	Wet	Wet
2000	Normal	Above Normal	Above Normal

Appendix C - Comparison Matrices

C.1 – R-NYR Methods Mean Signed Difference Matrix (CFS)

Mean Signed Difference Matrix	R-NYS-V1	R-NYS-V2	R-NYS-V1-Norm	R-NYS-V2-Norm	R-NYS-V1-wet	R-NYS-V2-Wet
R-NYS-V1		152.22	-51.51	125.48	10.54	154.62
R-NYS-V2	-152.22		-203.73	-26.74	-141.68	2.40
R-NYS-V1-Norm	51.51	203.73		176.99	62.05	206.13
R-NYS-V2-Norm	-125.48	26.74	-176.99		-114.94	29.14
R-NYS-V1-wet	-10.54	141.68	-62.05	114.94		144.09
R-NYS-V2-Wet	-154.62	-2.40	-206.13	-29.14	-144.09	

C.2 – R-NYR Methods Correlation Matrix

Correlation Matrix	R-NYR-V1	R-NYR-V2	R-NYR-V1-Norm	R-NYR-V2-Norm	R-NYR-V1-wet	R-NYR-V2-Wet
R-NYR-V1		0.86	0.98	0.82	1.00	0.86
R-NYR-V2	0.86		0.92	0.99	0.87	1.00
R-NYR-V1-Norm	0.98	0.92		0.90	0.98	0.92
R-NYR-V2-Norm	0.82	0.99	0.90		0.83	0.99
R-NYR-V1-wet	1.00	0.87	0.98	0.83		0.87
R-NYR-V2-Wet	0.86	1.00	0.92	0.99	0.87	

C.3 – C-OR Methods Mean Signed Difference Matrix (CFS)

Mean Signed Difference Matrix	C-OR All Data	C-Or Wet Season-All Years	C-OR Wet Season-Wet Year
C-OR All Data		-0.39	1.29
C-Or Wet Season-All Years	0.39		1.67
C-OR Wet Season-Wet Year	-1.29	-1.67	

C.4 – C-OR Methods Correlation Matrix

Correlation Matrix	C-OR All Data	C-Or Wet Season-All Years	C-OR Wet Season-Wet Year
C-OR All Data		1	1
C-Or Wet Season-All Years			1
C-OR Wet Season-Wet Year			