Sierra Nevada Network Lake Monitoring Protocol

SOP 14. Data Analysis

Version 1.00, October 2010

Prepared by Leigh Ann Harrod Starcevich and Andrea M. Heard

Revision History Log

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

Contents

Page

Figures....4

Tables....5

Appendixes....6

1. Introduction....7

1.1. Suggested Reading....7

2. Status: Water Chemistry....9

2.1. Descriptive Statistics....9

2.1.1. Status (Descriptive Statistics) Estimation in R....11

2.2. Threshold Conditions....14

3. Trend: Water Chemistry....16

3.1. Time Series Plots....16

3.2. Linear Mixed-Model....16

3.2.1. Degrees of Freedom....19

3.2.2. Trend Tests....20

3.2.3. Trend Estimates....20

3.3. Seasonal Kendall Test....24

4. Streamflow Analyses....31

4.1. Reference Materials....31

4.2. Individual Discharge Computations....31

4.2.1. Mid-section Method....31

4.2.2. Rhodamine Slug Injection Method....32

4.2.3. Salt Injection Method....35

4.3. Preparation of Continuous Stage Data for Analysis....35

4.3.2. Correcting Water Stage Data 39

4.4. Converting Stage to Discharge 43

4.4.1. Computation of Mean Gage Height 43

4.4.2. Establishing Stage-Discharge Relationships 43

4.4.3. Computation of 15-minute and Mean Daily Discharge 49

4.5. Routine Data Summaries for Annual Report 49

4.5.1. Station Analysis 50

4.5.2. Daily Values Table 50

4.5.3. Hydrographs 50

4.5.4. Rating Tables and Curves 50

4.5.5. Photographs 50

4.6. Infrequent Data Summaries for Long-term Report 55

5. Literature Cited 56

Figures

Page

Figure SOP 14.1. Lognormal quantile plot of Y.....13

Figure SOP 14.2. Example of a concentration-discharge graph for calcium.....28

Figure SOP 14.3. Midsection method of discharge measurement.....32

Figure SOP 14.4. Instantaneous discharge calculation example using the SlugDyeQCalcs.xls spreadsheet. 34

Figure SOP 14.5. Flow chart of data processing procedures for determination of instantaneous stream discharge.....36

Figure SOP 14.6. Correcting stage data for barometric pressure and elevation. 37

Figure SOP 14.7. Combining date and time fields into a single date:time field.....39

Figure SOP 14.8. Counting stage records in Excel.....41

Figure SOP 14.9. Example of drift correction through linear interpolation using Microsoft Excel.....45

Figure SOP 14.10. Rating shift at Redwood Creek, CA stream gaging station 46

Figure SOP 14.11. WT2005 rating curve for Pine Gulch Creek, Point Reyes National Seashore. 49

Figure SOP 14.12. Mean daily discharge and rainfall for Olema Creek at Bear Valley Bridge, Marin Co., CA. Water year 1998 (Example). 54

Tables

Page

Table SOP 14.1. Data analysis procedures with corresponding objectives. 7

Table SOP 14.2. Data format for lake chemistry analysis. 11

Table SOP 14.3. Status codes corresponding to steps in the S-ESTREND process. 26

Table SOP 14.4. Excel spreadsheet with paired individual discharge measurements and mean gage height for WY2005 rating. 48

Table SOP 14.5. Mean daily discharge (example). 52

Table SOP 14.6. Daily rainfall (Example). 53

Appendixes

Page

Appendix A: Adjusting Sample Inclusion Probabilities for Panel Surveys 59

Appendix B: Example Excel File Used to Create a Tab-delimited Text File for the Mixed Linear Model. 63

1. Introduction

This SOP provides guidance for the data analysis methods and reporting requirements. The protocol lead is responsible for performing the following data analyses: time series plots, descriptive statistics, status estimates, trend analyses, and hydrologic analyses (Table SOP 14.1). All analyses, with the exception of trend, are performed annually. Trend analyses are calculated at least every four years (in sync with completion of the full panel rotation), once there is a minimum of five years of data.

Programs or templates referred to in this SOP can be found on the SEKI network in: J:\sien\I_M\monitoring\water\data\tabular\analyses\LakeChemAnalysis_Programs&Templates

Table SOP 14.1. Data analysis procedures with corresponding objectives.

Inference Goal	Data Analysis Procedure	Monitoring Objective
Status	Descriptive statistics	– Characterize Sierra Nevada Network lakes – Quality control
Status	Threshold conditions	– Determine the proportion of Sierra Nevada Network lakes above threshold values for selected constituents
Trend	Time series plots	– Characterize Sierra Nevada Network lakes – Visually detect long-term trends in lake water chemistry for Sierra Nevada Network lakes – Visually detect intra- and inter-annual trends in lake water chemistry for Sierra Nevada Network index lakes – Visually detect intra- and inter-annual trends in lake level and outflow for Sierra Nevada Network index sites – Quality control
Trend	Mixed linear model	Statistically detect long-term trends in lake water chemistry for Sierra Nevada Network lakes
Trend	Seasonal Kendall test	Statistically detect intra- and inter-annual trends in lake water chemistry for Sierra Nevada Network index lakes
Status and Trend	Streamflow analysis	- Characterize Sierra Nevada index lake outlet flows - Visually detect intra- and inter-annual trends in lake level and outflow for Sierra Nevada Network index sites (Note: It is a future goal of the network to develop quantitative methods for detecting trends in streamflow)

1.1. Suggested Reading

Helsel, D. 2005. Nondetects and data analysis, statistics for censored environmental data. John Wiley & Sons, Inc., Denver.

Rantz, S. E., et al. 1982. Measurement and computation of streamflow. Volumes 1: Measurement of stage and discharge. U.S. Geological Survey-Water Supply Paper 2175. U.S. Government

Printing Office, Washington DC. Available at http://pubs.usgs.gov/wsp/wsp2175/#table (accessed 2007).

Rantz, S. E., et al. 1982. Measurement and computation of streamflow. Volumes 2: Computation of discharge. U.S. Geological Survey-Water Supply Paper 2175. U.S. Government Printing Office, Washington DC. Available at http://pubs.usgs.gov/wsp/wsp2175/#table (accessed XXXX).

2. Status: Water Chemistry

2.1. Descriptive Statistics

Water chemistry descriptive statistics are calculated with preliminary data as a quality check on the data and exploratory data analysis. Follow procedures outlined in Section 3.1 for identifying and documenting any atypical data points. In addition to the descriptive statistic calculations, we recommend presenting the data graphically using graphs such as boxplots and histograms.

Once data are certified, the protocol lead calculates 'final' summary statistics for the annual or comprehensive reports. For annual reports, data are calculated for the current field season. For comprehensive reports, which are completed at least once every four years following one full rotation of the panel, statistics are also computed for the most recent full panel rotation. Descriptive statistics may also be calculated for the larger data set or subsets as deemed applicable. The protocol lead may use any reputable statistical program that s/he is comfortable working in. R and S-Plus applications are currently (2007) available to NPS staff.

Descriptive statistics should include the following calculations for the water quality measures—mean, median, variance, standard deviation, standard error, minimum, maximum, sample size, and range. When computing the mean and variance, both censored data approaches and the Generalized Random Tessellation Stratified (GRTS) neighborhood variance estimator (Stevens Jr. and Olsen 2003, Stevens Jr. and Olsen 2004) are incorporated when possible. Software to compute GRTS estimators can be obtained for R and S-Plus applications at the following web site: *http://www.epa.gov/nheerl/arm/analysispages/software.htm*.

The mean is calculated as a Horvitz-Thompson estimate (Horvitz and Thompson 1952). The variance of the mean is calculated using the GRTS neighborhood variance estimator (Stevens Jr. and Olsen 2003, Stevens Jr. and Olsen 2004). The neighborhood variance estimator [$V_{NBH}(Z_M)$] for a mean is:

$$\hat{V}_{NBH}\left(\hat{\mu}\right)=\left(\sum_{s_j\in R}\frac{1}{\pi\left(s_j\right)}\right)^2\sum_{s_j\in R}\sum_{s_i\in D\left(s_j\right)}w_{ij}\left(\frac{z\left(s_j\right)}{\pi\left(s_j\right)}-\sum_{s_k\in D\left(s_i\right)}w_{ik}\frac{z\left(s_k\right)}{\pi\left(s_k\right)}\right)^2,$$

where:

$\hat{\mu}$ is the estimator of the population mean, μ,

$s_{i,j,\ or\ k}$ are sample points,

R is the domain of the sampled population defined as a set of points occupied by the population elements,

D (s_i) is the local neighborhood for site *i*,

w_{ij} are weights chosen to reflect the behavior of the pairwise inclusion function for GRTS, and are constrained so that $\Sigma_i\, w_{ij} = \Sigma_j\, w_{ij} = 1$,

$z(s_i)$ is the real-valued outcome measured at the ith point, and

$\pi(s_i)$ is the inclusion density for site *i.*

Methods to account for censored data are also needed to obtain summary statistics. Sample size and percent of censored data need to be considered when selecting a method. Details on the analysis methods are found in Helsel's book, Nondetects and Data Analysis, Statistics for Censored Environmental Data (Helsel 2005).

The robust maximum likelihood estimation (MLE) approach (Helsel 2005) is used to estimate missing values so that a complete data set may be used to obtain status estimates. The robust MLE approach by Kroll and Stedinger (1996) avoids transformation bias found in small and/or skewed samples. By regressing the logged response on the expected quantiles from a lognormal distribution, a model is obtained which can be used to impute censored values that are less than known thresholds. This technique can also accommodate multiple thresholds and is not reliant on correlated covariates for modeling. The authors suggest using a single imputation of values to obtain a complete data set from which to calculate moment estimates. However, multiple imputation techniques (Little and Rubin 2002) may increase the robustness of this procedure by examining a range of possible imputed values and by incorporating the uncertainty from substituting values for missing data. Therefore, the robust MLE approach is used to create several complete data sets, and each data set is used to obtain estimates of status based on the GRTS design. These status estimates are combined into a single status estimator that accounts for the spatially balanced sample, the detection limits, and the substitution of values to create complete data sets. This approach is discussed in more detail in Appendix B of the Protocol Narrative.

The robust MLE approach is implemented in the R workspace *LakeChem.RData*. This workspace contains all of the functions needed to obtain single-year status estimates for lake chemistry outcomes. Please note that some of these functions can take several minutes to run. The data must be formatted precisely; data columns are defined in Table SOP 14.2. The censoring format is similar to Helsel's (2005) Table 6.3.

Table SOP 14.2. Data format for lake chemistry analysis.

Data Column	Description
Y	The outcome of interest
Year	The survey year
WYear	A year index that starts at 0
Lake	Unique **station** code identifier
Panel	Revisit design panel index
Long	UTMx in NAD83
Lat	UTMy in NAD83
Cen	Indicator of censoring; Cen = 1 if the data are censored and 0 if otherwise
LowerDL	Lower detection limit for censored data and observed outcome for uncensored data
UpperDL	Upper detection limit for censored data and observed outcome for uncensored data
InclProb	Sample design inclusion probability
PanelProb	Panel inclusion probability
AdjInclProb	Adjusted inclusion probability for panel design

Inclusion probabilities are derived from the sampling design and are necessary for design-based estimation (see Thompson (1992) for more on inclusion probabilities). If the samples have a panel structure that requires some panels to be skipped intermittently over time, the initial sample drawn for the entire set of panels will be larger than the sample size within any given year. In this case, the inclusion probabilities are based on larger samples than are observed in any given year and should be adjusted for unbiased annual estimates of status. See Appendix A for more discussion and details on how to compute adjusted inclusion probabilities.

We will estimate status annually but also for larger periods of time, specifically a full panel rotation. If lakes are sampled without replacement and assigned to panels, then the panels are not independent (McDonald 2003). Panels that are revisited within a rotation are correlated through time. Variance estimates for multi-year estimates of status do not account for this added correlation and are naïve in assuming independence among panels. However, simulation results indicate that confidence interval coverage is not compromised due to this omission. See Appendix A for further discussion.

2.1.1. Status (Descriptive Statistics) Estimation in R

A test data file is provided in the *LakeChem.RData* R workspace called "LakeChem." This data set is simulated from variance component estimates of NO3 outcomes from pilot data. The UTM coordinates were simulated from observed ranges of lakes in the Western Lakes survey (Eilers et al. 1989, Clow et al. 2002). These data were simulated as test data only and no inference should be made from results. The formatting necessary for data analysis can be obtained from examining this data set. To see the data set, type "LakeChem" at the prompt in R after the workspace has been loaded.

Status estimates may be obtained using the following approach:

1. Import data:

```
LakeChem<-read.table("LakeChem.txt", header=T, sep=",")
```

attach(LakeChem)

If the data are separated by tabs, use *sep="\t"*.

2. Load libraries for R (download from *http://www.r-project.org/*):

```
library(lme4)
library(NADA)
library(mitools)
library(spsurvey)
```

NOTE: These libraries must be loaded at the beginning of every R session for these analyses. Libraries are not saved within R workspaces.

3. Check that the lognormal assumption is met for all uncensored data: Compare uncensored outcomes against lognormal quantiles. Here, the uncensored data from 2010 (*WYear*=2) will be used and the plot is given in Figure SOP 14.1.

```
LakeChem2010<- LakeChem[LakeChem$Year==2010,]
Obs2010<-LakeChem2010[LakeChem2010$Cen==0,]
qqnorm(log(Obs2010$Y), main="")
qqline(log(Obs2010$Y), col = 2) # Adds red line for
lognormal expected values
```

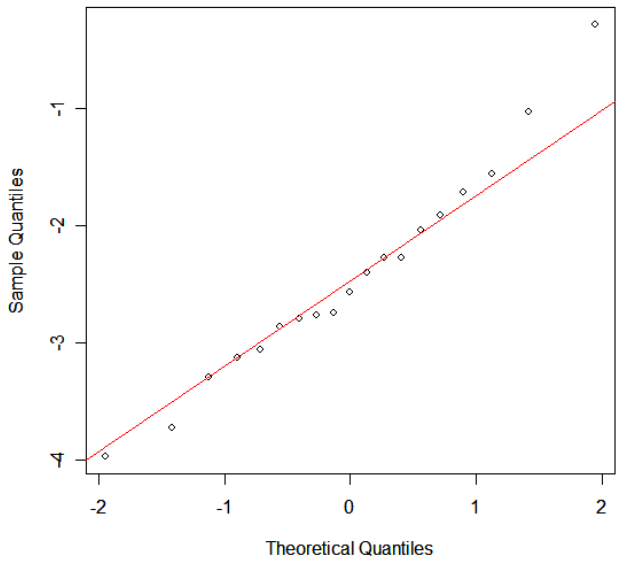


Figure SOP 14.1. Lognormal quantile plot of Y.

The observations fall approximately on the straight line indicating expected lognormal quantiles, so the lognormal distributional assumption should be appropriate.

4. Annual descriptive statistics: Use the robust MLE method with the GRTS estimators in a multiple imputation setting to obtain unbiased estimates of the mean with the following command for 10 imputations:

```
StatusEst(LakeChem2010,imputenum=10)
```

Output:

```
Mean    SE      CI low   CI high
0.0953 0.0330 0.0409   0.1496
```

The output is the mean, the SE of the mean, and the 90%-confidence interval endpoints for the mean.

5. Descriptive statistics for a full panel of years: Use the robust MLE method with the GRTS estimators in a multiple imputation setting to obtain unbiased estimates of the mean. Create the dataset with the subset of years for which a status estimate is desired:

```
LakeChem2008to2011<- LakeChem[LakeChem$Year %in%
2008:2011,]
```

```
StatusEst(LakeChem2008to2011,imputenum=10)
```

Output:

```
Mean   SE   CI low  CI high
0.1513 0.1176 -0.0422  0.3449
```

2.2. Threshold Conditions

Status calculations are calculated on an annual basis for extensive sites. The proportion of lakes that exceed a given threshold condition are determined. For annual reports, status estimates are calculated for the current field season; multiple seasons may also be included. For comprehensive reports, which are completed at least once every four years following one full panel rotation, proportions are computed for the most recent full panel rotation. Proportions may also be calculated for the larger data set or subsets as deemed applicable.

Proportions are calculated by dividing the number of samples that exceed the given threshold by the total number of samples. The following method is valid for any distribution assuming the data are uncorrelated and random. To estimate p_c, the proportion of the population exceeding a threshold *c*, compute an indicator variable X_c, such that:

$$X_c = \begin{cases} 1, & \text{if Y>c} \\ 0, & \text{if Y} \le \text{c} \end{cases}.$$

Then p_c is estimated as the mean of X_c using the GRTS estimators for spatially balanced samples.

For example, consider the estimate of the proportion of NO3 measurements that exceed a threshold, and assume that threshold is set at 0.08. In R, this analysis can be conducted with the following command in the R workspace, *LakeChem.RData:*

```
StatusEst(LakeChem2010,imputenum=10, threshold=0.08, direction=">")
```

Output:

```
Mean   SE     CI low  CI high

0.2763 0.0757 0.1518  0.4009
```

From the test data, the estimated proportion of lakes exceeding the threshold is calculated as 27.63% with a 90%-confidence interval of 15.18% to 40.09%.

A multi-year estimate can be computed using a similar command and the naïve variance estimator for multiple years (as outlined in Appendix A):

```
StatusEst(LakeChem2008to2011,imputenum=10, threshold=0.08, direction=">")
```

Output:

```
Mean   SE     CI low  CI high

0.4178 0.0799 0.2863  0.5493
```

To estimate the proportion of outcomes that lie below a threshold, use the input `direction="<"`.

SIEN plans to identify threshold conditions after three years of monitoring data are available. Water quality standards can be used as a management trigger; however, due to the dilute nature of the Sierra Nevada lakes, ecological thresholds unique to these systems will be far more successful in protecting SIEN lakes. Establishing ecological thresholds is not a trivial task. It will involve input from park staff and outside area experts and likely will require additional research.

3. Trend: Water Chemistry

3.1. Time Series Plots

One of the first steps in evaluating water chemistry, stage, and discharge data are to plot them versus time (i.e. scatter plot). The protocol lead creates and evaluates preliminary plots shortly after data are obtained. This is an important step in the data verification and validation process (Refer to SOP 4. QAPP, Section 4). Preliminary plots are graphed using water chemistry data from the 'entry side' of the database. The protocol lead identifies any atypical data points. If a cause can be determined (e.g., analytical error, storm event), it should be documented in the database by flagging the result with an appropriate result code, if applicable, and/or documenting in comment fields (Refer to SOP 13. Database User's Manual for detailed database procedures). For example, a laboratory or handling error is documented with a result quality code and possibly also in a comment field---if it has not already been done by the lab. A known naturally occurring event, such as an unusual storm, should be documented in the comments field—if it has not already been documented during data entry. If it is determined to be a data entry error, the error is corrected in the database and the correction documented. If it is suspected that there is an analytical error, the laboratory should be contacted immediately for clarification. If determined appropriate and possible, the sample may be re-analyzed.

Once data are certified, the protocol lead creates final time series plots that are used, in conjunction with the trend analyses results, to visually evaluate the data for temporal trends at extensive and index sites in water chemistry and lake outlet flow. Time series plots are presented and discussed in annual and comprehensive reports. Refer to Section 4 for streamflow analyses.

Censored data are presented following guidelines in Helsel's book: *Nondetects and Data Analysis, Statistics for Censored Environmental Data* (Helsel 2005). Helsel recommends using intervals such as dashed, grayed-out, line segments that span from zero to the detection limit. The use of an interval, instead of a single point at a subjectively selected number (e.g., zero or the detection limit), conveys the uncertainty present in censored data.

The protocol lead may use any reputable graphing software s/he is comfortable working in. We suggest SigmaPlot, S-Plus, MS Excel, R---these programs are currently (2007) available to I&M staff.

3.2. Linear Mixed-Model

A linear mixed-model is used to test for trend at extensive sites ($\alpha = 0.10$). VanLeeuwen et al. and Piepho and Ogutu (1996, 2002) used this model to address trend estimation for correlated data. A mixed model allows some effects to be considered fixed and some to be considered random. Fixed effects contribute to the mean of the outcome and random effects contribute to the variance. Random effects are used to estimate variation of linear trends among subjects (lakes) and over time (years). Restricted maximum likelihood (REML) is used to obtain the estimates for fixed and random effects. The linear mixed model is a parametric model, requiring the assumptions of independent and normally distributed errors with equal variance. These assumptions will be verified using histograms and Q-Q plots of the residuals.

Piepho and Ogutu (2002) improve the estimator proposed by VanLeeuwen et al. (1996) by modeling the random site effect as correlated with the random slope. This modification allows an

invariant t-test or F-test of trend from standard analysis output in statistical programs such as SAS and R. In addition, Piepho and Ogutu (2002) suggest that the site effect may be modeled as either fixed or random. The site intercept is modeled as random if the sample of lakes has been chosen using a probability sample and modeled as a fixed effect otherwise. However, Piepho and Ogutu (2002) recommend modeling the site intercept as fixed so that convergence problems are avoided and to optimize test power when residual variance is large. Because REML provides similar results for tests of trend regardless of how the lake intercept is modeled, we will adopt the recommended approach of Piepho and Ogutu (2002) and model the intercept as fixed. For more discussion of the linear mixed modeling approach for trend estimation and testing, see Appendix B of the Protocol Narrative.

The mixed model proposed in both articles is:

$$y_{ijk} = \mu + w_j\beta + b_j + a_i + w_j t_i + c_{ij} + e_{ijk},$$

where i=1,..,m_a; j=1,..,m_b; k=1,..,m and

m_a = the number of sites in the sample;

m_b = the number of consective years in the sample;

m = the number of measurements taken within a site and year;

w_j = constant representing the jth year (covariate);

μ and β = fixed intercept and slope of the linear time trend;

b_j = random effect of the jth year;

a_i = random intercept of ith site, independent and identically distributed as $N\left(0,\sigma_a^2\right)$;

t_i = random slope of ith site, independent and identically distributed as $N\left(0,\sigma_t^2\right)$;

c_{ij} = random effect of site by year, independent and identically distributed as $N\left(0,\sigma_c^2\right)$; and

e_{ijk} = unexplained error, independent and identically distributed as $N\left(0,\sigma_e^2\right)$.

Because we are interested in measuring net trend over time as a percent change, the response must be logged so that exponential change may be estimated. In the model given above, the response y_{ijk} is actually the natural log of the response being modeled, i.e. $\log\left(y_{ijk}\right)$. Therefore, inference on the original scale is actually made on median trend rather than mean trend.

The null and alternative hypotheses you are testing are no trend (β=0) versus trend (β≠0):

$$H_o : \beta = 0 \text{ vs } H_A : \beta \neq 0$$

As defined above, β is the coefficient of the WYear variable and represents annual trend of the outcome on the log scale. This test is analogous to the test of:

$$H_o : \delta = 0 \text{ vs } H_A : \delta \neq 0$$

where δ is the net change as a proportion. For example, a net change of δ =0.4 implies a 40% increase of the population parameter over the specified period of time, whereas δ = -0.4 implies a 40% decrease. The test statistic is derived for the two-sided hypothesis and the rejection region is based on a *t*-distribution Type I error level of α = 0.10. Satterthwaite degrees of freedom are recommended (VanLeeuwen et al. 1996).

Steps for running trend analysis:

1. In Excel, save the data file as a tab-delimited .txt file. The data must include a sequential year index called WYear which begins at 0. Assume that the Excel file is named *LakeChem.txt*. Make sure that the R workspace and data file are in the same directory and change the working directory in R to that directory.

2. Open R workspace *LakeChem.Rdata*.

3. Load the lme4 library with the command: *library(lme4)*

4. Run the model and summarize the results:

```
TrendFit<- lmer(log(Y) ~ WYear + factor(Lake) + (1|Year) +(-
1+WYear|Lake), data=LakeChem)

TrendFitSummary<-summary(TrendFit)

TrendFitSummary
```

A portion of the model output is provided below. The model output first includes the model specification. Then model selection criteria are provided. These criteria are helpful in selecting the appropriate model when additional covariate information is available. However, the model specified above is the most reduced form and should not be altered. Estimates of the random effects and the standard errors of those estimates are then provided. Then the estimates of fixed effects, their standard errors, and *t*-values for hypothesis testing are provided. Trend inference will be obtained from the estimate of β, the coefficient of the *WYear* variable.

Example output from R software

```
Linear mixed-effects model fit by REML
```

```
Formula: log(Y) ~ WYear + factor(Lake) + (1 | Year) + (-1 + WYear |
Lake)

   Data: LakeChem

  AIC  BIC logLik MLdeviance REMLdeviance

 1217 1533 -529.5       1076         1059

Random effects:

 Groups   Name        Variance   Std.Dev.

 Lake     WYear       0.00014002 0.011833

 Year     (Intercept) 0.12794130 0.357689

 Residual             0.95659588 0.978057

number of obs: 404, groups: Lake, 76; Year, 20


Fixed effects:

                  Estimate Std. Error t value

(Intercept)      -1.788155   0.503251  -3.553

WYear            -0.005841   0.016494  -0.354

factor(Lake)7    -0.732957   0.532058  -1.378

factor(Lake)12   -0.759270   0.753911  -1.007

factor(Lake)22   -1.241362   0.660372  -1.880

factor(Lake)29    0.094732   0.660372   0.143

factor(Lake)32    0.762358   0.660372   1.154

factor(Lake)48   -1.250074   0.757432  -1.650

factor(Lake)89   -1.852131   0.697618  -2.655.

.

.
```

3.2.1. Degrees of Freedom

Satterthwaite degrees of freedom (υ) must be calculated (Piepho and Ogutu 2002) for tests of trend and confidence interval construction. Satterthwaite degrees of freedom may be computed

using the approach described by Giesbrecht and Burns (1985) using the *SatterthwaiteDF* function in the *LakeChem* workspace. Users should note that Satterthwaite degrees of freedom are model-dependent. Changes to the model will result in changes to the computation of Satterthwaite degrees of freedom. For the given model, Satterthwaite degrees of freedom are computed with the following commands:

```
LakeChemNoNA<-LakeChem[!is.na(LakeChem$Y),]
n<-dim(LakeChemNoNA)[1]
LakeIndMat<-LakeInd(LakeChemNoNA$Lake)
X<-cbind(1, LakeChemNoNA$WYear, LakeIndMat)
sig2b<- VarCorr(TrendFit)$Year[1,1]
sig2t<- VarCorr(TrendFit)$Lake[1,1]
sig2c<- attr(VarCorr(TrendFit),"sc")^2
Q1<- GetQ(LakeChemNoNA$Year)  # Design matrix for random effect
for year
Q2<- GetQ(LakeChemNoNA$Lake)  # Design matrix for random effect
for lake
Q3<-diag(n)                   # Design matrix for random error

eta<- SatterthwaiteDF(X= cbind(1, LakeChemNoNA$WYear,
LakeIndMat),Q=list(Q1,Q2,Q3),lambda= c(sig2b,
sig2t,sig2c),index=2)
eta
```

Output:

```
16.09935
```

3.2.2. Trend Tests

To test the hypothesis, $H_o : \delta = 0$ vs $H_A : \delta \neq 0$, use the following code:

```
tstat<-(attr(TrendFitSummary,"coefs"))[2,3]
p_value<- 2*pt(abs(tstat),eta,lower=FALSE)
cbind(tstat, p_value)
```

Output:

```
 tstat      p_value

-0.3541     0.7278
```

3.2.3. Trend Estimates

We describe two estimates of trend using the mixed linear model approach: 1) Estimating annual trend on the original scale, and 2) Estimating multiplicative trend on the original scale. Mean

annual trend estimates the proportion by which the population changes from year to year. Multiplicative trend estimates the net change over a specific span of time. Analyzing the annual trend may be helpful when comparing two trend estimates taken over differing spans of time. Net trend estimates are helpful in interpreting overall changes in the population over time.

Two methods of estimating annual trend are used and differ slightly. The first method employs the linear mixed model but does not account for censoring. This method is helpful to obtain the Satterthwaite degrees of freedom. The second method uses multiple imputation in conjunction with the robust MLE approach (Kroll and Stedinger 1996) to account for censored data. Neither method accounts for the GRTS survey design; both methods assume simple random sampling.

1. *Annual trend on the original scale* is estimated by $e^{\hat{\beta}}$-1. Confidence intervals for $e^{\hat{\beta}}$-1 are found by applying the exponential function to the endpoints of the confidence interval for $\hat{\beta}$ and subtracting 1 from each confidence limit. In other words, if the (1-α)100% confidence interval for $\hat{\beta}$ is (*a*,*b*), then the (1-α)100% confidence interval for $e^{\hat{\beta}}$-1 is $\left(e^{a}-1, e^{b}-1\right)$. For example, the annual trend on the original scale is estimated as $e^{\hat{\beta}}-1 = e^{-0.0058}-1 = 0.9942\text{-}1 = \text{-}0.0058$. The 90%-confidence interval is $\left(e^{-0.0338}-1, e^{0.0222}-1\right) = \left(-0.0333, 0.0224\right)$. In R,

```
beta<- fixef(TrendFitSummary)[2]

SEbeta<-sqrt(vcov(TrendFit)[2,2])

alpha<-0.1

t_mult<- qt(1-alpha/2,eta)

CIlow<-beta-(t_mult*SEbeta)

CIhigh<-beta+(t_mult*SEbeta)

AnnualTrend<- exp(beta)-1

ATCIlow<- exp(CIlow)-1

ATCIhigh<- exp(CIhigh)-1

AnnualTrendEsts<-round(cbind(AnnualTrend, ATCIlow, ATCIhigh),4)

names(AnnualTrendEsts)<-c("AnnualTrend","ATCIlow","ATCIhigh")

AnnualTrendEsts
```

Output:

```
AnnualTrend ATCIlow   ATCIhigh

-0.0116     -0.0485   0.0267
```

The trend analysis above does not account for censoring of data values. A function that uses a multiple imputation approach in conjunction with the robust MLE approach (Kroll and Stedinger 1996) may be used to obtain unbiased estimates of trend when the data set contains censored data. However, confidence intervals should be constructed using a *t*-statistic based on the Satterthwaite degrees of freedom from the unimputed data set. Estimates of trend and its standard error may be obtained from the function *TrendEst* in the *LakeChem.Rdata* workspace.

```
TrendMI<-TrendEst(LakeChem, eta=eta)
```

For the trend estimates found with multiple imputation, annual trend on the original scale would be estimated as:

```
AnnualTrendMI<- exp(TrendMI[1])-1

ATMICIlow<- exp(TrendMI[3])-1

ATMICIhigh<- exp(TrendMI[4])-1

AnnualTrendMIEsts<-round(cbind(AnnualTrendMI, ATMICIlow, ATMICIhigh),4)

names(AnnualTrendMIEsts)<-c("AnnualTrendMI","ATMICIlow","ATMICIhigh")

AnnualTrendMIEsts
```

Output:

```
AnnualTrendMI ATMICIlow   ATMICIhigh

-0.0114       -0.0491     0.0276
```

Notice that the estimates and confidence intervals are nearly identical in this example, indicating that missing data do not greatly affect inference if the robust MLE model (Kroll and Stedinger 1996) is correct.

2. *Multiplicative net trend on the original scale* is estimated by $\hat{\delta} = e^{m\hat{\beta}} - 1$, where m_b is the number of years over which the trend is tested. For example, an estimate annual trend on the logged scale of $\hat{\beta}$=-0.0058 over m_b=20 years implies a net change on the original scale of $\hat{\delta} = e^{20*(-0.0058)} - 1$= -0.1095 or about an 11% decline in the population parameter over the 20-year period. The 90%-confidence interval is found by exponentiating the confidence interval bounds multiplied by the number of years for which the trend is estimated.

```
m<-attr(TrendFitSummary,"ngrps")
mb<-m[2]

deltahat<- exp(mb*beta)-1

deltaCIlow<- exp(mb*CIlow)-1

deltaCIhigh<- exp(mb*CIhigh)-1

deltaests<-round(cbind(deltahat, deltaCIlow, deltaCIhigh),4)

names(deltaests)<-c("deltahat", "deltaCIlow", "deltaCIhigh")

deltaests
```

Output:

```
deltahat   deltaCIlow    deltaCIhigh

-0.1103    -0.4997       0.5823
```

For the trend estimates found with multiple imputation, net trend on the original scale would be estimated as:

```
m<-attr(TrendFitSummary,"ngrps")
```

```
mb<-m[2]

deltahatMI<- exp(mb*TrendMI[1])-1

deltaCIlowMI<- exp(mb*TrendMI[3])-1

deltaCIhighMI<- exp(mb*TrendMI[4])-1

deltaMIests<-round(cbind(deltahatMI, deltaCIlowMI, deltaCIhighMI),4)

names(deltaMIests)<-c("deltahatMI", "deltaCIlowMI", "deltaCIhighMI")

deltaMIests
```

Output:

```
AnnualTrendMI ATMICIlow   ATMICIhigh

-0.2055      -0.6343        0.7229
```

Results indicate that neither estimates of net trend are significantly different from zero at the α=0.10 level.

3.3. Seasonal Kendall Test

Trend at *individual index sites* is computed using the Seasonal Kendall Test (SKT) modified to account for serial correlation (α = 0.10) (Hirsch and Slack 1984). The SKT is a non-parametric test commonly used to test for long-term water quality trends at single sampling stations. It works well with censored data---results below detection limits are treated as ties. The Sen Slope method is used to estimate magnitude of the trends. However, Sen Slope may only be applied when using data sets containing few censored data points (~ less than 5%). A minimum of 5 years of data (10 often recommended) is required before conducting trend analyses.

Once a minimum of 5-10 years of data points are collected for an individual *extensive* site, the SKT may also be used to estimate trend at individual extensive lakes. These results will provide a comparison to the population-level estimates and provide managers with additional site specific data.

Water quality concentrations are often correlated with streamflow. For example, constituents with relatively constant inputs into receiving waters (e.g., Ca, Mg, ANC) typically decrease (i.e. are diluted) in concentration when streamflows increase. As a result, trend analyses are run on both raw concentrations and flow-adjusted concentrations for chemistry data measured at outlet stations that are correlated with flow. Before performing the trend analyses concentration-discharge relationships are evaluated using scatter plots and regression analysis. Flow-adjusted

concentrations are then tested by modeling the variation due to discharge using a loess routine and conducting trend analyses on the residuals.

The SKT is computed using S-Plus with the USGS S-ESTREND library (Slack et al. 2003). (The program is currently installed on the Physical Scientist's computer or it may be downloaded at http://water.usgs.gov/software/S-PLUS/). Once installed, the USGS library is accessed from the S-Plus main menu bar—labeled 'USGS'. ESTREND is a subdirectory of USGS. There are multiple options under ESTREND---selecting each option, in order, steps you through the trend analysis process. Step-by-step S-ESTREND procedures, accompanied by examples, are well described by Lorenz (2003) in the S-ESTREND documentation. We outline the steps below and provide additional guidance specific to the lake protocol trend analyses. Follow these steps in conjunction with the detailed procedures in Lorenz (2003).

1. **Create a new S-Plus chapter**
   Create a new subdirectory and separate S-Plus chapter for each new project. All files associated with the trend analysis project are stored in the new subdirectory.

2. **Create a data frame in S-Plus**
   S-ESTREND assumes data are in an S-Plus data frame and follow a specific format. Once data are queried and exported from the database, follow the instructions and examples in Lorenz (2003) carefully to ensure your data frame is correct.

3. **Select Data**
   Select the name of the data frame containing the water-quality data to be analyzed for trends and click OK

4. **Create Data Structure**
   Verify the name of the data frame containing the water-quality data to be analyzed for trends and click OK

5. **Review Status**
   You may refer back to and select review status throughout the procedure. Status should be checked after each of the steps.

   To print the status of all stations, make sure that the 'Print Status' is checked and click OK or Apply. To view the status of any constituent and station, simply select those desired and the status will be displayed. Do not click OK or Apply.

   To change the status of any constituent and station, simply select those desired and the status will be displayed. Make sure that 'Print Status' is not checked and check 'Update Status.' Then select the correct status and click OK or Apply.

Table SOP 14.3. Status codes corresponding to steps in the S-ESTREND process.

Step	Code	Explanation
2. Create Data Structure	skip	User-set to skip analysis
	no data	There are no data available for analysis
	insufficient data	There are fewer than 50 observations
	short record	The record is less than 5 years in length
	data OK	The data passed all criteria-ready for step
5. Define Seasons	season defined	At least one season has been defined and is ready for step 6
6. Seasonal Comparisons	season selected	The defined seasons have been analyzed and the 'best' has been selected. Ready for steps 7 and 8.
8. Select Flow Model	ready	Flow models have been selected or set to none and the data are ready for step 9.
9. Run Trend Tests	done	The trend tests have been completed and the results can be exported to a data set.

If Apply was clicked, click Cancel to exit or the last action will be repeated.

6. **Explore Seasonal Patterns**

In this step you plot the data as time series graphs, boxplots, and/or bar charts to evaluate the data before defining seasons. Sampling frequency for index sites is scheduled so the data may be binned by month—each month from May-October is a season. This is assuming the data meet the requirement that a minimum of 50% of the possible comparisons need to be made for 80% of the seasons. This is determined in Step 5.

To plot the data:
Plot Specs page→Plot Specifications group→ Select the Constituent and any combination of stations (must select at least one station) and the Plot Type.

To create hardcopy, use the Device page:
Device page→Output Device group→Select the output format type, orientation, height and width, and the output file name (Save In box).

Important Note: There is an error in the program—graphs may be mislabeled. The time label for first data point on the x-axis is always labeled January. This is a problem when

you graph by water year and the first month is October. The data are plotted in the correct order—just mislabeled.

Click Apply or OK when ready; if Apply was clicked, click Cancel to exit.

7. **Define Seasons**

   Sampling frequency for index sites is scheduled so the data may be binned by month—each month from May-October is a season. To define the seasons:

   a. Select page
   b. Initial group
   c. Check Initial Definition if seasons have not been previously defined.
   d. Check Print only and click OK or Apply if a summary printout is desired.
   e. Update group. If Initial Definition is unchecked, Constituents and Stations boxes become active, select what ever constituents and stations will be modified, (must select at least one of each).
   f. The remaining pages indicate which groups are on which page. The groups are identified by the number of season per year.
      To select a seasonal definition, check the Number of Seasons box and enter the ending month and day for each of the periods in that seasonal definition. Any seasonal definition that is not checked will not be used, so to make a change, all seasons must be defined, not just the one to be changed.
   g. When everything is ready, click OK or Apply, click Cancel to exit or the last action will be repeated.

8. **Compare Seasons**

   No changes can be made after Compare Seasons has been run.

   The ‘Percent of Possible Comparisons’ is the criterion for trend tests within each season, for the beginning-ending and middle periods. Enter the value, or use the spinner to change it. 50 is recommened.

   The ‘Minimum Percent of Seasons to Qualify’ is the criterion for comparisons between each season, for the beginning-ending and middle periods. 80 is recommended.

   The 'best' season definition is the one with the most seasons that meet these criteria.

   Click OK when ready.

9. **Select Best Season**

   If only a summary of the results of the Compare Seasons analysis is desired, make sure that Print Summary is checked and click OK or Apply.

   If a 'selected' season is to be changed, make sure the Print Summary is not checked, select the constituent and station, then check Update Seasonal Selection and change Selected.

Click OK or Apply when ready. If Apply was clicked, click Cancel to exit or the last action will be repeated.

10. **Select Flow-adjustment Model**

Before running the flow-adjustment model, evaluate the concentration-discharge relationships for each constituent using scatter plots and regression analysis (Figure SOP 14.2). Run the flow-adjusted model when constituent concentrations are correlated with streamflow.

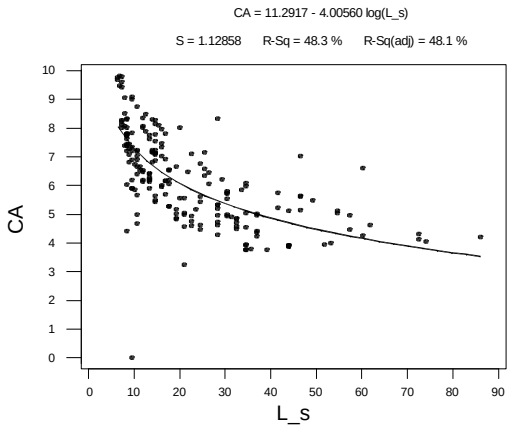


Figure SOP 14.2. Example of a concentration-discharge graph for calcium.

Nothing can be changed after Select Flow-Adjustment Model has been run.
Parameters group: Select the Constituent and Stations for the analysis. The Cut-off for Censored Values criterion is used to set the model to 0 for any set where the percent of censored values exceeds this value.

Flow-Adjustment Models group: Check the desired Flow-adjustment model for the constituent and stations. When running trend analyses on raw concentration data, the FAC model should be set to zero—check: Set all to '0-none'. For flow-adjusted concentrations we recommend using the loess model (13).

Click Apply when ready. To exit, click Cancel.

11. **Trend Test**

Nothing can be changed after the trend tests have been run.

Data to Analyze group: Select the Constituent and station for the analysis. Select the Trend Test Type that is appropriate for the constituent.

a. Criteria for use of the uncensored SKT:
   i. Less than 5% of the data must be uncensored

ii. The record must span a minimum of 5 years as determined by the difference in years between the beginning and ending observations.

iii. The minimum number of observations in the record must be at least three times the number of designated annual seasons, and must be greater than or equal to 10.

iv. A minimum percentage (50 and 80) of the total possible number of seasonal water-quality values in the beginning and ending fifths of the record must be present in the record. The beginning and ending fifths of the record are determined as described in section 4.2 of Schertz (1991).

b. Criteria for the censored SKT:

i. May be used when greater than 5% of the data are censored

ii. The record must span a minimum of fiver years as determined by the difference in years between the beginning and ending observations.

iii. The minimum number of detected observations in the record must be at least three times the number of designated annual seasons, and must be greater than or equal to 10.

iv. A minimum of one observation per year must be present in the beginning and ending fifths of the record.

Beginning and Ending Dates group: Enter the Calendar Year to Start and the Number of Years to Analyze. The Seasonal Kendal test requires at least 5 years.

Seaken Parameters group: For the Uncensored Seasonal Kendall test, enter the Minimum Percent Values, which is the minimum acceptable percentage of values that are tested that must be non-missing. For the Censored Seasonal Kendall test, Enter the value to be used for all censored values.

Click Apply when ready and Cancel to exit.

12. **Extract Data by constituent**

Select the Constituent for extracting the results of the trend tests.

Enter the Value to Use for the Significance Level.

Click Apply when ready or Cancel to exit.

The data are printed to the report window and stored in a data frame of the name trend.CONSTITUENT, where CONSTITUENT is the name specified in the Constituent box.

13. **Extract Data by station**

Select the Station id for extracting the results of the trend tests.

Enter the Value to Use for the Significance Level.

Click Apply when ready or Cancel to exit.

The data are printed to the report window and stored in a data frame of the name trend.STATION, where STATION is the name of the station specified in that box.

4. Streamflow Analyses

The streamflow analyses sections are adapted from the San Francisco Bay Area Network Stream Flow Monitoring Protocol (Fong 2007).

The hydrologic data analysis section provides a description of the data processing procedures that are needed to provide the data for annual summaries of streamflow conditions as well as procedures to conduct long-term assessments of flood frequency and flow duration that are anticipated for our 4-year reports. The procedures include the calculation of individual discharge measurements using various measurement techniques, formatting of continuous gaging station records, creation of stage-discharge relationships, and simple tabular summaries of data for reports. The standard procedures for discharge data analyses have been developed and tested by the USGS to analyze records from over 7,000 gaging stations nationwide. The intent of this SOP is to refer to or summarize these procedures rather than to adopt new data analysis methods.

Almost all of the analyses will be conducted using Microsoft Excel and Access. SIEN's Microsoft Access Water Database and Discharge Measurement Database are used to manage, respectively, continuous stage/flow data and instantaneous discharge measurements. Calculations for instantaneous flow are currently computed in the Discharge Measurement Database (for mid-section method) and the Dye Dilution Calculation spreadsheet (for dye tracer method). In the future, we will be working with our Data Manager (position has been vacant for over a year) to either incorporate the spreadsheet calculations for the dye tracer method into the Discharge Measurement Database or ensure the two tools are integrated. Presently, rating curves will be developed for each recording gaging station using the spreadsheet developed by the San Francisco Bay Area Network. However, SIEN is looking into purchasing rating curve software---in particular, *Aquarius* by Aquatics Informatics (http://www.aquaticinformatics.com/main/?aquarius).

4.1. Reference Materials

Procedures for stream discharge analyses have been obtained from two main USGS reference documents: Kennedy (1983)- Computation of continuous records of streamflow and Rantz et al. (1982b)- Measurement and computation of streamflow: Volume 2. Computation of discharge. These documents are available electronically on the web and the reader is referred to those documents for a more specific description of methods.

4.2. Individual Discharge Computations

The procedures used to calculate measured discharges are specific to the particular field sampling techniques and for our purposes include the USGS's mid-section (for current meters), and slug injection methods for salt and rhodamine. These computational procedures are used in the Discharge Measurement Database and the Dye Dilution Calculation Spreadsheet.

4.2.1. Mid-section Method

For current meter measurements, individual discharge measurements will be calculated using USGS's mid-section method. This method divides the channel into sections. The discharge is the sum of the partial discharge estimates for all the sections and is based on the section's width, depth, and average velocity (Figure SOP 14.3). The basic formula is

$$Q = \sum (a\overline{V})$$

where ***a*** is the rectangular area of the subsection (product of depth and width) and $\overline{V}$ is the mean velocity in a subsection (Harrelson et al. 1994). The width of each section is the distance between the mid-points of two adjacent points (**b_{n+1} - b_n**) (Figure SOP 14.3). The mid-section method does not include the triangular section of channel next to each bank and assumes that partial discharge in these sections is negligible. (Note: The Measurement Discharge Database uses the basic formula listed above to calculate discharge).

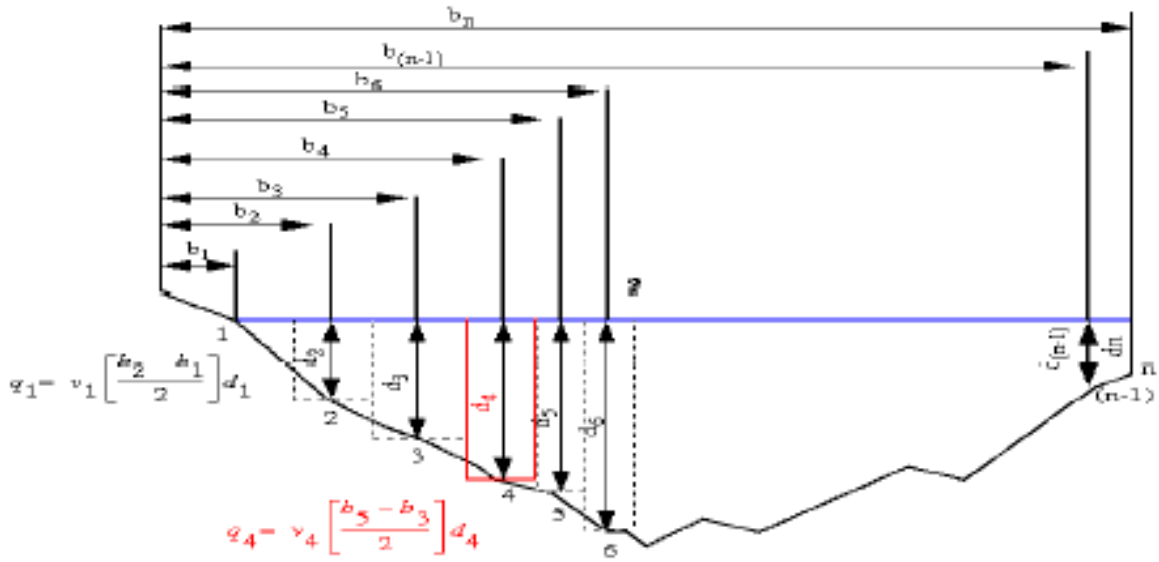


Figure SOP 14.3. Midsection method of discharge measurement (Rantz et al. 1982a).

4.2.2. Rhodamine Slug Injection Method

For the rhodamine slug injection method, individual discharge measurements are calculated using USGS methods described in Rantz et al. (1982b, 214). Discharge (Q) is computed from:

$$Q = mRwt/(\Sigma(C_i - C_b)dt)$$

where

mRwt = the mass of Rwt (rhodamine water tracer) used (µg as active ingredient)

C_i = the tracer concentration in the stream at time i

C_b = the background concentration in the stream

t = time

Calculations are computed using an Excel spreadsheet: *SlugDyeQCalc.xls*. The spreadsheet template is located on the SEKI network in the SIEN folder *J:\sien\I_M\monitoring\water\data\tabular\analyses\Q_calcs*. In the spreadsheet, blue cells indicate cells where field observations are entered and yellow or white cells indicate calculated values (Figure SOP 14.4).

From the field data sheets enter the field observations in cells B5-18 (fields are described in the spreadsheet). Starting in cell C18 enter the data from the slug injection run: date, time, and Rwt in stream concentrations (ug/l).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	To calculate Q, enter fields in bold									Q = mRwt/(Σ(Ci-Cb)dt)		(Rantz et al., p. 214)		
2		Results:		Σ(Ci-Cb)dt =		681.0				where				
3	Q =	10,485	L/s		Cb =	-1.0	0.00 begin (min.)			mRwt	is the mass of Rwt used (µg as active ingredient)			
4	Q =	296.9	CFS			-1.0	8.52 end (min.)			Ci	is the concentration in the stream at time *I*			
5	mStock=	**35.7**	g	**Enter g 20% Rwt stock solution used**						Cb	is the background concentration in the stream			
6	VolSlug (L) =	**15.0**	L	**Enter slug volume (water only)**										
7	Theor. Inj. C =	**0.475**	g/L Rwt as active ing	**Calculated**										
8	Meas. Inj. C =	**0.478**	g/L Rwt as active ing	**Calculated**						Cp	Tp	Q CFS	Mstock	CpTpQ
9	inj. time=	**5/19/04 13:59:00**		**Enter injection time**						6.3	1.77	296.9	35.7	3304.8
10	Site Name=	**Merced River above High Sierra Camp**		**Enter site name**										
11	transducer (ft)=	**2.80**		**Enter transducer reading**										
12	staff (ft)=	**2.70**	new staff on stump	**Enter staff reading**										
13	tape down (ft)=	**2.10**	on stump	**Enter tape down value, description**										
14	20 ppb reading=	**21.5**	**ppb**	**Enter reading of 20 ppb std**										
15	std checked @	**5/19/04 13:45**		**Enter DateTime of std check**										
16	**Enter time and concentrations of Rwt measurements in stream**													
17	sec. after inj.	min. after inj.	DateTime	Rwt in stream (µg/L)	(Ci-Cb) (µg/L)	dt (s)	(Ci-Cb)dt (µg*s)/L	g Rwt (active)						
18	1	0.02	5/19/04 13:59:01	-1.1	-0.1									
19	16	0.27	5/19/04 13:59:16	-0.9	0.1	15	1	0.02						
20	31	0.52	5/19/04 13:59:31	-0.6	0.4	15	6	0.06						
21	46	0.77	5/19/04 13:59:46	-0.6	0.4	15	6	0.06						
22	61	1.02	5/19/04 14:00:01	-0.5	0.5	15	8	0.08						
23	76	1.27	5/19/04 14:00:16	-0.3	0.7	15	11	0.11						
24	91	1.52	5/19/04 14:00:31	2.4	3.4	15	51	0.53						
25	106	1.77	5/19/04 14:00:46	5.3	6.3	15	95	0.99						
26	121	2.02	5/19/04 14:01:01	5.2	6.2	15	93	0.98						
27	136	2.27	5/19/04 14:01:16	3.6	4.6	15	69	0.72						
28	151	2.52	5/19/04 14:01:31	2.5	3.5	15	53	0.55						

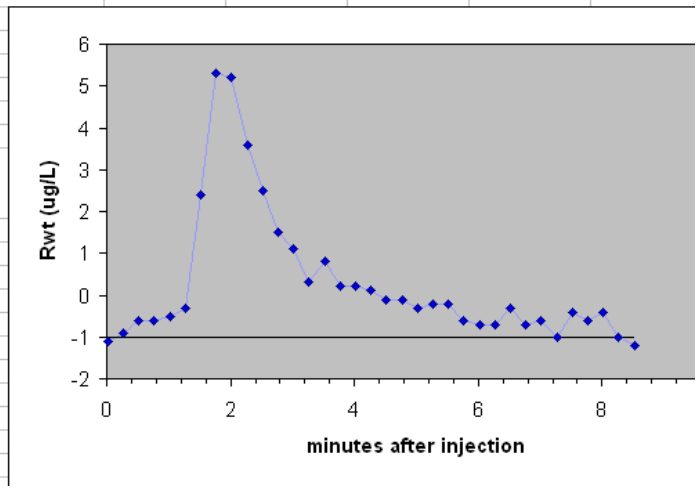


Figure SOP 14.4. Instantaneous discharge calculation example using the SlugDyeQCalcs.xls spreadsheet.

The spreadsheet will automatically calculate the remaining information and graph the time-concentration curve. The instantaneous flow results are at the top of the sheet (cells B3 and B4).

4.2.3. Salt Injection Method

For the salt-dilution slug injection method, individual discharge measurements are calculated using USGS methods described in Rantz et al. (1982b) (pg 214 and 255). Discharge (Q) is computed from:

$$Q = (V_l P_p)/(F +/- \Delta F)$$

where

Vl = volume of the injected salt solution (cubic meters)

Pp = relative conductance of the injected solution (tenths of a percent)

F = product of the sampling interval (seconds), multiplied by the sum of the observed values of relative conductance

ΔF = correction factor for any change in reading of the relative conductance of the natural river water between the start and end of the measurement:

$\Delta F = ((P_{start} - P_{end})/2)\ (t_n - t_1)$, where $t_n - t_1$ is time (s) that elapsed during the run

SIEN is proposing to use the rhodamine slug injection method as their primary tracer method. As a result, we do not have spreadsheet or databases set-up to facilitate instantaneous discharge calculations for the salt dilution method.

4.3. Preparation of Continuous Stage Data for Analysis

Streamflow data analysis procedures described include step-by-step instructions for processing continuous gaging station data. An overview of this process, including how these data are integrated with stage-discharge rating curves, is provided in Figure SOP 14.5.

Crews will return from the field with the most recent data stored on the Solinst Leveloader *(Refer to SOP 10. Hydrological Sampling Methods for field instructions)*. Data are transferred to the computer using Leveloader Gold Software. Downloading instructions are in the Leveloader Gold User Guide: http://www.solinst.com/Downloads/LeveloaderGold-V3.pdf.

A standardized file naming convention, consistent with SIEN's Data Management Plan, is used for all raw recording gaging station data files. The file name begins with 'RawStageData', followed by an underscore and the station code, followed by underscore and the park code, followed by the date using a 4-digit year code, 2-digit month code, and 2-digit date which correspond to the date of download. Solinst saves its files as *.lev. For example, a hypothetical raw data file for a download date of February 2, 2007 at Kuna Peak Lake would be "RawStageData_KUNA_yose_20070202.lev". Station codes and corresponding metadata are found in SIEN's Water database.

After the raw data are downloaded, the files are transferred to the SIEN network drive (J:\sien\I_M\monitoring\water\data\tabular\original_data\stage). Each gaging station has its own folder under the 'stage' folder.

The 'raw' datalogger files (e.g., filename.lev) can be viewed as a text file in Notepad. These files are imported into Microsoft Excel spreadsheets (*Refer to SOP 13. Database User's Manual*). Although each station/datalogger model may produce slightly different output, a core set of fields will be imported for each station. These fields include date and time (Pacific Standard Time), raw water stage (instantaneous, 15-minute), and temperature.

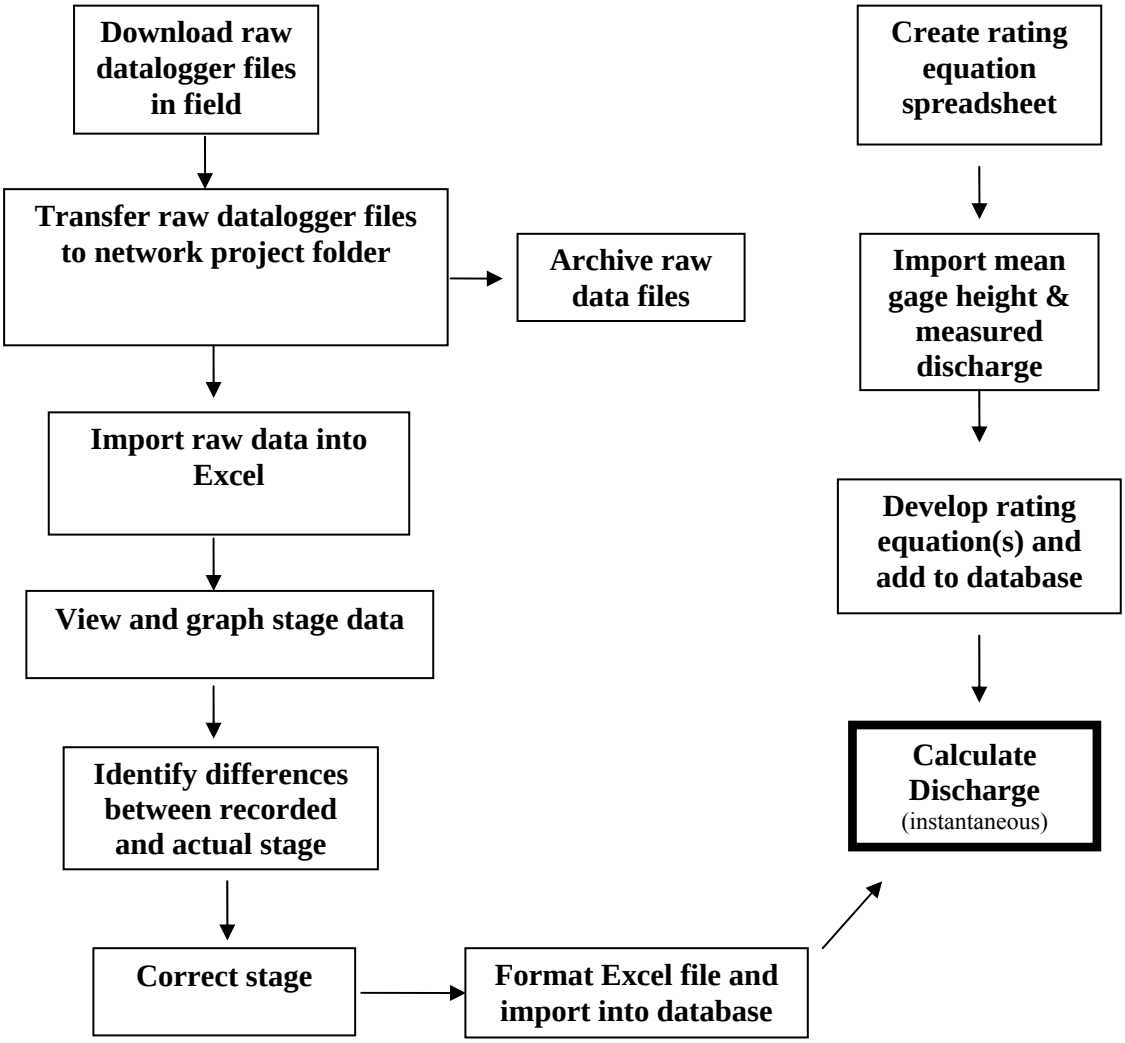


Figure SOP 14.5. Flow chart of data processing procedures for determination of instantaneous stream discharge.

The Solinst is a sealed pressure transducer and therefore, records water pressure plus atmospheric pressure. Since we are just interested in the water pressure (i.e. stream stage), the data need to be corrected by subtracting atmospheric pressure. Atmospheric pressure is measured separately by a barometer, which is often located in a different location and elevation than the pressure transducer (this way we can use one barometer to for several gaging stations). To correct for atmospheric pressure:

1. Import the raw stage data into Excel and the name the worksheet 'stage_raw'
2. Create a new/empty worksheet in the raw stage Excel file and rename it 'stage_corr'. Copy both the stage data and the atmospheric pressure data into this worksheet. The dates and time should be lined up and match as accurately as possible.
3. Subtract the atmospheric measure (cm) from the stage data (cm).
4. Fix the elevations at the beginning of the record. In the example below (Figure SOP 14.6), the first record has been adjusted to actual water surface elevation. The offset between the recorded depth (19.554 cm) and the water surface elevation (81.78 feet) is used to calculate the sensor elevation (81.14 feet). Each remaining recorded depth then is added to the sensor elevation to get water surface elevations.

Yosemite National Park				
Project:	Looking Downstream, Poopenaut Valley Hydrology			
Instrument:	Upstream Stage Recorder		Solinst SN#0041023011	
Elevation of staff plate (6.66ft)		87.22feet		
Start Time	14:42:00	Stage =		0.22feet
Start Date	4/6/2007	Water Surface Elevation =		81.78feet
		Sensor Elevation =		81.14feet
End Time	16:05:00	Stage =		feet
End Date	6/15/2007	Water Surface Elevation =		feet
		Sensor Elevation =		feet

Date	Time (PDT)	Depth (cm)	Temperature C	Water Surface Elevation (ft)
4/6/2007	14:30:00	19.554	11.234	81.78156674
4/6/2007	14:45:00	19.162	10.655	81.76870522
4/6/2007	15:00:00	19.351	10.663	81.77490631
4/6/2007	15:15:00	19.461	10.832	81.77851541
4/6/2007	15:30:00	19.796	11	81.78950676
4/6/2007	15:45:00	19.903	11.109	81.79301743
4/6/2007	16:00:00	20.016	11.172	81.79672496
4/6/2007	16:15:00	20.079	11.277	81.79879199
4/6/2007	16:30:00	20.124	11.332	81.80026844
4/6/2007	16:45:00	20.265	11.353	81.80489465
4/6/2007	17:00:00	20.206	11.373	81.80295886

Figure SOP 14.6. Correcting stage data for barometric pressure and elevation.

5. The final calculated water surface elevation should then be compared to the measured water surface elevation. If these two differ by greater than 0.15 feet than an adjustment is necessary (see other section).

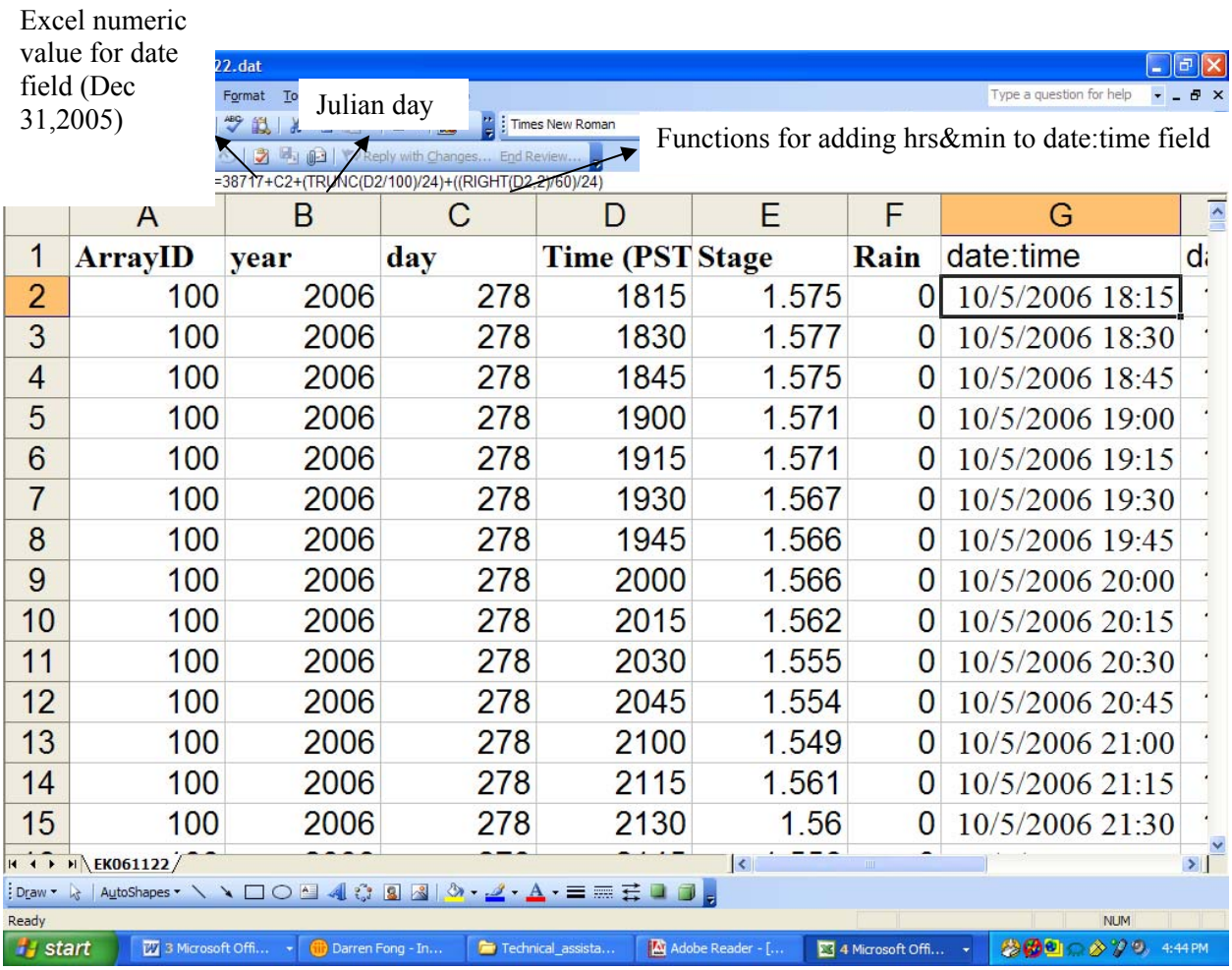
Before importing into the water database, the corrected raw stage data need to be checked for problems or inaccuracies. Graph the stage data over time. Note: to accomplish this you will need to join the date and time fields into one field.

4.3.1.1. *Excel Tips for Preparing Raw Date:Time Fields from Datalogger*

To graph stage data the date and time field need to be joined as a single date:time field. Excel stores dates as sequential whole numbers starting from January 1, 1900 while hours and minutes are stored as fractional values. The Excel formula to transform year, Julian date, and time to a composite Date:Time format (e.g., 3/31/2005 13:45 hr):

Date:Time = Excel Date + Julian day + (**TRUNC**(Time/100)/24) + ((**RIGHT**(Time,2)/60)/24)

where Excel Date is the numeric format for December 31 of prior year, [**TRUNC**] and [**RIGHT**] commands converts hours and minutes, respectively to decimal day. The general formula can also be found in Figure SOP 14.7 that includes a screenshot of our Excel spreadsheet.



	A	B	C	D	E	F	G
1	ArrayID	year	day	Time (PST	Stage	Rain	date:time
2	100	2006	278	1815	1.575	0	10/5/2006 18:15
3	100	2006	278	1830	1.577	0	10/5/2006 18:30
4	100	2006	278	1845	1.575	0	10/5/2006 18:45
5	100	2006	278	1900	1.571	0	10/5/2006 19:00
6	100	2006	278	1915	1.571	0	10/5/2006 19:15
7	100	2006	278	1930	1.567	0	10/5/2006 19:30
8	100	2006	278	1945	1.566	0	10/5/2006 19:45
9	100	2006	278	2000	1.566	0	10/5/2006 20:00
10	100	2006	278	2015	1.562	0	10/5/2006 20:15
11	100	2006	278	2030	1.555	0	10/5/2006 20:30
12	100	2006	278	2045	1.554	0	10/5/2006 20:45
13	100	2006	278	2100	1.549	0	10/5/2006 21:00
14	100	2006	278	2115	1.561	0	10/5/2006 21:15
15	100	2006	278	2130	1.56	0	10/5/2006 21:30

Figure SOP 14.7. Combining date and time fields into a single date:time field.

4.3.2. Correcting Water Stage Data

The water level information is converted to discharge data through application of stage-discharge relations. Ensuring the accuracy of gage-height record is, therefore, a necessary component of ensuring the accuracy of computed discharges. Preparatory work, before the data are imported into the database is needed to adjust datalogger output to corrected water level stage. Often, datalogger records may not reflect actual water level stage due to movement of sensor (e.g., cleaning and calibration checks of transducer), the need for datum corrections, missing data, erroneous data, or sensor reading drift. These procedures to adjust and check raw water stage data are described below.

4.3.2.1. *Sensor Movement*

The position of the sensor may change due to deliberate actions such as cleaning, calibration checks, or downloading. The change in sensor position can be determined by comparing water stage data to staff gage readings, which are recorded every visit and prior to and after expected sensor movement. This difference can be used to adjust the offset and recorded water stage by simple addition or subtraction.

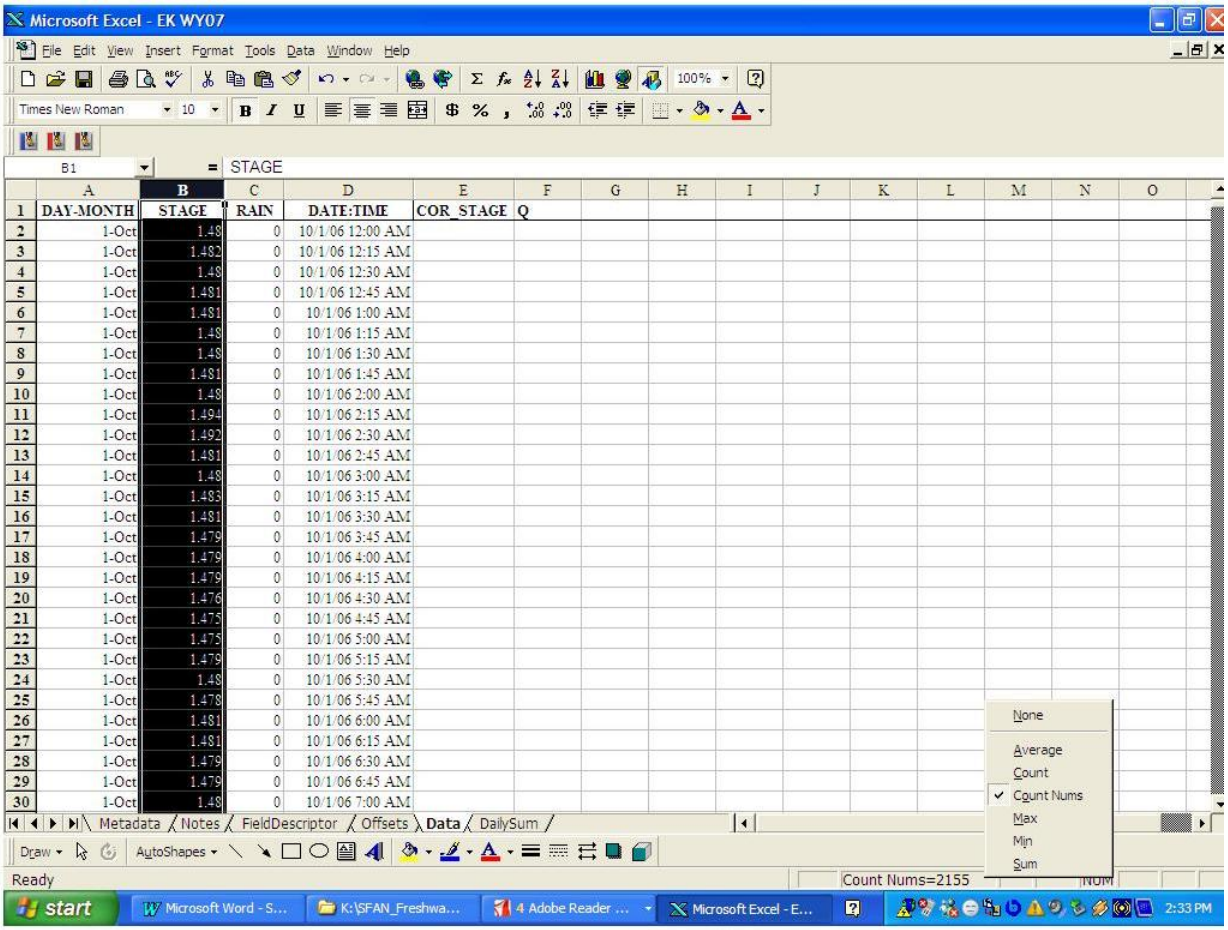
4.3.2.2. *Datum Corrections: From Norris and Fisher (2005).*
A correction applied to gage-height readings to compensate for the effect of settlement or uplift of the gage is usually measured by levels and is called a "datum correction" (Kennedy 1983, p. 9). Datum corrections are applied to gage-height record in terms of magnitude (in feet) and in terms of when the datum change occurred. In the absence of any evidence indicating exactly when the change occurred, the change is assumed to have occurred gradually from the time the previous levels were run, and the correction is prorated with time (Rantz et al. 1982b, p. 545). Datum corrections are applied when the magnitude of the vertical change is equal to or greater than 0.015 ft.

4.3.2.3. *Missing Data*
Sometimes data may not be recorded by the datalogger due to a equipment or power failures. Data gaps in the 15-minute record can be identified using the Excel spreadsheet. To do this, the actual number of data records are compared to the expected number. The actual number of stage records saved by the datalogger is counted by highlighting the 'Stage' field, right-clicking the bottom menu bar, and selecting [**Count Nums**]. Figure SOP 14.8 shows a computer screen image of this process. In the case of our WY07 Easkoot Creek dataset, we have 2155 records between October 1, 2006 1200 am to October 23, 2006 1030 am. To calculate the expected number of 15-minute records between this time, subtract the last and first date:time fields to obtain the decimal days. Convert the decimal days to number of 15-minute records:

$$EN = DD\left(\frac{24hr}{day}\right)\left(\frac{60\min}{1hr}\right)\left(\frac{record}{15\min}\right)$$

where ***EN*** is the expected number of 15-minute records and ***DD*** is the decimal days. If the expected number of records does not match up with the actual number of records, you probably have some missing records that you need to find and document. Excel's [**Pivot Table**] feature should be used to display the number of 15-minute records per day. Any day with less 96 records has missing data.

Missing records are documented in the individual station logs and in the comments field in the database. Should a substantial portion of a day's record be missing and the stage appears to be rapidly changing, the remaining stage values for that day can be converted to text values. Conversion to text values will prevent mean daily discharge and stage from being calculated from just a few values. In all cases of missing data, all affected data files, whether they be recorded data or summaries based thereon, should be clearly marked to identify the period of missing data.



	A	B	C	D	E	F
1	DAY-MONTH	STAGE	RAIN	DATE:TIME	COR_STAGE	Q
2	1-Oct	1.48	0	10/1/06 12:00 AM		
3	1-Oct	1.482	0	10/1/06 12:15 AM		
4	1-Oct	1.48	0	10/1/06 12:30 AM		
5	1-Oct	1.481	0	10/1/06 12:45 AM		
6	1-Oct	1.481	0	10/1/06 1:00 AM		
7	1-Oct	1.48	0	10/1/06 1:15 AM		
8	1-Oct	1.48	0	10/1/06 1:30 AM		
9	1-Oct	1.481	0	10/1/06 1:45 AM		
10	1-Oct	1.48	0	10/1/06 2:00 AM		
11	1-Oct	1.494	0	10/1/06 2:15 AM		
12	1-Oct	1.492	0	10/1/06 2:30 AM		
13	1-Oct	1.481	0	10/1/06 2:45 AM		
14	1-Oct	1.48	0	10/1/06 3:00 AM		
15	1-Oct	1.483	0	10/1/06 3:15 AM		
16	1-Oct	1.481	0	10/1/06 3:30 AM		
17	1-Oct	1.479	0	10/1/06 3:45 AM		
18	1-Oct	1.479	0	10/1/06 4:00 AM		
19	1-Oct	1.479	0	10/1/06 4:15 AM		
20	1-Oct	1.476	0	10/1/06 4:30 AM		
21	1-Oct	1.475	0	10/1/06 4:45 AM		
22	1-Oct	1.475	0	10/1/06 5:00 AM		
23	1-Oct	1.479	0	10/1/06 5:15 AM		
24	1-Oct	1.48	0	10/1/06 5:30 AM		
25	1-Oct	1.478	0	10/1/06 5:45 AM		
26	1-Oct	1.481	0	10/1/06 6:00 AM		
27	1-Oct	1.481	0	10/1/06 6:15 AM		
28	1-Oct	1.479	0	10/1/06 6:30 AM		
29	1-Oct	1.479	0	10/1/06 6:45 AM		
30	1-Oct	1.48	0	10/1/06 7:00 AM		

Figure SOP 14.8. Counting stage records in Excel.

In some cases, it may be important to synthesize missing data. However, an attempt to fill in missing data should be made if there are reasonably accurate means available to do so. In the simplest cases, linear or non-linear interpolation can provide a good means to fill in a string of missing data. However, this can only be applied to periods of regular rise or fall of the hydrograph (rising or falling limb of storm hydrograph) and is not useful for estimating peak stages. In the case of missing peaks, a thorough field inspection soon after a flood for which data are missing can be instrumental in re-creating a missing storm peak. Often, high water marks (HWM) recorded by crest gages at the gaging station can approximate the peak stage. From this, a missing hydrograph can be synthesized to conform to the HWM data. Note that HWM 'age' rather quickly, so it is important make a field inspection soon after a problem is discovered.

Lacking a reliable HWM, the next best method for synthesizing missing data is to use data from a nearby gage that is similar in basic hydrologic responses to rainfall and had similar rainfall during the subject event. Regression analysis is used to develop a predictive relationship from a period of similar hydrology when both gages were operational (either before or after the period of missing data), then the missing data is filled in with stages predicted by the operational gage using the regression equation.

If no suitable 'surrogate' gage data are available, and the missing data are of substantial importance in the monitoring program, then other more intensive techniques may be applied, such as rainfall-runoff models that use unit hydrograph or other approaches (Dunne and Leopold 1978). Simple models can be manually applied while more sophisticated models are better applied using computer software (e.g., HEC-HMS). Only those experienced, or advised by experienced staff, should attempt to apply complex models.

4.3.2.4. *Identifying Erroneous Data*

It is extremely important to ensure that electronic stage data are as accurate as possible. Because of the exponential relationship between stage and discharge, small errors in stage result in large errors in estimated discharge. USGS's Office of Surface Water memorandum 93.07 (Boning 1992) note that a 1 percent error in the effective stage input to the rating would translate into a 3 percent error in the computed discharge.

Once gage height corrections have been applied to the dataset, the preliminary corrected stage data can be checked to identify erroneous data. Peak values for electronic stage data can be compared to observed high marks and crest gage data (Boning 1992). The minimum stage values in the electronic data should also be reviewed for accuracy. Occasionally, negative stage values may occur due to equipment error or user error (e.g., pulling transducer from a stilling well for cleaning and forgetting to accurately document time of actions).

If after initial review, the suspect data still appear to be erroneous, the suspected data fields should be deleted and action noted in recorded data files and summary reports. If the data for this period are essential (e.g., occurring during peak storm event), new data can be synthesized using the approach described for missing data. In all cases of corrected data, all affected data files, whether they be recorded data or summaries based thereon, should be clearly marked with notations on the period of corrected data and how that period was dealt with (e.g., the method of correction used and data sources used for to assist corrections, who did the corrections and when, and so forth).

4.3.2.1. *Gage-height/Stage Corrections*

A correction applied to gage-height readings to compensate for differences between the recording gage and the base gage is called a "gage-height correction" (Rantz et al. 1982b) (page 563). Gage height corrections are applied so that the recorded data agree with the base-gage data. These corrections are applied when the gage-height difference between the recording gage and the base gage is equal to or greater than 0.02 ft, or for as small a difference as 0.01 ft when warranted due to low-water conditions when the percent difference from the rating is excessive. The typical gage height correction is associated with sensor drift. Between data downloads the readings from the pressure transducers may "drift," so that it will no longer be in agreement with the base gage (our staff plates). A drift correction—usually a linear proration with time—is applied to compensate for drift in the transducer's offset calibration (Rantz et al. 1982b) (p. 563).

To rectify the difference, calculate the difference between the staff plate and recorded water stage at the beginning and the end of the logging period. If the difference is less than 0.01 ft, there is no need for correction because of the accuracy of staff plate reading is no better than 0.01 ft. The more frequently the staff plate is recorded the better the chance of knowing when the

drift began. To correct for drift, the amount of drift must be distributed over the applicable time period by linear interpolation.

Microsoft Excel is used for drift correction. The linear interpolation is calculated for each 15-minute data record and used to correct the raw stage height. An example of how this is calculated is found in Figure SOP 14.9.

4.4. Converting Stage to Discharge

Once the instantaneous (15-minute) water stage data has been corrected, additional steps are needed to convert water stage data to discharge. These steps include computation of mean gage height, the establishment of stage-discharge relationship, and finally, computation of 15-minute and mean daily discharges.

4.4.1. Computation of Mean Gage Height

Occasionally, discharge measurements are made during periods of stage changes. Under these conditions, the computation of the mean gage height is required and described in detail by Rantz et al. (1982a, p. 170–173). When stage changes during the discharge measurement period are small (<0.15 ft) and uniform, the individual gage heights can be averaged. If the change in stage is greater than 0.15 ft (0.05 m) or if the change in stage has not been uniform, the mean gage height is obtained by weighting the gage heights corresponding to the clock-time observations. The *Discharge Measurement Database* incorporates these guidelines for its computation of mean gage heights.

4.4.2. Establishing Stage-Discharge Relationships

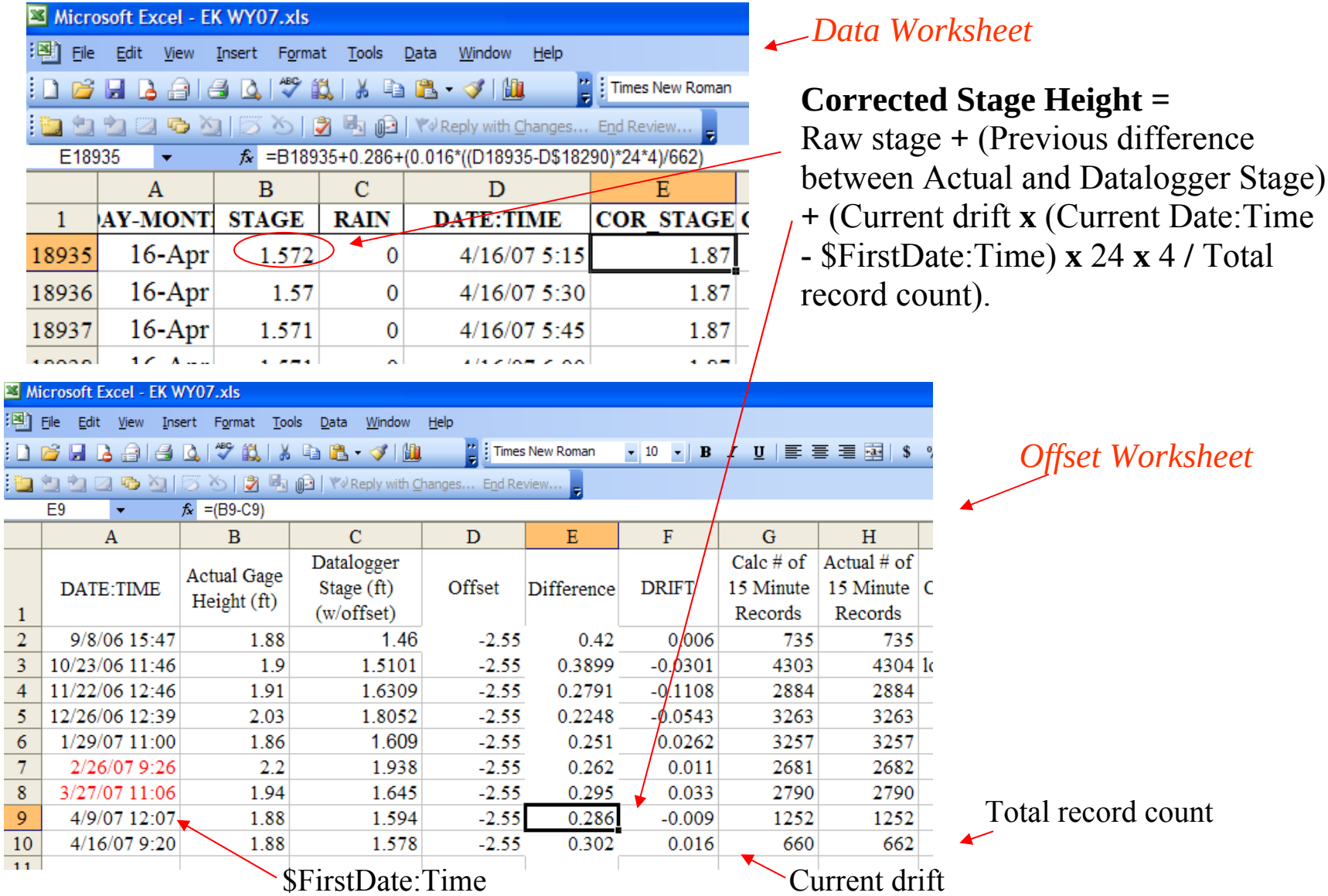
The development of the stage-discharge relation, also called the rating, is one of the principal tasks in computing discharge records. The rating is usually the relation between gage height and discharge (simple rating). Ratings for some special sites involve additional factors, such as rate of change in stage or fall in slope reach (complex ratings) (Kennedy 1983) (p. 14). Procedures for the development, modification, and application of ratings are described in Kennedy (1984), and guidelines pertaining to rating and records computation are presented in Kennedy (1983, p. 14) and in Rantz et al. (1982b, chap. 10–14 and p. 549).

A rating curve or stage-discharge relationship is then developed from numerous stage measurements and discharge computations made at the site during variations in flow by plotting stage versus discharge (typically gage height in feet versus discharge in cubic feet per second) on log-log paper. The more points, the more precise the rating curve is likely to be.

Discharge rating curves are usually determined empirically by means of periodic measurements of discharge and stage using a current meter (minimum of 10 per year is recommended initially). However the rating curve may shift over time and periodic measurements are necessary after the first year to either confirm the permanence of the rating or to follow changes/shifts in the rating. It is important that the rating curve include measurements made at flow extremes (e.g., flood conditions) and under extreme low flow conditions to be most accurate.

Stage-discharge relationships, particularly for low and mid-flow conditions, may only be consistent for a few years before changing due to bed conditions; although this is less of an issue in high-elevation granitic streambeds. As an example, Stillwater Sciences, a hydrologic consultant firm, evaluated streamflow monitoring data at Redwood Creek in Golden Gate

National Recreation Area and noticed rating shifts under all flow conditions (Figure SOP 14.10). Based on this experience, it is likely that new stage-discharge relationships would be required on an annual basis for each of the gaging stations.



	A	B	C	D	E
1	AY-MONT	STAGE	RAIN	DATE:TIME	COR_STAGE
18935	16-Apr	1.572	0	4/16/07 5:15	1.87
18936	16-Apr	1.57	0	4/16/07 5:30	1.87
18937	16-Apr	1.571	0	4/16/07 5:45	1.87

	A	B	C	D	E	F	G	H
1	DATE:TIME	Actual Gage Height (ft)	Datalogger Stage (ft) (w/offset)	Offset	Difference	DRIFT	Calc # of 15 Minute Records	Actual # of 15 Minute Records
2	9/8/06 15:47	1.88	1.46	-2.55	0.42	0.006	735	735
3	10/23/06 11:46	1.9	1.5101	-2.55	0.3899	-0.0301	4303	4304
4	11/22/06 12:46	1.91	1.6309	-2.55	0.2791	-0.1108	2884	2884
5	12/26/06 12:39	2.03	1.8052	-2.55	0.2248	-0.0543	3263	3263
6	1/29/07 11:00	1.86	1.609	-2.55	0.251	0.0262	3257	3257
7	2/26/07 9:26	2.2	1.938	-2.55	0.262	0.011	2681	2682
8	3/27/07 11:06	1.94	1.645	-2.55	0.295	0.033	2790	2790
9	4/9/07 12:07	1.88	1.594	-2.55	0.286	-0.009	1252	1252
10	4/16/07 9:20	1.88	1.578	-2.55	0.302	0.016	660	662

Figure SOP 14.9. Example of drift correction through linear interpolation using Microsoft Excel.

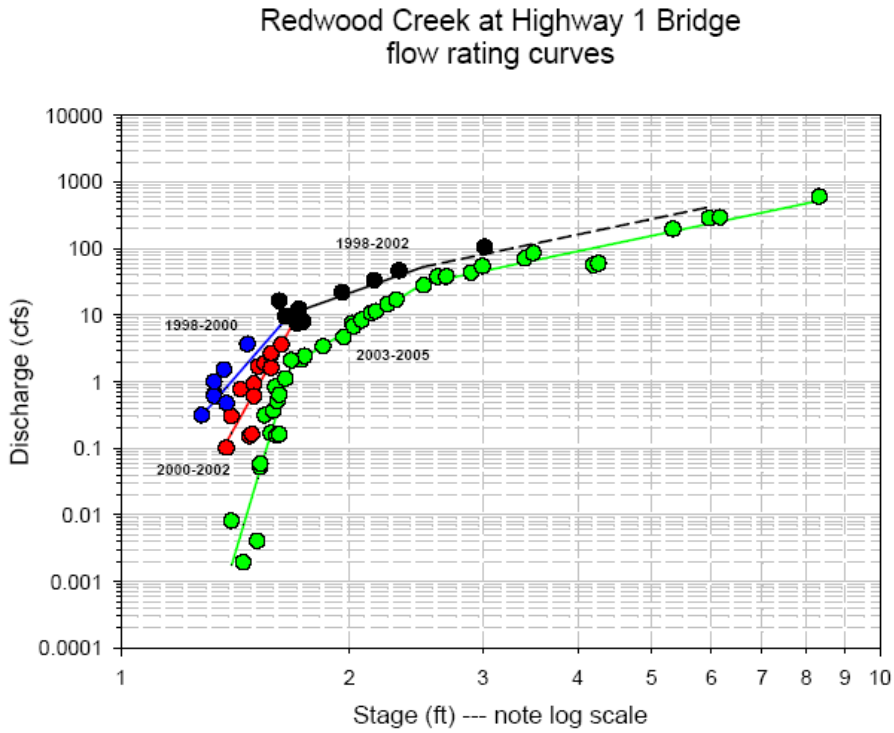


Figure SOP 14.10. Rating shift at Redwood Creek, CA stream gaging station (Stillwater Sciences 2005).

4.4.2.1. *Guidelines for Stage-discharge Rating Curves*

Presently, rating curves will be developed for each recording gaging station using Microsoft Excel. However, SIEN is looking into purchasing rating curve software---in particular, *Aquarius* by Aquatics Informatics.

The technician and protocol lead will create a new spreadsheet for each Water Year and station. In this spreadsheet, individual discharge measurements and related gage heights will be imported from the *Discharge Measurement Database.* Data may be imported from prior years if the technician and protocol lead believe that stage-discharge relationships have not changed. An example of this spreadsheet table is shown in Table SOP 14.4. With the exception of near zero flow conditions, these paired values will be plotted in log-log format in Excel to determine the best-fit rating equations based on natural breaks in slope as well as measurement dates. The final rating equation(s) will be plotted in log-log format and annotated to include the following:

- Rating equation and individual measurements
- Coefficient of determination (r^2)- which can be thought of as the strength of the linear equation (Zar 1984)
- Period to which the rating equation pertains
- Stage height ranges to which the rating equation pertains

An example of a typical rating curve is provided in Figure SOP 14.7. With the exception of low flow ratings, the relationship between stage and discharge is a straight line on logarithmic paper. This is expressed as a power law equation,

$$Q=a(h-z)^b$$

where **h** represents gage height or water surface elevation, **z** is gage height at zero flow, and **a** and **b** are regression coefficients. Analysis of past data indicate up to three different and seasonal stage-discharge relationships (pre-winter, winter-spring, and post-spring) (Figure SOP 14.11).

Different rating equations will be needed for extreme low flow conditions. As discharge approaches zero, Rantz et al. (1982b, 333–334) recommend rectilinear plotting of the data because zero cannot be plotted on logarithmic paper. Extreme low flow rating equations require gage height at zero flow.

An evaluation of the predicted and actual discharge measurements can also be done to check the suitability of the rating equation at various gage heights. Figure SOP 14.11 shows a poor fit between measured discharges and gage heights during the late fall for Pine Gulch Creek under low flow conditions. Assuming that the discharge measurements were accurate, the poor fit may reflect a temporary, shifting control over this period. During late fall, leaf packs often form at the control points of the gages, temporarily raising water surface elevations. In this situation, field datasheets should be checked to see if the notes indicate this phenomenon and to make sure that gage height at zero flow had been recorded and entered into the discharge database. Similar problems may also be avoided by more frequent discharge measurements below 0.1 cfs using proper equipment (e.g., Parshall flume). In this example, the annual report and daily discharge values table should note possible inaccuracies in estimated discharges below 0.1 cfs.

Table SOP 14.4. Excel spreadsheet with paired individual discharge measurements and mean gage height for WY2005 rating.

Date	Stop Time	Mean Gage Height (ft)	Gage Height@ Zero flow	Q (cfs)	Est. Q (cfs)	Rating Equation	% Diff	Comment
5/10/2004	1239	0.35		2.10	1.42			
6/9/2004	1517	0.22		0.71	0.82			
7/8/2004	1515	0.16		0.77	0.56			
8/4/2004	1315	0.15		0.48	0.52			
9/8/2004		0.05		0.01	0.14			
10/13/2004								Extreme outlier-not used in rating eqn. Possible error
11/2/2004	1040	0.25		0.83	0.91	y = 21.725x^2.2871	9	
12/2/2004	1115	0.29		1.10	1.28		16	
12/20/2004	1240	0.50		2.47	7.71	y = 28.041x^1.8620	212	Poor fit, check data sheet
12/30/2004	1421	1.575		66.36	65.33		-2	
1/18/2005	1039	0.64		11.95	12.22		2	Check mean gage heights from datasheet, some typos found
1/31/2005	1240	0.55		9.61	9.21		-4	
2/18/2005	1305	1.07		29.83	31.81		7	
2/19/2005	1341	0.84		20.73	20.27		-2	
2/20/2005		0.94		24.04	24.99		4	
2/21/2005	1325	1.15		31.68	36.38		15	
3/21/2005	1346	0.89		24.57	22.57		-8	
3/28/2005	1427	1.48		64.90	58.19		-10	
4/7/2005	1450	0.73		19.94	20.73	y = 33.6328x^1.5370	4	
4/18/2005	1138	0.53		12.28	12.68		3	
5/6/2005	1307	0.36		6.95	7.00		1	
5/16/2005	1155	0.41		9.32	8.54		-8	
5/19/2005	1135	0.88		28.72	27.63		-4	
5/20/2005	1159	0.73		21.31	20.73		-3	
6/20/2005	1110	0.32		5.07	5.84		15	
7/11/2005	1306	0.19		2.96	2.62		-11	
11/7/2005	1220	0.19		2.48	2.62		6	

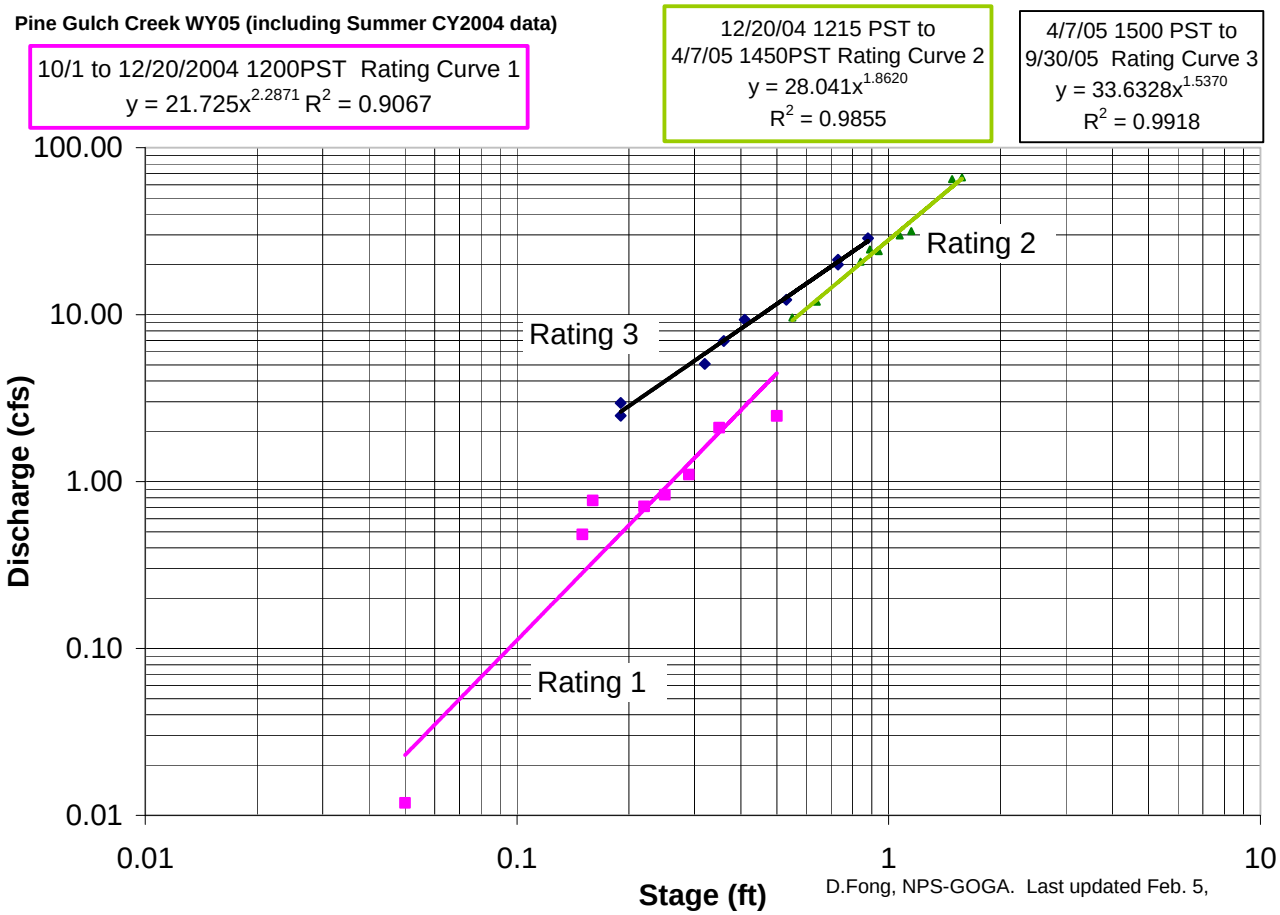


Figure SOP 14.11. WT2005 rating curve for Pine Gulch Creek, Point Reyes National Seashore.

4.4.3. Computation of 15-minute and Mean Daily Discharge

Once the stage-discharge equations have been defined, equations are inputted into SIEN's Water database. The rating curves are easily applied to the stage to convert the corrected 15-minute stage data to discharge. Mean daily discharge and daily total discharge are also easily calculated (simple as clicking the 'Calculate' button) in the Water database. *Refer to SOP 13: Database User's Manual for detailed instructions.*

4.5. Routine Data Summaries for Annual Report

Once the recording stream gage data have been processed, several routine analyses are performed in order to summarize hydrologic characteristics for each complete water year by station. The data are compiled in annual reports. The hydrologic information specific to each gaging station (station analysis, daily values table, hydrograph, rating curves, and key photographs) will be placed in the appendices and organized by gaging station. These analyses include many of the same summaries used by the USGS, including: 1) annual yield data (acre-feet), 2) minimum, maximum and mean daily discharge, 3) minimum, peak, and mean monthly discharge, and 4) minimum, peak, and mean annual discharge. These data would be presented in Daily Values table in a format similar to USGS's tabular summaries.

4.5.1. Station Analysis

Annual station analysis summaries are prepared that synthesize discharge information including station equipment, description of rating procedures, remarks about accuracy of data, and recommendations. The station analysis should include information regarding estimated or synthesized records including the potential cause and explanation of the estimation process. The analysis provides a basis for review and to serve as a reference in case questions arise about the record at some future date (Rantz et al. 1982b, 580). The standardized content for these station analysis summaries is provided by the USGS (Rantz et al. 1982b, Meyer 1996, U.S. Geological Survey 2006).

4.5.2. Daily Values Table

For all recording gaging stations, a daily mean discharge value table is prepared for each Water Year (Table SOP 14.5). The table has basic data about the station (e.g., station name and coordinates). It also includes summary information such as annual and monthly yield data above the gaging station and daily and instantaneous peak discharge values. Using the nearest and/or most appropriate weather station data, a daily precipitation table is prepared in a similar format (Table SOP 14.6).

4.5.3. Hydrographs

A discharge hydrograph is a plot of daily mean discharges (vertical axis) versus time (horizontal axis) (Figure SOP 14.12). Where data are available, daily precipitation information is superimposed on the same graph. All hydrographs are plotted in a consistent format so that a plot for one station can be compared directly to that of another station or another Water Year. Information placed on the hydrograph for each station includes station name, water year, date the hydrograph was plotted, drainage area, plot of daily mean discharge data, plots of measurements, and any other information that may be of importance (U.S. Geological Survey 2006). Any estimated discharges may be indicated in red.

Hydrographs are an important analysis tool. Evaluation of hydrographs, further described in Rantz et al. (1982b, 575) is an effective means for evaluating the validity of datum or gage-height correction applications, identifying periods of faulty gage-height data, and estimating discharges for periods of missing record or periods of no stage-discharge relation.

4.5.4. Rating Tables and Curves

The development of the stage-discharge relation, also called the rating, is one of the principal tasks in computing discharge record. The annual summary reports will include graphs of rating curves for each gaging station by Water Year on logarithmic scale (Figure SOP 14.11). The graphs will include the dates and mean gage heights appropriate for specific rating curves, the rating equation, and the squared correlation coefficient value (r^2). The rating curve would display all measurements that were used to develop the rating. In addition, the annual summary report would include the rating table with dates, mean gage heights, measured discharges, and estimated discharges.

4.5.5. Photographs

Photographs are taken by field personnel for the purpose of documenting important conditions at the gaging station and creek. Photographs that document important conditions (e.g., changes in control, flood conditions, or drought conditions) would be included in the annual report for each gaging station. Photographs should be taken in the field using digital cameras with the highest

possible quality setting and saved as TIFF files. The photographs should be archived on the SEKI network drive in the water folder (J:\sien\I_M\monitoring\water\data\photos_videos) and sorted by year and site name.

Table SOP 14.5. Mean daily discharge (example).

UNITED STATES DEPARTMENT OF THE INTERIOR - NATIONAL PARK SERVICE - WATER RESOURCES DIVISION
STATION NUMBER 375353122381901 EASKOOT CREEK AT STINSON BEACH, CA STREAM SOURCE
LATITUDE 375353 LONGITUDE 1223819 DRAINAGE AREA 1.7 sq. mi. DATUM 16.08 ft. msl
PROVISIONAL DATA SUBJECT TO REVISION
DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1999 TO SEPTEMBER 2000
DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.01	0.05	0.98	0.02	0.97	7.4	0.57	0.16	0.15	0.15	0.08	0.24
2	0.01	0.04	0.73	0.02	1.0	5.0	0.54	0.15	0.08	0.13	0.08	0.23
3	0.01	0.04	0.61	0.01	1.1	3.4	0.51	0.15	0.09	0.15	0.09	0.21
4	0.01	0.05	0.41	0.01	0.86	3.8	0.5	0.11	0.10	0.17	0.08	0.16
5	0.01	0.05	0.30	0.01	1.1	6.8	0.55	0.09	0.07	0.24	0.08	0.13
6	0.01	0.06	0.23	0.01	1.3	4.9	0.59	0.1	0.13	0.27	0.09	0.17
7	0.01	0.45	0.18	0.01	1.1	3.6	0.59	1.3	0.32	0.27	0.09	0.17
8	0.01	0.28	0.19	0.01	1.0	3.5	0.55	4.2	0.44	0.33	0.11	0.14
9	0.01	0.10	0.54	0.01	0.87	3.4	0.55	2.0	0.24	0.37	0.09	0.12
10	0.01	0.08	0.25	0.01	4.4	3.0	0.54	1.4	0.19	0.38	0.09	0.09
11	0.01	0.06	0.25	1.6	10	2.6	0.49	1.0	0.14	0.41	0.07	0.10
12	0.01	0.05	0.25	0.94	19	2.2	0.59	0.85	0.10	0.33	0.07	0.15
13	0.01	0.05	0.20	0.51	65	2.0	0.7	0.8	0.11	0.31	0.07	0.22
14	0.01	0.06	0.14	0.30	37	1.7	0.87	1.8	0.06	0.40	0.05	0.08
15	0.01	0.05	0.11	0.30	9.7	1.5	0.71	4.1	0.07	0.33	0.03	0.07
16	0.01	0.24	0.18	1.9	4.9	1.3	2.8	3.3	0.12	0.29	0.04	0.12
17	0.01	0.12	0.10	1.1	3.0	1.2	11	2.3	0.18	0.25	0.07	0.17
18	0.01	0.10	0.10	1.7	2.3	1.0	4.1	1.8	0.15	0.19	0.08	0.15
19	0.01	0.60	0.10	2.6	1.9	0.97	2.4	1.4	0.18	0.16	0.08	0.19
20	0.01	0.25	0.10	4.5	2.0	0.95	1.6	1.2	0.19	0.18	0.12	0.21
21	0.01	0.22	0.09	3.5	2.3	0.89	1.2	0.93	0.18	0.12	0.17	0.25
22	0.01	0.16	0.07	3.2	4.6	0.79	0.86	0.83	0.18	0.08	0.19	0.25
23	0.01	0.13	0.05	19	9.7	0.77	0.65	0.70	0.25	0.07	0.16	0.11
24	0.01	0.10	0.05	42	5.5	0.78	0.55	0.64	0.12	0.06	0.14	0.10
25	0.01	0.10	0.05	9.6	3.6	0.69	0.44	0.45	0.14	0.07	0.16	0.12
26	0.01	0.09	0.04	3.9	6.2	0.64	0.37	0.36	0.18	0.05	0.18	0.11
27	0.85	0.07	0.03	2.1	14	0.62	0.3	0.30	0.17	0.06	0.22	0.09
28	0.57	0.05	0.03	1.4	7.9	0.61	0.22	0.29	0.16	0.11	0.15	0.11
29	0.10	0.29	0.03	0.99	9.4	0.59	0.18	0.26	0.20	0.14	0.17	0.18
30	0.07	1.5	0.02	1.0	---	0.57	0.16	0.21	0.17	0.14	0.19	0.21
31	0.05	---	0.02	0.98	---	0.56	---	0.16	---	0.10	0.22	---
TOTAL	1.9	5.49	6.43	103.24	231.7	67.73	35.68	33.34	4.86	6.31	3.51	4.65
MEAN	0.06	0.18	0.21	3.33	7.99	2.18	1.19	1.08	0.16	0.20	0.11	0.16
MAX	0.85	1.5	0.98	42	65	7.4	11	4.2	0.44	0.41	0.22	0.25
MIN	0.01	0.04	0.02	0.01	0.86	0.56	0.16	0.09	0.06	0.05	0.03	0.07
AC-FT	3.8	11	13	205	460	134	71	66	9.6	13	7.0	9.2

SUMMARY STATISTICS	WATER YEAR 2000		
HIGHEST DAILY MEAN	65	Feb 13 2000	
LOWEST DAILY MEAN	0.01	Oct 17 2000	
ANNUAL SEVEN-DAY MINIMUM	0.01	Oct 01 2000	
INSTANTANEOUS PEAK FLOW	108	Feb 13 2000	1930 hr
INSTANTANEOUS PEAK STAGE	2.40	Feb 13 2000	1930 hr
INSTANTANEOUS LOW FLOW	0.01	Oct 17 0000	1230 hr

Table SOP 14.6. Daily rainfall (Example).

UNITED STATES DEPARTMENT OF THE INTERIOR - NATIONAL PARK SERVICE – GOLDEN GATE NATIONAL RECREATION AREA
Easkoot Creek Below Entrance Station Road Water Year 2006 Daily Rainfall (inches)
PROVISIONAL DATA SUBJECT TO REVISION

	Oct-05	Nov-05	Dec-05	Jan-06	Feb-06	Mar-06	Apr-06	May-06	Jun-06	Jul-06	Aug-06	Sep-06
1	0	0.01	1.87	0.21	2.16	0.26	0.18	0.00	0.00	0.00	0.00	0.00
2	0	0.02	0.02	0.67	0.56	0.16	0.57	0.00	0.00	0.00	0.01	0.00
3	0	0.1	0	0.16	0.02	0.61	0.35	0.00	0.00	0.00	0.00	0.00
4	0	0.05	0	0	0.42	0.1	0.81	0.00	0.00	0.00	0.00	0.00
5	0	0.01	0	0	0	0.76	0.09	0.00	0.00	0.00	0.00	0.00
6	0	0.24	0.01	0.08	0	0.67	0.00	0.00	0.00	0.00	0.00	0.00
7	0	0.17	0.02	1.1	0	0.22	0.33	0.00	0.00	0.00	0.00	0.00
8	0	0.23	0.01	0	0	0	0.00	0.00	0.00	0.00	0.00	0.02
9	0	0	0	0.01	0	0.25	0.07	0.00	0.00	0.00	0.00	0.00
10	0.01	0.01	0	0.02	0	0.24	0.11	0.00	0.00	0.00	0.01	0.01
11	0	0.15	0	0.59	0	0.12	1.89	0.00	0.00	0.00	0.00	0.01
12	0	0.01	0	0.01	0	0.27	0.85	0.00	0.00	0.00	0.00	0.00
13	0	0.01	0	0.19	0.02	0.30	0.00	0.00	0.00	0.00	0.00	0.00
14	0.14	0	0.01	0.34	0.01	0.90	0.00	0.00	0.01	0.00	0.00	0.00
15	0.03	0	0	0.00	0.00	0.02	0.90	0.00	0.00	0.00	0.00	0.00
16	0	0	0	0.00	0.00	0.78	0.02	0.00	0.00	0.00	0.00	0.00
17	0	0	0.61	0.55	0.33	0.01	0.01	0.00	0.00	0.00	0.00	0.00
18	0.01	0	2.01	0.26	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0	0	0.06	0.00	0.02	0.00	0.00	0.24	0.00	0.00	0.00	0.00
20	0	0	0.89	0.02	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00
21	0	0	0.73	0.78	0.00	0.03	0.00	0.09	0.00	0.00	0.00	0.00
22	0.01	0	1.45	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
23	0	0.01	0.03	0.02	0.10	0.00	0.02	0.01	0.00	0.00	0.00	0.00
24	0.02	0.01	0.03	0	0.00	0.92	0.01	0.02	0.00	0.00	0.00	0.00
25	0.02	0.87	0.83	0.14	0.10	0.32	0.00	0.00	0.00	0.00	0.00	0.00
26	0.29	0	0.14	0.06	0.44	0.01	0.00	0.00	0.00	0.00	0.00	0.00
27	0	0	0.65	0.48	1.01	0.26	0.00	0.00	0.00	0.00	0.00	0.00
28	0.32	0.94	0.54	0.9	0.11	0.19	0.00	0.00	0.00	0.02	0.00	0.00
29	0	1.51	0.03	0.02		0.70	0.01	0.00	0.00	0.09	0.00	0.00
30	0.01	0.17	1.34	0.98		0.02	0.01	0.00	0.00	0.00	0.00	0.00
31	0		1.66	0.02		0.47		0.00		0.00	0.00	
TOTAL	**0.86**	**4.52**	**12.94**	**7.61**	**5.44**	**9.08**	**6.23**	**0.36**	**0.01**	**0.11**	**0.02**	**0.04**
MEAN	**0.03**	**0.15**	**0.42**	**0.25**	**0.19**	**0.29**	**0.21**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**
MAX	**0.32**	**1.51**	**2.01**	**1.10**	**2.16**	**0.92**	**1.89**	**0.24**	**0.01**	**0.09**	**0.01**	**0.02**
MIN	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Max 15-min	**0.08**	**0.12**	**0.19**	**0.19**	**0.11**	**0.23**	**0.16**	**0.02**	**0.01**	**0.01**	**0.01**	**0.01**
WATER YR TOTAL	**47.22**											

NOTES: Rain gage was only recording 75% of actual rainfall before calibration on 6/01/06 at 1240 (Pacific Standard Time). After calibration rain gage recording 98% of actual rainfall. Data uncorrected.

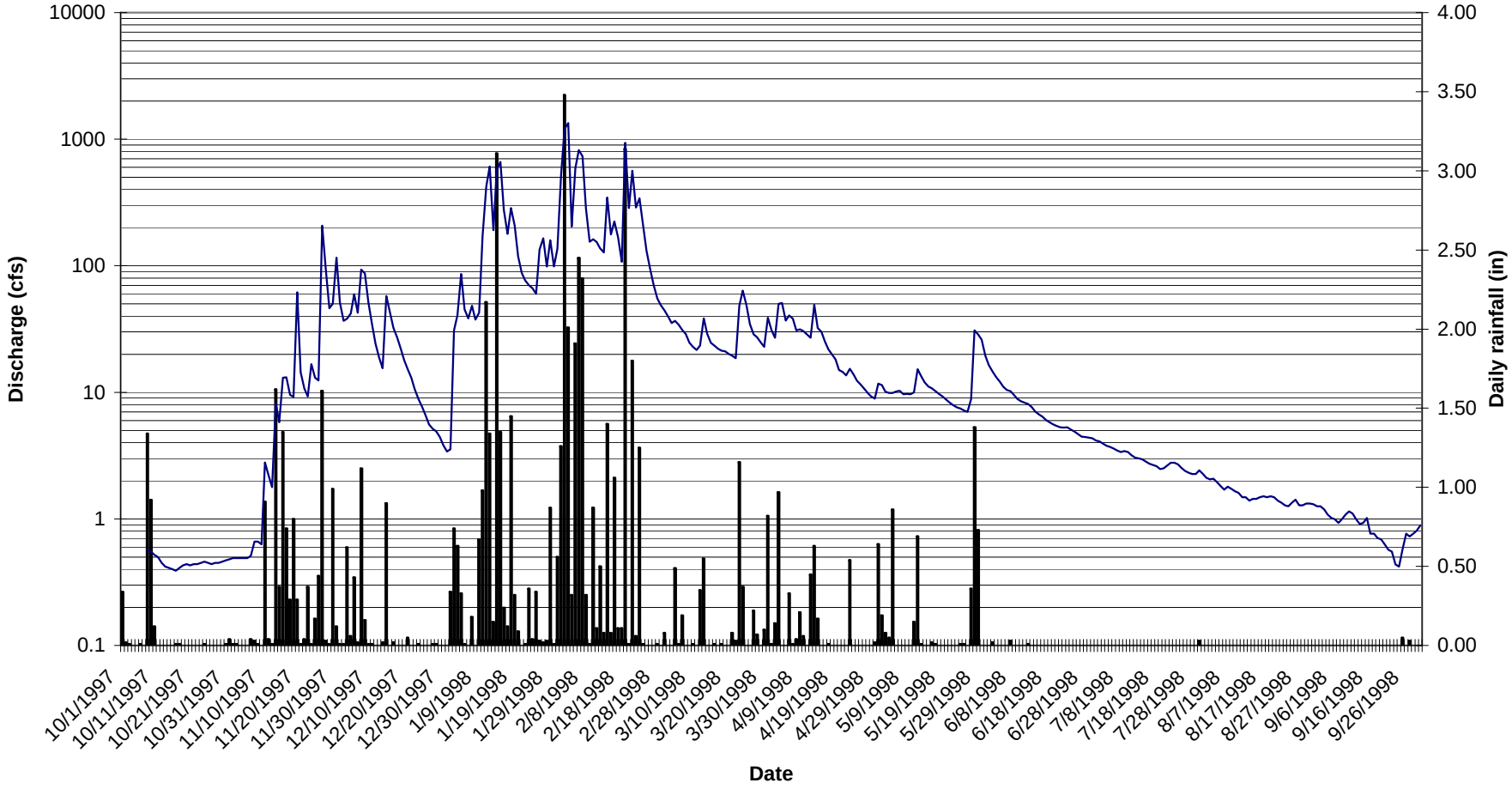


Figure SOP 14.12. Mean daily discharge and rainfall for Olema Creek at Bear Valley Bridge, Marin Co., CA. Water year 1998 (Example).

4.6. Infrequent Data Summaries for Long-term Report

Using the routine summary data described above, several additional analyses can be performed infrequently for the 4 year summary annual report. These include: 1) flood frequency analysis and 2) flow duration analysis.

The flood frequency analyses allow hydrologists to assess the probability of a certain size of flood or greater occurring in any year. By convention, maximum discharges for each year of the gaging record are ranked and plotted as a cumulative frequency curve. In the United States, the log-Pearson Type III distribution has been most frequently used to describe flood frequencies (Linsley et al. 1982). A recurrence interval (the number of years within which a flood of a given magnitude or greater is likely to occur) may be calculated as an alternative way of expressing the flood frequency (Gore 1996). However, this analysis usually requires a minimum of 10 years of annual maxima to be reliable.

A flow-duration curve is a semi-logarithmic plot of discharge versus the percentage of the time in a given year that a given discharge is equaled or exceeded. If the curve has an overall steep slope, the catchment has a large amount of direct runoff. If the curve is relatively flat, there is substantial storage within the catchment, either as surface or groundwater (Morisawa 1968). Flow duration analyses can be conducted on, at a minimum, a single year's worth of average daily discharge data, but the data must be complete (e.g., no missing values). Thus where segments of missing or unreliable data exist, those records must be synthesized for flow duration analyses to be performed. Methods to be followed for analyzing flow duration (exceedence probabilities) and flood recurrence intervals (flood frequency analyses) are described in Dunne and Leopold (1978) and Linsley et al. (1982). Analyses can be easily completed using Microsoft Excel.

5. Literature Cited

Boning, C. W. 1992. Policy statement on stage accuracy. USGS Office of Surface Water Technical Memorandum No. 93.07. Sent December 4, 1992.

Clow, D. W., R. G. Striegl, M. Nanus, M. A. Mast, D. H. Campbell, and D. P. Krabbenhoft. 2002. Chemistry of selected high-elevation lakes in seven national parks in the western United States. Water Air and Soil Pollution 2:139–164.

Dunne, T., and L. B. Leopold. 1978. Water in environmental planning. W. H. Freeman and Company, San Francisco.

Eilers, J. M., D. F. Brakke, D. H. Landers, and W. S. Overton. 1989. Chemistry of wilderness lakes in the Western United States. Environmental Monitoring and Assessment 12:3-21.

Fong, D., D. Press, M. Koenen, and M. DeBlasi. 2010. San Francisco Bay Area Network (SFAN) stream flow monitoring protocol: narrative and appendixes - version 2.92. Natural Resource Report NPS/SFAN/NRR---2010/XXX. National Park Service, Fort Collins, CO.

Giesbrecht, F. G., and J. C. Burns. 1985. Two-stage analysis based on a mixed model: Large sample asymptotic theory and small-sample simulation results. Biometrics 41:477–486.

Gore, J. A. 1996. Discharge measurements and streamflow analysis. Chapter 3 *in* R. Hauer and G. A. Lamberti, editors. Methods in stream ecology. Academic Press, New York.

Harrelson, C. C., C. L. Rawlins, and J. P. Potyondy. 1994. Stream channel reference site: An illustrated guide to field techniques. General Technical Report RM-245, USDA Forest Service, Fort Collins, CO.

Helsel, D. 2005. Nondetects and data analysis, statistics for censored environmental data. John Wiley & Sons, Inc., Denver.

Hirsch, R. A., and J. R. Slack. 1984. A nonparametric trend test for seasonal data with serial dependence. Water Resources Research 20:727–732.

Horvitz, D. G., and D. T. Thompson. 1952. A generalization of sampling without replacement from a finite universe. Journal of the American Statistical Association 47:663–685.

Kennedy, E. J. 1983. Computations of continuous records of streamflow. Page 53 *in* U.S. Geological Survey, editor. Techniques of water-resources investigations.

Kennedy, E. J. 1984. Discharge ratings at gaging stations. Page 59 *in* U.S. Geological Survey, editor. Techniques of Water-Resources Investigations. Book 3, Chapter A10. Available at http://pubs.usgs.gov/twri/twri3-a10/.

Kroll, C. N., and J. R. Stedinger. 1996. Estimation of moments and quantiles using censored data. Water Resources Research 32:1005-1012.

Linsley, R. K., M. A. Kohler, and J. L. H. Paulhus. 1982. Hydrology for engineers. Third edition. McGraw-Hill, New York.

Little, R. J. A., and D. B. Rubin. 2002. Statistical analysis with missing data. John Wiley and Sons, Inc., New Jersey.

Lorenz, D. 2003. Documentation for S-ESTREND, Version 1.2. Developed for the U.S. Geological Survey. Mounds View, Minnesota.

Meyer, R. W. 1996. Surface-water quality-assurance plan for the California district of the U.S. Geological Survey. Open-file Report 96-618. USGS, Sacramento, CA.

Morisawa, M. 1968. Streams: Their dynamics and morphology. McGraw-Hill, New York.

Norris, M., and G. Fisher. 2005. National Capitol Region Network surface water dynamics protocol. National Park Service. Washington DC. http://science.nature.nps.gov/im/units/ncrn/

Piepho, H. P., and J. O. Ogutu. 2002. A simple mixed model for trend analysis in wildlife populations. Journal of Agriculture, Biological, and Environmental Statistics 7:350–360.

Rantz, S. E., et al. 1982a. Measurement and computation of streamflow. Volume 1, Measurment of stage and discharge. U.S. Geological Survey Water-Supply Paper 2175, U.S. Government Printing Office, Washington DC.

Rantz, S. E., et al. 1982b. Measurement and computation of streamflow. Volume 2, Computation of discharge. U.S. Geological Survey Water-Supply Paper 2175, U.S. Government Printing Office, Washington DC.

Schertz, T. L., R. B. Alexander, and D. J. Ohe. 1991. The computer program Estimate Trend (ESTREND), a system for the detection of trends in water quality data. Water-Resources Investigations Report 91-4040, U. S. Geological Survey, Reston, Virginia.

Slack, J. R., et al. 2003. USGS library for S-Plus for Windows -- Release 2.1. Open-File Report 03-357, U.S. Geological Survey. http://water.usgs.gov/software/S-PLUS/.

Stevens Jr., D. L., and A. R. Olsen. 2003. Variance estimation for spatially balanced samples of environmental resources. Environmetrics 14:593–610.

Stevens Jr., D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of American Statistical Association 99:262–278.

Stillwater Sciences. 2005. Redwood Creek stream flow data analysis. Technical Memorandum. Sent to: S. Ortega. September 1, 2005. Berkeley, CA.

Thompson, S. K. 1992. Sampling. John Wiley and Sons, Inc, New York.

U.S. Geological Survey. 2006. Guidelines for the collection, preparation, and standardization of streamflow data furnished to the USGS for review and publicaton DRAFT.

VanLeeuwen, D. M., L. W. Murray, and N. S. Urquart. 1996. A mixed model with both fixed and random trend components across time. Journal of Agriculture, Biological, and Environmental Statistics 1:435–453.

Appendix A: Adjusting Sample Inclusion Probabilities for Panel Surveys

When estimating status using a panel survey, the sample for a single year is part of a larger random sample. The inclusion probabilities for the overall random sample do not apply directly to a single year. Therefore, the inclusion probabilities that would be obtained from the survey design and in GRTS sample output would give an inclusion probability that is too large for an estimate of annual status. We recommend adjusting the sample inclusion probability with a panel inclusion probability to obtain unbiased estimates of status.

Methods

Two methods of weighting the inclusion probability were examined. Define a panel grouping as a set of panels that have the same revisit schedule. Let

N = population size

n = original sample size for all panels combined

n_g = sample size of panel grouping g, where g=1,..,G

n_{gj} = sample size of panel j within grouping g, where j=1,..,J_g

n_t = sample size surveyed in year t, where t = 1,...,T

Assume that a simple random sample of n is drawn from the population of N units for a sample inclusion probability of $\frac{n}{N}$. The panel inclusion probability is calculated conditionally on inclusion in the sample and may be estimated in two ways. Let

$$p_{gj} = \frac{n_{gj}}{n_g} \text{ and } p_t = \frac{n_t}{n}.$$

The panel inclusion probability p_{gj} represents the proportion of each panel grouping surveyed in any given year and p_t is the proportion of sampling units included in the sample in any given year (note that indexing for year is suppressed). The principal difference between the two weights is that p_{gj} weights within a panel grouping and p_t weights across groupings.

Note that, when sample sizes are equal across panels within a grouping, the panel inclusion probability can be easily calculated for panels within that grouping as $p_{gj} = \frac{a_g}{a_g + b_g}$ for all j=1,..,J_g where $\left(a_g - b_g\right)$ indexes the revisit pattern within panel grouping g. For example, a [1-0] design has one grouping and a [(1-0),[1-3)] design has two groupings. The panel inclusion probability for grouping 1 would be calculated as $p_{1j} = \frac{1}{1+0}$=1. The panel inclusion

probability for grouping 2 would be calculated as $p_{2j} = \frac{1}{1+3} = 0.25$ for all panels within panel grouping 2. Rotating panels ([1-n], [2-n], etc.) would not be given any weight and would receive a panel probability of 1.

Two unbiased estimators of the population mean are considered:

$$\hat{\mu}_1 = \frac{1}{T}\sum_{t=1}^{T}\frac{1}{N}\sum_{g=1}^{G}\sum_{j=1}^{J_g}\sum_{i=1}^{n_{gj}}\frac{Y_i}{\pi_i'} = \frac{1}{T}\sum_{t=1}^{T}\frac{1}{N}\sum_{g=1}^{G}\sum_{j=1}^{J_g}\sum_{i=1}^{n_{gj}}\frac{Y_i}{\pi_i p_{gj}} = \frac{1}{T}\sum_{t=1}^{T}\sum_{g=1}^{G}\sum_{j=1}^{J_g}\sum_{i=1}^{n_{gj}}\frac{n_g Y_i}{n_{gj} n}$$

$$\hat{\mu}_2 = \frac{1}{T}\sum_{t=1}^{T}\frac{1}{N}\sum_{i=1}^{n_t}\frac{Y_i}{\pi_i'} = \frac{1}{T}\sum_{t=1}^{T}\frac{1}{N}\sum_{i=1}^{n_t}\frac{Y_i}{\pi_i p_t} = \frac{1}{T}\sum_{t=1}^{T}\sum_{i=1}^{n_t}\frac{Y_i}{n_t}$$

Example

Status estimates are needed annually and over full panel rotations in a [(1-0),[1-3)] design (augmented serially alternating panel visited once then rested for 3 years). For this panel revisit schedule, there are G=2 panel groupings. In the first panel grouping (1-0) there is one panel and in the second grouping (1-3) there area 4 panels. A sample of 25 sites will be sampled each year; $n_1 = n_{11} = 8$ sites will be allotted to the annual panel and $n_2 = 68$ sites will be randomly assigned to $J_2 = 4$ panels of $n_{21} = n_{22} = n_{23} = n_{24} = 17$ sites each.

The revisit schedule is represented as:

	Year							
	0	1	2	3	4	5	6	7
1	8	8	8	8	8	8	8	8
2	17				17			
3		17				17		
4			17				17	
5				17				17

Initially, a sample of 76 sites will be drawn without replacement (using a GRTS sample). Assume the sample size is N=2000. Therefore, the sample inclusion probability is $\pi_i = \frac{76}{2000} =$ 0.038 and the panel inclusions probabilities are computed as:

Method 1: $p_{1j} = \frac{8}{8}$ =1 and $p_{2j} = \frac{17}{68}$ =0.25.

Method 2: $p_t = \frac{25}{76} = 0.3289.$

Then the adjusted inclusion probabilities π_i' are calculated as:

Method 1: $\pi_i' = \pi_i p_{1j} = 0.038 * 1 = 0.038$ =1 and $\pi_i' = \pi_i p_{2j} = 0.038 * 0.25 = 0.0095$.

Method 2: $\pi_i' = \pi_i p_t = 0.038 * 0.3289 = 0.0125$.

Variance Estimation

These adjusted inclusion probabilities may be used in a standard Horvitz-Thompson estimator (Horvitz and Thompson 1952). Note that sample sizes within a grouping and panel are planned and sampling units are randomized to panels, so the variance estimator does not need to account for random sample sizes or post-strata as in a post-stratification estimator when status is estimated within a year.

However, when estimates of status are computed over time, panels that are visited more than once during a schedule will be correlated over time when the second method of panel inclusion probability estimation is used. This correlation is likely to be positive and variance estimators will likely underestimate the true variance of multi-year status. When data are collected from GRTS samples, the standard Horvitz-Thompson variance estimator, which is known to be conservative for spatially-balanced data, may be used to offset the bias variance of using the adjusted inclusion probabilities until further work may be done on variance estimation.

Simulation

Simulations were used to determine which of the two estimators is more accurate and precise in estimating the population mean. A population was simulated over time and samples of 61 lakes were drawn from a population of 2000 lakes with the [(1-0),[1-3)] revisit design. The two mean estimators were used with the two methods of estimating the panel response probability. A total of 10,000 iterations were used to sample from the population, calculate the mean estimates, and compute the bias as the difference between the estimated and true means. The simulation results are given in Table SOP 14.A.1.

Table SOP 14.A.1. Simulation results for two methods of estimating panel inclusion probabilities.

Status objective	Method 1: Mean Bias (SE)	Method 2: Mean Bias (SE)
Year 0	-0.00001 (0.0054)	-0.00004 (0.0048)
Years 0 through 4	0.0029 (0.0026)	0.0021 (0.0030)

Simulations indicate that both methods are unbiased, accurate, and similarly precise. The difference between the two methods is that, in the first method, only the means within a grouping are used to extrapolate to the unsurveyed panels while, in the second method, all sites surveyed within a year contribute to the extrapolation to unsurveyed sites. Confidence interval coverage was found to be about 99% for both methods, indicating that variances may be relatively large. However, the variance estimators are naïve and do not account for the correlation over time, so undercoverage is not an issue.

Recommendations

Since both methods are equally accurate and similarly precise, either method of estimating panel inclusion probabilities would be acceptable. Simulations indicate that confidence interval coverage is similar for both estimators.

Appendix B: Example Excel File Used to Create a Tab-delimited Text File for the Mixed Linear Model.

Panel	Year	WYear	Lake	Y	Lat	Long	InclProb	PanelProb	AdjInclProb	Cen	LowerDL	UpperDL
1	2008	0	7	0.0471	36.19431962	-118.1456162	0.038	1	0.038	0	0.0471	0.0471
1	2008	0	120	0.1522	37.33181468	-118.7791427	0.038	1	0.038	0	0.1522	0.1522
1	2008	0	309	0.1271	36.25561667	-118.1107381	0.038	1	0.038	0	0.1271	0.1271
1	2008	0	501	0.6327	36.58023049	-118.4736053	0.038	1	0.038	0	0.6327	0.6327
1	2008	0	901	0.0307	36.24261946	-118.5802275	0.038	1	0.038	0	0.0120	0.0380
1	2008	0	1016	0.6391	37.1268936	-118.7344506	0.038	1	0.038	0	0.6391	0.6391
1	2008	0	1493	0.5222	37.70813276	-118.7323446	0.038	1	0.038	0	0.5222	0.5222
1	2008	0	1888	0.0545	38.47797016	-118.4316883	0.038	1	0.038	0	0.0545	0.0545
1	2009	1	7	0.0952	36.19431962	-118.1456162	0.038	1	0.038	0	0.0952	0.0952
1	2009	1	120	0.2480	37.33181468	-118.7791427	0.038	1	0.038	0	0.2480	0.2480
1	2009	1	309	NA	36.25561667	-118.1107381	0.038	1	0.038	1	0.0000	0.0120
1	2009	1	501	0.0580	36.58023049	-118.4736053	0.038	1	0.038	0	0.0580	0.0580
1	2009	1	901	0.0767	36.24261946	-118.5802275	0.038	1	0.038	0	0.0767	0.0767
1	2009	1	1016	1.7783	37.1268936	-118.7344506	0.038	1	0.038	0	1.7783	1.7783
1	2009	1	1493	NA	37.70813276	-118.7323446	0.038	1	0.038	1	0.0000	0.0120
1	2009	1	1888	NA	38.47797016	-118.4316883	0.038	1	0.038	1	0.0000	0.0120
1	2010	2	7	0.0616	36.19431962	-118.1456162	0.038	1	0.038	0	0.0616	0.0616
1	2010	2	120	0.1306	37.33181468	-118.7791427	0.038	1	0.038	0	0.1306	0.1306
1	2010	2	309	0.2119	36.25561667	-118.1107381	0.038	1	0.038	0	0.2119	0.2119
1	2010	2	501	0.1804	36.58023049	-118.4736053	0.038	1	0.038	0	0.1804	0.1804
1	2010	2	901	0.0469	36.24261946	-118.5802275	0.038	1	0.038	0	0.0469	0.0469
1	2010	2	1016	0.3595	37.1268936	-118.7344506	0.038	1	0.038	0	0.3595	0.3595
1	2010	2	1493	0.0190	37.70813276	-118.7323446	0.038	1	0.038	0	0.0120	0.0380
1	2010	2	1888	0.1033	38.47797016	-118.4316883	0.038	1	0.038	0	0.1033	0.1033
1	2011	3	7	0.0956	36.19431962	-118.1456162	0.038	1	0.038	0	0.0956	0.0956
1	2011	3	120	0.0247	37.33181468	-118.7791427	0.038	1	0.038	0	0.0120	0.0380
1	2011	3	309	NA	36.25561667	-118.1107381	0.038	1	0.038	1	0.0120	0.0380
1	2011	3	501	0.0540	36.58023049	-118.4736053	0.038	1	0.038	0	0.0540	0.0540
1	2011	3	901	0.0718	36.24261946	-118.5802275	0.038	1	0.038	0	0.0718	0.0718
1	2011	3	1016	0.0194	37.1268936	-118.7344506	0.038	1	0.038	0	0.0120	0.0380
1	2011	3	1493	0.2736	37.70813276	-118.7323446	0.038	1	0.038	0	0.2736	0.2736
1	2011	3	1888	NA	38.47797016	-118.4316883	0.038	1	0.038	1	0.0000	0.0120
1	2012	4	7	0.1251	36.19431962	-118.1456162	0.038	1	0.038	0	0.1251	0.1251

LakeChem