HIGHWAY RUNOFF DILUTION AND LOADING MODEL DOCUMENTATION

Analysis of Highway Stormwater Water Quality Effects for Endangered Species Act Consultations

Prepared for

Washington State Department of Transportation

January 2009

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Analysis of Highway Stormwater Water Quality Effects for Endangered Species Act Consultations

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Introduction

To support the preparation of biological assessments for Endangered Species Act (ESA) Section 7 consultations for highway and other transportation-related construction projects, a legally defensible and technically valid analytical approach is needed for assessing the potential water quality effects of highway runoff on ESA-listed aquatic species. This approach must be practical enough to apply at early stages in a project's design process while also providing a meaningful basis for identifying when potential impacts may occur and whether these impacts are likely to be significant. Furthermore, to adequately support the ESA consultation process, this approach must reflect the "best available scientific and commercial information."

To address this need, the Washington State Department of Transportation (WSDOT) initiated a joint project with the Federal Highway Administration (FHWA), the U.S. Fish and Wildlife Services (USFWS), and the National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NOAA Fisheries) to develop a mutually acceptable approach for assessing the potential water quality effects of highway runoff on ESA-listed aquatic species. To initiate this process, four white papers (Herrera 2007a, 2007b; GeoSyntec 2008; Pacific EcoRisk 2008) were prepared to summarize the current state of knowledge in each of the following areas:

- Pollutants found in untreated highway runoff
- Pollutants found in treated highway runoff
- Bioavailability of pollutants in treated highway runoff and their effects on ESA-listed fish
- Currently or recently used analytical approaches for assessing the potential water quality effects of highway runoff on ESA-listed aquatic species.

Agency representatives subsequently discussed these white papers at a series of workshops to review the available information, promote a shared understanding of the potential water quality effects of highway runoff on listed species, evaluate the strengths and weaknesses of various assessment methods, and achieve consensus on the state of the available information and the conclusions based on this information. The white papers and discussions from these workshops then provided the basis for identifying key attributes that should be incorporated into any new approach for assessing the potential water quality effects of highway runoff on ESA-listed aquatic species.

Work to develop this new approach was then conducted in two distinct phases to ensure there would be adequate review and collective buy-in from the agencies involved in the project at critical milestones in the process. The first phase involved development of a technical approach for estimating pollutant concentrations and loads in highway runoff at the point of discharge to receiving waters (i.e., end-of-pipe). The second phase involved the development of a technical approach for quantifying pollutant concentrations in receiving waters after mixing and dilution.

This work culminated in the development of a spreadsheet model to support the consultation process. This spreadsheet model is hereafter identified as the Highway Runoff Dilution and Loading (HI-RUN) model. Based on feedback from the multi-agency workgroup associated with the project, the following attributes were incorporated into the HI-RUN model:

- Can be utilized with the limited amount of data available at the design phase of a highway project
- Can be used to estimate the probability that a specific pollutant concentration will be observed at outfalls that are discharging treated and/or untreated highway runoff
- Can be used to estimate the probability of discharge durations observed during individual storm events in any given month of the year at outfalls that are discharging treated and/or untreated highway runoff
- Can be used to estimate the probability that annual pollutant loads from the proposed highway project will exceed those from baseline conditions
- Can incorporate information on the treatment efficiency of specific best management practices (BMPs) for estimating pollutant loads and concentrations
- Can incorporate infiltration losses of specific BMPs for estimating pollutant loads and concentrations.

Using these attributes of the HI-RUN model, the loadings and concentrations of select water quality constituents in highway runoff can be predicted probabilistically, and the potential effects of these constituents on ESA-listed aquatic species can now be assessed using a “risk-based” approach. Specifically, the HI-RUN model permits the user to determine the probability that an identified threshold of concern could be exceeded given underlying uncertainties in associated water quality and hydrologic data that stem from natural temporal and spatial variability (e;g., variations in the size of storm events across a given region) and measurement variability (e.g., laboratory analytical imprecision). This differs from previous approaches used in ESA Section 7 consultations, which generally used a single representative value to determine whether a threshold of concern was exceeded while not incorporating any of the underlying data uncertainty into this prediction.

While the HI-RUN model was specifically developed to address some of the shortcomings that have been identified in previous analytical approaches used in ESA Section 7 consultations, there are still limitations associated with its use that warrant consideration in the consultation process. Most notably, it should be recognized that pollutant concentrations in highway runoff are influenced by numerous factors, including site-specific considerations (e.g., proximity to urban areas, traffic volumes, basin size), storm event characteristics (e.g., antecedent dry period, precipitation depth), and regional weather patterns (Herrera 2007a). The quantity, timing, and duration of highway runoff are also influenced by a similar suite of factors. Because it is impossible to accurately predict how these factors may interact to affect highway runoff at any given site, their influence could not be directly incorporated into the HI-RUN model. Another limitation of the model is that the available water quality data that were used as input to the HI-RUN model were derived from a relatively small number of monitoring locations and BMP types. Although these data are considered the most representative for this particular application, some extrapolation of the data is required to estimate pollutant concentrations across the full range of conditions that are likely to be encountered at highway projects in western Washington.

In view of these limitations, output from the HI-RUN model should not be misinterpreted as providing highly accurate estimates of pollutant concentrations for a specific project; rather, the output is intended to provide a general assessment of the risk of potential effects on ESA-listed species due to highway runoff. Where this assessment indicates that the potential risk exceeds a predefined threshold, a more detailed assessment (quantitative or qualitative) of the project should be performed to determine whether there are mitigating factors that are not reflected in the output of the HI-RUN model. This more detailed assessment would examine potential site characteristics not accounted for in the HI-RUN model that would minimize water quality or flow impacts (i.e. open conveyance, distance from outfall to receiving waterbody), quality and suitability of habitat for various lifestages of species, and anticipated timing of discharges relative to the anticipated use and timing of species in the receiving waterbody. The Stormwater chapter in WSDOT's *Advanced Training Manual: Writing Biological Assessments for Transportation Projects* describes the process of analyzing stormwater impacts in detail.

This document provides detailed documentation on the HI-RUN model, including a description of the steps that were used to preprocess water quality and hydrologic data that are used as input to the HI-RUN model, and the actual calculations and programming steps that were used in its development. In addition, key assumptions and decision criteria for the stormwater quality impacts analysis process that is used in conjunction with the HI-RUN model are documented herein. A User's Guide, providing step-by-step instructions for using HI-RUN to assess potential stormwater impacts, is provided in a separate document (Herrera 2008a).

Detailed Documentation of Highway Runoff Dilution and Loading Model

Development of the HI-RUN model was conducted in the following three general phases:

- Water quality data preprocessing
- Hydrologic data preprocessing
- Spreadsheet model programming.

Each of these phases is described in detail in the following sections, along with a separate section describing the hydraulic mixing model (RIVPLUM6) used in the dilution analysis subroutine.

Water Quality Data Preprocessing

The HI-RUN model uses Monte Carlo simulation to determine the probability that an identified threshold of concern will be exceeded given underlying uncertainties in the water quality data for treated and untreated highway runoff. (A Monte Carlo simulation calculates multiple scenarios of a model by repeatedly sampling values for uncertain variables from computer-generated probability distributions. In this way, a probability distribution can be derived that indicates which predicted values for the model have a higher probability of occurrence.) In order to build this capability into the HI-RUN model, the following steps were performed to preprocess the water quality data that is required as input:

- Compile and perform preliminary analyses on representative water quality data for untreated and treated highway runoff

- Determine the theoretical distribution for each target parameter in untreated and treated highway runoff

- Calculate summary statistics for reproducing these theoretical distributions within the HI-RUN model.

Each of these steps is described in more detail within the following subsections.

Compilation and Preliminary Analysis of Data

It was the general consensus of the multi-agency workgroup associated with this project that input for the HI-RUN model should be obtained from local studies of highway runoff to the extent possible. More specifically, input water quality data for the HI-RUN model should be derived from BMP performance monitoring studies that were performed pursuant to requirements identified in WSDOT's National Pollution Discharge Elimination System (NPDES) permit (Ecology 2007). In connection with this monitoring, WSDOT collected samples of untreated and treated runoff from 11 different structural BMPs over the period from

2005 to 2008 (Herrera 2007c, 2007d, 2007e, 2007f; WSDOT 2007). Summary information for the specific BMPs that were monitored in connection with this effort is provided in Table 1. Quality Assurance Project Plans (QAPPs) and associated addenda, data validation memoranda, and raw data from this monitoring can be accessed via WSDOT's website using the following link: <http://www.wsdot.wa.gov/Environment/waterquality/#NPDES>.

Additional water quality data for the HI-RUN model were also obtained from special studies implemented by WSDOT to evaluate the performance of specific BMPs that provide enhanced (i.e., dissolved metal) treatment of highway runoff. One these studies involved an ecology embankment located at MP 16.36 on SR 167, which was monitored over the period from 2001 to 2005 (Taylor Associates 2001; Taylor Associates 2002; Herrera 2006). Summary information for this ecology embankment is also provided in Table 1. Raw data and associated data quality assurance review information from the study are presented in a Technology Evaluation and Engineering Report (Herrera 2006) that can be accessed via WSDOT's website: <http://www.wsdot.wa.gov/NR/rdonlyres/3D73CD62-6F99-45DD-B004-D7B7B4796C2E/0/EcologyEmbankmentTEER.pdf>.

The other special study involves monitoring of a CAVFS on Interstate 5 (I-5) at MP 185 (Herrera 2004, 2005, 2007g, 2008b). This study, initiated in 2004, is ongoing. Summary information for this CAVFS is also provided in Table 1. Raw data and associated data quality assurance review information from this study are presented in separate annual data reports for water years 2007 and 2008, respectively (Herrera 2007g, 2008b).

As described above, the HI-RUN model can be used to determine the probability of observing a specific concentration of the following parameters in treated and untreated highway runoff: TSS, TCu, DCu, TZn, and DZn. In order to calculate these probabilities, a sufficient amount of data must be available for each parameter to accurately characterize their underlying distribution. Because the HI-RUN model will be used to estimate these probabilities across the wide range of conditions that are likely to be encountered at highway projects in western Washington, these data must also be obtained from a representative number of sites. Table 2 summarizes the total number of BMP sites and samples that are available to characterize the underlying distribution of each parameter based on the compiled data from the studies described above. This information is summarized in Table 2 for each individual BMP type (e.g., bioswale, wetpond, etc.), for each major BMP category (i.e., enhanced and basic), and for untreated runoff.

To characterize the distribution of each parameter in untreated runoff, data from 13 different sites were pooled (see Table 2) to ensure an adequate number of samples would be available for this purpose. The associated number of samples from these sites ranges from 198 for DCu and TCu, to 210 for DZn, TZn, and TSS. It should be noted that untreated runoff may be discharged directly to receiving water via a stormwater conveyance system with little or no physical or biological processing. Alternatively, this runoff may reach the receiving water via ditches or other natural conveyance systems. In the latter case, some processing and ancillary treatment of the runoff may occur. To reflect this reality, the data used to characterize untreated runoff in the HI-RUN model were obtained from a mix of site locations, including edge-of-pavement, piped stormwater conveyance systems, and natural conveyance systems (e.g., ditches).

Table 1. Summary information for BMPs that were monitored to obtain to representative data for treated and untreated highway runoff.

Type of BMP	BMP Location	Years Monitored	Number of Samples	Average Annual Daily Traffic	Purpose of Monitoring	Study References
Bioswale	I205 MP34.29	2006 – 2007	17	57,500	NPDES Permit	Herrera 2007c; Herrera 2007d; Herrera 2007e; Herrera 2007f; WSDOT 2007
Bioswale	SR14 MP10.39	2006	11	50,000	NPDES Permit	Herrera 2007c; Herrera 2007d; Herrera 2007e; Herrera 2007f; WSDOT 2007
Bioswale	SR18 MP13.13	2006 – 2008	14	2,400	NPDES Permit	Herrera 2007c; Herrera 2007d; Herrera 2007e; Herrera 2007f; WSDOT 2007
Bioswale	SR18 MP20.35	2006 – 2007	16	1,700	NPDES Permit	Herrera 2007c; Herrera 2007d; Herrera 2007e; Herrera 2007f; WSDOT 2007
CAVFS	I5 MP185	2005 – 2008	15	93,000	Special Study	Herrera 2004, Herrera 2005, Herrera 2007g, Herrera 2008b
Ecology Embankment	SR167 MP16.36	2001 – 2005	25, 13 [a]	60,000	Special Study	Taylor Associates 2001; Taylor Associates 2002; Herrera 2006
Ecology Embankment	SR18 MP18.51	2006 – 2008	17	11,750	NPDES Permit	Herrera 2007c; Herrera 2007d; Herrera 2007e; Herrera 2007f; WSDOT 2007
Ecology Embankment	SR167 MP16.36	2007 – 2008	4	60,000	NPDES Permit	Herrera 2007c; Herrera 2007d; Herrera 2007e; Herrera 2007f; WSDOT 2007
Wet Pond	I5 MP15.52	2006 – 2007	17	70,000	NPDES Permit	Herrera 2007c; Herrera 2007d; Herrera 2007e; Herrera 2007f; WSDOT 2007
Wet Pond	SR18 MP8.04	2006 – 2008	15	45,000	NPDES Permit	Herrera 2007c; Herrera 2007d; Herrera 2007e; Herrera 2007f; WSDOT 2007
Wet Pond	SR500 MP5.38	2006	11	18,000	NPDES Permit	Herrera 2007c; Herrera 2007d; Herrera 2007e; Herrera 2007f; WSDOT 2007
Wet Pond	SR522 MP16.30	2005 – 2006	12	30,000	NPDES Permit	Herrera 2007c; Herrera 2007d; Herrera 2007e; Herrera 2007f; WSDOT 2007
Wet Pond	SR525 MP1.58	2005 – 2006	11	50,000	NPDES Permit	Herrera 2007c; Herrera 2007d; Herrera 2007e; Herrera 2007f; WSDOT 2007
Wet Pond	SR 525 MP2.52	2005 – 2006	15	50,000	NPDES Permit	Herrera 2007c; Herrera 2007d; Herrera 2007e; Herrera 2007f; WSDOT 2007

[a] Twenty-five samples were analyzed for total zinc, dissolved zinc, and TSS. Thirteen samples were analyzed for total copper and dissolved copper.
CAVFS: Compost amended vegetated filter strip

Table 2. Number of sites and samples (in parentheses) that are available to characterize the probability distribution of each parameter analyzed using the Highway Runoff Dilution and Loading model.

Best Management Practice Type or Category	Dissolved Copper	Total Copper	Dissolved Zinc	Total Zinc	TSS
Untreated Runoff					
Untreated	13(198)	13(198)	13(210)	13(210)	13(210)
Basic Treatment BMPs					
Bioswale	4(57)	4(57)	4(57)	4(57)	4(57)
Wet Pond	6(86)	6(86)	6(86)	6(86)	6(86)
All Basic Treatment BMPs	10(143)	10(143)	10(143)	10(143)	10(143)
Enhanced Treatment BMPs					
Ecology Embankment	2(35)	2(35)	2(47)	2(47)	2(47)
CAVFS	1(15)	1(15)	1(15)	1(15)	1(15)
All Enhanced Treatment BMPs	3(50)	3(50)	3(62)	3(62)	3(62)

CAVFS: compost amended vegetated filter strip.
TSS: total suspended solids.
BMP: best management practice.

In order to characterize the probability distribution of each parameter in treated runoff, data from basic treatment BMPs (bioswales and wetponds) and enhanced treatment BMPs (ecology embankments and CAVFS), respectively, were pooled separately and subject to preliminary evaluations. In connection with these evaluations, statistical analyses (i.e., Mann-Whitney U-tests) were performed to determine whether there are significant differences in the concentrations measured for each parameter in runoff from basic and enhanced treatment BMPs, respectively, that would warrant incorporating these BMP categories as two distinctly different populations within the HI-RUN model.

Results from these analyses (Table 3) showed there were significant differences ($\alpha = 0.05$) in runoff concentration for DCu, TCu, and TSS between basic and enhanced treatment BMPs. In all cases, concentrations of each parameter were higher in the runoff from enhanced treatment BMPs relative to basic treatment BMPs. There were no significant differences ($\alpha = 0.05$) in runoff concentrations for DZn and TZn between basic and enhanced treatment BMPs. A closer examination of the data for DCu, TCu, and TSS indicated the differences between the enhanced and basic treatment BMPs were related to unusually high influent concentrations for these parameters at one enhanced treatment BMP site (at MP 16.36 on SR 167), for which data are available.

Given this anomaly at one of the enhanced BMP sites, and the fact that there is a relatively small number (three) of enhanced treatment BMP sites in total, a decision was made to pool data from all the basic and enhanced treatment BMP sites for the purpose of characterizing the probability distribution of each parameter in treated runoff. The pooled data set included samples from a total of 13 BMP sites (10 basic treatment BMP sites and three enhanced treatment BMP sites). The associated number of samples from these sites ranges from 193 for DCu and TCu, to 205 for

DZn, TZn, and TSS. As described in the next subsection, additional analyses were subsequently performed on these data to determine the theoretical distribution for each parameter in treated runoff. These theoretical distributions were then incorporated into the HI-RUN model for use in Monte Carlo simulation analyses.

Table 3. Results from Mann-Whitney U-tests comparing runoff data from basic and enhanced treatment BMPs for each parameter analyzed using the Highway Runoff Dilution and Loading model.

Parameter	Basic Treatment Rank Sum	Enhanced Treatment Rank Sum	Mann-Whitney U-Statistic	p-level
Dissolved Copper	12,174	6,547	1,878	**< 0.0001**
Total Copper	11,991	6,730	1,695	**< 0.0001**
Dissolved Zinc	14,783	6,332	4,379	0.8899
Total Zinc	14,434	6,681	4,138	0.4495
TSS	13,623	7,492	3,327	**0.0046**

Values in **bold** indicate there is significant difference between enhanced and basic treatment BMPs for the indicated parameter at an $\alpha = 0.05$.
BMP: best management practice.

Finally, it should be noted that WSDOT's BMPs performance monitoring efforts are ongoing. As additional data are gathered through these efforts, the HI-RUN model can be easily updated to incorporate new information.

Determination of Theoretical Distribution

As described previously, the HI-RUN model uses Monte Carlo simulation to determine the probability that an identified threshold of concern will be exceeded given underlying uncertainties in the compiled data for each water quality parameter. In order to perform these calculations, the theoretical distribution for each parameter in untreated and treated runoff must first be determined. The HI-RUN model is then programmed to draw values from these distributions at random in order to predict the concentrations of each parameter that have highest and lowest probabilities of occurrence.

To complete this step in the HI-RUN model's development, the data sets identified in the previous subsection for treated and untreated runoff were analyzed using the Crystal Ball software package (Desicioneering Inc. 2007). This software packages evaluates that actual distribution of the data against 14 different theoretical distributions. It then uses three different goodness-of-fit measures (Anderson-Darling, Kolmogorov-Smirnov, and Chi-Square) to identify the theoretical distribution that best represents the actual distribution of the data.

The results from these tests, including histograms derived from the raw data and individual goodness of fit scores from each test, are documented in Appendix A. In general, these results indicate that a lognormal distribution provides the best fit for the majority of parameters in treated and untreated runoff. Consequently, the HI-RUN model was programmed to use this distribution in all related calculations.

Calculation of Summary Statistics for Use as Model Input

In order to accurately simulate the lognormal distribution for each parameter within the HI-RUN model, the mean and standard deviation from the associated raw data must be calculated and used as input to the model (within Water Quality Table 1). The actual mean and standard deviation values that were calculated for this purpose are documented in Table 4. Note that these summary statistics were computed using the regression on order statistics (ROS) method to account for non-detect values in the raw data (CALTRANS 2001). Additional summary statistics that were computed for the data using the ROS method are provided in Appendix B.

Table 4. Mean and standard deviation for each parameter analyzed using the Highway Runoff Dilution and Loading model.

	Untreated Runoff (mg/L)	Treated Runoff (mg/L)
Total Suspended Solids		
Mean	106.4	11.8
Standard Deviation	149.8	21.7
Dissolved Copper		
Mean	0.0051	0.0036
Standard Deviation	0.0050	0.0025
Total Copper		
Mean	0.0219	0.0057
Standard Deviation	0.0216	0.0035
Dissolved Zinc		
Mean	0.0423	0.0193
Standard Deviation	0.0507	0.0139
Total Zinc		
Mean	0.1348	0.0283
Standard Deviation	0.1353	0.0196

Hydrologic Data Preprocessing

Similar to the water quality analyses described above, the HI-RUN model uses Monte Carlo simulation to estimate the probability that a specific discharge and discharge duration will be observed at an outfall during any given storm event based on the variability of local precipitation patterns. The model uses the same approach to estimate the probability that a specific annual discharge volume will be observed at an outfall. In order to build this capability into the HI-RUN model, information was generated for use as input to the model. This information includes:

- Monthly statistics on discharge throughout different precipitation regions in western Washington

- Monthly statistics on discharge durations throughout different precipitation regions in western Washington

- Annual statistics on runoff volume throughout different precipitation regions in western Washington.

To develop this data, the continuous simulation hydrologic model developed for and used by WSDOT to design stormwater management facilities (MGSFlood) was used. The modeling approach involved identifying the precipitation regions of interest, modeling prototype 1-acre impervious basins to provide scalable runoff information, and analyzing model output to generate statistics of interest. Other site conditions that were captured in the model runs include varying rates of runoff infiltration in treatment BMPs, and application of detention to meet flow control requirements. A summary of model runs performed in connection with this effort is provided in Appendix C. The methods and results of these analysis steps are described in the sections below.

Precipitation Regions

MGSFlood uses two separate methods to generate a precipitation time series for a given project location:

- Extended precipitation time series – three primary regions of extended time series data are available for ranges of mean annual precipitation (MAP) values: Puget West (MAP 32 to 60), Puget East (MAP 24 to 60), and Vancouver (MAP 40 to 60). In addition, time series data for Pierce County is also available: Pierce County Central (MAP 38), Pierce County West (MAP 40 to 52), and Pierce County East (MAP 38 to 52).

- Individual rain gauge data – rainfall data for individual rain gauges may be used for project sites located outside of the extended precipitation time series region. In MGS Flood, the modeler selects a rain gauge to be used and the model scales the rainfall data to the site based on the ratio of 25-year, 24-hour precipitation for the target and source sites.

For the current version of the HI-RUN model, hydrologic data was generated for the three primary extended time series regions and selected individual rain gauges. The Pierce County extended time series rainfall data were not analyzed because they are statistically similar to Puget East. The model can be easily expanded in the future to include additional individual rain gauge data and scaled individual rain gauge data in order to represent other geographic regions of western Washington not covered by the extended precipitation time series. The geographic range of the Puget West, Puget East, and Vancouver extended time series regions, and MAP isopluvials are provided in Appendix D. Also provided in Appendix D is a figure showing individual rain gauge locations and the regions in which each is appropriate to use (outside of the extended time series regions).

Modeling was performed for low, medium, and high annual precipitation volumes for each primary extended time series region (Appendix C). The results from these model runs were interpolated to represent other mean annual rainfall volumes in these regions, as explained in more detail below. Modeling was also performed for the following individual rain gauges:

- Astoria
- Burlington
- Clearwater
- Darrington
- Frances
- Montesano
- Port Angeles
- Quilcene
- Sappho.

Discharge Analysis

MGSFlood was run for prototype 1-acre impervious basins under each of several conditions. These include:

- Direct discharge to outfall with no infiltration and no detention to meet flow control requirements.

- Infiltration in treatment BMP – infiltration rates of 20, 40, 60, and 80 percent calculated as a proportion of the annual runoff volume. Infiltration was modeled using an infiltration trench sized to meet the desired long-term infiltration rate. Appendix C provides a summary of the infiltration trench sizing assumptions and results.

- Detention to meet duration flow control standard in combination with each of the infiltration rate assumptions listed above. Type C/D soils were assumed for all cases, since flow control would likely be accomplished by infiltration alone in Type A/B soils. A summary of the resulting detention volumes sized to meet the flow control standards is provided in Appendix C.

The runoff time series generated by MGSFlood was exported as average hourly discharge values. To statistically reconstruct the theoretical distribution for discharge in each month, various theoretical distributions were fit to the hourly discharge data with the Crystal Ball software package using the approach described above for preprocessing water quality data. This analysis was performed for selected modeling results, including results for the “direct discharge” (i.e., no infiltration, no detention) and the "80 percent infiltration with flow control" scenarios for the Puget West precipitation time series with 32 inches per year of rainfall. Analysis was performed for the months of January and June. The results of this analysis indicate that a lognormal distribution provides a suitable fit for all of the data evaluated. Therefore, the HI-RUN model was programmed to use this distribution in all associated Monte Carlo simulations. As described above in the section for water quality data preprocessing, the mean and standard deviation values for discharge in each month were used as input to the model for reconstructing the lognormal distribution. Results from the analyses performed using the Crystal Ball software package are documented in Appendix E. These results include histograms that were generated from the raw discharge data for January from the Puget West 32 precipitation time series.

Discharge Duration Analysis

Using the runoff time series exported from MGSFlood, the discharge durations during individual storms were identified by month using an Excel macro that applied the following storm criteria:

- Discharge rates less than 0.01 cfs were considered "no discharge" for the purposes of delineating storms
- A period of 6 hours with no discharge was used to define a break between independent storms.

The Excel macro routine calculated the mean and standard deviation for discharge durations in each month of the year based on these data. These statistics were subsequently used as input in the HI-RUN model (within Hydrology Table 1) for simulating the probability distribution of discharge durations during storm events in each month of the year. As described above in the *Precipitation Regions* section, modeling was performed for low, medium, and high mean annual precipitation. The resulting means and standard deviation values for discharge duration were interpolated to estimate discharge durations for other mean annual rainfall values. For instance, modeling was performed for Puget West 32, 44, and 60. For Puget West 36, the mean and standard deviation values for discharge duration were interpolated based on the modeling results for Puget West 32 and 44.

To statistically reconstruct the theoretical distribution for discharge duration in each month, various theoretical distributions were fit to the raw data using the Crystal Ball software package using the approach described above for preprocessing water quality data. This analysis was performed for selected modeling results, including results for the "direct discharge" (no infiltration, no detention) and the "80 percent infiltration with flow control" scenarios for the Puget West precipitation time series with 32 inches per year of rainfall. Analysis was performed for the months of January and June. The results of this analysis indicate that a lognormal distribution provides a suitable fit for all of the data evaluated. Therefore, the HI-RUN model was programmed to use this distribution in all associated Monte Carlo simulations. As described above in the section for water quality data prepocessing, the mean and standard deviation values for discharge duration in each month were used as input to the model for reconstructing the lognormal distribution. Results from the analyses performed using the Crystal Ball software package are documented in Appendix F. These results include histograms that were generated from the raw discharge duration data for January and June from the Puget West 32 precipitation time series.

Annual Runoff Volume Analysis

Using the exported MGSFlood runoff data generated in the discharge duration analysis described above, annual runoff volume was calculated for each year of simulation. To statistically reconstruct the theoretical distribution for annual runoff volume, various theoretical distributions were fit to the raw data with the Crystal Ball software package using the approach described above for preprocessing water quality data. This analysis was performed for selected modeling results, including results for the "direct discharge" (i.e., no infiltration, no detention) and the "80 percent infiltration with flow control" scenarios for the Puget West precipitation time series with 32 inches per year of rainfall. The results of this analysis indicate that a normal distribution provides a suitable fit for all of the data evaluated. Therefore, the HI-RUN model was programmed to use this distribution in all associated Monte Carlo simulations. As described above in the section for water quality data preprocessing, the mean and standard deviation values for annual runoff volume were used as input to the model for reconstructing the normal distribution. Results from the analyses performed using the Crystal Ball software package are documented in Appendix G. These results include histograms that were generated from the annual runoff volume data for the Puget West 32 precipitation time series.

Highway Runoff Dilution and Loading Model Programming

HI-RUN model programming is documented in separate sections below for the concentration and loading analysis subroutines, respectively. The Visual Basic code that was developed to run these subroutines is presented in Appendix H.

Concentration Analysis Subroutine

Calculations are run for individual drainage subbasins (subsets of TDAs) using a Visual Basic macro composed of the following steps:

Step 1: Calculate Scaling Factors

Three scaling factors are calculated to assist with calculation of a "flow-weighted" concentration. The scaling factors are for areas discharging to basic and enhanced treatment BMPs (X_{basic}, X_{enh}), and areas discharging untreated (X_{none}). Scaling factors for basic and enhanced treatment areas are calculated using the following formulas:

$$X_{basic} = \frac{\sum_i A_{i,basic} \times (1-i)}{A_{sub}}$$

$$X_{enh} = \frac{\sum_i A_{i,enh} \times (1-i)}{A_{sub}}$$

Where: i = infiltration rate (-) of 0, 0.2, 0.4, 0.6, and 0.8,

$A_{i,basic}$ = area (in acres) of impervious area draining to a basic treatment BMP with infiltration rate of i,

$A_{i,enh}$ = area (in acres) of impervious area draining to an enhanced treatment BMP with infiltration rate of i,

A_{sub} = total impervious area (in acres) in the subbasin.

The scaling factor for areas receiving no runoff treatment (X_{none}) is calculated using the following formula:

$$X_{none} = \frac{A_{none}}{A_{sub}}$$

Where: A_{none} = area (in acres) of impervious area receiving no treatment,

A_{sub} = total impervious area (in acres) in the subbasin.

Step 2: Conduct Monte Carlo Simulation of Concentrations

A Monte Carlo simulation is used to generate 1,000 random concentration values for three treatment cases (C_{basic}, C_{enh}, C_{none}). These values are generated for each of the selected pollutants of interest by applying a lognormal distribution to the mean and standard deviation values in Water Quality Table 1.

Step 3: Combine Concentration Distributions

Each of the 1,000 individual concentration values in the three concentration distributions generated in Step 2 are scaled by the factors calculated in Step 1, and summed to provide a combined concentration distribution that represents mixed effluent concentration from the project subbasin.

$$C_{comb,1} = (X_{basic} \times C_{basic,1}) + (X_{enh} \times C_{enh,1}) + (X_{none} \times C_{none,1})$$

Where: $C_{comb,1}$ = concentration value #1 of 1,000 (mg/L) in the combined pollutant concentration distribution,

X_{basic}, X_{enh}, X_{none} = area scaling factor (-) for runoff subject to basic treatment, enhanced treatment, and no treatment calculated in Step 1,

$C_{basic,1}$, $C_{enh,1}$, $C_{none,1}$ = concentration value #1 of 1,000 (mg/L) in the pollutant concentration distributions generated in Step 2.

Step 4: Calculate Concentration Probability Values

Probability values are calculated for ranges of concentration values (intervals) for each selected water quality parameter using the following formula:

$$P_{DCu1-DCu2} = \frac{n_{DCu1-DCu2}}{n_T}$$

Where: $P_{DCu1-DCu2}$ = probability (-) that dissolved copper (DCu) concentration is between two specified values (DCu1, DCu2),

$n_{DCu1-DCu2}$ = number of DCu concentration values (-) between two specified values (DCu1, DCu2) in combined concentration distribution,

n_T = total number of DCu concentration values (-) in combined concentration distribution (1,000).

Step 5: Conduct Monte Carlo Simulation of Storm Durations

A Monte Carlo simulation is used to generate 1,000 storm duration values of storm duration for each of the infiltration cases (0, 20, 40, 60, and 80 percent), and each month of interest ($Dur_{i,month}$). If detention is applicable to the subbasin of interest, a distribution of storm durations associated with detention will also be generated. These values are generated by applying a lognormal distribution to mean and standard deviation values listed in Hydrology Table 1. For each month, the infiltration case with the greatest storm durations will be used in the following analysis step.

Step 6: Calculate Storm Duration Probability Values

Using the infiltration case with the greatest associated storm durations, probability values are calculated for ranges of storm duration values (intervals) for each selected month using the following formula:

$$P_{Dur1-Dur2} = \frac{n_{Dur1-Dur2}}{n_T}$$

Where: $P_{Dur1-Dur2}$ = probability (-) that storm duration is between two specified values (*Dur1*, *Dur2*),

$n_{Dur1-Dur2}$ = number of storm duration values (-) between two specified values (*Dur1*, *Dur2*) in storm duration distribution,

n_T = total number of storm duration values (-) in storm duration distribution (1,000).

Step 7: Output Values to Tables

Output tables are generated for existing and proposed conditions for all selected water quality parameters and months of interest. Tables are configured with columns representing storm duration intervals and rows representing concentration intervals. Each cell in the table is populated with a probability value (P_{cell}) calculated as the product of the probabilities for the associated storm duration interval and concentration interval.

$$P_{cell} = P_{Dur1-Dur2} \times P_{DCu1-DCu2}$$

Where: $P_{Dur1\text{-}Dur2}$ = Probability that the storm duration will be between two predetermined values (*Dur1*, *Dur2*),

P_{DCu1}-P_{DCu2} = Probability that the pollutant concentration (DCu in this example) will be between two predetermined values (*DCu1*, *DCu2*).

Figure 1 provides an example of a concentration output table.

Loading Analysis Subroutine

Calculations are run for entire TDA using a Visual Basic macro composed of the following steps:

Step 1: Conduct Monte Carlo Simulation of Concentrations

A Monte Carlo simulation is used to generate 1,000 random concentration values for each of the treatment cases (C_{basic}, C_{enh}, C_{none}). These values are generated for each of the selected pollutants of interest by applying a lognormal distribution to the mean and standard deviation values in Water Quality Table 1.

Step 2: Calculate Adjusted Drainage Areas

Each subarea (combination of treatment type and infiltration rate) is adjusted by the infiltration rate incidental to the associated treatment BMP to assist with calculation of a volume-weighted concentration. Drainage subareas are adjusted using the following formulas:

$$A'_{i,basic} = A_{i,basic} \times (1 - i)$$

$$A'_{i,enh} = A_{i,enh} \times (1 - i)$$

$$A'_{0,none} = A_{0,none}$$

Where: $A'_{i,basic}$, $A'_{i,enh}$, $A'_{0,none}$ = Adjusted drainage area (in acres) draining to basic treatment BMPs, enhanced treatment BMPs, and no treatment BMPs with incidental infiltration of *i*,

Concentration Analysis Report - Subbasin 1

This model is for stormwater analysis associated with biological assessments, and is not a design tool.

Date/Time of Run: 8/18/08 07:18
Outfall ID: Test Project,
Rain Gaug Puget West 32
Descriptioı

Baseline Condition
No Treatment 0% Infiltration - 10 acres

Proposed Condition
Basic Treatment 0% Infiltration - 10 acres Enhanced Treatment 60% Infiltration - 2 acres with detention

Dissolved Zinc - February - Probability of Occurrence

Conc. (mg/L)	Baseline Conditions										Proposed Conditions								
		0 - 3	**3 - 6**	**6 - 12**	**12 - 24**	**24 - 48**	**48 - 96**	**96 - 192**	**>192**			**0 - 3**	**3 - 6**	**6 - 12**	**12 - 24**	**24 - 48**	**48 - 96**	**96 - 192**	**>192**
> 0.1	0.084	0.006	0.021	0.03	0.019	0.006	0.001	0	0	**> 0.1**	0.002	0	0	0.001	0	0	0	0	0
0.09 - 0.1	0.02	0.001	0.005	0.007	0.005	0.001	0	0	0	**0.09 - 0.1**	0.002	0	0	0.001	0	0	0	0	0
0.08 - 0.09	0.02	0.001	0.005	0.007	0.005	0.001	0	0	0	**0.08 - 0.09**	0.002	0	0.001	0.001	0.001	0	0	0	0
0.07 - 0.08	0.033	0.002	0.008	0.012	0.008	0.002	0	0	0	**0.07 - 0.08**	0.004	0	0.001	0.001	0.001	0	0	0	0
0.06 - 0.07	0.042	0.003	0.011	0.015	0.01	0.003	0	0	0	**0.06 - 0.07**	0.005	0	0.001	0.002	0.001	0	0	0	0
0.05 - 0.06	0.061	0.004	0.015	0.022	0.014	0.004	0.001	0	0	**0.05 - 0.06**	0.015	0.001	0.004	0.005	0.003	0.001	0	0	0
0.04 - 0.05	0.085	0.006	0.021	0.03	0.02	0.006	0.001	0	0	**0.04 - 0.05**	0.032	0.002	0.008	0.011	0.007	0.002	0	0	0
0.03 - 0.04	0.113	0.008	0.029	0.041	0.026	0.008	0.001	0	0	**0.03 - 0.04**	0.084	0.006	0.021	0.03	0.019	0.006	0.001	0	0
0.02 - 0.03	0.171	0.012	0.043	0.061	0.04	0.013	0.002	0	0	**0.02 - 0.03**	0.209	0.016	0.052	0.075	0.048	0.016	0.003	0	0
0.01 - 0.02	0.23	0.016	0.058	0.082	0.054	0.017	0.003	0	0	**0.01 - 0.02**	0.434	0.032	0.108	0.155	0.099	0.033	0.005	0	0
0 - 0.01	0.141	0.01	0.036	0.051	0.033	0.01	0.002	0	0	**0 - 0.01**	0.212	0.016	0.053	0.076	0.049	0.016	0.003	0	0
		0.07	0.254	0.357	0.233	0.073	0.011	0.001	0			0.074	0.249	0.357	0.229	0.077	0.013	0.001	0

Discharge Duration (hrs)

Figure 1. Sample output page for the end-of-pipe loading subroutine of the HI-RUN model.

$A_{i,basic}$, $A_{i,enh}$, $A_{0,none}$	=	Area (in acres) draining to basic treatment BMPs, enhanced treatment BMPs, and no treatment BMPs with incidental infiltration of *i*,
i	=	infiltration rate (-) of 0, 0.2, 0.4, 0.6, and 0.8.

Step 3: Conduct Monte Carlo Simulation of Annual Runoff Volume

A Monte Carlo simulation is used to generate 1,000 values of annual runoff volume per acre (cubic feet/acre) for each of the infiltration cases (0, 20, 40, 60, and 80 percent; Vi). These values are generated by applying a normal distribution to the mean and standard deviation values listed in Hydrology Table 2 using a minimum value of zero, and no fixed maximum value.

Step 4: Calculate Combined Annual Runoff Volumes

Three combined annual runoff volume distributions are calculated by multiplying the adjusted areas calculated in Step 2 to the per acre runoff volume values generated in Step 3. Each value in the three combined annual runoff volume distributions is calculated using the following formula:

$$V_{basic} = \sum_i \left(A'_{i,basic} \times V_i \right)$$

$$V_{enh} = \sum_i \left(A'_{i,enh} \times V_i \right)$$

$$V_{none} = A'_{o,none} \times V_0$$

Where:	V_{basic}, V_{enh}, V_{none}	=	annual runoff volume (cubic feet),
	i	=	infiltration rate (-) of 0, 0.2, 0.4, 0.6, and 0.8,
	$A'_{i,basic}$, $A'_{i,enh}$, $A'_{0,none}$	=	adjusted area (acre) calculated in Step 2 draining to basic treatment BMPs, enhanced treatment BMPs, and no treatment BMP, with incidental infiltration rate of *i*,
	V_i	=	annual runoff volume per acre (cubic feet/acre) generated using mean and standard deviation values in Hydrology Table 2 (see Step 3).

Step 5: Calculate Combined Load Distribution

Each individual value in the three concentration distributions (basic, enhanced, and no treatment – from Step 1) and three combined annual runoff volume distributions (basic, enhanced, and no treatment – from Step 4) are combined to provide a combined pollutant load distribution that represents mixed effluent concentration from the project subbasin. Each value in the combined load distribution is calculated using the following formula:

$$L = F_c \times \left(\left[C_{basic} \times V_{basic} \right] + \left[C_{enh} \times V_{enh} \right] + \left[C_{none} \times V_{none} \right] \right)$$

Where: L = annual pollutant load (pounds),

F_c = unit conversion factor (6.243×10^{-5} L-lb/cf-mg),

C_{basic}, C_{enh}, C_{none} = pollutant concentration (in mg/L) associated with basic treatment BMPs, enhanced treatment BMPs, and untreated runoff (from Step 1),

V_{basic}, V_{enh}, V_{none} = annual runoff volume (cubic feet) associated with treatment type (from Step 4).

Step 6: Calculate Pollutant Load Statistics and Probability Values

The following annual pollutant load (pounds) statistics are calculated for existing and proposed conditions for all selected pollutants of interest:

- Minimum
- 25th percentile
- Median (50th percentile)
- 75th percentile
- Maximum.

In addition, for the 1,000 values in the existing and proposed load distributions, the number of instances where the proposed pollutant load value exceeds the existing pollutant load value will be counted. The probability of exceedance will then be calculated using the following formula:

$$P_{exceed} = \frac{n_{exceed}}{n_T}$$

Where: P_{exceed} = probability (-) that pollutant load in the proposed condition will exceed the pollutant load in the existing condition,

n_{exceed} = number of instances (-) in the pollutant load distribution where the proposed pollutant load value exceeds the existing pollutant load value,

n_T = total number of pollutant load values (-) in the pollutant load distribution (1,000).

Step 7: Output Values to Tables

Output tables are generated for existing and proposed conditions that display results for all selected water quality parameters. Tables are configured with columns existing and proposed conditions. Statistics described in Step 6 are provided, as well as the exceedance probability (see Step 6). Figure 2 provides an example of a pollutant load output table.

TDA Pollutant Load and Outfall Concentration Analysis Report

This model is for stormwater analysis associated with biological assessments, and is not a design tool.

Date/Time of Run: 8/18/08 07:18
Outfall ID: Test Project,
Rain Gauge: Puget West 32

No Treatment
0% Infiltration - 10 acres

Basic Treatment
0% Infiltration - 10 acres
Enhanced Treatment
60% Infiltration - 2 acres

Load Analysis

	Dissolved Zinc Load (lb/yr)	
	Baseline	**Proposed**
Max	52.6	12
75th Percentile	2.88	1.4
Median	1.52	0.92
25th Percentile	0.82	0.59
Min	0.021	0.083
P (exceed)		0.329

Concentration Analysis

Subbasin 1	Dissolved Zinc Conc (mg/L)	
	Baseline	**Proposed**
Max	0.833	0.122
75th Percentile	0.052	0.024
Median	0.028	0.016
25th Percentile	0.015	0.011
Min	0.001	0.002
P (Exceed)		0.313

Figure 2. Sample output page for the end-of-pipe loading subroutine of the HI-RUN model.

Dilution Analysis Subroutine

Calculations are run for individual drainage subbasins (subsets of TDAs) using a Visual Basic macro composed of the steps described below. Many of these steps are identical to those described above in the *Concentration Analysis Subroutine* section.

Step 1: Calculate Scaling Factors

Three scaling factors are calculated to assist with calculation of a "flow-weighted" concentration. The scaling factors are for areas discharging to basic and enhanced treatment BMPs (X_{basic}, X_{enh}), and areas discharging untreated stormwater (X_{none}). Scaling factors for basic and enhanced treatment areas are calculated using the following formulas:

$$X_{basic} = \frac{\sum_i A_{i,basic} \times (1-i)}{A_{sub}}$$

$$X_{enh} = \frac{\sum_i A_{i,enh} \times (1-i)}{A_{sub}}$$

Where: i = infiltration rate (-) of 0, 0.2, 0.4, 0.6, and 0.8,

$A_{i,basic}$ = area (in acres) of impervious area draining to a basic treatment BMP with infiltration rate of i,,

$A_{i,enh}$ = area (in acres) of impervious area draining to an enhanced treatment BMP with infiltration rate of i,

A_{sub} = total impervious area (in acres) in the subbasin.

The scaling factor for areas receiving no runoff treatment (X_{none}) is calculated using the following formula:

$$X_{none} = \frac{A_{none}}{A_{sub}}$$

Where: A_{none} = area (in acres) of impervious area receiving no treatment,

A_{sub} = total impervious area (in acres) in the subbasin.

Step 2: Conduct Monte Carlo Simulation of Concentrations

A Monte Carlo simulation is used to generate 1,000 random concentration values for three treatment cases (C_{basic}, C_{enh}, C_{none}). These values are generated for each of the selected pollutants of interest by applying a lognormal distribution to the mean and standard deviation values in Water Quality Table 1.

Step 3: Combine Concentration Distributions

Each of the 1,000 individual concentration values in the three concentration distributions generated in Step 2 are scaled by the factors calculated in Step 1, and summed to provide a combined concentration distribution that represents mixed effluent concentration from the project subbasin.

$$C_{comb,1} = \left(X_{basic} \times C_{basic,1}\right) + \left(X_{enh} \times C_{enh,1}\right) + \left(X_{none} \times C_{none,1}\right)$$

Where: $C_{comb,1}$ = concentration value #1 of 1,000 (mg/L) in the combined pollutant concentration distribution,

X_{basic}, X_{enh}, X_{none} = area scaling factor (-) for runoff subject to basic treatment, enhanced treatment, and no treatment calculated in Step 1,

$C_{basic,1}$, $C_{enh,1}$, $C_{none,1}$ = concentration value #1 of 1,000 (mg/L) in the pollutant concentration distributions generated in Step 2.

Step 4: Conduct Monte Carlo Simulation of Discharge

A Monte Carlo simulation is used to generate 1,000 random discharge values ($Q_{i,fc}$)for each of the project areas associated with different incidental infiltration rates (0, 20, 40, 60, and 80 percent) and flow control assumptions (detention and no detention). These values are generated by applying a lognormal distribution to the mean and standard deviation values in Hydrology Table 3.

Step 5: Calculate Outfall Discharge

The discharge values calculated in Step 4 above for each of the project areas will be combined to estimate a single distribution of "combined" discharge values at the project outfall. This combined discharge distribution (Q_{comb}) will be calculated using the following formula:

$$Q_{comb,1} = \sum_{i,fc} \left(A_{i,fc} \times Q_{i,fc,1}\right)$$

Where: $Q_{comb,1}$ = discharge value #1 of 1,000 cfs in the combined discharge distribution,

$A_{i,fc}$ = area (acres) of portion of subbasin that discharges to a runoff treatment BMP with incidental infiltration value of *i* (0, 20, 40, 60, 80 percent) and appropriate flow control (detention, no detention),

$Q_{i,fc,1}$ = discharge value #1 of 1,000 (cfs) calculated in Step 4 above.

Step 6: Conduct Monte Carlo Simulation of Ambient Concentrations

A Monte Carlo simulation is used to generate 1,000 ambient receiving water concentration values (C_{amb}). These values are generated by applying lognormal distributions (as appropriate – see the *Hydrologic Data Preprocessing* section) to the mean and standard deviation values supplied by the user in the Dilution Analysis input page. If the user selects the Single Value analysis option, the value in the "Mean Concentration" box will be used for all 1,000 values.

Step 7: Calculate Dilution Factors

RIVPLUM6 is used to estimate dilution factors (*DF*) for a point downstream of the outfall defined by the user. RIVPLUM6 is run 1,000 times using the combined discharge distribution calculated in Step 5 above and user inputs for receiving water conditions. A discussion of RIVPLUM6 is provided in the *Hydraulic Mixing Model* section below.

Step 8: Calculate Mixed Concentrations

Pollutant concentrations in mixed project and receiving water are calculated for each of the 1,000 values of project discharge concentrations (C_{comb} from Step 3) and dilution factors (*DF* from Step 6) using the following formula:

$$C_{mix,1} = \frac{\left(C_{comb,1} - C_{amb,1}\right)}{DF_1} + C_{amb,1}$$

Where: $C_{mix,1}$ = concentration value #1 of 1,000 (mg/L) in the mixed discharge distribution,

$C_{comb,1}$ = concentration value #1 of 1,000 (mg/L) in the combined project discharge concentration distribution,

$C_{amb,1}$ = concentration value #1 of 1,000 (mg/L) in the ambient concentration distribution,

DF_1 = dilution factor #1 of 1,000 (no units) in the dilution factor distribution.

Step 9: Calculate Concentration Probability Values

Probability values are calculated for ranges of concentration values (intervals) for each selected water quality parameter using the following formula:

$$P_{DCu1-DCu2} = \frac{n_{DCu1-DCu2}}{n_T}$$

Where: $P_{DCu1-DCuS2}$ = probability (-) that dissolved copper (DCu) concentration is between two specified values (DCu1, DCu2),

$n_{DCu1\text{-}DCu2}$	=	number of DCu concentration values (-) between two specified values (DCu1, DCu2) in combined concentration distribution,
n_T	=	total number of DCu concentration values (-) in combined concentration distribution (1,000).

Step 10: Conduct Monte Carlo Simulation of Storm Durations

A Monte Carlo simulation is used to generate 1,000 storm duration values of storm duration for each of the infiltration cases (0, 20, 40, 60, and 80 percent), and each month of interest ($Dur_{i,month}$). If detention is applicable to the subbasin of interest, a distribution of storm durations associated with detention will also be generated. These values are generated by applying a lognormal distribution to mean and standard deviation values listed in Hydrology Table 1. For each month, the infiltration case with the greatest storm durations will be used in the following analysis step.

Step 11: Calculate Storm Duration Probability Values

Using the infiltration case with the greatest associated storm durations, probability values are calculated for ranges of storm duration values (intervals) for each selected month using the following formula:

$$P_{Dur1-Dur2} = \frac{n_{Dur1-Dur2}}{n_T}$$

Where:	$P_{Dur1\text{-}Dur2}$	=	probability (-) that storm duration is between two specified values (*Dur1*, *Dur2*),
	$n_{Dur1\text{-}Dur2}$	=	number of storm duration values (-) between two specified values (*Dur1*, *Dur2*) in storm duration distribution,
	n_T	=	total number of storm duration values (-) in storm duration distribution (1,000).

Step 12: Output Values to Tables

Output tables are generated for existing and proposed conditions for all selected water quality parameters and months of interest. Tables are configured with columns representing storm duration intervals and rows representing concentration intervals. Each cell in the table is populated with a probability value (P_{cell}) calculated as the product of the probabilities for the associated storm duration interval and concentration interval.

$$P_{cell} = P_{Dur1-Dur2} \times P_{DCu1-DCu2}$$

Where:	$P_{Dur1\text{-}Dur2}$	=	probability that the storm duration will be between two predetermined values (*Dur1*, *Dur2*),
	$P_{DCu1}\text{-}P_{DCu2}$	=	probability that the pollutant concentration (DCu in this example) will be between two predetermined values (*DCu1*, *DCu2*).

Hydraulic Mixing Model

The hydraulic mixing model used to generate dilution factors for the dilution analysis subroutine is RIVPLUM6, a model provided by Ecology in their PWSPREAD water quality spreadsheet. RIVPLUM6 is a model of longitudinal and horizontal dispersion that implements an algorithm from Fischer et al. (1979). RIVPLUM6 is appropriate for modeling point discharges to shallow, unidirectional flow. In RIVPLUM6, dispersion is limited to the confines of banks through the use of superposition of solutions (Ecology 2000). The flow should be shallow enough that vertical gradients are zero. The applicability of RIVPLUM6 to shallow, unidirectional, confined flows makes it useful as a stand-alone model for modeling point discharges of stormwater to streams.

Inputs to the RIVPLUM6 model include effluent discharge rate, receiving water characteristics (depth, velocity, width, and Manning's n or slope), distance of discharge from shoreline, and transverse mixing coefficient. Manning's n is used in the calculation of the shear velocity which is in turn used to estimate dispersion coefficients. The user also elects whether to run the original Fisher et al. (1979) equations or to include a correction for effective origin. The correction for effective origin is recommended if the output point of interest is near the discharge location. The outputs are automatic via Microsoft Excel formulas. Appendix I includes step-by-step guidance on using RIVPLUM5 (which uses the same formulas as RIVPLUM6) from Ecology (2000).

In the HI-RUN model, the "Distance Downstream to Point of Interest" cell will be varied iteratively by the user until the resulting tables indicate that the project risk threshold has been met/exceeded. The "Distance from Nearest Shoreline" and "Transverse Mixing Coefficient Constant" inputs to the RIVPLUM6 model are not included as user inputs in HI-RUN. The "Distance from Nearest Shoreline" input associated with the downstream point of interest is programmed to be equal to the "Discharge Distance from Nearest Shoreline" value. This is because the highest pollutant concentration downstream from the outfall will be the same distance from shore as the point of discharge. The "Transverse Mixing Coefficient Constant" is set at 0.6, the model's default value.

Stormwater Quality Effect Analysis Process Assumptions and Decision Criteria

As described in the HI-RUN Model User's Guide, a number of key assumptions and decision criteria have been incorporated into the stormwater quality effects analysis process, most notably:

- Indicator pollutant used for the loading analysis
- Threshold values used for loading analysis
- Threshold value used for simplified dilution analysis
- Project risk limit
- Potential influences on pollutant concentrations in highway runoff
- HI-RUN Model input data.

The following sections provide background and justification for incorporating these assumptions and decision criteria in the analysis process.

Indicator Pollutant Used for the Loading Analysis

The first step in the stormwater quality effect analysis process for a given threshold discharge area (TDA) is to compare the P(exceed) value for dissolved zinc to two threshold values to determine the level of dilution modeling that may be necessary. (The subsection that follows describes P(exceed) value the associated threshold values in more detail.) Dissolved zinc was chosen for this initial screening step because monitoring data compiled by WSDOT for this parameter have generally shown it is a good indicator of stormwater treatment system performance. In contrast, dissolved copper was not used as a predictor because existing monitoring suggests that concentrations of this parameter in highway runoff are present at levels that are so low as to be considered nearly untreatable with best management practices (BMPs) that are currently used in highway settings.

Threshold Values Used for Loading Analysis

As discussed in the HI-RUN Model User's Guide, P(exceed) is an expression of the probability that a pollutant load or concentration will be higher in the proposed condition than in the baseline condition. A P(exceed) value of 0.5 represents conditions where baseline and proposed conditions are generally the same. P(exceed) values of less than 0.5 generally indicate that loadings (or end of pipe concentrations) for the proposed conditions are likely lower than those for baseline conditions, and P(exceed) values greater than 0.5 indicate that loadings (or concentrations) are likely higher than those for baseline conditions. Dissolved zinc loading P(exceed) thresholds of 0.45 and 0.35 are used in part to determine if detailed dilution modeling (using the HI-RUN Receiving Water Dilution subroutine) is necessary for the effects analysis. In order to select these values, a range of theoretical treatment scenarios were examined using the HI-RUN model as shown in Table 5. Specific threshold values were then selected to provide a conservative estimate of potential effects from highway project.

For example, the primary loading P(exceed) threshold value of 0.45 for dissolved zinc represents a conservative estimate of conditions where pollutant loading is not likely increasing. This threshold provides a cushion of 0.05 (or 5 percent) below the “no change” value of 0.5 to account for uncertainty in the loading estimates. To illustrate this with an example, this value represents a hypothetical treatment scenario where baseline conditions include 10 acres of untreated impervious area, and proposed conditions include an increase of 5 acres of impervious area (50 percent of the baseline area) with runoff treatment for all new and existing area (15 acres; see scenario 4 in Table 5).

The secondary loading P(exceed) threshold value of 0.35 for dissolved zinc represents an even greater level of protection against uncertainty in the analysis methods. This threshold provides a cushion of 0.15 (or 15 percent) below the “no change” value of 0.5. This dissolved zinc loading P(exceed) value represents a hypothetical treatment scenario similar to that described in the paragraph above, but where runoff from the 5 acres of new impervious area is treated using state of the art BMPs that achieve substantial infiltration of runoff (see scenario 5 in Table 5).

Threshold Value Used for Simplified Dilution Analysis

Project TDAs that contain impervious area totals that are less than 5 percent of the upstream receiving water watershed area are considered to provide adequate dilution of project runoff when the dissolved zinc loading P(exceed) value is below the primary threshold of 0.45. Because the P(exceed) value is below this threshold, it is already understood that the probability of degrading water quality conditions in the receiving water under the proposed condition is low relative to the baseline condition. However, the consequences of this risk are related to the contribution of runoff to the receiving water flow and to the existing conditions of the receiving water. If the project discharge accounts for a substantial portion of receiving water flow, that receiving water will be very sensitive to uncertainty and variability in the runoff quality data. Degraded receiving waters are less likely to be able to assimilate minor additions of pollutants than receiving waters which are properly functioning. The 5 percent threshold was adopted for use in the stormwater analysis process based on dilution analyses that were performed using Monte Carlo simulations. Specifically, Monte Carlo simulations were performed to determine the probably of exceeding thresholds for potential water quality effects on ESA-listed aquatic species given the following input data for the analysis:

- Representative dissolved zinc and copper concentrations in untreated highway runoff that were described above in the section for Water Quality Data Preprocessing

Table 5. Theoretical treatment scenarios examined using the HI-RUN model (version 1.0).

Scenario	Baseline TDA (acres)	Baseline TDA Treatment	Proposed TDA (acres)	Proposed TDA Treatment	D. Zinc P(exceed)	D. Copper P(exceed)	TSS P(exceed)
1	10	10 acres untreated	10	10 acres untreated	0.50	0.50	0.50
2	10	10 acres untreated	15	15 acres untreated	0.62	0.63	0.61
3	10	10 acres untreated	10	10 acres treated @ 0% infiltration	0.33	0.43	0.07
4	10	10 acres untreated	15	15 acres treated @ 0% infiltration	0.45	0.58	0.11
5	10	10 acres untreated	15	10 acres treated @ 0% infiltration 5 acres treated @ 60% infiltration	0.35	0.47	0.07
6	10	10 acres untreated	15	5 acres treated @ 0% infiltration 10 acres treated @ 60% infiltration	0.22	0.30	0.04
7	10	10 acres untreated	15	15 acres treated @ 60% infiltration	0.06	0.07	0.01
8	10	10 acres untreated	15	10 acres untreated 5 acres treated @ 60% infiltration	0.53	0.53	0.51

Theoretical scenarios were run using the Puget West32 precipitation time series.

- Representative dissolved zinc and copper concentration in western Washington receiving waters that were obtained through a query of the Washington State Department of Ecology's Environmental Information Management database (Ecology 2006). In this analysis, the 75th percentile values from these data were used to provide a more conservative estimate of potential receiving water effects.

Results from this analysis showed there was only a 5 percent chance of exceeding the thresholds for potential water quality effects when the percentage of the project TDA's impervious area relative to upstream receiving water watershed area was less than 5 percent. This low probability was considered sufficiently conservative to justify the use of this value in the stormwater analysis process. All results from this analysis are documented in Appendix J.

Project Risk Limit

As described in the HI-RUN Model User's Guide, a probability of 0.05 was chosen for determining the acceptable risk limit for exceeding the identified thresholds for potential water quality effects on ESA-listed aquatic species. To put it another way, this indicates that a more detailed assessment of the project should be performed if there is only a 5 percent or greater probability that these thresholds will be exceeded within the receiving water. Given the relatively large amount of inherent uncertainty associated with stormwater data, this relatively low probability for potential effects was considered sufficiently conservative by agency representatives that were involved in the development of the stormwater analysis process.

Potential Influences on Pollutant Concentrations in Highway Runoff

There are numerous potential influences on highway runoff pollutant concentrations that warrant consideration in the stormwater analysis process for ESA section 7 consultations (Herrera 2007a). Preliminary analyses that were performed during the development of the HI-RUN model to specifically examine the influence of the following factors using the available data from WSDOT's NPDES monitoring program:

- Average daily traffic volume
- First flush
- Storm duration.

Results from these analyses showed there were weak trends related to these factors for some of the parameters that were analyzed. However, because there is currently insufficient data available to accurately predict how these factors may interact to affect highway runoff at any given site, their influence could not be directly incorporated into the HI-RUN model.

HI-RUN Model Input Data

It was the general consensus of the multi-agency workgroup associated with this project that input for the HI-RUN model should be obtained from local studies of highway runoff to the extent possible. More specifically, input water quality data for the HI-RUN model should be derived from BMP performance monitoring studies that were performed pursuant to requirements identified in WSDOT's National Pollution Discharge Elimination System (NPDES) permit (Ecology 2007). These data were believed to be the most representative of highway runoff pollutant concentrations in western Washington.

References

CALTRANS. 2001. CALTRANS Data Analysis Tool. Ver. 31. California Department of Transportation (CALTRANS).

Decisioneering Inc. 2007. Crystal Ball, Ver. 7.3. Denver, Colorado.

Ecology. 2000. Spreadsheets for Water Quality-Based NPDES Permit Calculations. Electronic document downloaded from Ecology website: <http://www.ecy.wa.gov/programs/eap/pwspread/pwspread.html>. Accessed on May 12, 2008.

Ecology. 2006. Database retrieval: Water quality data from river systems for hardness, total suspended solids, turbidity, total zinc, total copper, and total lead. Environmental Information Management (EIM) system (<http://www.ecy.wa.gov/eim/index.htm>), Washington State Department of Ecology, Olympia, Washington. March 17, 2006.

Ecology. 2007. Phase I Municipal Stormwater Permit: National Pollutant Discharge Elimination System and State Waste Discharge General Permit for Discharges from Large and Medium Municipal Separate Storm Sewer Systems. Washington State Department of Ecology, Olympia, Washington.

Fischer, H.B., J.E. List, C.R. Koh, J. Imberger, and N.H. Brooks. 1979. Mixing in inland and coastal waters. Academic Press Inc.

GeoSyntec Consultants. 2008. Final White Paper: BMP Effectiveness Assessment for Highway Runoff in Western Washington. Prepared for the Washington State Department of Transportation by GeoSyntec Consultants, Portland, Oregon. March 2008.

Herrera. 2004. Quality Assurance Project Plan: Compost-Amended Vegetated Filter Strip Performance Monitoring Project. Prepared for Washington State Department of Transportation by Herrera Environmental Consultants, Inc., Seattle, Washington.

Herrera. 2005. Water Year 2005 Data Report: Compost-Amended Vegetated Filter Strip Performance Monitoring Project. Prepared for Washington State Department of Transportation by Herrera Environmental Consultants, Inc., Seattle, Washington.

Herrera. 2006. Technology Evaluation and Engineering Report: WSDOT Ecology Embankment. Prepared for Washington Department of Transportation, by Herrera Environmental Consultants, Inc., Seattle, Washington.

Herrera. 2007a. White Paper: Untreated Highway Runoff in Western Washington. Prepared for the Washington State Department of Transportation by Herrera Environmental Consultant, Seattle, Washington. May 2007.

Herrera. 2007b. White Paper: Recent Analytical Approaches for Evaluation of Stormwater Quality Impacts. Prepared for the Washington State Department of Transportation by Herrera Environmental Consultant, Seattle, Washington. December 2007.

Herrera. 2007c. Quality Assurance Project Plan Addendum: WSDOT Stormwater Management Program Monitoring Site Information. Prepared for Washington State Department of Transportation by Herrera Environmental Consultants, Inc., Seattle, Washington.

Herrera. 2007d. Addendum for 2005/2006 Sampling Season: WSDOT Stormwater Characterization/Water Quality Management Effectiveness Monitoring. Prepared for Washington State Department of Transportation by Herrera Environmental Consultants, Inc., Seattle, Washington.

Herrera. 2007e. Addendum for 2006/2007 Sampling Season: WSDOT Stormwater Characterization/Water Quality Management Effectiveness Monitoring. Prepared for Washington State Department of Transportation by Herrera Environmental Consultants, Inc., Seattle, Washington.

Herrera. 2007f. Quality Assurance Project Plan – Effectiveness Monitoring of WSDOT Stormwater Management Program During Water Year 2008 and 2009. Prepared for Washington State Department of Transportation by Herrera Environmental Consultants Inc., Seattle, Washington.

Herrera. 2007g. Water Year 2006 Data Report: Compost-Amended Vegetated Filter Strip Performance Monitoring Project. Prepared for Washington State Department of Transportation by Herrera Environmental Consultants, Inc., Seattle, Washington.

Herrera. 2008a. Highway Runoff Dilution and Loading Model User's Guide: ESA Highway Stormwater Runoff Effects Analysis. Prepared for Washington State Department of Transportation by Herrera Environmental Consultants, Inc., Seattle, Washington. August 2008.

Herrera. 2008b. Water Year 2007 Data Report: Compost-Amended Vegetated Filter Strip Performance Monitoring Project. (Draft). Prepared for Washington State Department of Transportation by Herrera Environmental Consultants, Inc., Seattle, Washington

Pacific EcoRisk. 2008. White Paper: Potential Effects of Highway Runoff on Priority Fish Species in Western Washington. Prepared for the Washington State Department of Transportation by Pacific EcoRisk, Fairfield, California.

Taylor Associates. 2001. SR 167 Ecology Embankment Monitoring Project Quality Assurance Project Plan (QAPP). Prepared for Washington State Department of Ecology by Taylor Associates Inc., Seattle, Washington.

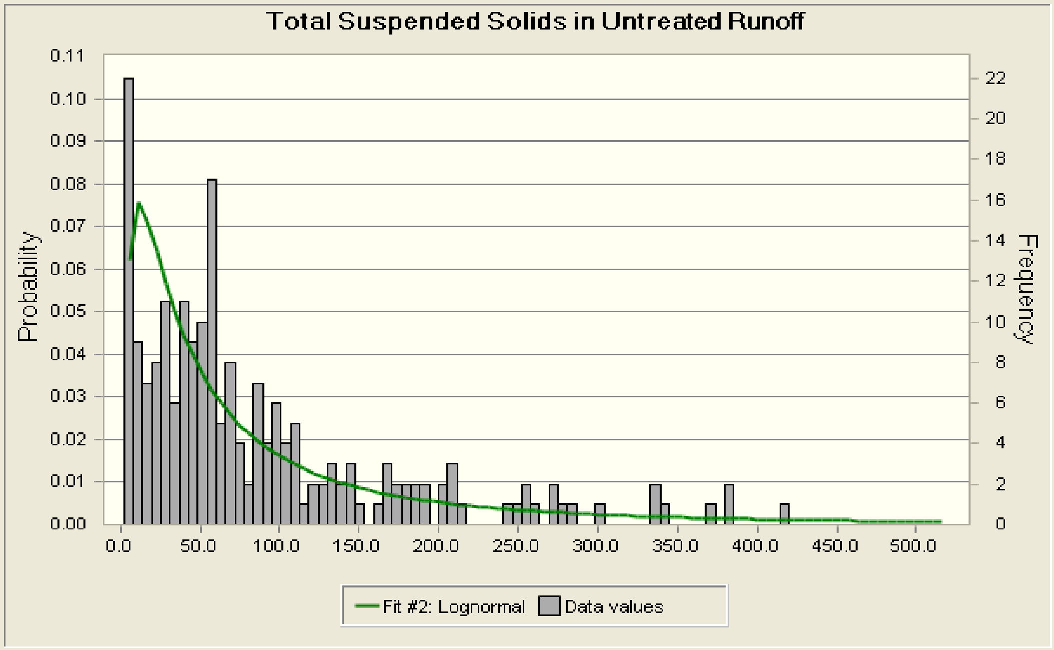
Taylor Associates. 2002. SR 167 Ecology Embankment Monitoring Project Final Report. Prepared for Washington State Department of Ecology by Taylor Associates Inc., Seattle, Washington.

WSDOT. 2007. 2007 Stormwater Report. Washington Department of Transportation, Olympia, Washington.

WSDOT. 2008. BA Writers Guidance for Preparing the Stormwater Section of Biological Assessments. Washington State Department of Transportation, Olympia, Washington. January 2008.

APPENDIX A

Histograms for Water Quality Data Used as Input to the Highway Runoff Dilution and Loading Model

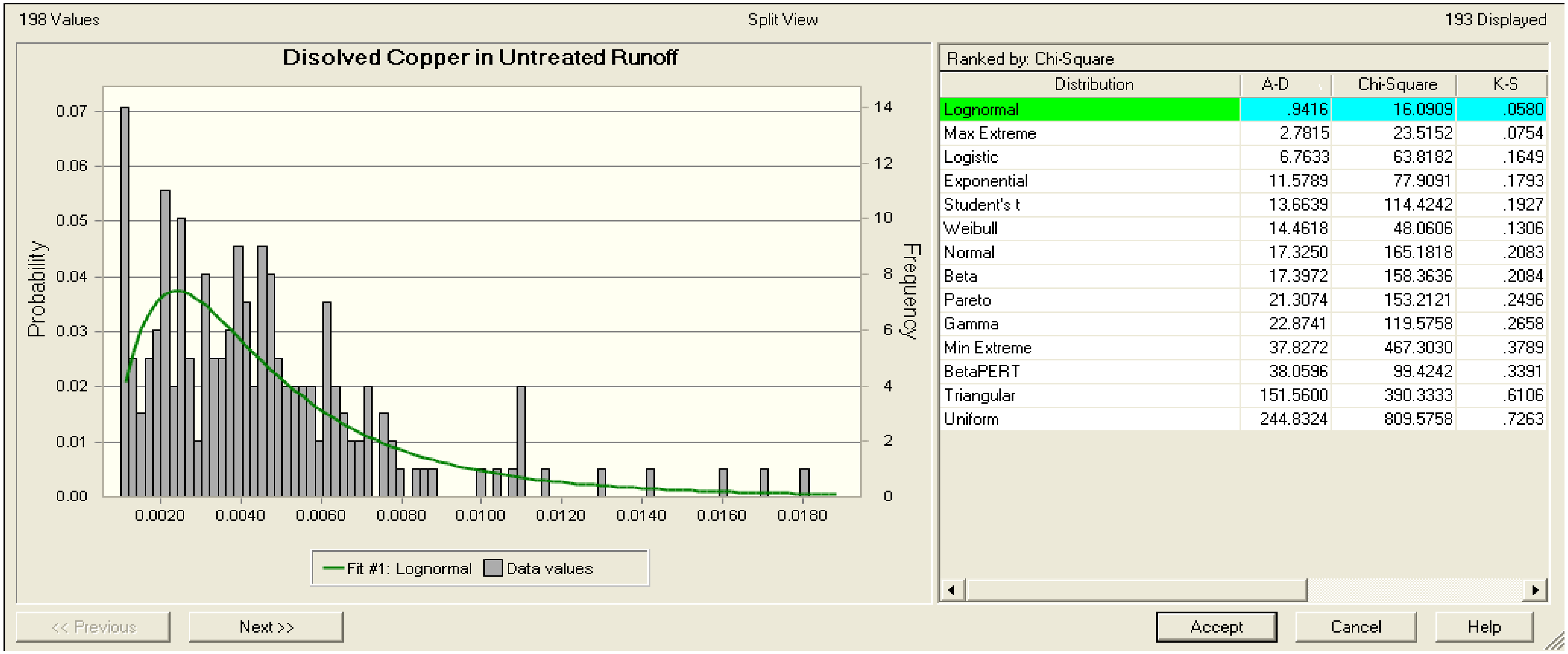


Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Gamma	1.8965	29.5714	.0741
Lognormal	2.4700	26.2857	.0928
Exponential	2.8425	18.0000	.0982
Weibull	3.1878	35.7143	.1151
Max Extreme	7.2991	69.2857	.1480
Logistic	11.7302	138.4286	.2277
Student's t	17.5995	169.8571	.2201
Normal	21.1269	211.0000	.2404
Beta	21.1929	211.0000	.2406
Pareto	33.6116	283.0000	.3193
Min Extreme	40.1869	604.1429	.3969
BetaPERT	67.4482	155.8571	.3845
Triangular	201.5093	564.8571	.5973
Uniform	301.5841	1,127.7143	.7187

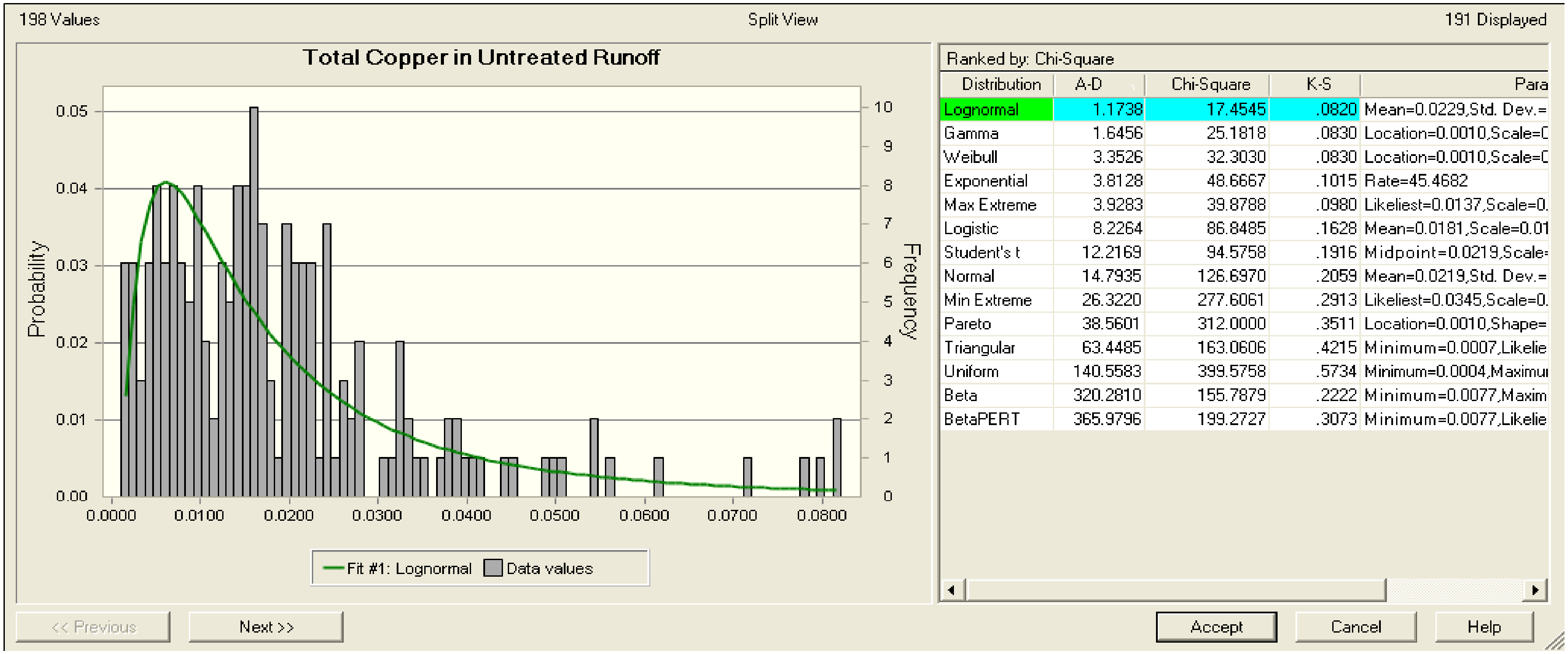
<< Previous | Next >> | Accept | Cancel | Help

Figure A1. Histograph and distribution goodness-of-fit analysis results for total suspended solids concentrations in untreated runoff.



Distribution	A-D	Chi-Square	K-S
Lognormal	.9416	16.0909	.0580
Max Extreme	2.7815	23.5152	.0754
Logistic	6.7633	63.8182	.1649
Exponential	11.5789	77.9091	.1793
Student's t	13.6639	114.4242	.1927
Weibull	14.4618	48.0606	.1306
Normal	17.3250	165.1818	.2083
Beta	17.3972	158.3636	.2084
Pareto	21.3074	153.2121	.2496
Gamma	22.8741	119.5758	.2658
Min Extreme	37.8272	467.3030	.3789
BetaPERT	38.0596	99.4242	.3391
Triangular	151.5600	390.3333	.6106
Uniform	244.8324	809.5758	.7263

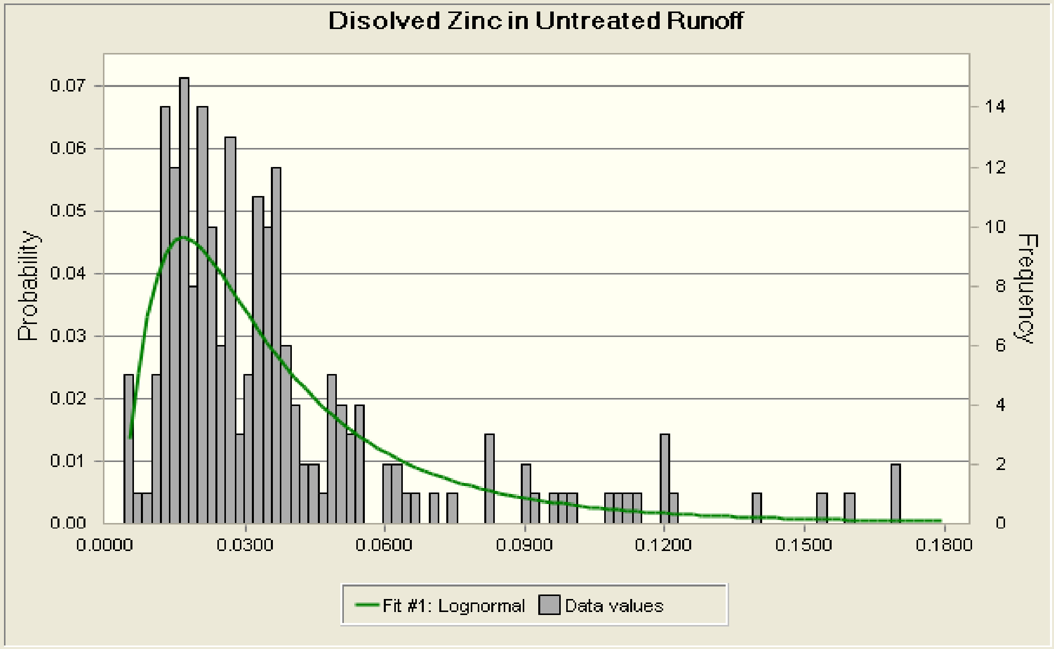
Figure A2. Histograph and distribution goodness-of-fit analysis results for dissolved copper concentrations in untreated runoff.



Distribution	A-D	Chi-Square	K-S	Para
Lognormal	1.1738	17.4545	.0820	Mean=0.0229,Std. Dev.=
Gamma	1.6456	25.1818	.0830	Location=0.0010,Scale=[
Weibull	3.3526	32.3030	.0830	Location=0.0010,Scale=[
Exponential	3.8128	48.6667	.1015	Rate=45.4682
Max Extreme	3.9283	39.8788	.0980	Likeliest=0.0137,Scale=0.
Logistic	8.2264	86.8485	.1628	Mean=0.0181,Scale=0.01
Student's t	12.2169	94.5758	.1916	Midpoint=0.0219,Scale=
Normal	14.7935	126.6970	.2059	Mean=0.0219,Std. Dev.=
Min Extreme	26.3220	277.6061	.2913	Likeliest=0.0345,Scale=0.
Pareto	38.5601	312.0000	.3511	Location=0.0010,Shape=
Triangular	63.4485	163.0606	.4215	Minimum=0.0007,Likelie
Uniform	140.5583	399.5758	.5734	Minimum=0.0004,Maximu
Beta	320.2810	155.7879	.2222	Minimum=0.0077,Maxim
BetaPERT	365.9796	199.2727	.3073	Minimum=0.0077,Likelie

Figure A3. Histograph and distribution goodness-of-fit analysis results for total copper concentrations in untreated runoff.

210 Values | Split View | 206 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Lognormal	1.7139	28.8571	.0875
Gamma	4.8252	51.4286	.1361
Max Extreme	8.2524	78.7143	.1529
Exponential	10.1274	90.7143	.1887
Weibull	12.5370	94.1429	.2198
Logistic	13.4773	125.4286	.2074
Student's t	20.0645	238.7143	.2579
Normal	23.7964	318.7143	.2459
Pareto	38.5480	254.8571	.3638
Min Extreme	45.2154	743.8571	.4089
Triangular	204.5724	664.4286	.6500
Beta	214.7155	113.7143	.1762
Uniform	308.0454	1,183.2857	.7363
BetaPERT	881.7020	2,680.4286	.8992

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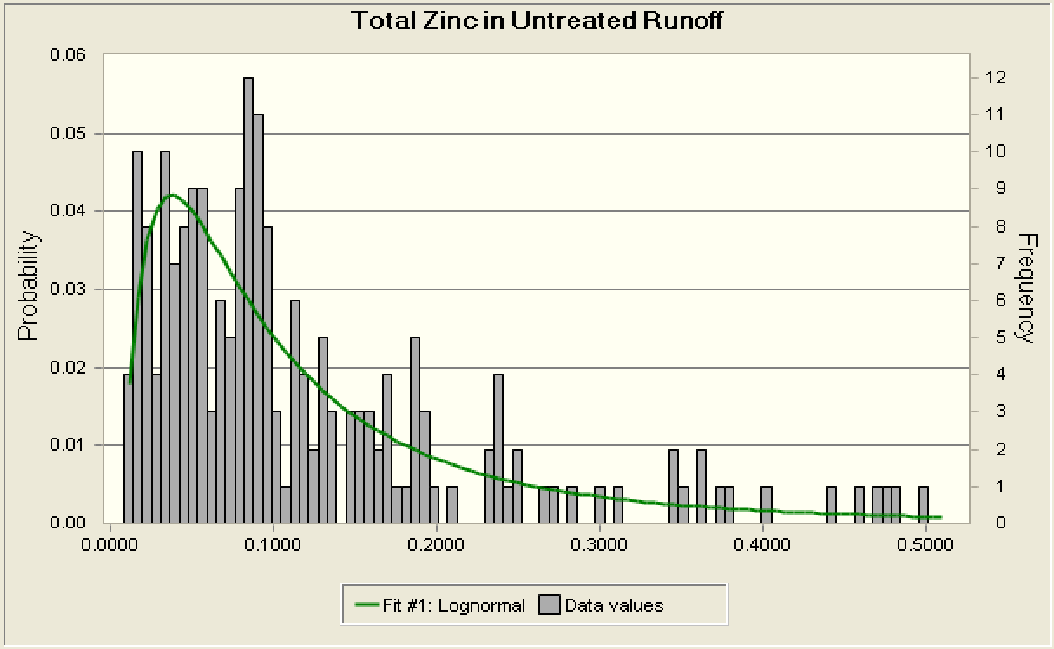
Figure A4. Histograph and distribution goodness-of-fit analysis results for dissolved zinc concentrations in untreated runoff.

210 Values | Split View | 202 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Lognormal	.4477	21.4286	.0473
Gamma	1.5459	26.2857	.0853
Weibull	1.8792	24.1429	.0664
Exponential	3.3963	34.2857	.0831
Max Extreme	6.7312	67.7143	.1425
Logistic	11.0725	137.0000	.1865
Normal	16.5821	177.0000	.1972
Student's t	17.1571	208.4286	.2115
Min Extreme	25.5157	347.1429	.2784
Pareto	35.0092	241.7143	.3114
Triangular	50.5959	148.5714	.3472
Uniform	124.7596	339.8571	.5212
Beta	224.0210	120.8571	.1810
BetaPERT	247.6790	148.1429	.2221

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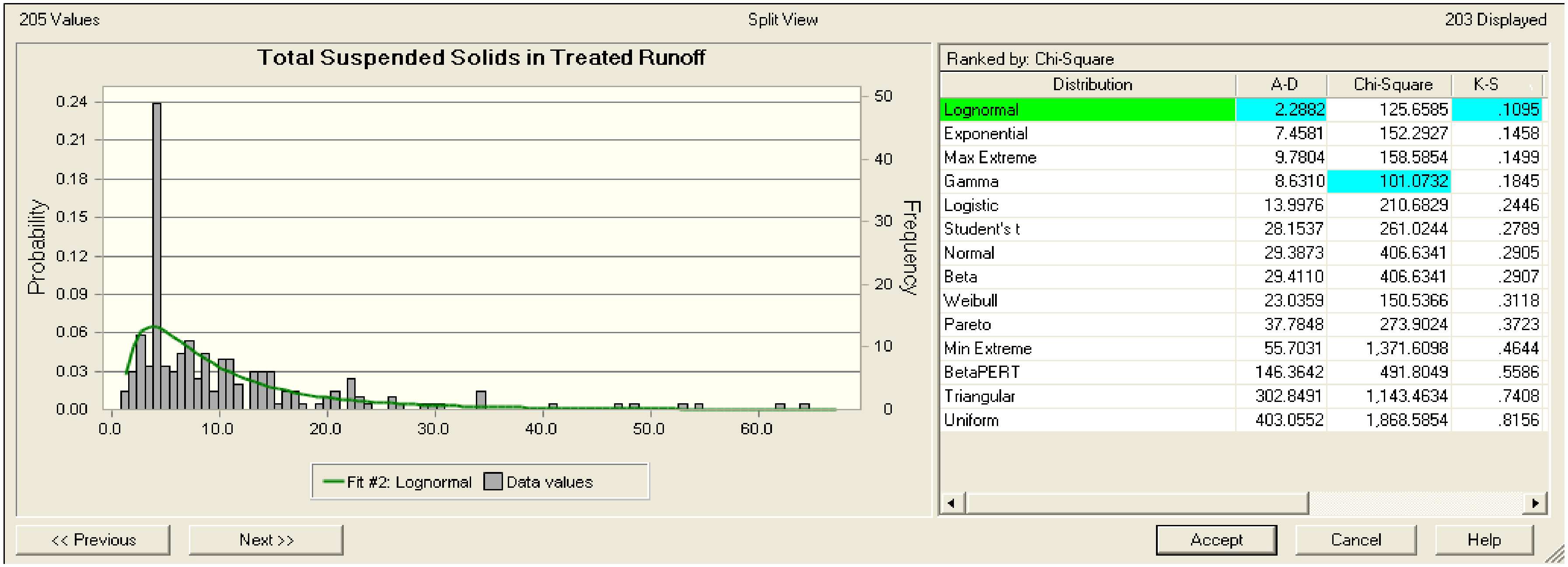
Figure A5. Histograph and distribution goodness-of-fit analysis results for total zinc concentrations in untreated runoff.



Distribution	A-D	Chi-Square	K-S
Lognormal	2.2882	125.6585	.1095
Exponential	7.4581	152.2927	.1458
Max Extreme	9.7804	158.5854	.1499
Gamma	8.6310	101.0732	.1845
Logistic	13.9976	210.6829	.2446
Student's t	28.1537	261.0244	.2789
Normal	29.3873	406.6341	.2905
Beta	29.4110	406.6341	.2907
Weibull	23.0359	150.5366	.3118
Pareto	37.7848	273.9024	.3723
Min Extreme	55.7031	1,371.6098	.4644
BetaPERT	146.3642	491.8049	.5586
Triangular	302.8491	1,143.4634	.7408
Uniform	403.0552	1,868.5854	.8156

Figure A6. Histograph and distribution goodness-of-fit analysis results for total suspended solids concentrations in treated runoff.

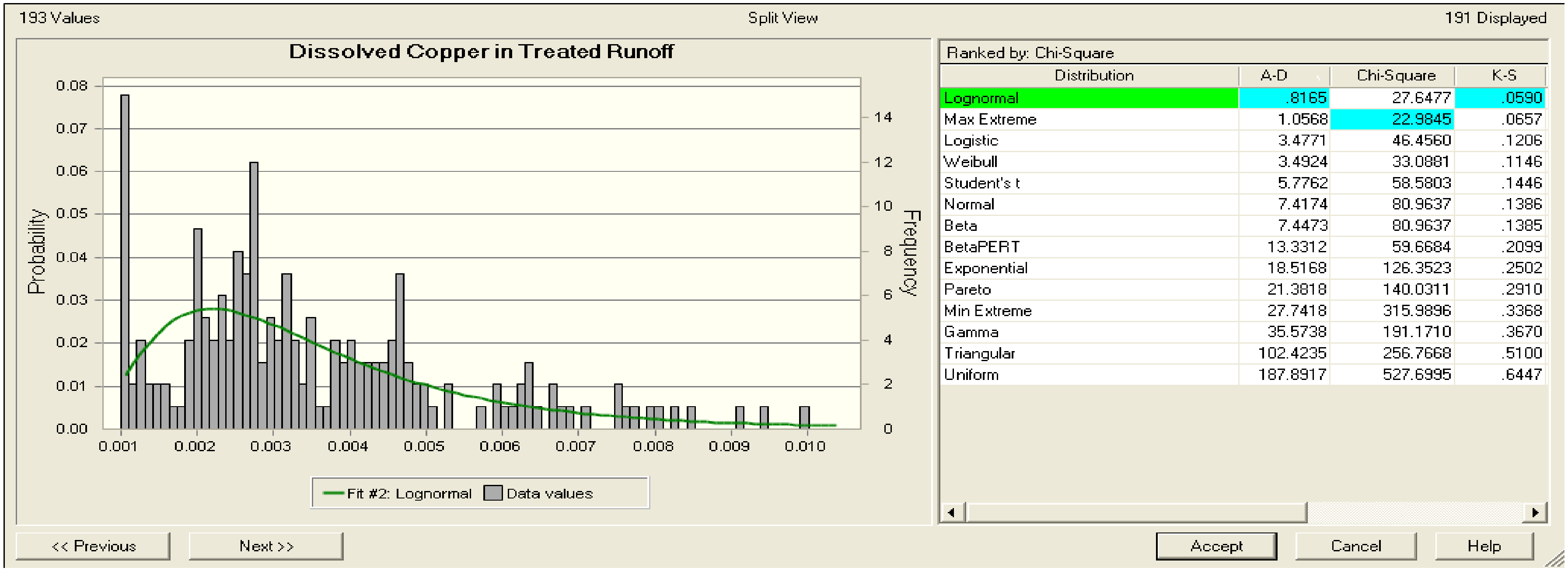
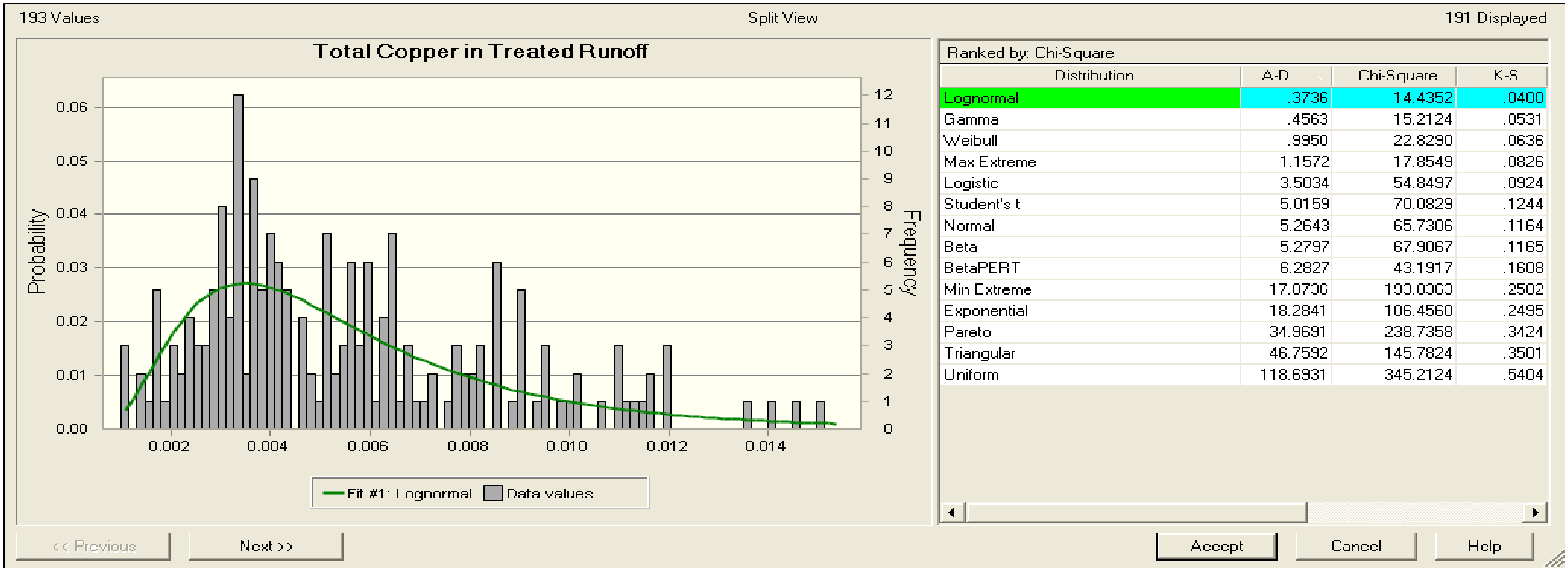


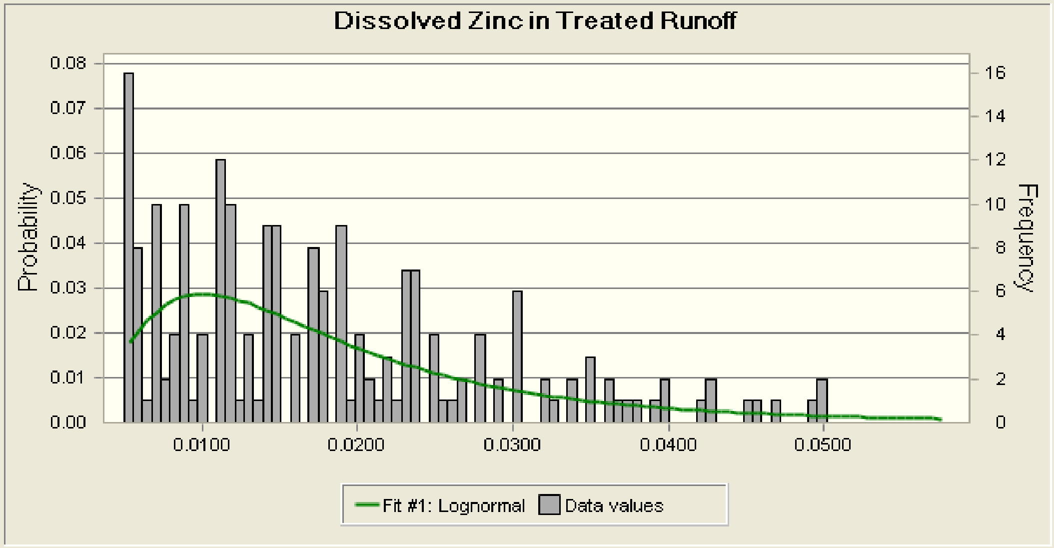
Figure A7. Histograph and distribution goodness-of-fit analysis results for dissolved copper concentrations in treated runoff



Distribution	A-D	Chi-Square	K-S
Lognormal	.3736	14.4352	.0400
Gamma	.4563	15.2124	.0531
Weibull	.9950	22.8290	.0636
Max Extreme	1.1572	17.8549	.0826
Logistic	3.5034	54.8497	.0924
Student's t	5.0159	70.0829	.1244
Normal	5.2643	65.7306	.1164
Beta	5.2797	67.9067	.1165
BetaPERT	6.2827	43.1917	.1608
Min Extreme	17.8736	193.0363	.2502
Exponential	18.2841	106.4560	.2495
Pareto	34.9691	238.7358	.3424
Triangular	46.7592	145.7824	.3501
Uniform	118.6931	345.2124	.5404

Figure A8. Histograph and distribution goodness-of-fit analysis results for total copper concentrations in treated runoff

205 Values | Split View | 200 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Lognormal	.6239	8.1463	.0439
Weibull	2.1521	15.0244	.0585
Max Extreme	2.0185	59.8049	.0780
Beta	89.9421	35.3659	.1171
Student's t	6.8367	58.7805	.1398
Normal	7.7541	101.2195	.1495
Logistic	4.5451	80.1463	.1514
Exponential	13.0164	79.7073	.2270
Pareto	14.7844	108.9756	.2281
Gamma	20.5830	88.6341	.2481
Min Extreme	19.6367	243.3171	.2774
Triangular	52.3399	113.6585	.3366
BetaPERT	194.2828	240.8293	.4608
Uniform	127.3810	296.0000	.5187

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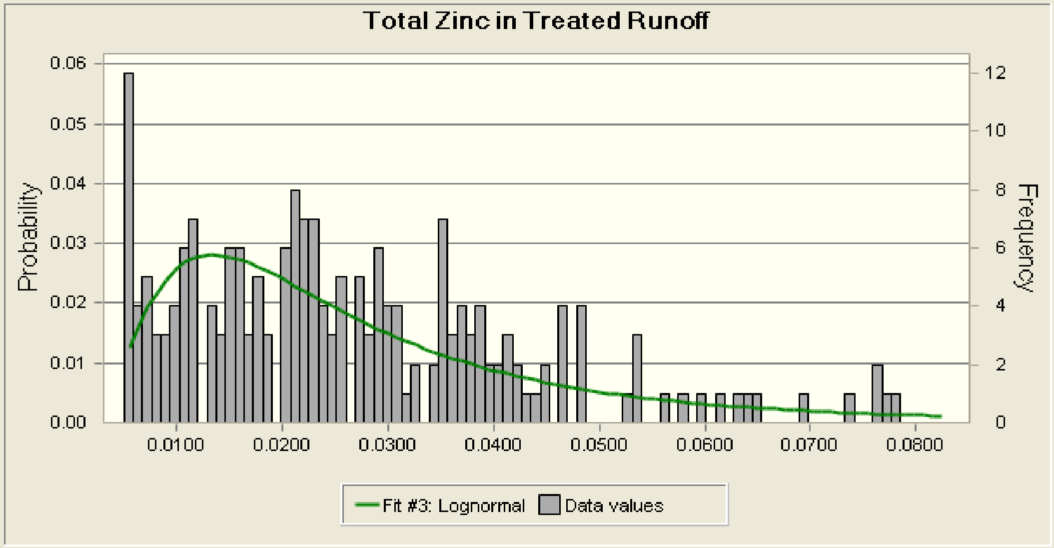
Figure A9. Histograph and distribution goodness-of-fit analysis results for dissolved zinc concentrations in treated runoff.

205 Values | Split View | 200 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Max Extreme	.9482	7.4146	.0504
Weibull	1.0356	16.1951	.0622
Lognormal	1.2155	17.2195	.0759
Logistic	3.0539	36.8293	.1191
Student's t	5.0021	47.6585	.1197
Normal	5.4152	55.2683	.1160
Exponential	11.1531	62.4390	.1611
Min Extreme	15.4110	138.0976	.2358
Beta	16.4546	17.8049	.0646
Gamma	17.8554	83.9512	.2212
Pareto	24.0094	189.4634	.2662
Triangular	35.7735	82.9268	.3035
BetaPERT	62.6466	105.4634	.3461
Uniform	105.7696	247.5610	.5007

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Figure A10. Histograph and distribution goodness-of-fit analysis results for total zinc concentrations in treated runoff.

APPENDIX B

Summary Statistics for Water Quality Data Used as Input to the Highway Runoff Dilution and Loading Model

Table B1. Summary statistics for total suspended solids data used as input to the Highway Runoff Dilution and Loading Model.

	Total Suspended Solids	
	Untreated Runoff	Treated Runoff
n	**210**	**205**
Percent detected	**93.8%**	**81.0%**
Mean (mg/L)	106.4	11.8
Standard Deviation (mg/L)	149.8	21.7
Coefficient of Variation	1.41	1.83
Lower 95% Confidence Limit about Mean (mg/L)	86.1	8.9
Upper 95% Confidence Limit about Mean (mg/L)	126.6	14.8
25th percentile (mg/L)	**28.3**	3.5
50th percentile (mg/L)	**60.0**	6.9
75th percentile (mg/L)	**124.5**	13.7
Inter Quartile Range (mg/L)	**96.2**	10.2
Minimum Detected Value (mg/L)	**2.3**	**2.0**
Maximum Detected Value (mg/L)	**1246**	**243.0**
Minimum Reporting Limit (mg/L)	**4.0**	**0.8**
Maximum Reporting Limit (mg/L)	**4.0**	**4.0**

Note: Bolded values are exact calculations. Unbolded values are estimated using regression on ordered statistics (ROS).

Table B2. Summary statistics for dissolved copper data used as input to the Highway Runoff Dilution and Loading Model.

	Dissolved Copper	
	Untreated Runoff	Treated Runoff
n	**198**	**193**
Percent detected	**95.5%**	**93.3%**
Mean (mg/L)	0.0051	0.0036
Standard Deviation (mg/L)	0.0050	0.0025
Coefficient of Variation	0.99	0.68
Lower 95% Confidence Limit about Mean (mg/L)	0.0044	0.0033
Upper 95% Confidence Limit about Mean (mg/L)	0.0058	0.0040
25th percentile (mg/L)	**0.0024**	**0.0022**
50th percentile (mg/L)	**0.0041**	**0.0031**
75th percentile (mg/L)	**0.0060**	**0.0046**
Inter Quartile Range (mg/L)	**0.0035**	**0.0024**
Minimum Detected Value (mg/L)	**0.0010**	**0.0010**
Maximum Detected Value (mg/L)	**0.0430**	**0.0220**
Minimum Reporting Limit (mg/L)	**0.0010**	**0.0010**
Maximum Reporting Limit (mg/L)	**0.0010**	**0.0010**

Note: Bolded values are exact calculations. Unbolded values are estimated using regression on ordered statistics (ROS).

Table B3. Summary statistics for total copper data used as input to the Highway Runoff Dilution and Loading Model.

	Total Copper	
	Untreated Runoff	Treated Runoff
n	**198**	**193**
Percent detected	**98.5%**	**99.0%**
Mean (mg/L)	0.0219	0.0057
Standard Deviation (mg/L)	0.0216	0.0035
Coefficient of Variation	0.99	0.61
Lower 95% Confidence Limit about Mean (mg/L)	0.0189	0.0052
Upper 95% Confidence Limit about Mean (mg/L)	0.0249	0.0062
25th percentile (mg/L)	**0.0083**	**0.0033**
50th percentile (mg/L)	**0.0158**	**0.0050**
75th percentile (mg/L)	**0.0245**	**0.0076**
Inter Quartile Range (mg/L)	**0.0162**	**0.0043**
Minimum Detected Value (mg/L)	**0.0011**	**0.0011**
Maximum Detected Value (mg/L)	**0.1200**	**0.0260**
Minimum Reporting Limit (mg/L)	**0.0010**	**0.0010**
Maximum Reporting Limit (mg/L)	**0.0010**	**0.0010**

Note: Bolded values are exact calculations. Unbolded values are estimated using regression on ordered statistics (ROS).

Table B4. Summary statistics for dissolved zinc data used as input to the Highway Runoff Dilution and Loading Model.

	Dissolved Zinc	
	Untreated Runoff	Treated Runoff
n	**210**	**205**
Percent detected	**98.1%**	**95.1%**
Mean (mg/L)	0.042	0.019
Standard Deviation (mg/L)	0.051	0.014
Coefficient of Variation	1.20	0.72
Lower 95% Confidence Limit about Mean (mg/L)	0.035	0.017
Upper 95% Confidence Limit about Mean (mg/L)	0.049	0.021
25th percentile (mg/L)	**0.017**	**0.009**
50th percentile (mg/L)	**0.028**	**0.016**
75th percentile (mg/L)	**0.044**	**0.024**
Inter Quartile Range (mg/L)	**0.027**	**0.015**
Minimum Detected Value (mg/L)	**0.004**	**0.005**
Maximum Detected Value (mg/L)	**0.493**	**0.080**
Minimum Reporting Limit (mg/L)	**0.005**	**0.005**
Maximum Reporting Limit (mg/L)	**0.005**	**0.005**

Note: Bolded values are exact calculations. Unbolded values are estimated using regression on ordered statistics (ROS).

Table B5. Summary statistics for total zinc data used as input to the Highway Runoff Dilution and Loading Model.

	Total Zinc	
	Untreated Runoff	Treated Runoff
n	**210**	**205**
Percent detected	**100.0%**	**96.1%**
Mean (mg/L)	**0.135**	0.028
Standard Deviation (mg/L)	**0.135**	0.020
Coefficient of Variation	**1.00**	0.69
Lower 95% Confidence Limit about Mean (mg/L)	**0.117**	0.026
Upper 95% Confidence Limit about Mean (mg/L)	**0.153**	0.031
25th percentile (mg/L)	**0.049**	**0.015**
50th percentile (mg/L)	**0.088**	**0.024**
75th percentile (mg/L)	**0.164**	**0.037**
Inter Quartile Range (mg/L)	**0.115**	**0.022**
Minimum Detected Value (mg/L)	**0.008**	**0.005**
Maximum Detected Value (mg/L)	**0.630**	**0.115**
Minimum Reporting Limit (mg/L)		**0.005**
Maximum Reporting Limit (mg/L)		**0.005**

Note: Bolded values are exact calculations. Unbolded values are estimated using regression on ordered statistics (ROS).

APPENDIX C

Example Output from MGSFlood Model Runs for Hydrologic Data Preprocessing

Table C1. MGS-Flood model iterations for hydrologic data preprocessing for Highway Runoff Dilution and Loading model.

Precipitation Zone[a]	Infiltration	Detention	Soil Type	Length of Infiltration Trench (ft)[b]	Live Storage Volume (ac-ft)
PugetWest32	None	None	na	na	na
PugetWest32	None	Yes	C/D	na	0.577
PugetWest32	20%	None	na	6.5	na
PugetWest32	20%	Yes	C/D	6.5	0.453
PugetWest32	40%	None	na	17	na
PugetWest32	40%	Yes	C/D	33	0.395
PugetWest32	60%	None	na	33	na
PugetWest32	60%	Yes	C/D	33	0.356
PugetWest32	80%	None	na	63	na
PugetWest32	80%	Yes	C/D	63	0.251
PugetWest44	None	None	na	na	na
PugetWest44	None	Yes	C/D	na	0.529
PugetWest44	20%	None	na	9	na
PugetWest44	20%	Yes	C/D	9	0.465
PugetWest44	40%	None	na	23	na
PugetWest44	40%	Yes	C/D	23	0.424
PugetWest44	60%	None	na	45	na
PugetWest44	60%	Yes	C/D	45	0.329
PugetWest44	80%	None	na	85	na
PugetWest44	80%	Yes	C/D	85	0.241
PugetWest60	None	None	na	na	na
PugetWest60	None	Yes	C/D	na	0.6
PugetWest60	20%	None	na	12	na
PugetWest60	20%	Yes	C/D	12	0.585
PugetWest60	40%	None	na	32	na
PugetWest60	40%	Yes	C/D	32	0.482
PugetWest60	60%	None	na	59	na
PugetWest60	60%	Yes	C/D	59	0.388
PugetWest60	80%	None	na	92	na
PugetWest60	80%	Yes	C/D	92	0.29
PugetEast24	None	None	na	na	na
PugetEast24	None	Yes	C/D	na	0[c]
PugetEast24	20%	None	na	4.9	na
PugetEast24	20%	Yes	C/D	na	0[c]
PugetEast24	40%	None	na	13	na
PugetEast24	40%	Yes	C/D	13	0[c]
PugetEast24	60%	None	na	26	na
PugetEast24	60%	Yes	C/D	26	0.333
PugetEast24	80%	None	na	50	na
PugetEast24	80%	Yes	C/D	50	0.116
PugetEast32	None	None	na	na	na
PugetEast32	None	Yes	C/D	na	0.738
PugetEast32	20%	None	na	5.8	na
PugetEast32	20%	Yes	C/D	5.8	0.44
PugetEast32	40%	None	na	15	na
PugetEast32	40%	Yes	C/D	15	0.314
PugetEast32	60%	None	na	30	na
PugetEast32	60%	Yes	C/D	30	0.242
PugetEast32	80%	None	na	55	na
PugetEast32	80%	Yes	C/D	55	0.206

Table C1 (continued). MGS-Flood model iterations for hydrologic data preprocessing for Highway Runoff Dilution and Loading model.

Precipitation Zone[a]	Infiltration	Detention	Soil Type	Length of Infiltration Trench (ft)[b]	Live Storage Volume (ac-ft)
PugetEast 60	None	None	na	na	na
PugetEast 60	None	Yes	C/D	na	0.615
PugetEast 60	20%	None	na	11	na
PugetEast 60	20%	Yes	C/D	11	0.439
PugetEast 60	40%	None	na	30	na
PugetEast 60	40%	Yes	C/D	30	0.357
PugetEast 60	60%	None	na	57	na
PugetEast 60	60%	Yes	C/D	57	0.282
PugetEast 60	80%	None	na	100	na
PugetEast 60	80%	Yes	C/D	100	0.223
Vancouver 40	None	None	na	na	na
Vancouver 40	None	Yes	C/D	na	0.565
Vancouver 40	20%	None	na	7.5	na
Vancouver 40	20%	Yes	C/D	7.5	0.449
Vancouver 40	40%	None	na	20	na
Vancouver 40	40%	Yes	C/D	20	0.388
Vancouver 40	60%	None	na	39	na
Vancouver 40	60%	Yes	C/D	39	0.359
Vancouver 40	80%	None	na	72	na
Vancouver 40	80%	Yes	C/D	72	0.216
Vancouver 48	None	None	na	na	na
Vancouver 48	None	Yes	C/D	na	0.569
Vancouver 48	20%	None	na	9	na
Vancouver 48	20%	Yes	C/D	9	0.457
Vancouver 48	40%	None	na	24	na
Vancouver 48	40%	Yes	C/D	24	0.389
Vancouver 48	60%	None	na	46	na
Vancouver 48	60%	Yes	C/D	46	0.306
Vancouver 48	80%	None	na	86	na
Vancouver 48	80%	Yes	C/D	86	0.221
Vancouver 60	None	None	na	na	na
Vancouver 60	None	Yes	C/D	na	0.597
Vancouver 60	20%	None	na	11.5	na
Vancouver 60	20%	Yes	C/D	11.5	0.551
Vancouver 60	40%	None	na	30	na
Vancouver 60	40%	Yes	A/B		
Vancouver 60	40%	Yes	C/D	30	0.475
Vancouver 60	60%	None	na	57	na
Vancouver 60	60%	Yes	C/D	57	0.346
Vancouver 60	80%	None	na	100	na
Vancouver 60	80%	Yes	C/D	100	0.274

Notes

na Not Applicable

a - Puget East 60 represents MGS Flood Puget East extended precipitation time zone with 60 inches of mean annual precipitation.

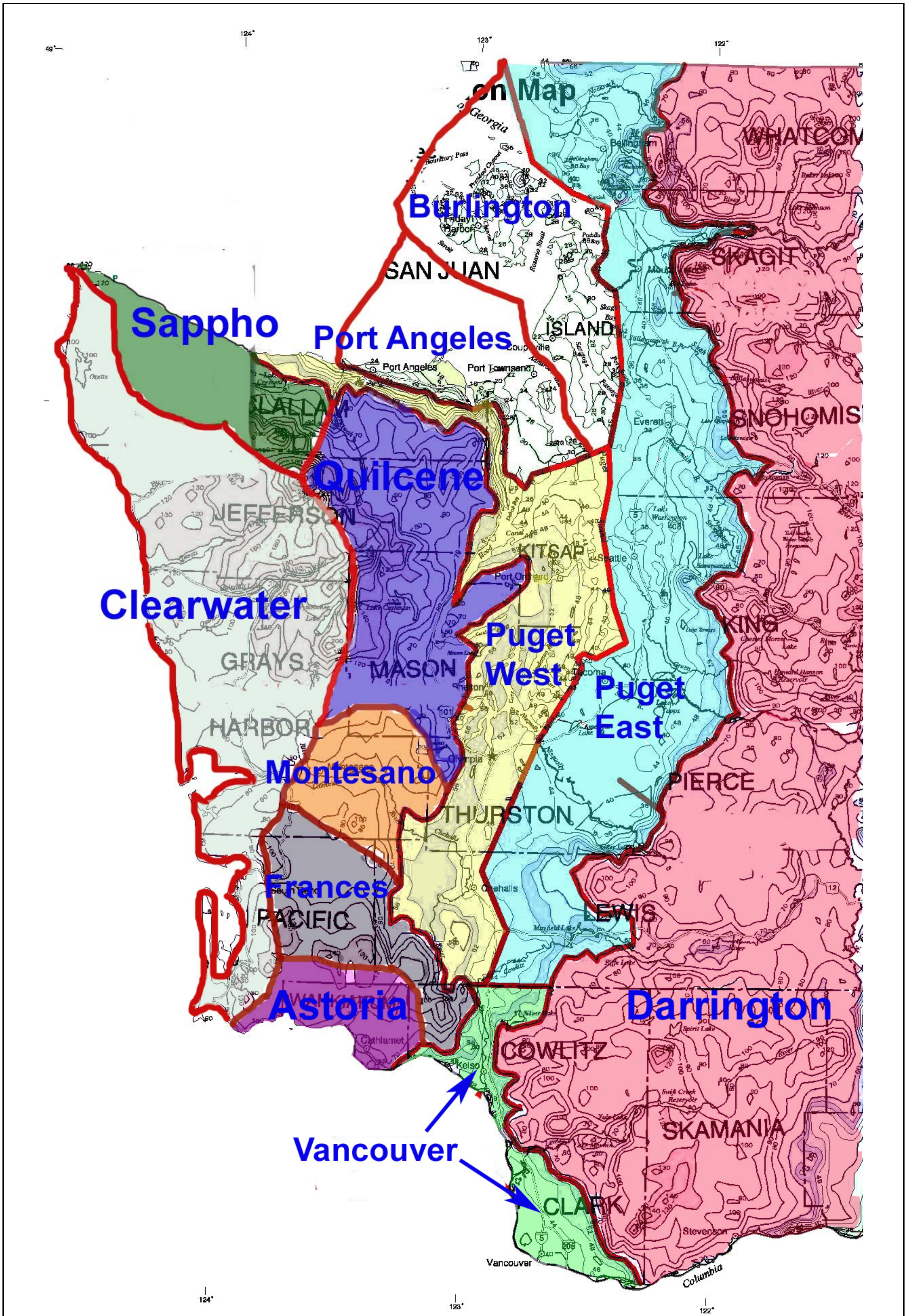
b - Infiltration trench sizing parameters:

Depth	4	ft
Width	4	ft
Porosity	40	%
Hydraulic Conductivity	2	inch/hour
Length	varies	
Depth to Water Table	100	ft

c - Detention sizing routine did not converge. Duration values set equal to corresponding values for Puget East 32 simulation results.

APPENDIX D

Extended Precipitation Time Series Zones Used by MGSFlood in Western Washington


Burlington
SAN JUAN
ISLAND
WHATCOM
SKAGIT
Sappho
Port Angeles
Port Angeles
Port Townsend
CLALLAM
SNOHOMISH
Everett
Quilcene
JEFFERSON
KITSAP
Seattle
Clearwater
KING
Puget
West
GRAYS
MASON
Puget
East
HARBOR
Montesano
PIERCE
THURSTON
Frances
PACIFIC
LEWIS
Astoria
Darrington
COWLITZ
Kelso
SKAMANIA
Vancouver
CLARK
Vancouver
Stevenson
Columbia

APPENDIX E

Example Histograms for Discharge Data Used as Input to the Highway Runoff Dilution and Loading Model

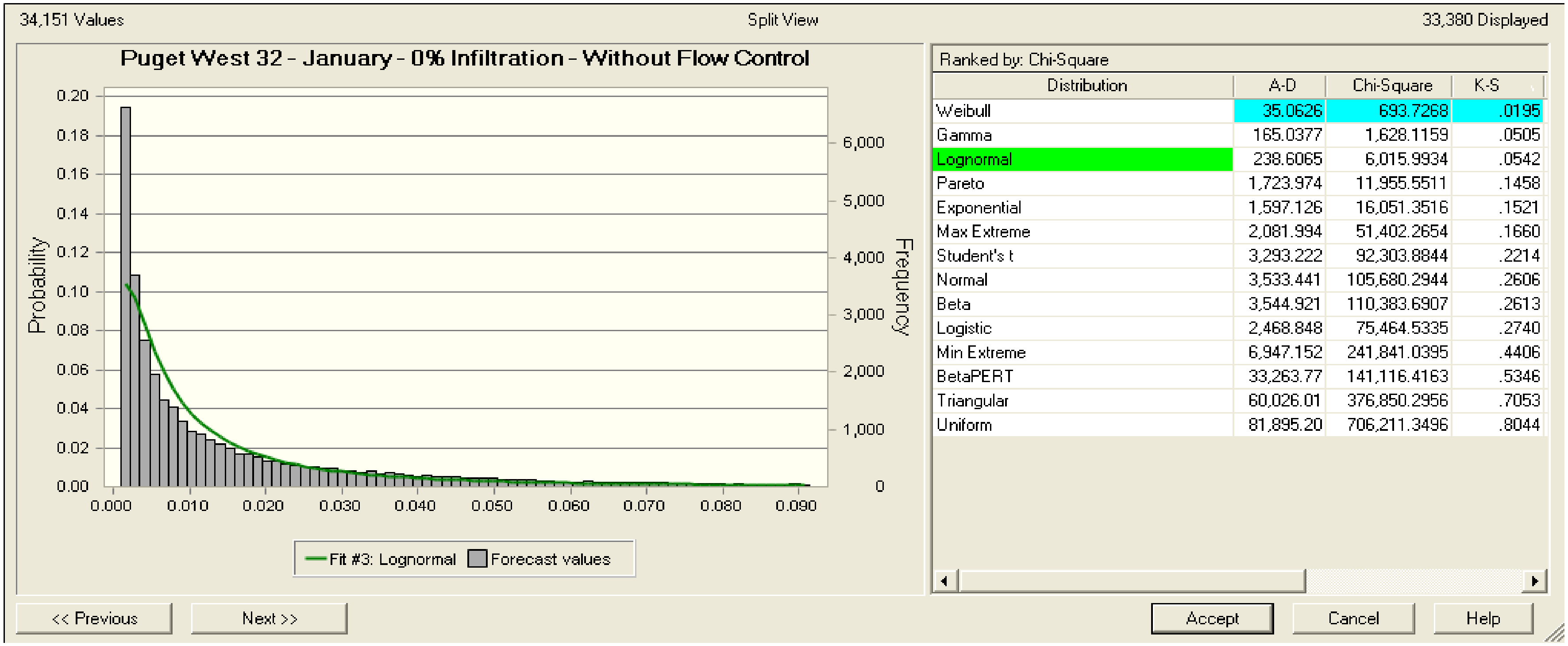
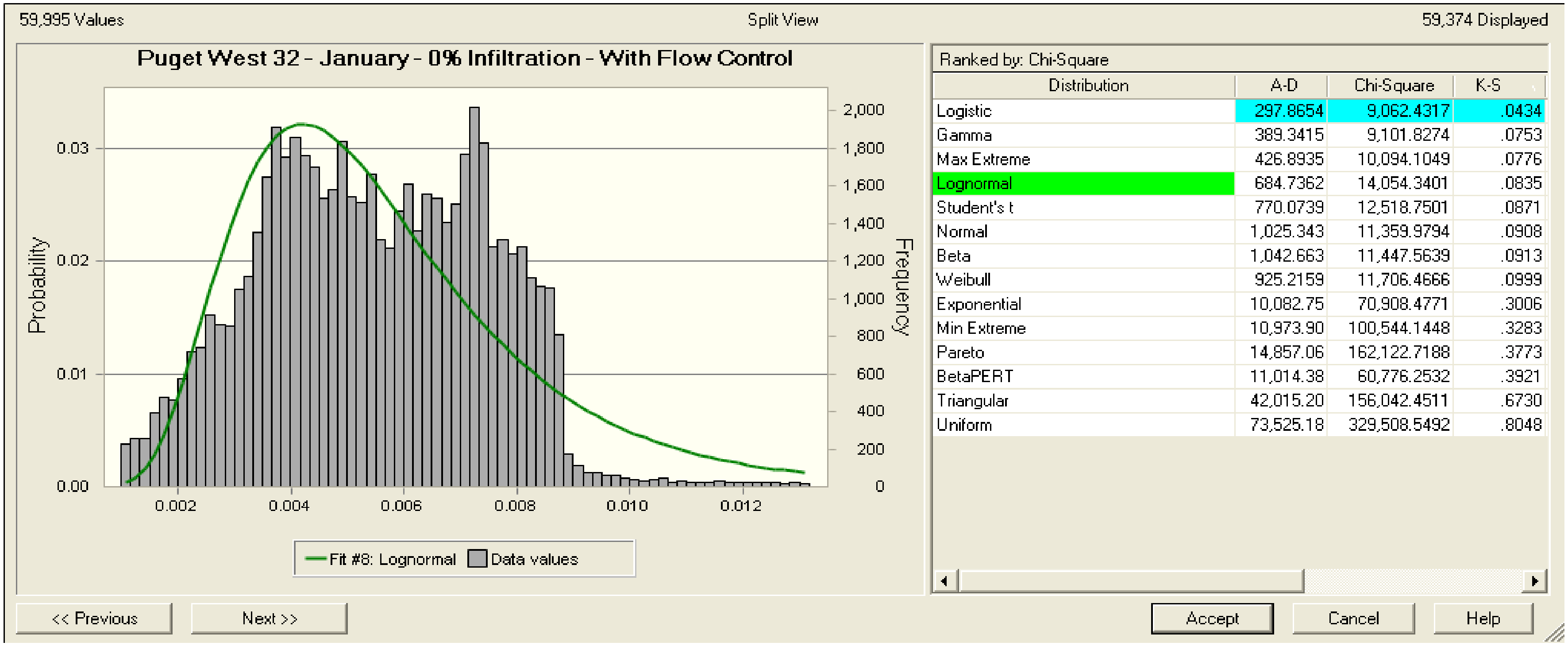
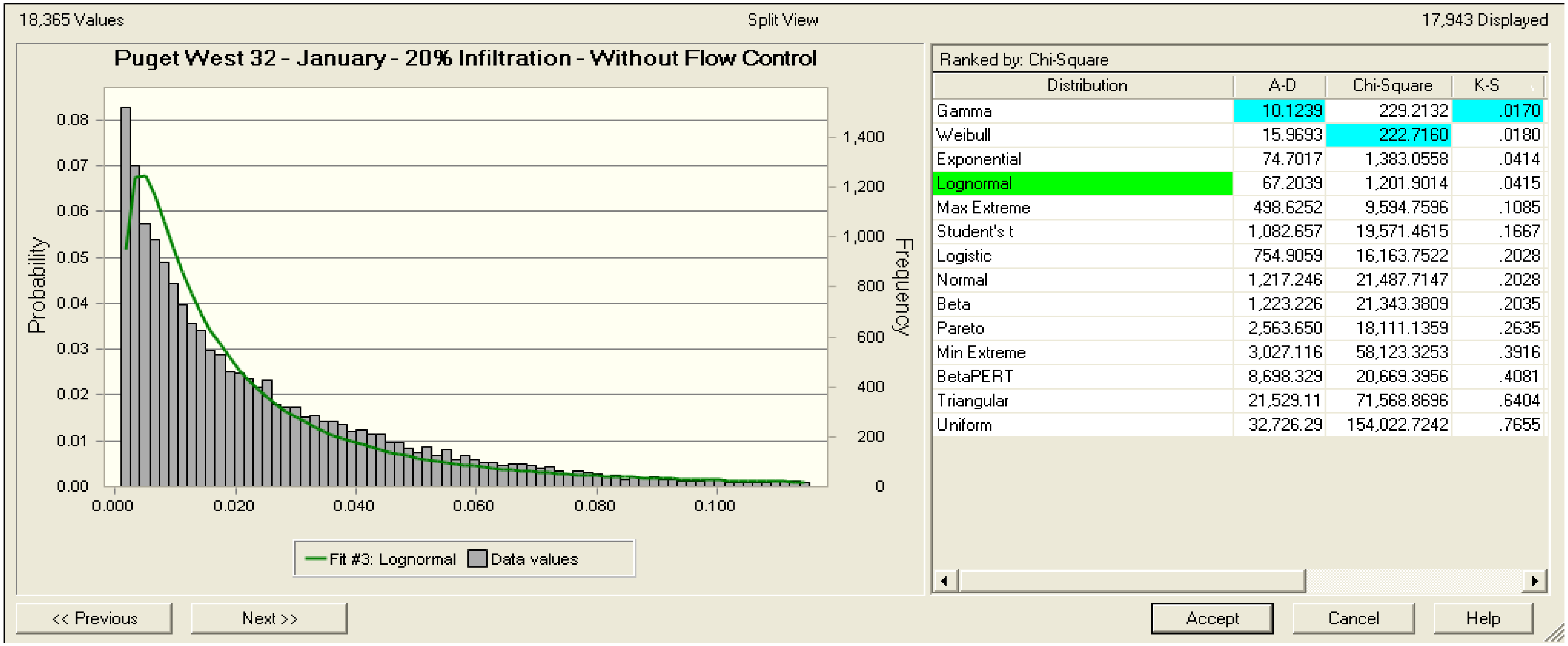


Figure E1. Histograph and distribution goodness-of-fit analysis results for Puget West 32 discharge data in January without flow control and 0 percent infiltration



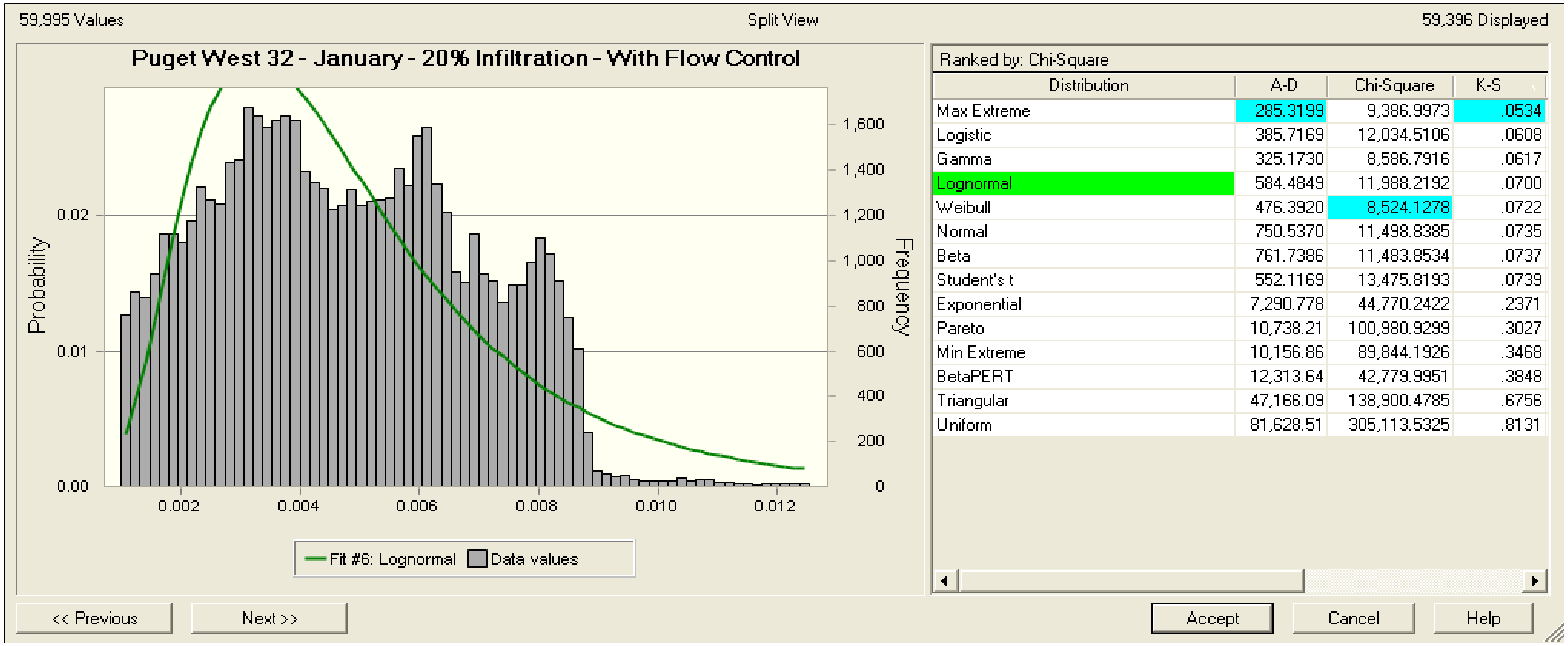
Distribution	A-D	Chi-Square	K-S
Logistic	297.8654	9,062.4317	.0434
Gamma	389.3415	9,101.8274	.0753
Max Extreme	426.8935	10,094.1049	.0776
Lognormal	684.7362	14,054.3401	.0835
Student's t	770.0739	12,518.7501	.0871
Normal	1,025.343	11,359.9794	.0908
Beta	1,042.663	11,447.5639	.0913
Weibull	925.2159	11,706.4666	.0999
Exponential	10,082.75	70,908.4771	.3006
Min Extreme	10,973.90	100,544.1448	.3283
Pareto	14,857.06	162,122.7188	.3773
BetaPERT	11,014.38	60,776.2532	.3921
Triangular	42,015.20	156,042.4511	.6730
Uniform	73,525.18	329,508.5492	.8048

Figure E2. Histograph and distribution goodness-of-fit analysis results for Puget West 32 discharge data in January with flow control and 0 percent infiltration



Distribution	A-D	Chi-Square	K-S
Gamma	10.1239	229.2132	.0170
Weibull	15.9693	222.7160	.0180
Exponential	74.7017	1,383.0558	.0414
Lognormal	67.2039	1,201.9014	.0415
Max Extreme	498.6252	9,594.7596	.1085
Student's t	1,082.657	19,571.4615	.1667
Logistic	754.9059	16,163.7522	.2028
Normal	1,217.246	21,487.7147	.2028
Beta	1,223.226	21,343.3809	.2035
Pareto	2,563.650	18,111.1359	.2635
Min Extreme	3,027.116	58,123.3253	.3916
BetaPERT	8,698.329	20,669.3956	.4081
Triangular	21,529.11	71,568.8696	.6404
Uniform	32,726.29	154,022.7242	.7655

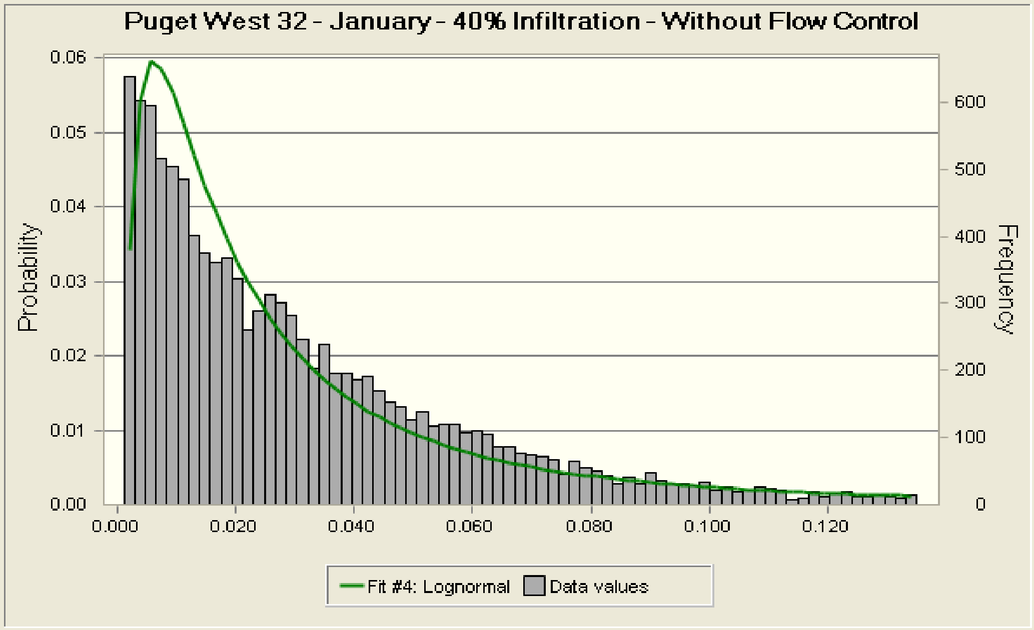
Figure E3. Histograph and distribution goodness-of-fit analysis results for Puget West 32 discharge data in January without flow control and 20 percent infiltration



Distribution	A-D	Chi-Square	K-S
Max Extreme	285.3199	9,386.9973	.0534
Logistic	385.7169	12,034.5106	.0608
Gamma	325.1730	8,586.7916	.0617
Lognormal	584.4849	11,988.2192	.0700
Weibull	476.3920	8,524.1278	.0722
Normal	750.5370	11,498.8385	.0735
Beta	761.7386	11,483.8534	.0737
Student's t	552.1169	13,475.8193	.0739
Exponential	7,290.778	44,770.2422	.2371
Pareto	10,738.21	100,980.9299	.3027
Min Extreme	10,156.86	89,844.1926	.3468
BetaPERT	12,313.64	42,779.9951	.3848
Triangular	47,166.09	138,900.4785	.6756
Uniform	81,628.51	305,113.5325	.8131

Figure E4. Histograph and distribution goodness-of-fit analysis results for Puget West 32 discharge data in January with flow control and 20 percent infiltration

11,095 Values | Split View | 10,837 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Gamma	2.2333	111.7405	.0110
Weibull	10.8951	159.4333	.0205
Exponential	18.2679	445.3513	.0295
Lognormal	57.7232	726.9668	.0557
Max Extreme	210.6554	3,956.1739	.0879
Student's t	535.7589	8,791.5693	.1494
Logistic	364.8536	7,376.6865	.1776
Normal	606.6768	9,564.1735	.1784
Beta	609.9460	9,769.6098	.1790
Pareto	1,938.659	14,901.8059	.2976
BetaPERT	3,123.539	6,599.6954	.3280
Min Extreme	1,597.347	25,173.7346	.3616
Triangular	10,120.69	27,738.4055	.5882
Uniform	16,595.40	62,645.0892	.7275

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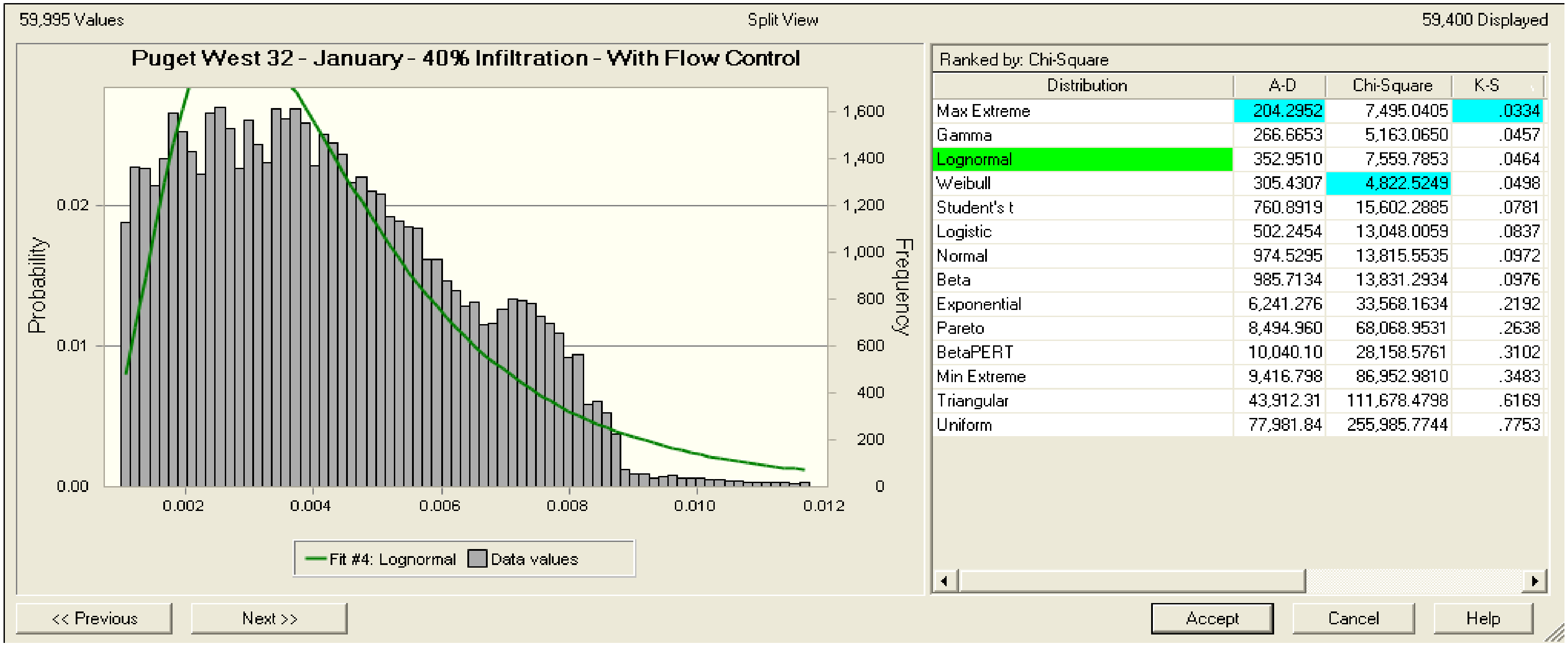
Figure E5. Histograph and distribution goodness-of-fit analysis results for Puget West 30 flow duration data in January without flow control and 40 percent infiltration

59,995 Values | Split View | 59,400 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Max Extreme	204.2952	7,495.0405	.0334
Gamma	266.6653	5,163.0650	.0457
Lognormal	352.9510	7,559.7853	.0464
Weibull	305.4307	4,822.5249	.0498
Student's t	760.8919	15,602.2885	.0781
Logistic	502.2454	13,048.0059	.0837
Normal	974.5295	13,815.5535	.0972
Beta	985.7134	13,831.2934	.0976
Exponential	6,241.276	33,568.1634	.2192
Pareto	8,494.960	68,068.9531	.2638
BetaPERT	10,040.10	28,158.5761	.3102
Min Extreme	9,416.798	86,952.9810	.3483
Triangular	43,912.31	111,678.4798	.6169
Uniform	77,981.84	255,985.7744	.7753

Figure E6. Histograph and distribution goodness-of-fit analysis results for Puget West 32 discharge data in January with flow control and 40 percent infiltration

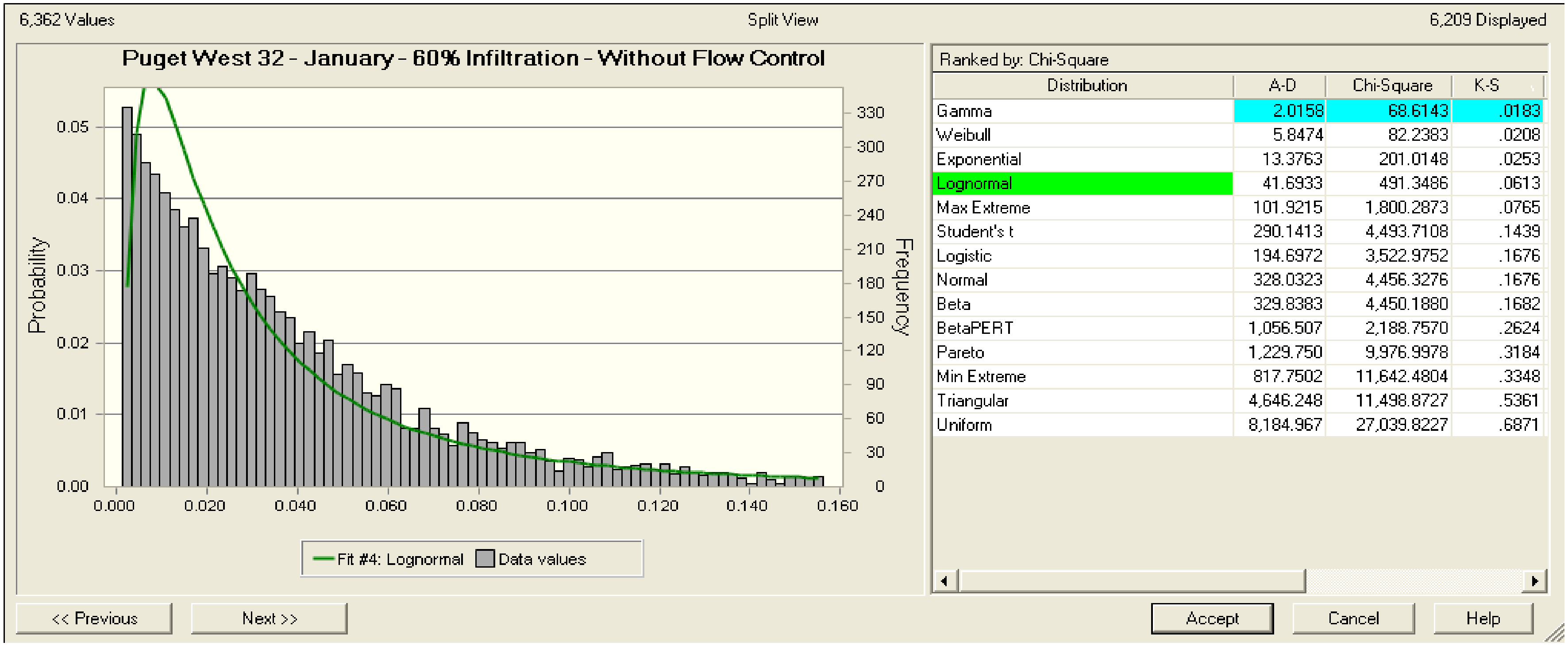
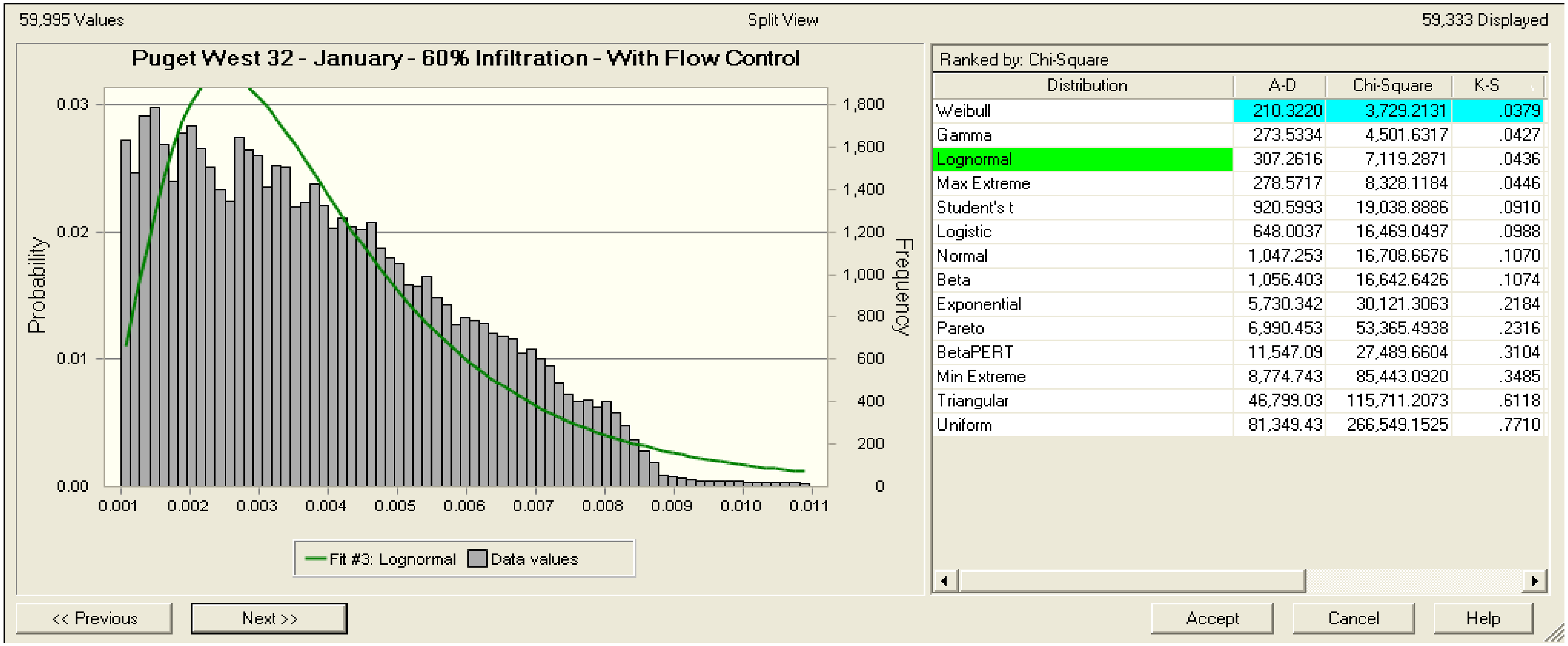
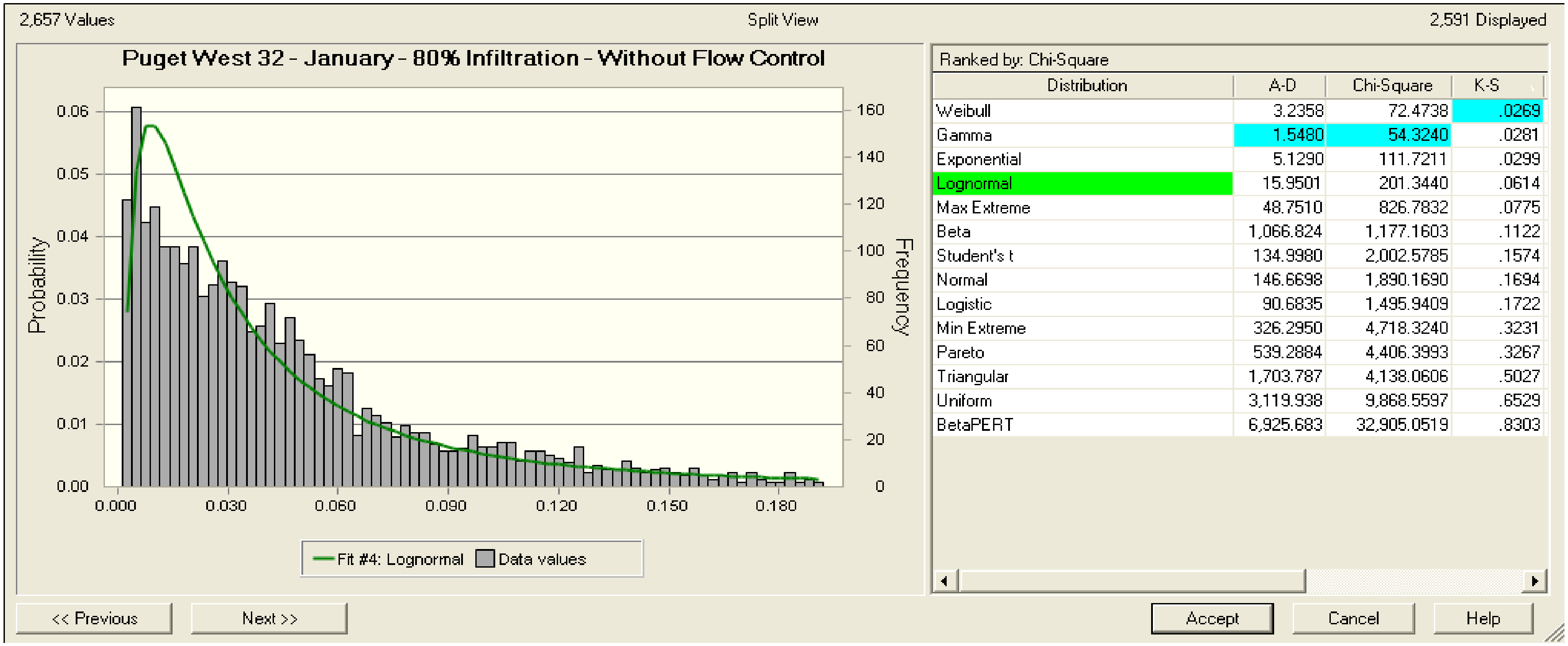


Figure E7. Histograph and distribution goodness-of-fit analysis results for Puget West 32 discharge data in January without flow control and 60 percent infiltration



Distribution	A-D	Chi-Square	K-S
Weibull	210.3220	3,729.2131	.0379
Gamma	273.5334	4,501.6317	.0427
Lognormal	307.2616	7,119.2871	.0436
Max Extreme	278.5717	8,328.1184	.0446
Student's t	920.5993	19,038.8886	.0910
Logistic	648.0037	16,469.0497	.0988
Normal	1,047.253	16,708.6676	.1070
Beta	1,056.403	16,642.6426	.1074
Exponential	5,730.342	30,121.3063	.2184
Pareto	6,990.453	53,365.4938	.2316
BetaPERT	11,547.09	27,489.6604	.3104
Min Extreme	8,774.743	85,443.0920	.3485
Triangular	46,799.03	115,711.2073	.6118
Uniform	81,349.43	266,549.1525	.7710

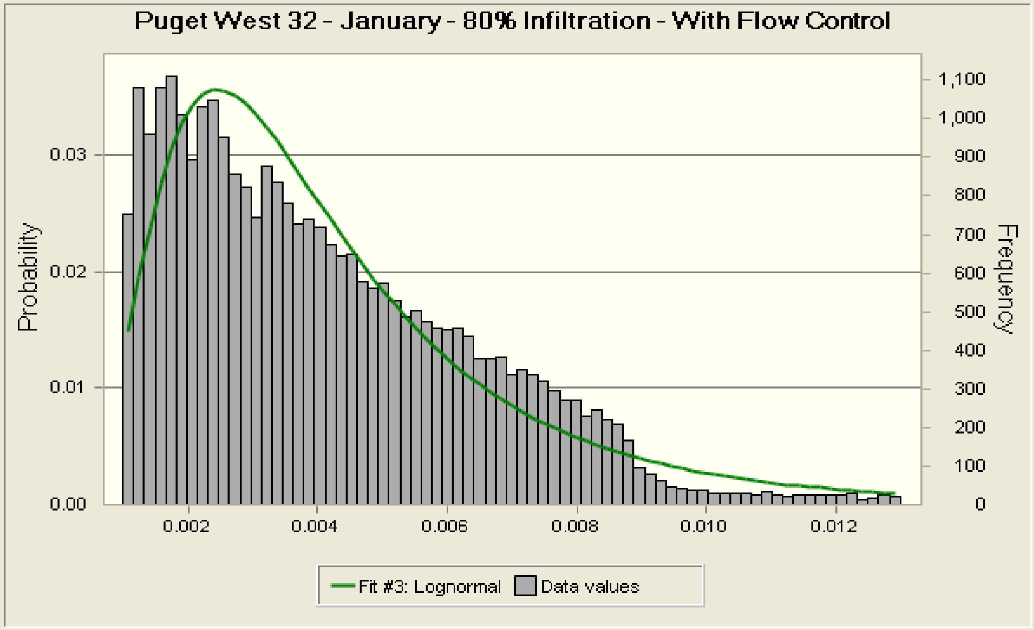
Figure E8. Histograph and distribution goodness-of-fit analysis results for Puget West 32 discharge data in January with flow control and 60 percent infiltration



Distribution	A-D	Chi-Square	K-S
Weibull	3.2358	72.4738	.0269
Gamma	1.5480	54.3240	.0281
Exponential	5.1290	111.7211	.0299
Lognormal	15.9501	201.3440	.0614
Max Extreme	48.7510	826.7832	.0775
Beta	1,066.824	1,177.1603	.1122
Student's t	134.9980	2,002.5785	.1574
Normal	146.6698	1,890.1690	.1694
Logistic	90.6835	1,495.9409	.1722
Min Extreme	326.2950	4,718.3240	.3231
Pareto	539.2884	4,406.3993	.3267
Triangular	1,703.787	4,138.0606	.5027
Uniform	3,119.938	9,868.5597	.6529
BetaPERT	6,925.683	32,905.0519	.8303

Figure E9. Histograph and distribution goodness-of-fit analysis results for Puget West 32 discharge data in January without flow control and 80 percent infiltration

30,218 Values Split View 29,721 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Lognormal	92.4188	2,805.9846	.0303
Gamma	51.3432	1,344.4338	.0353
Weibull	115.4387	1,633.1708	.0424
Max Extreme	213.3059	5,031.5969	.0585
Student's t	798.8196	13,566.6756	.1142
Logistic	499.4389	10,618.4607	.1225
Normal	978.6314	13,516.2418	.1370
Beta	987.5162	13,538.3916	.1376
Exponential	2,327.533	12,583.9424	.2126
Pareto	3,239.753	22,422.3071	.2237
BetaPERT	7,289.133	16,121.3858	.3310
Min Extreme	4,699.693	54,104.7102	.3612
Triangular	25,916.04	66,431.1440	.6246
Uniform	43,557.61	150,777.4012	.7720

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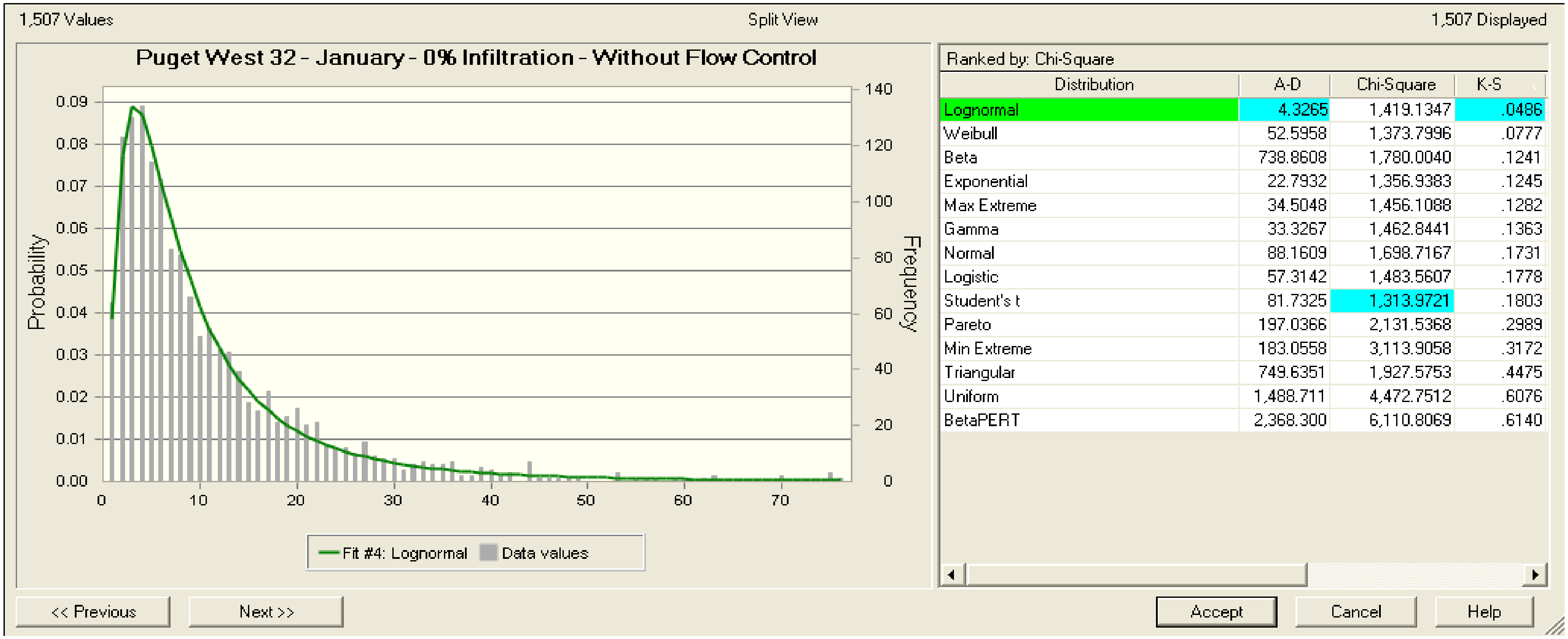
Figure E10. Histograph and distribution goodness-of-fit analysis results for Puget West 32 discharge data in January with flow control and 80 percent infiltration

APPENDIX F

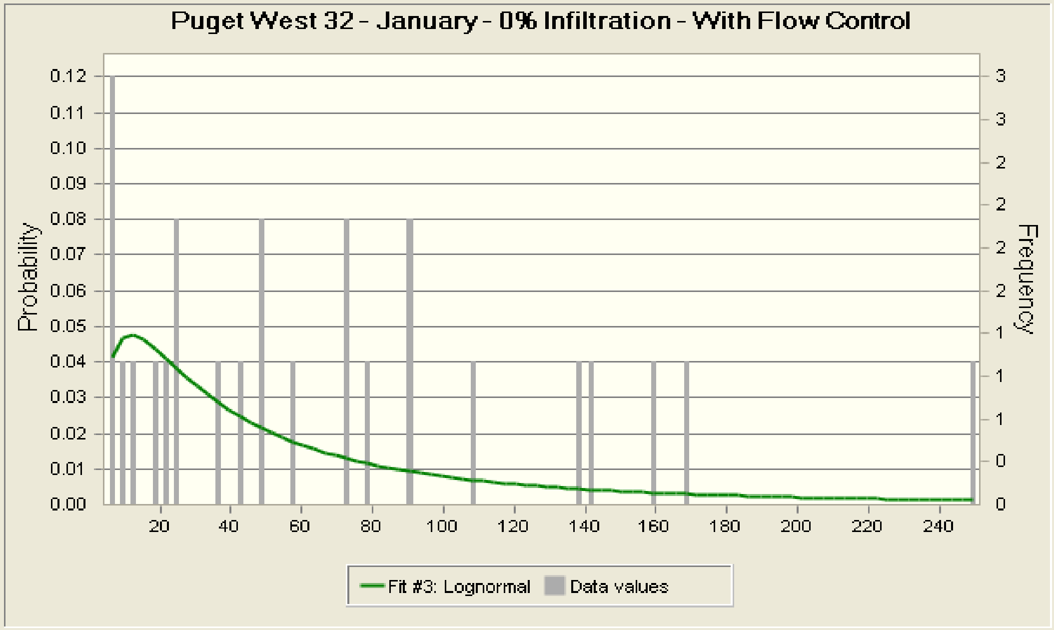
Example Histograms for Discharge Duration Data Used as Input to the Highway Runoff Dilution and Loading Model



Distribution	A-D	Chi-Square	K-S
Lognormal	4.3265	1,419.1347	.0486
Weibull	52.5958	1,373.7996	.0777
Beta	738.8608	1,780.0040	.1241
Exponential	22.7932	1,356.9383	.1245
Max Extreme	34.5048	1,456.1088	.1282
Gamma	33.3267	1,462.8441	.1363
Normal	88.1609	1,698.7167	.1731
Logistic	57.3142	1,483.5607	.1778
Student's t	81.7325	1,313.9721	.1803
Pareto	197.0366	2,131.5368	.2989
Min Extreme	183.0558	3,113.9058	.3172
Triangular	749.6351	1,927.5753	.4475
Uniform	1,488.711	4,472.7512	.6076
BetaPERT	2,368.300	6,110.8069	.6140

Figure F1. Histograph and distribution goodness-of-fit analysis results for Puget West 32 flow duration data in January without flow control and 0 percent infiltration

25 Values | Split View | 25 Displayed



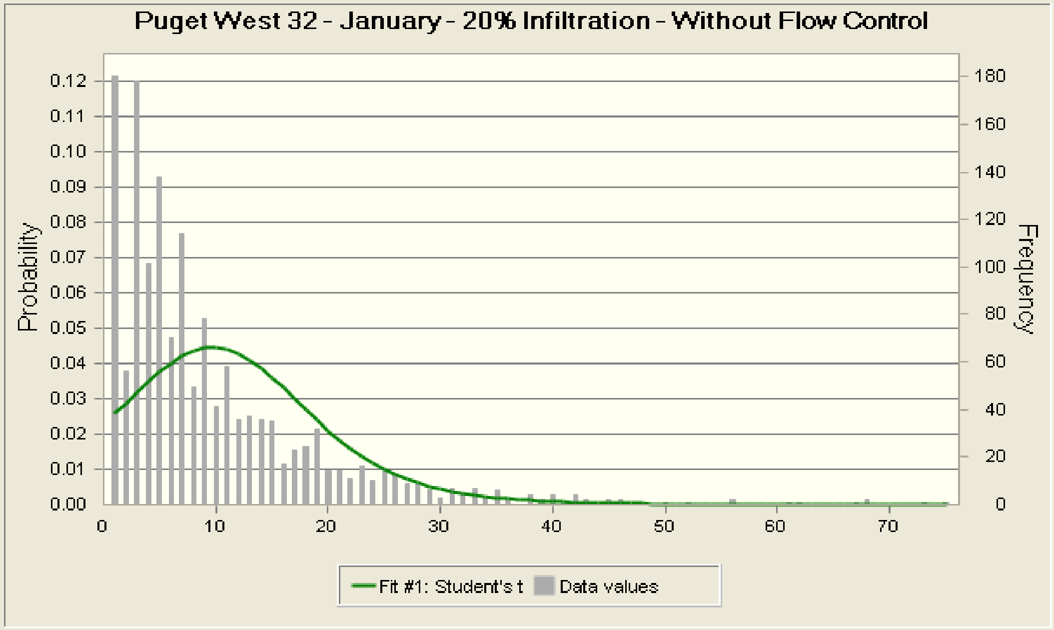
Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Beta	.1542	.4000	.0690
Exponential	.1851	.4000	.0760
Lognormal	.4487	1.2000	.1222
Max Extreme	.5363	2.0000	.1449
BetaPERT	.7283	2.0000	.1490
Logistic	.7377	1.2000	.1661
Weibull	.8069	2.0000	.1350
Normal	.9370	2.8000	.1532
Student's t	.9765	4.4000	.1820
Gamma	1.6478	6.0000	.2107
Min Extreme	1.6823	20.0000	.2366
Pareto	2.5422	20.8000	.2737
Triangular	3.6465	6.0000	.2664
Uniform	7.8067	14.8000	.4051

<< Previous | Next >> | Accept | Cancel | Help

Figure F2. Histograph and distribution goodness-of-fit analysis results for Puget West 32 flow duration data in January with flow control and 0 percent infiltration

1,486 Values | Split View | 1,486 Displayed

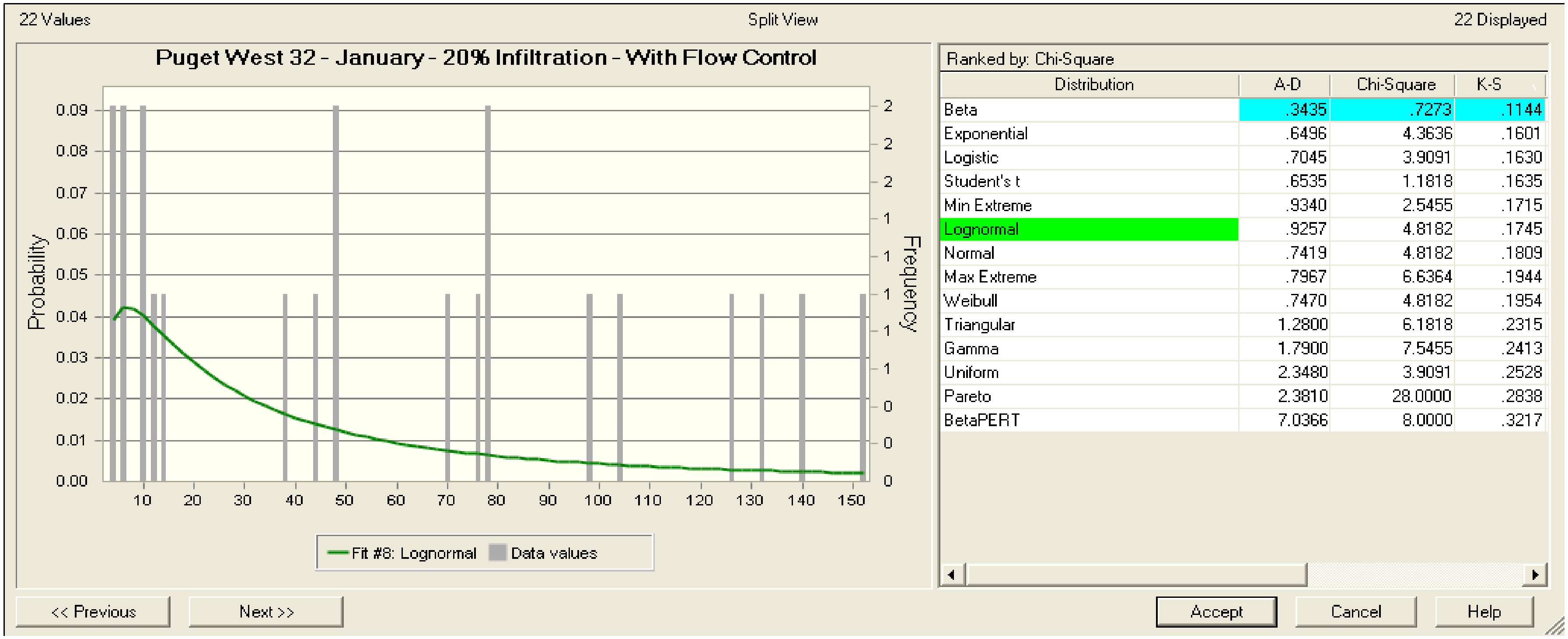


Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Lognormal	12.5571	1,949.3271	.0879
Exponential	14.0159	1,889.4266	.1070
Max Extreme	33.4658	1,971.8412	.1311
Logistic	55.3286	2,017.1440	.1901
Student's t	79.2571	1,802.3903	.1817
Normal	84.1710	1,831.7685	.1836
Gamma	144.2975	2,080.2019	.2912
Min Extreme	180.2359	3,185.2705	.3285
Pareto	218.7152	2,595.4643	.2934
Weibull	373.3776	1,855.7012	.1211
Beta	694.5098	1,855.7012	.1211
Triangular	955.8355	2,415.3055	.4765
Uniform	1,690.118	5,620.6864	.6333
BetaPERT	3,707.223	14,609.2705	.8120

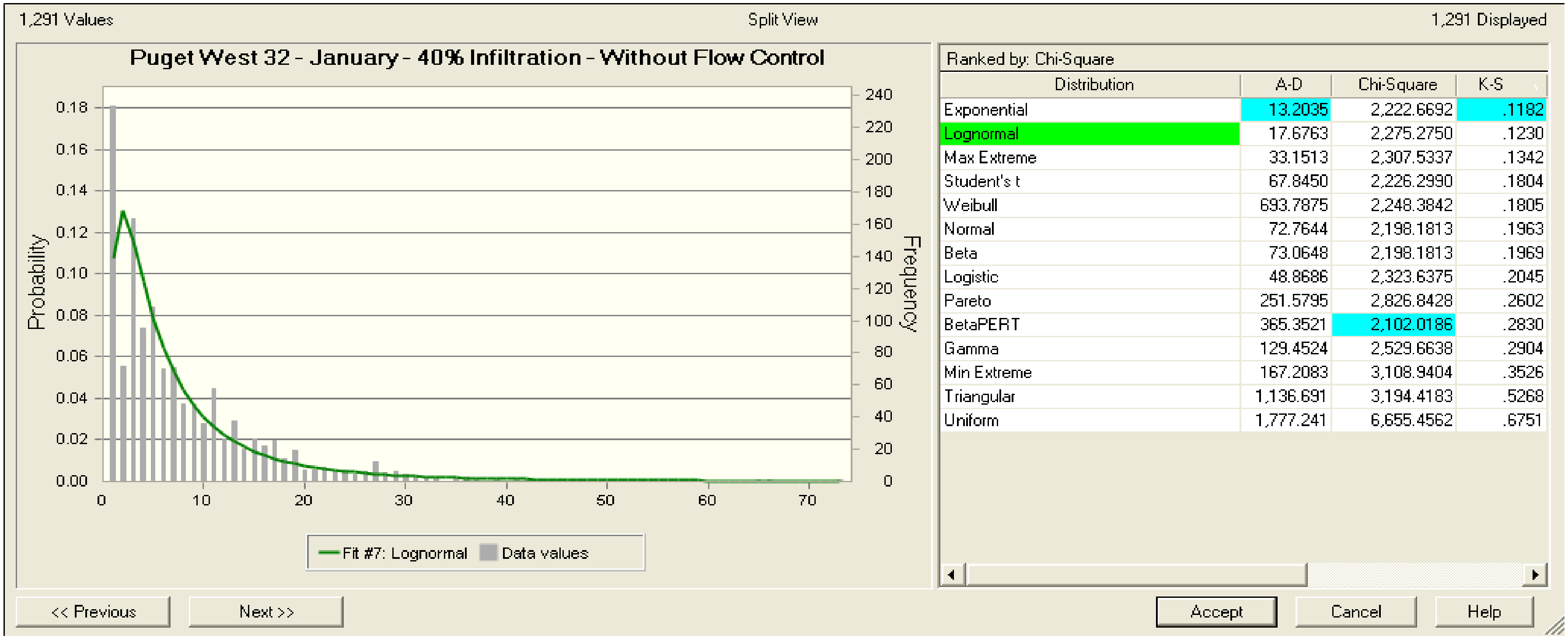
<< Previous | Next >> | Accept | Cancel | Help

Figure F3. Histograph and distribution goodness-of-fit analysis results for Puget West 32 flow duration data in January without flow control and 20 percent infiltration



Distribution	A-D	Chi-Square	K-S
Beta	.3435	.7273	.1144
Exponential	.6496	4.3636	.1601
Logistic	.7045	3.9091	.1630
Student's t	.6535	1.1818	.1635
Min Extreme	.9340	2.5455	.1715
Lognormal	.9257	4.8182	.1745
Normal	.7419	4.8182	.1809
Max Extreme	.7967	6.6364	.1944
Weibull	.7470	4.8182	.1954
Triangular	1.2800	6.1818	.2315
Gamma	1.7900	7.5455	.2413
Uniform	2.3480	3.9091	.2528
Pareto	2.3810	28.0000	.2838
BetaPERT	7.0366	8.0000	.3217

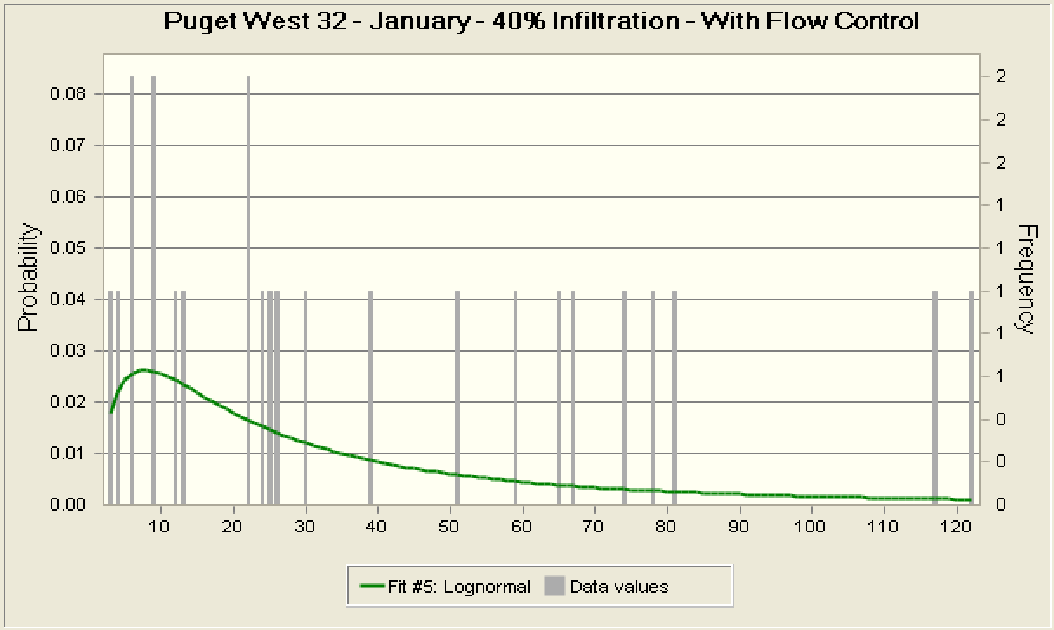
Figure F4. Histograph and distribution goodness-of-fit analysis results for Puget West 32 flow duration data in January with flow control and 20 percent infiltration



Distribution	A-D	Chi-Square	K-S
Exponential	13.2035	2,222.6692	.1182
Lognormal	17.6763	2,275.2750	.1230
Max Extreme	33.1513	2,307.5337	.1342
Student's t	67.8450	2,226.2990	.1804
Weibull	693.7875	2,248.3842	.1805
Normal	72.7644	2,198.1813	.1963
Beta	73.0648	2,198.1813	.1969
Logistic	48.8686	2,323.6375	.2045
Pareto	251.5795	2,826.8428	.2602
BetaPERT	365.3521	2,102.0186	.2830
Gamma	129.4524	2,529.6638	.2904
Min Extreme	167.2083	3,108.9404	.3526
Triangular	1,136.691	3,194.4183	.5268
Uniform	1,777.241	6,655.4562	.6751

Figure F5. Histograph and distribution goodness-of-fit analysis results for Puget West 30 flow duration data in January without flow control and 40 percent infiltration

24 Values | Split View | 24 Displayed

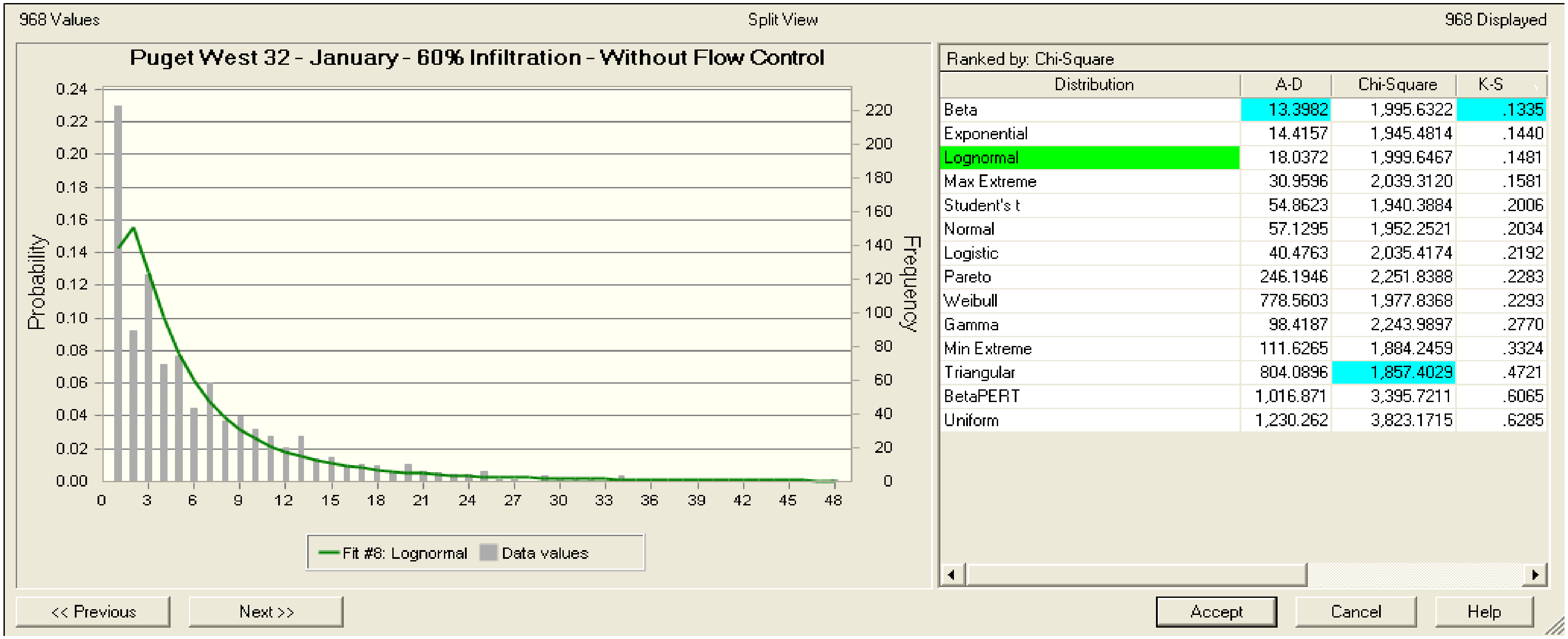


Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Beta	1.4381	1.4167	.0852
Exponential	.2776	2.2500	.0886
Lognormal	.4028	3.9167	.1172
Weibull	.7735	3.9167	.1414
Max Extreme	.7808	5.5833	.1540
Logistic	.9200	8.0833	.1650
Normal	1.0338	5.5833	.1977
Min Extreme	1.4926	24.3333	.2113
Gamma	1.5310	3.9167	.2134
Student's t	1.2331	6.4167	.2153
BetaPERT	5.2130	8.0833	.2322
Triangular	1.8840	6.0000	.2378
Pareto	2.6178	22.6667	.2757
Uniform	4.8568	8.9167	.3346

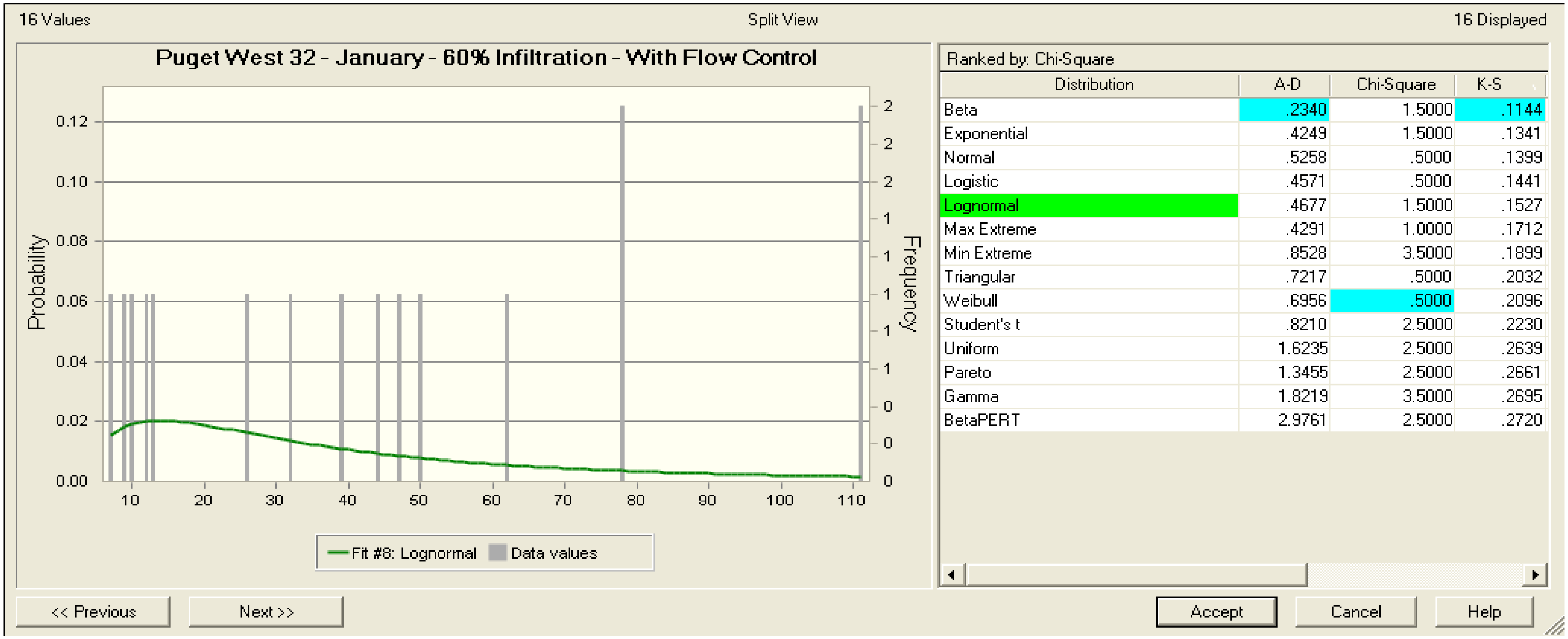
<< Previous | Next >> | Accept | Cancel | Help

Figure F6. Histograph and distribution goodness-of-fit analysis results for Puget West 32 flow duration data in January with flow control and 40 percent infiltration



Distribution	A-D	Chi-Square	K-S
Beta	13.3982	1,995.6322	.1335
Exponential	14.4157	1,945.4814	.1440
Lognormal	18.0372	1,999.6467	.1481
Max Extreme	30.9596	2,039.3120	.1581
Student's t	54.8623	1,940.3884	.2006
Normal	57.1295	1,952.2521	.2034
Logistic	40.4763	2,035.4174	.2192
Pareto	246.1946	2,251.8388	.2283
Weibull	778.5603	1,977.8368	.2293
Gamma	98.4187	2,243.9897	.2770
Min Extreme	111.6265	1,884.2459	.3324
Triangular	804.0896	1,857.4029	.4721
BetaPERT	1,016.871	3,395.7211	.6065
Uniform	1,230.262	3,823.1715	.6285

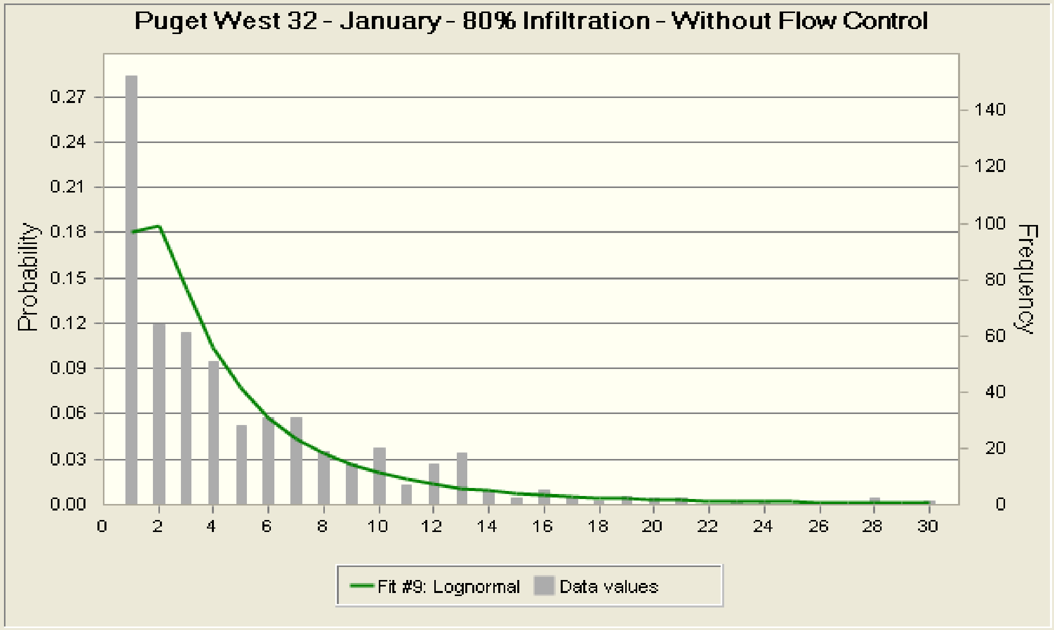
Figure F7. Histograph and distribution goodness-of-fit analysis results for Puget West 32 flow duration data in January without flow control and 60 percent infiltration



Distribution	A-D	Chi-Square	K-S
Beta	.2340	1.5000	.1144
Exponential	.4249	1.5000	.1341
Normal	.5258	.5000	.1399
Logistic	.4571	.5000	.1441
Lognormal	.4677	1.5000	.1527
Max Extreme	.4291	1.0000	.1712
Min Extreme	.8528	3.5000	.1899
Triangular	.7217	.5000	.2032
Weibull	.6956	.5000	.2096
Student's t	.8210	2.5000	.2230
Uniform	1.6235	2.5000	.2639
Pareto	1.3455	2.5000	.2661
Gamma	1.8219	3.5000	.2695
BetaPERT	2.9761	2.5000	.2720

Figure F8. Histograph and distribution goodness-of-fit analysis results for Puget West 32 flow duration data in January with flow control and 60 percent infiltration

537 Values | Split View | 537 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Beta	10.8363	1,142.4283	.1550
Max Extreme	20.7472	1,185.2588	.1616
Lognormal	14.8261	1,185.0875	.1800
Exponential	12.3908	1,142.4283	.1818
Normal	30.4158	1,132.8343	.2008
Logistic	23.9100	1,230.8305	.2239
Student's t	31.8273	1,109.5345	.2295
Pareto	175.1814	1,343.9888	.2812
Weibull	692.2985	1,152.0223	.2831
Min Extreme	53.0541	1,099.2551	.3128
BetaPERT	210.2807	1,093.8585	.3803
Gamma	114.2362	1,612.1080	.4132
Triangular	421.2291	1,085.2067	.4210
Uniform	616.7186	2,004.4358	.5714

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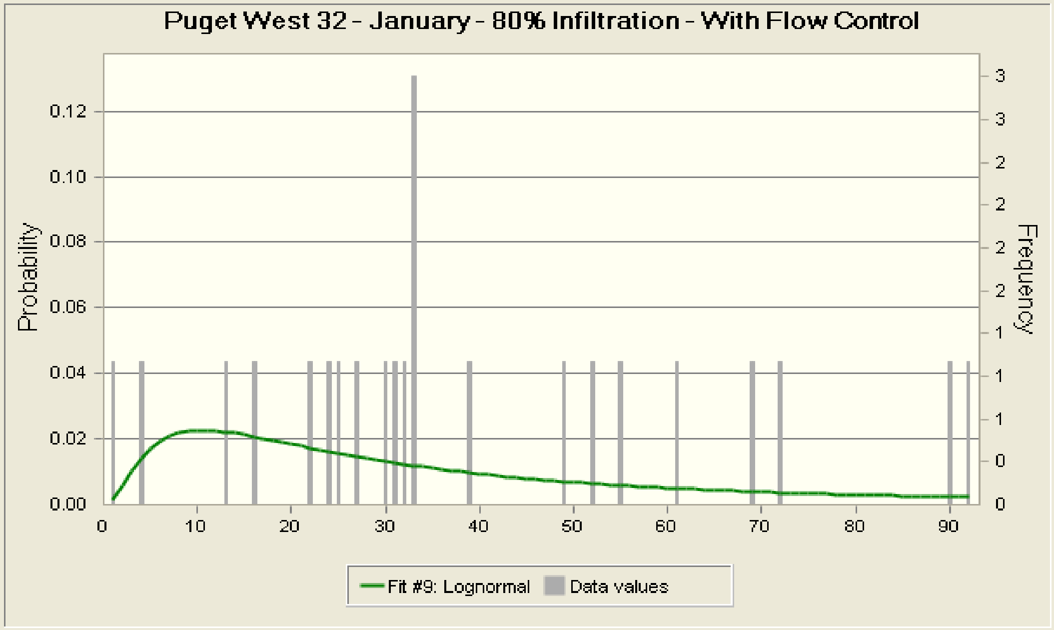
Figure F9. Histograph and distribution goodness-of-fit analysis results for Puget West 32 flow duration data in January without flow control and 80 percent infiltration

23 Values | Split View | 23 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Beta	1.8087	2.0000	.1416
Max Extreme	.2777	2.0000	.1480
Gamma	.2923	2.0000	.1500
BetaPERT	2.0771	1.1304	.1692
Logistic	.5007	1.1304	.1869
Weibull	.3973	.6957	.1927
Student's t	.5554	2.0000	.2068
Normal	.5690	2.0000	.2087
Lognormal	1.3396	6.3478	.2179
Triangular	.6663	9.3913	.2257
Min Extreme	1.1271	11.5652	.2269
Exponential	1.3612	9.3913	.2410
Uniform	1.4400	8.5217	.2447
Pareto	6.0447	56.7826	.4510

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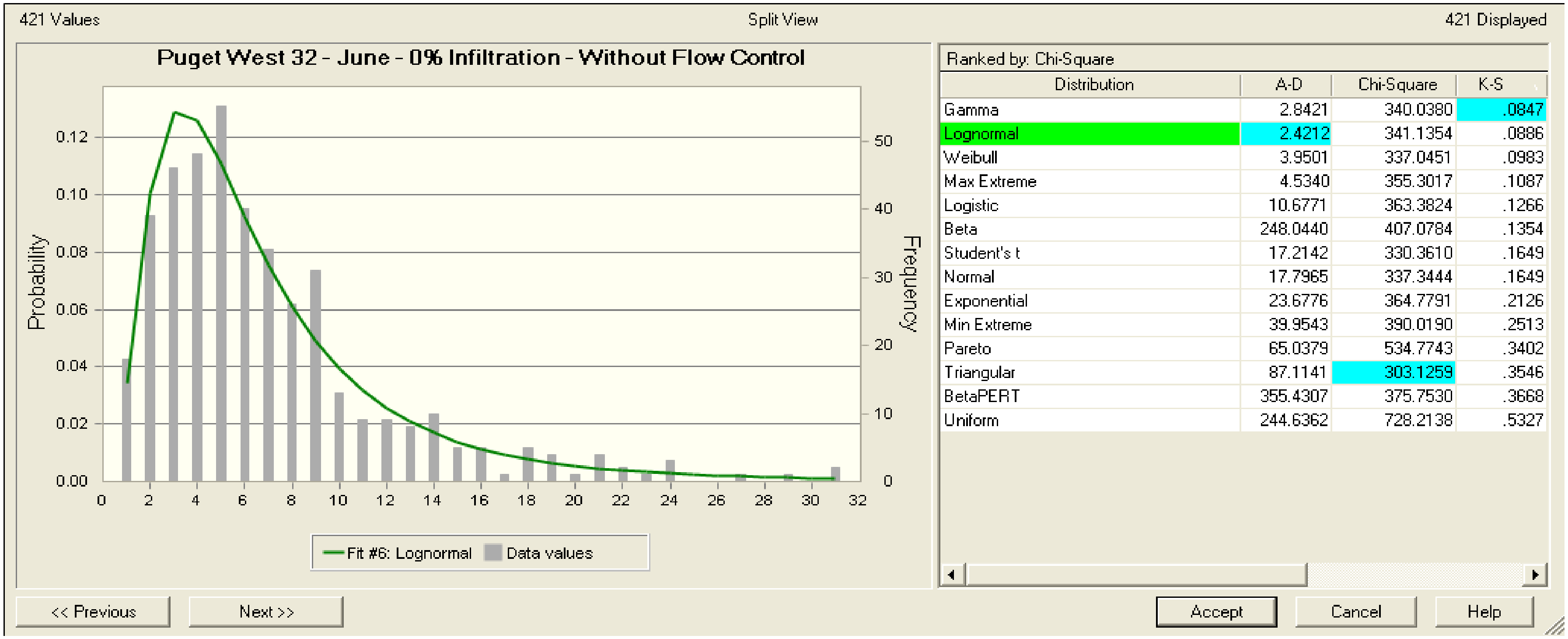
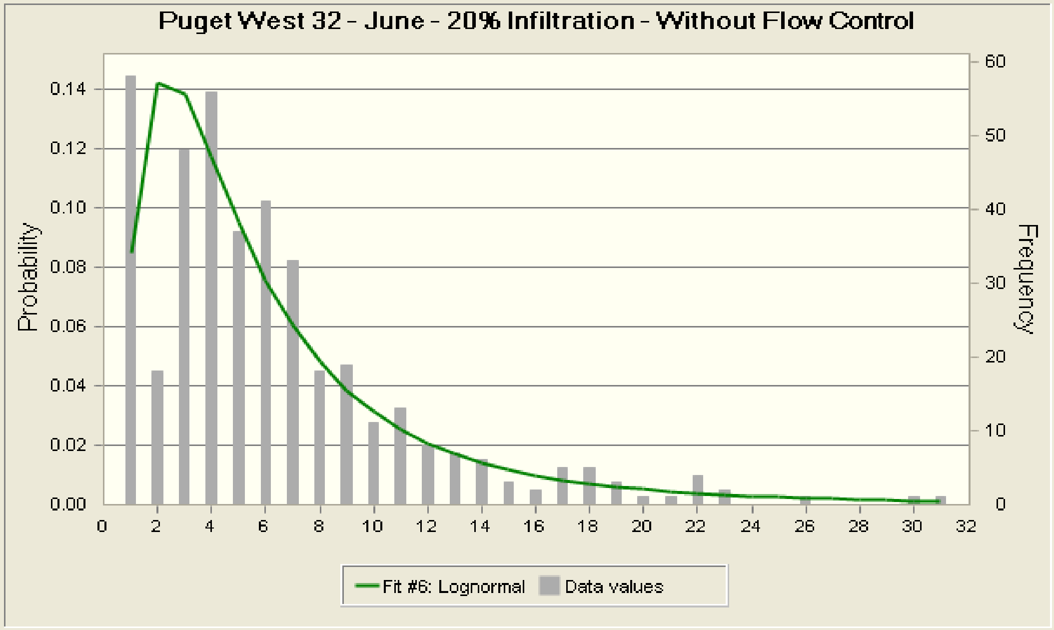
Figure F10. Histograph and distribution goodness-of-fit analysis results for Puget West 32 flow duration data in January with flow control and 80 percent infiltration



Distribution	A-D	Chi-Square	K-S
Gamma	2.8421	340.0380	.0847
Lognormal	2.4212	341.1354	.0886
Weibull	3.9501	337.0451	.0983
Max Extreme	4.5340	355.3017	.1087
Logistic	10.6771	363.3824	.1266
Beta	248.0440	407.0784	.1354
Student's t	17.2142	330.3610	.1649
Normal	17.7965	337.3444	.1649
Exponential	23.6776	364.7791	.2126
Min Extreme	39.9543	390.0190	.2513
Pareto	65.0379	534.7743	.3402
Triangular	87.1141	303.1259	.3546
BetaPERT	355.4307	375.7530	.3668
Uniform	244.6362	728.2138	.5327

Figure F11. Histograph and distribution goodness-of-fit analysis results for Puget West 32 flow duration data in June without flow control and 0 percent infiltration

402 Values Split View 402 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Max Extreme	4.9047	378.6965	.1045
Lognormal	6.8804	368.8458	.1230
Weibull	16.0635	364.8657	.1371
Beta	269.2685	366.6567	.1443
Logistic	9.8518	378.6965	.1488
Student's t	15.2429	355.4129	.1668
Normal	16.1746	359.9900	.1686
Exponential	13.8226	370.2388	.1889
Min Extreme	36.9885	429.8408	.2691
Pareto	63.3135	650.4378	.3234
Triangular	135.9451	324.0697	.3773
BetaPERT	384.0026	433.1244	.3801
Gamma	93.5117	638.5970	.4367
Uniform	289.7417	709.3433	.5481

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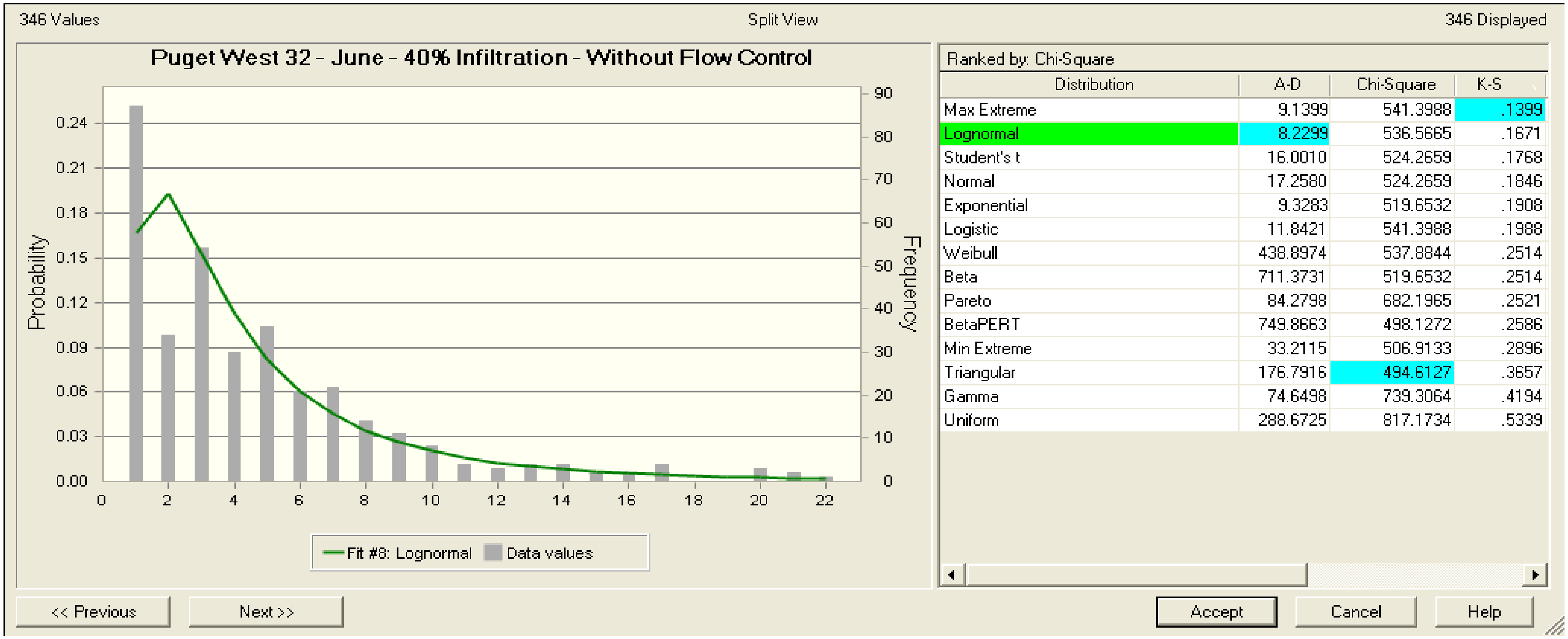
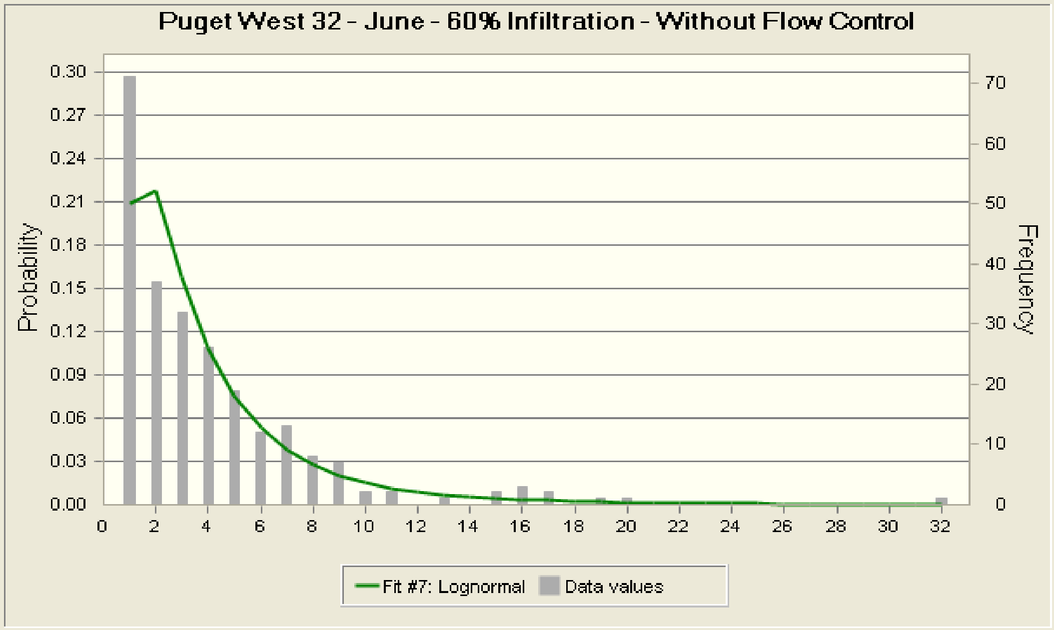
Figure F12. Histograph and distribution goodness-of-fit analysis results for Puget West 32 flow duration data in June without flow control and 20 percent infiltration



Distribution	A-D	Chi-Square	K-S
Max Extreme	9.1399	541.3988	.1399
Lognormal	8.2299	536.5665	.1671
Student's t	16.0010	524.2659	.1768
Normal	17.2580	524.2659	.1846
Exponential	9.3283	519.6532	.1908
Logistic	11.8421	541.3988	.1988
Weibull	438.8974	537.8844	.2514
Beta	711.3731	519.6532	.2514
Pareto	84.2798	682.1965	.2521
BetaPERT	749.8663	498.1272	.2586
Min Extreme	33.2115	506.9133	.2896
Triangular	176.7916	494.6127	.3657
Gamma	74.6498	739.3064	.4194
Uniform	288.6725	817.1734	.5339

Figure F13. Histograph and distribution goodness-of-fit analysis results for Puget West 32 flow duration data in January without flow control and 40 percent infiltration

240 Values | Split View | 240 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Max Extreme	8.9010	396.0000	.1699
Lognormal	6.6808	396.9333	.1849
Exponential	8.0785	379.8667	.2188
Normal	16.6584	366.5333	.2244
Student's t	15.6693	382.1333	.2259
Logistic	10.7463	382.1333	.2313
Pareto	68.7611	422.0000	.2917
Weibull	276.9605	406.5333	.2958
Beta	686.7145	377.7333	.2958
Min Extreme	35.1034	428.1333	.3695
Gamma	49.1470	577.2000	.4214
Triangular	240.5493	713.6000	.5420
Uniform	330.6518	863.3333	.6803
BetaPERT	1,248.390	2,944.6667	.8689

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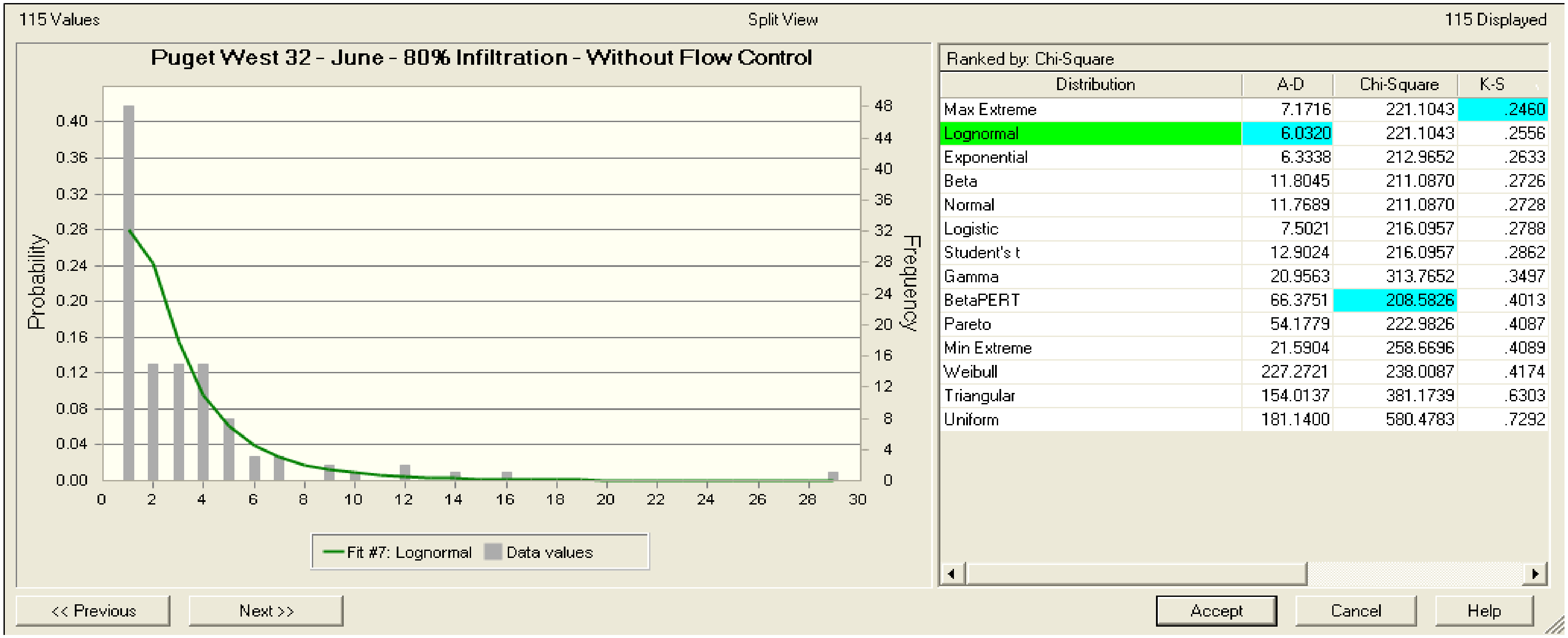
Figure F14. Histograph and distribution goodness-of-fit analysis results for Puget West 32 flow duration data in June without flow control and 60 percent infiltration



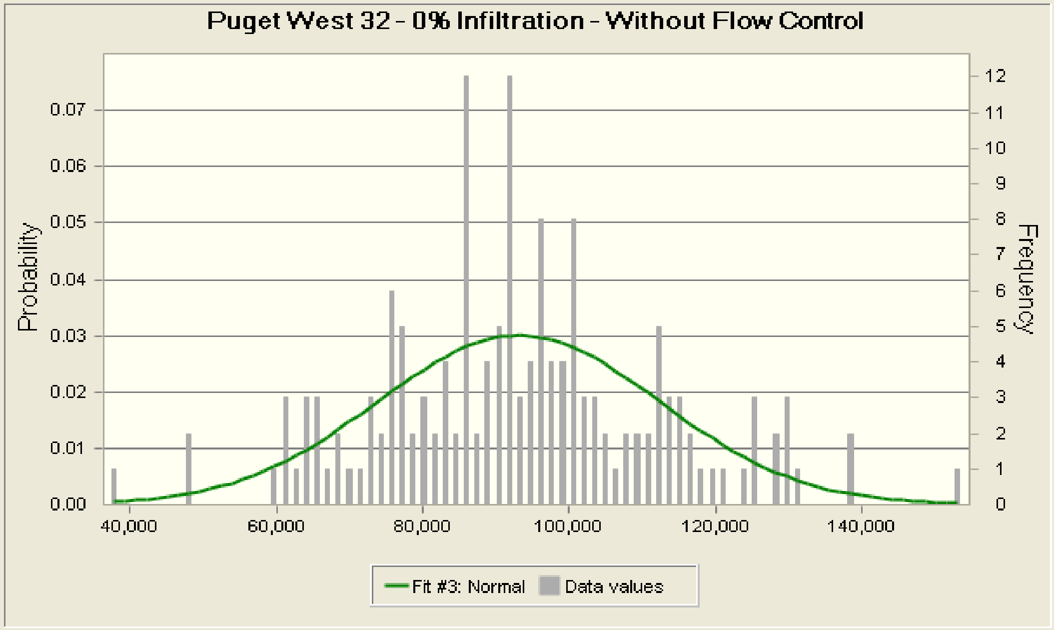
Distribution	A-D	Chi-Square	K-S
Max Extreme	7.1716	221.1043	.2460
Lognormal	6.0320	221.1043	.2556
Exponential	6.3338	212.9652	.2633
Beta	11.8045	211.0870	.2726
Normal	11.7689	211.0870	.2728
Logistic	7.5021	216.0957	.2788
Student's t	12.9024	216.0957	.2862
Gamma	20.9563	313.7652	.3497
BetaPERT	66.3751	208.5826	.4013
Pareto	54.1779	222.9826	.4087
Min Extreme	21.5904	258.6696	.4089
Weibull	227.2721	238.0087	.4174
Triangular	154.0137	381.1739	.6303
Uniform	181.1400	580.4783	.7292

Figure F15. Histograph and distribution goodness-of-fit analysis results for Puget West 32 flow duration data in June without flow control and 80 percent infiltration

APPENDIX G

Example Histograms for Annual Discharge Data Used as Input to the Highway Runoff Dilution and Loading Model

158 Values Split View 158 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Logistic	.3423	13.3671	.0418
Student's t	.4002	7.8734	.0541
Normal	.5002	9.4684	.0616
Beta	.5041	9.4684	.0616
Gamma	.4987	13.5443	.0694
Lognormal	.8204	16.3797	.0844
Max Extreme	1.9335	25.7722	.1021
BetaPERT	4.1809	35.1646	.1118
Triangular	5.3278	38.5316	.1181
Min Extreme	3.5910	32.6835	.1224
Weibull	3.9524	23.8228	.1385
Uniform	17.1807	121.8228	.2192
Pareto	42.5555	375.5949	.4053
Exponential	46.0184	421.8481	.4556

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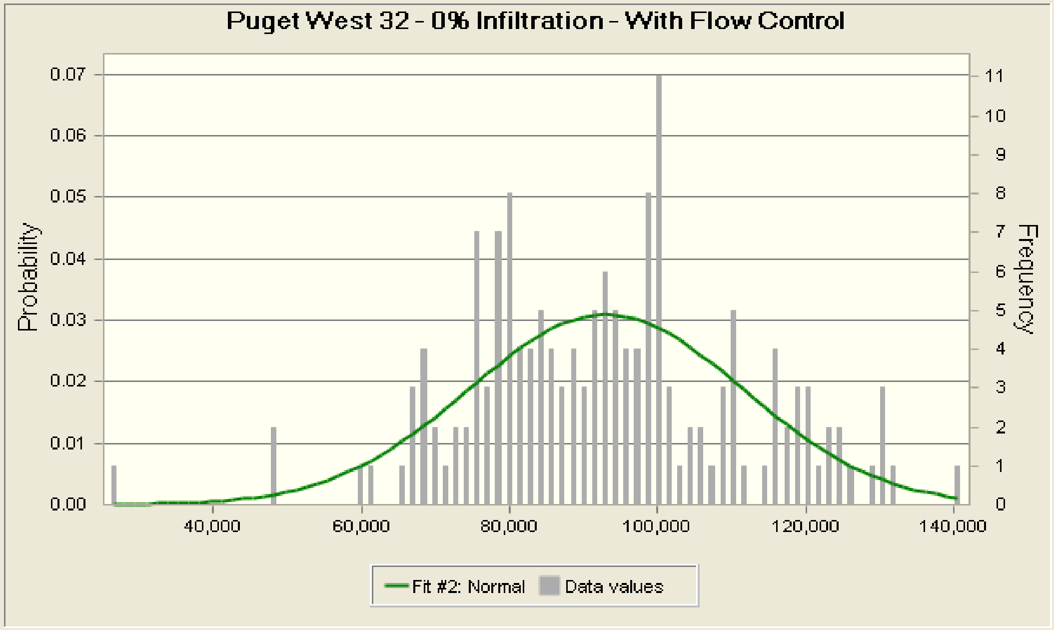
Figure G1. Histograph and distribution goodness-of-fit analysis results for Puget West 32 annual flow volume data without flow control and 0 percent infiltration

158 Values | Split View | 158 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Logistic	.7049	20.9873	.0502
Gamma	.6160	17.2658	.0561
Normal	.7016	19.5696	.0693
Beta	.7038	20.9873	.0693
Lognormal	1.0884	22.0506	.0706
Student's t	1.0992	24.3544	.0813
Max Extreme	2.8805	34.2785	.0938
Min Extreme	3.2717	41.3671	.1299
BetaPERT	4.7078	43.6709	.1375
Weibull	8.5652	46.3291	.1496
Triangular	7.5141	55.1899	.1898
Uniform	21.5359	166.3038	.3168
Exponential	46.9476	422.0253	.4736
Pareto	51.1874	627.7722	.4931

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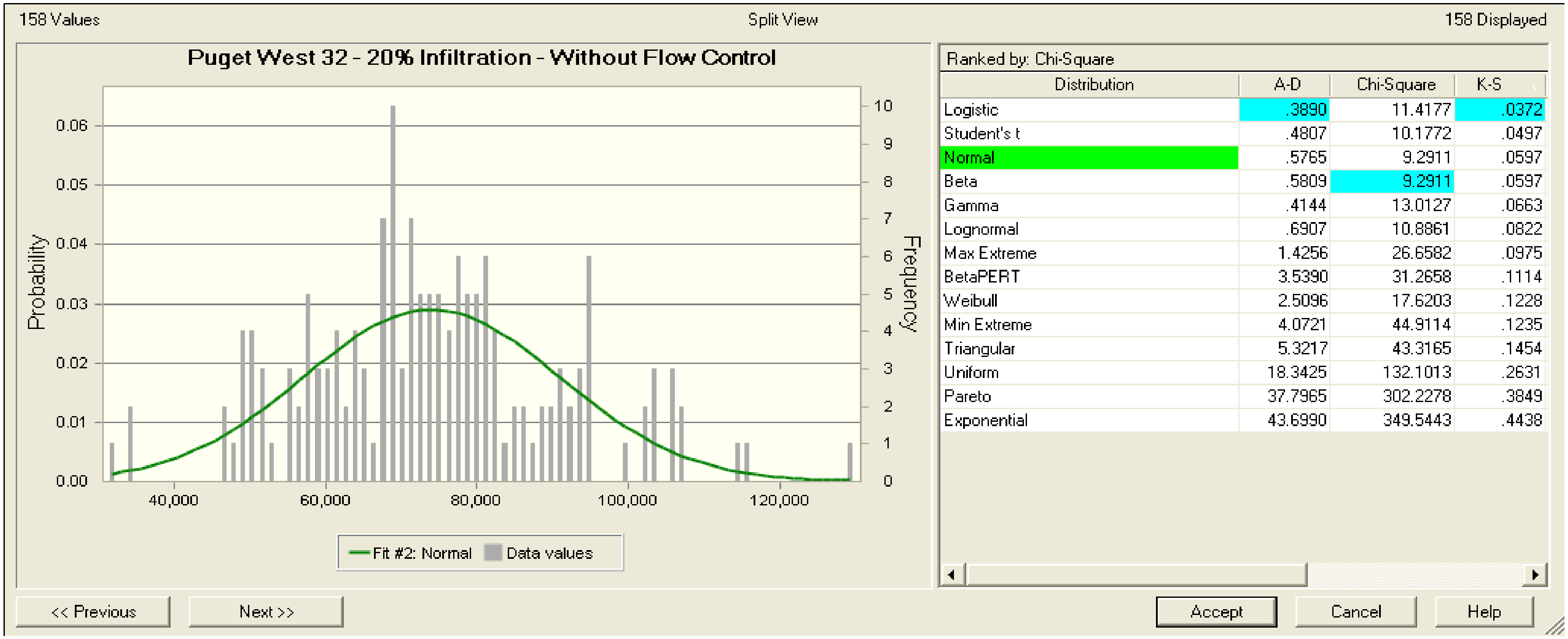
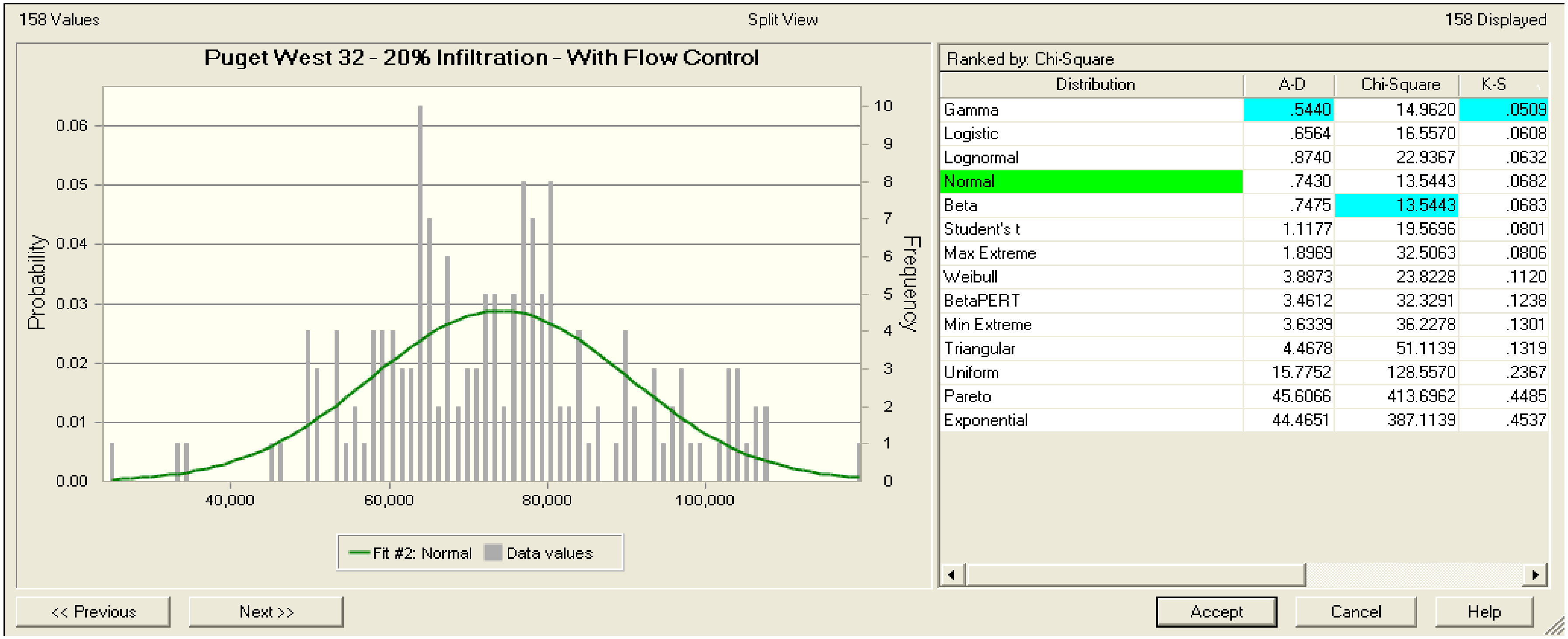
Figure G2. Histograph and distribution goodness-of-fit analysis results for Puget West 32 annual flow volume data with flow control and 0 percent infiltration



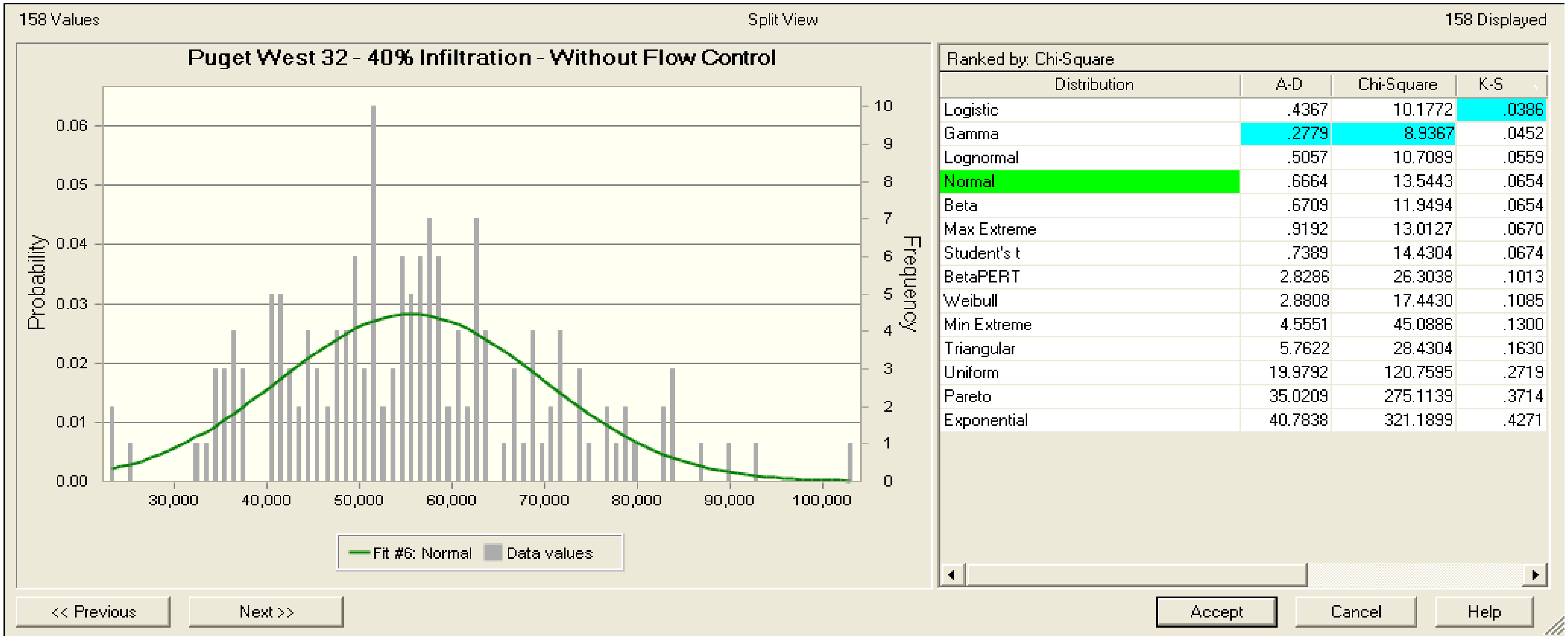
Distribution	A-D	Chi-Square	K-S
Logistic	.3890	11.4177	.0372
Student's t	.4807	10.1772	.0497
Normal	.5765	9.2911	.0597
Beta	.5809	9.2911	.0597
Gamma	.4144	13.0127	.0663
Lognormal	.6907	10.8861	.0822
Max Extreme	1.4256	26.6582	.0975
BetaPERT	3.5390	31.2658	.1114
Weibull	2.5096	17.6203	.1228
Min Extreme	4.0721	44.9114	.1235
Triangular	5.3217	43.3165	.1454
Uniform	18.3425	132.1013	.2631
Pareto	37.7965	302.2278	.3849
Exponential	43.6990	349.5443	.4438

Figure G3. Histograph and distribution goodness-of-fit analysis results for Puget West 32 annual flow volume data without flow control and 20 percent infiltration



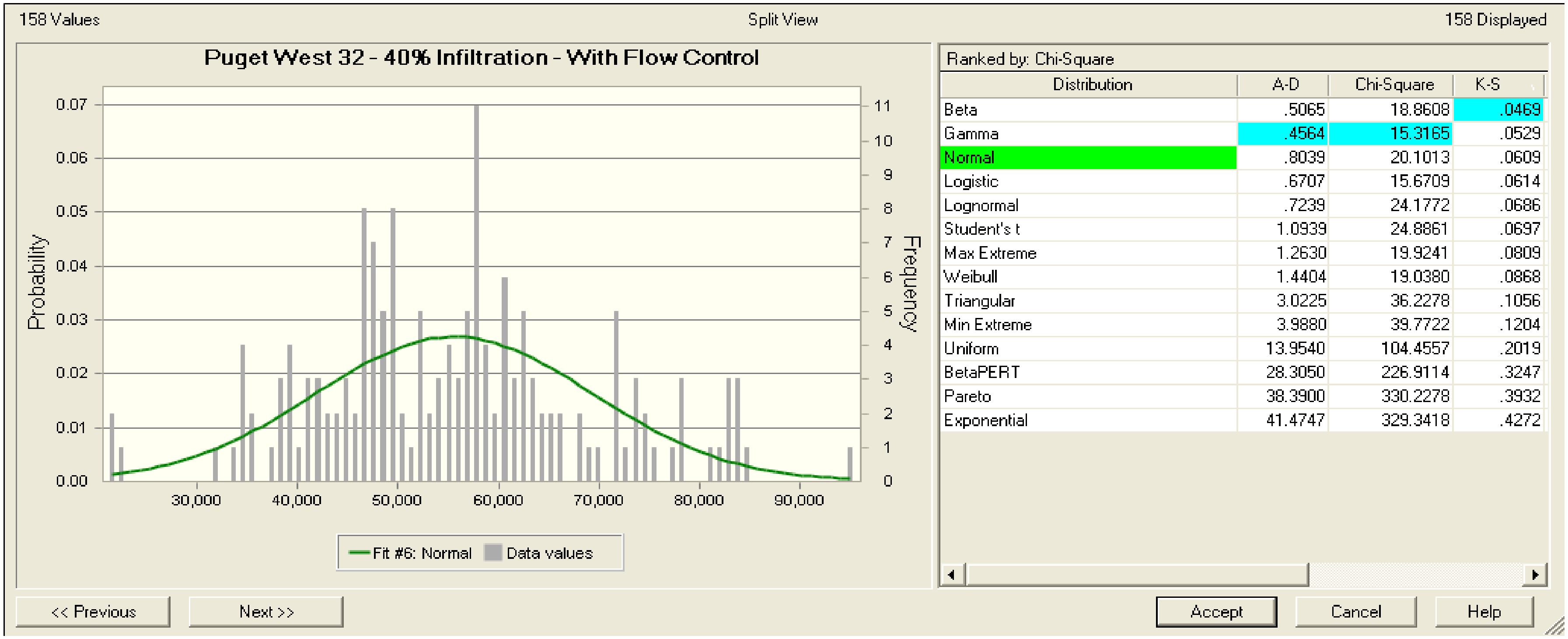
Distribution	A-D	Chi-Square	K-S
Gamma	.5440	14.9620	.0509
Logistic	.6564	16.5570	.0608
Lognormal	.8740	22.9367	.0632
Normal	.7430	13.5443	.0682
Beta	.7475	13.5443	.0683
Student's t	1.1177	19.5696	.0801
Max Extreme	1.8969	32.5063	.0806
Weibull	3.8873	23.8228	.1120
BetaPERT	3.4612	32.3291	.1238
Min Extreme	3.6339	36.2278	.1301
Triangular	4.4678	51.1139	.1319
Uniform	15.7752	128.5570	.2367
Pareto	45.6066	413.6962	.4485
Exponential	44.4651	387.1139	.4537

Figure G4. Histograph and distribution goodness-of-fit analysis results for Puget West 32 annual flow volume data with flow control and 20 percent infiltration



Distribution	A-D	Chi-Square	K-S
Logistic	.4367	10.1772	.0386
Gamma	.2779	8.9367	.0452
Lognormal	.5057	10.7089	.0559
Normal	.6664	13.5443	.0654
Beta	.6709	11.9494	.0654
Max Extreme	.9192	13.0127	.0670
Student's t	.7389	14.4304	.0674
BetaPERT	2.8286	26.3038	.1013
Weibull	2.8808	17.4430	.1085
Min Extreme	4.5551	45.0886	.1300
Triangular	5.7622	28.4304	.1630
Uniform	19.9792	120.7595	.2719
Pareto	35.0209	275.1139	.3714
Exponential	40.7838	321.1899	.4271

Figure G5. Histograph and distribution goodness-of-fit analysis results for Puget West 32 annual flow volume data without flow control and 40 percent infiltration



Distribution	A-D	Chi-Square	K-S
Beta	.5065	18.8608	.0469
Gamma	.4564	15.3165	.0529
Normal	.8039	20.1013	.0609
Logistic	.6707	15.6709	.0614
Lognormal	.7239	24.1772	.0686
Student's t	1.0939	24.8861	.0697
Max Extreme	1.2630	19.9241	.0809
Weibull	1.4404	19.0380	.0868
Triangular	3.0225	36.2278	.1056
Min Extreme	3.9880	39.7722	.1204
Uniform	13.9540	104.4557	.2019
BetaPERT	28.3050	226.9114	.3247
Pareto	38.3900	330.2278	.3932
Exponential	41.4747	329.3418	.4272

Figure G6. Histograph and distribution goodness-of-fit analysis results for Puget West 32 annual flow volume data with flow control and 40 percent infiltration

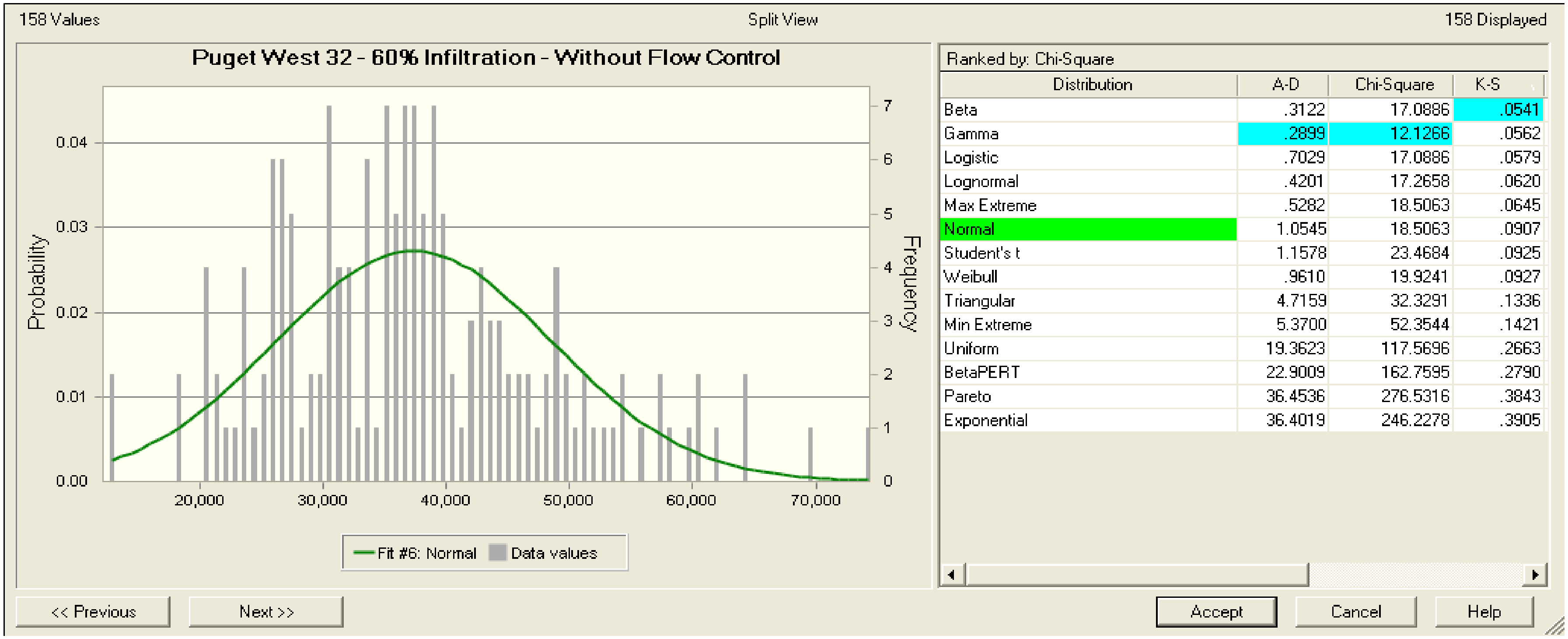
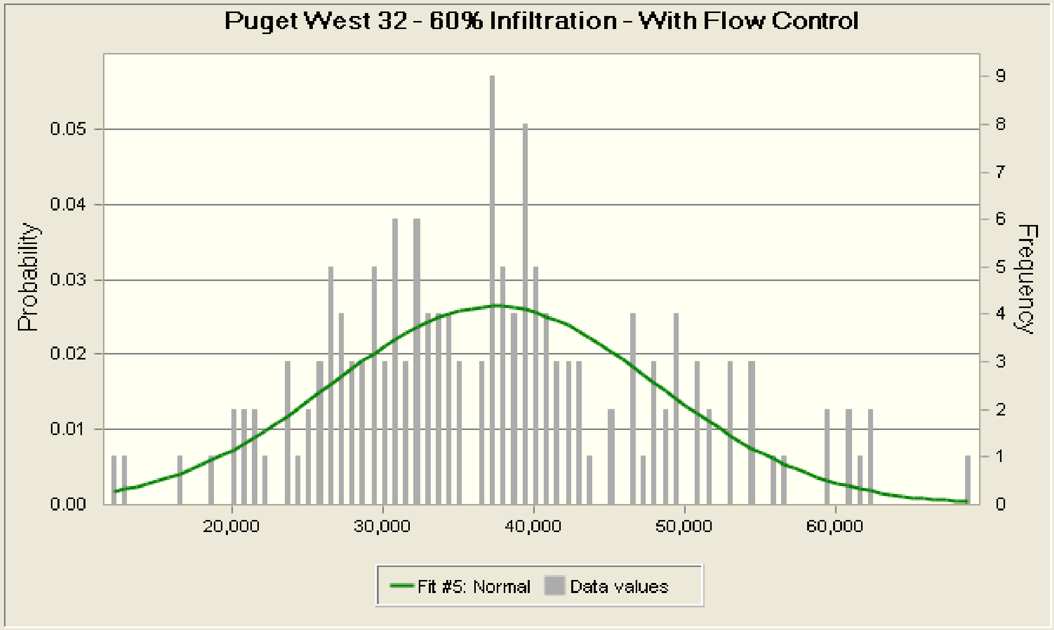


Figure G7. Histograph and distribution goodness-of-fit analysis results for Puget West 32 annual flow volume data without flow control and 60 percent infiltration

158 Values | Split View | 158 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Gamma	.2715	13.3671	.0425
Logistic	.7109	16.5570	.0484
Beta	.3432	15.4937	.0495
Max Extreme	.6435	13.3671	.0618
Lognormal	.4891	8.0506	.0622
Normal	.8689	15.8481	.0692
Student's t	1.3773	22.2278	.0831
Weibull	2.2899	20.9873	.0895
Triangular	2.6923	29.4937	.1066
Min Extreme	4.3707	43.8481	.1318
BetaPERT	12.7406	77.8734	.2091
Uniform	14.3238	103.0380	.2160
Exponential	37.0298	251.0127	.3968
Pareto	38.6885	325.7975	.3982

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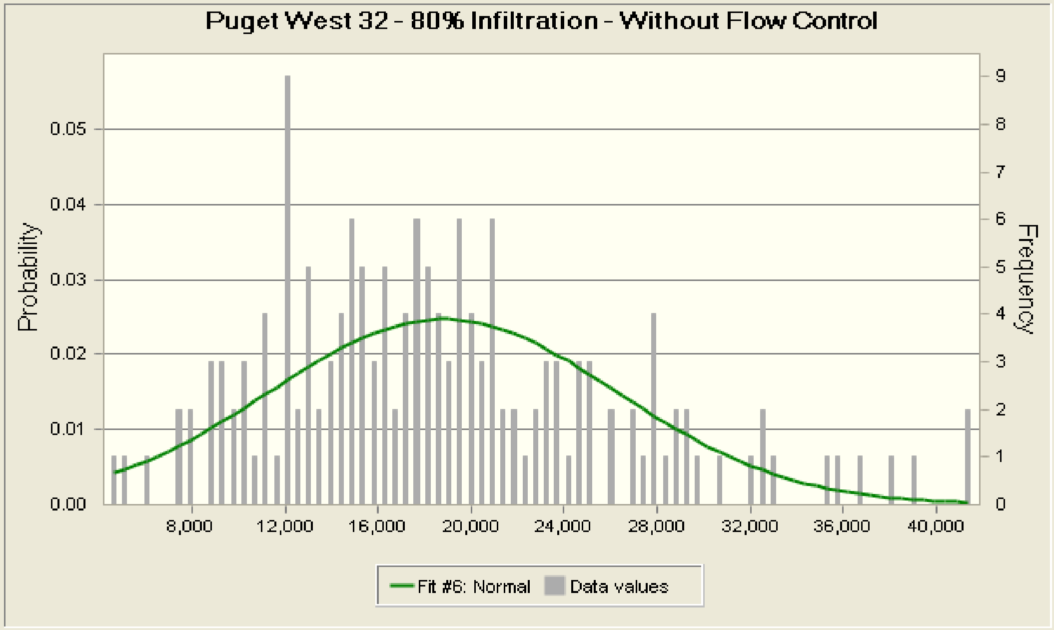
Figure G8. Histograph and distribution goodness-of-fit analysis results for Puget West 32 annual flow volume data with flow control and 60 percent infiltration

158 Values | Split View | 158 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Max Extreme	.1161	6.1013	.0313
Gamma	.1232	2.5570	.0353
Beta	.4395	5.2152	.0394
Lognormal	.3010	5.2152	.0439
Logistic	1.0000	15.4937	.0525
Weibull	.7271	8.0506	.0725
Normal	1.5493	15.4937	.0803
Student's t	1.5700	17.9747	.0821
Triangular	3.5831	20.9873	.1325
Min Extreme	6.3619	54.6582	.1420
BetaPERT	7.9404	46.3291	.1725
Uniform	19.1614	82.3038	.2754
Exponential	27.1600	151.4177	.3259
Pareto	35.3155	263.0633	.3703

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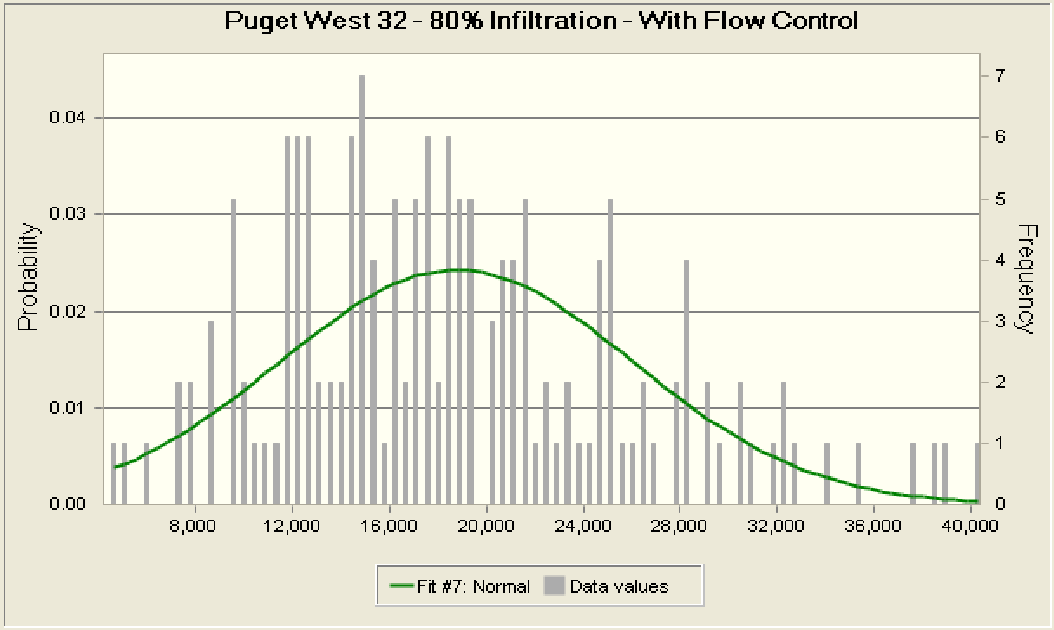
Figure G9. Histograph and distribution goodness-of-fit analysis results for Puget West 32 annual flow volume data without flow control and 80 percent infiltration

158 Values | Split View | 158 Displayed



Ranked by: Chi-Square

Distribution	A-D	Chi-Square	K-S
Max Extreme	.1775	8.0506	.0324
Gamma	.1506	10.5316	.0329
Beta	.4391	8.0506	.0420
Lognormal	.3762	8.4051	.0448
Logistic	1.0199	22.7595	.0504
Weibull	.6155	9.2911	.0689
Normal	1.3401	16.7342	.0819
Student's t	1.5741	16.7342	.0847
Triangular	2.5761	17.6203	.1123
Min Extreme	5.4013	52.0000	.1293
BetaPERT	3.8303	23.1139	.1296
Uniform	16.0652	83.3671	.2486
Exponential	27.5185	153.0127	.3315
Pareto	35.5863	267.8481	.3792

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Figure G10. Histograph and distribution goodness-of-fit analysis results for Puget West 32 annual flow volume data with flow control and 80 percent infiltration

APPENDIX H

Visual Basic Code for the Highway Runoff Dilution and Loading Model

Program Code

```
Sub BinStormData()

Dim r As Integer
Dim rmax As Integer
Dim iBin As Integer
Dim duration As Integer
Dim bincount As Integer

bincount = UBound(StormDurationBins)

'initialize counts to 0
For r = 1 To bincount + 1
   StormCounts(r, 1) = 0      'existing condition
   StormCounts(r, 2) = 0      'proposed condition
Next r

'loop through storm duration arrays and bin
For r = 1 To iterations
   'exisiting condition
   duration = StormDurations(r, 1)

   If duration > StormDurationBins(bincount, 1) Then
      StormCounts(bincount + 1, 1) = StormCounts(bincount + 1, 1) + 1
   Else
      For iBin = 1 To bincount
         If duration < StormDurationBins(iBin, 1) Then
            StormCounts(iBin, 1) = StormCounts(iBin, 1) + 1
            Exit For
         End If
      Next iBin
   End If

   'proposed conditions
   duration = StormDurations(r, 2)

   If duration > StormDurationBins(bincount, 1) Then
      StormCounts(bincount + 1, 2) = StormCounts(bincount + 1, 2) + 1
   Else
      For iBin = 1 To bincount
         If duration < StormDurationBins(iBin, 1) Then
            StormCounts(iBin, 2) = StormCounts(iBin, 2) + 1
            Exit For
         End If
      Next iBin
   End If
Next r

End Sub

Sub BinConcData(BinVal As Single, maxval As Single, Carray() As Single)
```

```
'*********************************************************************
'fills ConcBin array with bin increments and counts the number of values
'in each bin
'*********************************************************************

Dim r As Integer
Dim col As Integer
Dim iBin As Integer
Dim Conc As Single
Dim cnt As Integer

'Fill Concentration bin
ConcCount = CInt(maxval / BinVal) + 1
ReDim ConcBin(1 To ConcCount, 1 To 3)      'column 1 - max conc for bin, 2 - counts for existing
condition
                                     '3 - counts for proposed condition
'initialize array
Conc = BinVal
For r = 1 To ConcCount - 1
   ConcBin(r, 1) = Conc
   ConcBin(r, 2) = 0
   ConcBin(r, 3) = 0
   Conc = Conc + BinVal
Next r

ConcBin(ConcCount, 1) = maxval * 100
ConcBin(ConcCount, 2) = 0
ConcBin(ConcCount, 3) = 0

'loop through concentration array and bin
For r = 1 To iterations
   For col = 1 To 2            '1- existing condition, 2- proposed
      Conc = Carray(r, col)
      For iBin = 1 To ConcCount
         If Conc < ConcBin(iBin, 1) Then
            cnt = ConcBin(iBin, col + 1)
            ConcBin(iBin, col + 1) = cnt + 1
            Exit For
         End If
      Next iBin
   Next col
Next r

'For iBin = 1 To ConcCount
'   Debug.Print ConcBin(iBin, 1), ConcBin(iBin, 2), ConcBin(iBin, 3)
'Next iBin

End Sub

Sub CalcProbability()

'*********************************************************************
'calculates the probability of occurrence for existing and proposed conditions
'using the binned storm duration and concentration array
```

```
'*********************************************************************

Dim r1 As Integer
Dim r2 As Integer
Dim StormCount As Integer
Dim prob_S1 As Single
Dim prob_S2 As Single
Dim prob_C1 As Single
Dim prob_C2 As Single
Dim count1 As Integer
Dim count2 As Integer

count1 = UBound(StormDurationBins) + 1
ReDim Existing_Probability(1 To count1, 1 To ConcCount)
ReDim Proposed_Probability(1 To count1, 1 To ConcCount)

For r1 = 1 To count1
   For r2 = 1 To ConcCount
      prob_S1 = StormCounts(r1, 1) / iterations    'storm duration probability for existing conditions
      prob_S2 = StormCounts(r1, 2) / iterations    'storm duration probability for proposed conditions
      prob_C1 = ConcBin(r2, 2) / iterations        'concentration probability existing conditions
      prob_C2 = ConcBin(r2, 3) / iterations        'concentration probability proposed conditions

      Existing_Probability(r1, r2) = prob_S1 * prob_C1
      Proposed_Probability(r1, r2) = prob_S2 * prob_C2
   Next r2
Next r1

End Sub
Sub CalcConcentrationMain()

'*****************************************************************
'main procedure for that concentration calculation
'*****************************************************************

Dim iParameter As Integer
Dim i As Integer
Dim count As Integer
Dim BinIncrement As Single
Dim MaxBin As Single
Dim Detention As Integer
Dim E_Mean As Double       'existing condition mean storm duration
Dim E_SD As Double         'existing condition standard deviation storm duration
Dim P_Mean As Double
Dim P_SD As Double
Dim Dur_Row As Long
Dim Dur_Mean As Single
Dim row As Long
Dim lastrow As Integer
Dim iMon As Integer
Dim Infiltration As Integer
Dim StormMax As Integer
Dim ConcSettings() As Variant
Dim Parameter_Name As String
```

```
Dim blnOutput As Boolean
Dim col_out As Integer
Dim sheet As String
Dim iDet As Integer
Dim sResult As String

On Error GoTo EH
frmConfirm.Hide

If Sheets(1).chk1 = -1 Then
   Sheets("Test").Activate
   Cells.Select
   Selection.ClearContents
   blnOutput = True
   col_out = 6
Else
   blnOutput = False
End If

Sheets("Results").Visible = True

'clear results sheet
Sheets("Results").Activate
Cells.Select
Selection.Clear
With Selection.Interior
   .ColorIndex = 2
   .Pattern = xlSolid
End With

Range("A1:A2000").Select
Selection.RowHeight = 12.75

'put input parameters in results sheet
ListInputParameters

'get input parameters
iterations = Sheets("Ref").Cells(2, 13)

'redimensionalize arrays
ReDim C(1 To iterations, 1 To 3)              ' 1- no treatment, 2 - basic, 3 - enhanced
ReDim C_Scaled(1 To iterations, 1 To 2)       ' 1 - existing conditions, 2- proposed
ReDim StormDurations(1 To iterations, 1 To 2)

sGauge = Sheets(1).cmbGauge
sheet = Trim(Left(sGauge, Len(sGauge) - 2))
count = 0

'call sub to fill water quality parameter and month input arrays
FillInputArrays

'fill in storm duration bin array
Sheets("Bin Settings").Activate
row = 2
```

```
count = 0
Do Until Cells(row, 6) = ""
   row = row + 1
   count = count + 1
Loop

lastrow = row - 1
StormDurationBins = Sheets("Bin Settings").Range("F2:F" & lastrow).Value
count = UBound(StormDurationBins)
StormMax = StormDurationBins(count, 1)
ReDim StormCounts(1 To count + 1, 1 To 2)

'fill in concentration bins
ConcSettings = Sheets("Bin Settings").Range("B2:D6").Value

'calculate area-weighted scaling factors for concentration data for existing conditions
ReDim ConcScalingFactors(1 To 3, 1 To 2)
Call CalcScalingFactors(Existing, 1)
Call CalcScalingFactors(Proposed, 2)

'loop through WQ parameters
For i = 1 To UBound(Parameters)
   iParameter = Parameters(i)

   For row = 2 To 6
      If Sheets("Bin Settings").Cells(row, 1) = iParameter Then
         Parameter_Name = Sheets("Bin Settings").Cells(row, 2)
      End If
   Next row

   'get concentration range for WQ parameter
   MaxBin = ConcSettings(iParameter, 3)
   BinIncrement = ConcSettings(iParameter, 2)

   'call sub to fill concentration arrays
   Call FillConcArray(iParameter)
   ScaleConcentrations

   'loop through months
   For iMon = 1 To UBound(Months)

      'call sub to fill storm duration array for existing and proposed conditions
      sResult = FillStormDurationArray("Existing", iMon)
      If sResult <> "OK" Then
         MsgBox sResult
         Exit Sub
      End If

      sResult = FillStormDurationArray("Proposed", iMon)
      If sResult <> "OK" Then
         MsgBox sResult
         Exit Sub
      End If
```

```
        'bin concentration data
        Call BinConcData(BinIncrement, MaxBin, C_Scaled)

        'bin storm duration data for existing and proposed conditions
        BinStormData

        'calculate probabilities for existing and proposed condtions
        CalcProbability

        'output results
        Call OutputResults(Parameter_Name, MonthName(Months(iMon)))
        DoEvents
    Next iMon
Next i

Sheets("Results").Cells(1, 1).Select
frmConfirm.Hide
TransferResults ("Concentration")

Exit Sub

EH:
    'hide concentration results sheet if visible
    Sheets("Results").Visible = False

    MsgBox "The following error occurred: " & Err.Description


End Sub
Sub CalcScalingFactors(InputArray() As Single, col As Integer)

'****************************************************************************************************
' calculate area weighted scaling factors for basic, enhanced, and no treatment
'****************************************************************************************************
Dim A_sum As Single
Dim A_Scaled As Single
Dim A As Single
Dim inf As Single
Dim r As Integer
Dim iTreat As Integer
Dim Scaled_Area(1 To 3) As Single

For r = 1 To UBound(InputArray, 1)
    iTreat = InputArray(r, 1)
    inf = InputArray(r, 2)
    A = InputArray(r, 3)

    A_Scaled = Scaled_Area(iTreat + 1)
    A_Scaled = A_Scaled + A * (100 - inf) / 100
    Scaled_Area(iTreat + 1) = A_Scaled
    A_sum = A_sum + A
Next r

For iTreat = 0 To 2
```

```
   r = iTreat + 1
   ConcScalingFactors(r, col) = Scaled_Area(r) / A_sum
Next iTreat

End Sub
Function FillStormDurationArray(sType As String, iMonth As Integer) As String

'*****************************************************************************************************
' fill storm duration array using outfall setting with highest average storm duration
'*****************************************************************************************************

Dim col As Integer
Dim arrTemp() As Single
Dim MeanMax As Single
Dim SD_Dur As Single
Dim r As Long
Dim iDet As Integer
Dim row_data As Long
Dim s As String
Dim mean As Single
Dim SheetName As String
Dim inf As Integer
Dim rain As Integer
Dim iDist As Integer

SheetName = Trim(Left(sGauge, Len(sGauge) - 2))
rain = Right(sGauge, 2)

Select Case sType
   Case "Existing"
      arrTemp = Existing
      col = 1
   Case "Proposed"
      arrTemp = Proposed
      col = 2
End Select

MeanMax = 0
For r = 1 To UBound(arrTemp, 1)
   inf = arrTemp(r, 2)
   iDet = arrTemp(r, 4)
   row_data = FindRow(SheetName, rain, inf, iDet, iMonth)

   If row_data = -999 Then
      s = "Can't find storm duration data for " & sGauge & " Infiltration: " & inf & " Month: " &
MonthName(iMonth)
      GoTo ExitFunc
   End If

   mean = Sheets(SheetName).Cells(row_data, 5)
   iDist = Sheets(SheetName).Cells(row_data, 9)    'distribution type

   If mean > MeanMax Then
      MeanMax = mean
```

```
        SD_Dur = Sheets(SheetName).Cells(row_data, 6)
    End If
Next r

If MeanMax = 0 Then
    s = "The mean storm duration for the existing conditions is zero. " _
              & "Outfall concentration cannot be calculated"
    GoTo ExitFunc
End If

'fill storm duration array with 1000 random storm durations for existing conditions
For r = 1 To iterations
    StormDurations(r, col) = CInt(GenRand(MeanMax, SD_Dur, 1, iDist))
Next r

s = "OK"

ExitFunc:
FillStormDurationArray = s

End Function
Sub ListInputParameters()

'*************************************************************************
'put input parameters into header of the output results
'*************************************************************************

Dim row1 As Integer
Dim row2 As Integer
Dim colstart1 As Integer
Dim colstart2 As Integer
Dim col As Integer
Dim inf As Integer
Dim area As Single
Dim iTreat As Integer
Dim blnNoArea As Boolean
Dim iDet As Integer
Dim rLook As Integer

colstart1 = 8
colstart2 = 12

'put input parameters into results sheet
Sheets("Results").Activate
Cells(1, 1) = "Concentration Analysis Report"
Range("A1").Select
Selection.Font.Bold = True
Selection.Font.Size = 20
Rows("1:1").Select
Rows("1:1").EntireRow.AutoFit

Cells(4, 1) = "Date/Time of Run:"
Cells(4, 3) = "'" & Format(Now(), "m/d/yy hh:mm")
Cells(5, 2) = "Outfall ID:"
```

```
Cells(5, 3) = Sheets(1).tOutfall
Cells(6, 2) = "Rain Gauge:"
Cells(6, 3) = Sheets(1).cmbGauge
Cells(7, 2) = "Description:"

Select Case iRunType
   Case 1
      Cells(7, 3) = frmConfirm.tDesc
   Case 2, 3
      rLook = Sheets("Ref").Cells(iSub + 1, 3)
      Cells(7, 3) = Sheets("Dilution_Inputs").Cells(rLook, 9)
End Select

Range(Cells(7, 3), Cells(10, 6)).Select

With Selection
   .VerticalAlignment = xlTop
   .WrapText = True
   .MergeCells = True
End With

Cells(4, colstart1) = "Existing Condition"
Range(Cells(4, colstart1), Cells(4, colstart1 + 2)).Select
With Selection
   .Font.Bold = True
   .Interior.ColorIndex = 36
End With
Call MediumBorderOuter(4, 4, colstart1, colstart1 + 2)

row2 = 6

'list existing conditions
For iTreat = 0 To 2
   Select Case iTreat
      Case 0
         sTreat = "No Treatment"
      Case 1
         sTreat = "Basic Treatment"
      Case 2
         sTreat = "Enhanced Treatment"
   End Select

   Cells(row2, colstart1) = sTreat
   row2 = row2 + 1
   blnNoArea = True

   For row1 = 1 To UBound(Existing, 1)
      If iTreat = Existing(row1, 4) Then
         blnNoArea = False
         area = Round(Existing(row1, 3), 2)
         inf = Existing(row1, 2)
         Cells(row2, colstart1) = "        " & inf & "% Infiltration - " & area & " acres"
         row2 = row2 + 1
      End If
```

```
    Next row1

    If blnNoArea = True Then
        row2 = row2 - 1
        Cells(row2, colstart1) = ""
    End If
Next iTreat

Call MediumBorderOuter(4, row2 + 1, colstart1, colstart1 + 2)

r_output = row2 + 5

'list proposed conditions
Cells(4, colstart2) = "Proposed Condition"

Range(Cells(4, colstart2), Cells(4, colstart2 + 3)).Select
With Selection
    .Font.Bold = True
    .Interior.ColorIndex = 36
End With
Call MediumBorderOuter(4, 4, colstart2, colstart2 + 3)

row2 = 6

For iTreat = 0 To 2
    Select Case iTreat
        Case 0
            sTreat = "No Treatment"
        Case 1
            sTreat = "Basic Treatment"
        Case 2
            sTreat = "Enhanced Treatment"
    End Select

    Cells(row2, colstart2) = sTreat
    row2 = row2 + 1
    blnNoArea = True

    For row1 = 1 To UBound(Proposed, 1)
        If iTreat = Proposed(row1, 1) Then
            blnNoArea = False
            area = Round(Proposed(row1, 3), 2)
            inf = Proposed(row1, 2)
            iDet = Proposed(row1, 4)
            If iDet = 0 Then
                Cells(row2, colstart2) = "        " & inf & "% Infiltration - " & area & " acres"
            Else
                Cells(row2, colstart2) = "        " & inf & "% Infiltration - " & area & " acres with detention"
            End If
            row2 = row2 + 1
        End If
    Next row1

    If blnNoArea = True Then
```

```
        row2 = row2 - 1
        Cells(row2, colstart2) = ""
    End If
Next iTreat

Call MediumBorderOuter(4, row2 + 1, colstart2, colstart2 + 3)

If row2 + 5 > r_output Then
    r_output = row2 + 5
End If

End Sub
Sub OutputResults(sParameter As String, sMonth As String)

'**********************************************************************
'put calculated probabilities in results sheet
'**********************************************************************

Dim r As Integer
Dim r2 As Integer
Dim rStop As Integer
Dim rstart As Integer
Dim col As Integer
Dim rowC As Integer
Dim high As Single
Dim low As Single
Dim bincount As Integer
Dim i1 As Integer
Dim i2 As Integer
Dim lastcol As Integer
Dim col1 As Integer
Dim col2 As Integer
Dim sCat As String
Dim p1 As Single
Dim p2 As Single
Dim rsum() As Single

ReDim rsum(1 To ConcCount, 1 To 2)

bincount = UBound(StormDurationBins) + 1
Sheets("Results").Activate
Cells(r_output, 1) = sParameter & " - " & sMonth & " - Probability of Occurrence"

Cells(r_output + 1, 2) = "Existing Conditions"
Cells(r_output + 1, 3 + bincount) = "Proposed Conditions"

rstart = r_output + 2
rStop = rstart + ConcCount - 1
Cells(rStop + 3, 2) = "Discharge Duration (hrs)"
Cells(rStop, 1) = "Conc. (mg/L)"
Range(Cells(rstart, 1), Cells(rStop, 1)).Select
With Selection
    .Font.Bold = True
    .MergeCells = True
```

```
    .Orientation = 90
    .HorizontalAlignment = xlCenter
End With

'storm duration labels for existing conditions
r = rStop + 2
col1 = 4
col2 = col1 + bincount + 2

For i1 = 1 To bincount
    Select Case i1
        Case 1
            sCat = "0 - " & StormDurationBins(i1, 1)
        Case bincount
            sCat = "'>" & StormDurationBins(bincount - 1, 1)
        Case Else
            sCat = "'" & StormDurationBins(i1 - 1, 1) & " - " & StormDurationBins(i1, 1)
    End Select

    Cells(r, col1) = sCat
    Cells(r, col2) = sCat

    col1 = col1 + 1
    col2 = col2 + 1
Next i1


'concentration bin labels
col1 = 2
col2 = col1 + 2 + bincount

r = rStop
For i1 = 1 To ConcCount
    Select Case i1
        Case 1
            sCat = "0 - " & ConcBin(i1, 1)
        Case ConcCount
            high = ConcBin(i1 - 1, 1)
            Select Case high
                Case Is < 0.01
                    sCat = "> " & CStr(Round(high, 4))
                Case Is < 0.1
                    sCat = "> " & CStr(Round(high, 3))
                Case Is < 1
                    sCat = "> " & CStr(Round(high, 2))
                Case Else
                    sCat = "> " & high
            End Select
        Case Else
            high = ConcBin(i1, 1)
            low = ConcBin(i1 - 1, 1)
            Select Case high
                Case Is < 0.01
                    sCat = CStr(Round(low, 4)) & " - " & CStr(Round(high, 4))
```

```
            Case Is < 0.1
               sCat = CStr(Round(low, 3)) & " - " & CStr(Round(high, 3))
            Case Is < 1
               sCat = CStr(Round(low, 2)) & " - " & CStr(Round(high, 2))
            Case Else
               sCat = "" & low & " - " & high
         End Select
   End Select

   Cells(r, col1) = sCat
   Cells(r, col2) = sCat
   r = r - 1
Next i1

'fill results
col = 4
For i1 = 1 To bincount
   colsum1 = 0
   colsum2 = 0
   For i2 = 1 To ConcCount
      r = rStop - i2 + 1
      p1 = Existing_Probability(i1, i2)
      p2 = Proposed_Probability(i1, i2)
      colsum1 = colsum1 + p1
      colsum2 = colsum2 + p2

      Cells(r, col) = CStr(Round(p1, 3))
      Cells(r, col + bincount + 2) = CStr(Round(p2, 3))
      rsum(i2, 1) = rsum(i2, 1) + p1
      rsum(i2, 2) = rsum(i2, 2) + p2
   Next i2

   Cells(rStop + 1, col) = CStr(Round(colsum1, 3))
   Cells(rStop + 1, col + bincount + 2) = CStr(Round(colsum2, 3))

   col = col + 1
Next i1

r = rStop
For i1 = 1 To ConcCount
   Cells(r, 3) = CStr(Round(rsum(i1, 1), 3))
   Cells(r, 5 + bincount) = CStr(Round(rsum(i1, 2), 3))
   r = r - 1
Next i1

'format table
'center table header
Range(Cells(r_output, 1), Cells(r_output, 2 * bincount + 5)).Select
With Selection
   .Font.Bold = True
   .HorizontalAlignment = xlCenterAcrossSelection
   .RowHeight = 32.25
   .VerticalAlignment = xlCenter
End With
```

```
'center existing and proposed labels
Range(Cells(r_output + 1, 2), Cells(r_output + 1, 3 + bincount)).Select
Selection.Font.Bold = True
Selection.HorizontalAlignment = xlCenterAcrossSelection

Range(Cells(r_output + 1, 4 + bincount), Cells(r_output + 1, 5 + 2 * bincount)).Select
Selection.Font.Bold = True
Selection.HorizontalAlignment = xlCenterAcrossSelection

'center discharge duration label
Range(Cells(rStop + 3, 2), Cells(rStop + 3, 2 * bincount + 5)).Select
Selection.Font.Bold = True
Selection.HorizontalAlignment = xlCenterAcrossSelection

'bold concentration and storm duration labels
Range(Cells(rstart, 2), Cells(rStop, 2)).Select
Selection.Font.Bold = True

Range(Cells(rstart, 4 + bincount), Cells(rStop, 4 + bincount)).Select
Selection.Font.Bold = True

Range(Cells(rStop + 2, 2), Cells(rStop + 2, 2 * bincount + 5)).Select
Selection.Font.Bold = True

Range(Cells(rStop + 2, 4), Cells(rStop + 2, 5 + bincount * 2)).Select
Selection.HorizontalAlignment = xlCenter

Range(Cells(rstart, 2), Cells(rStop + 1, 5 + 2 * bincount)).Select
Selection.HorizontalAlignment = xlCenter

'inside cell borders
Range(Cells(rstart, 3), Cells(rStop, 3 + bincount)).Select
With Selection.Borders(xlInsideVertical)
    .LineStyle = xlContinuous
    .Weight = xlThin
    .ColorIndex = 48
End With
With Selection.Borders(xlInsideHorizontal)
    .LineStyle = xlContinuous
    .Weight = xlThin
    .ColorIndex = 48
End With

Range(Cells(rstart, 5 + bincount), Cells(rStop, 5 + 2 * bincount)).Select
With Selection.Borders(xlInsideVertical)
    .LineStyle = xlContinuous
    .Weight = xlThin
    .ColorIndex = 48
End With

With Selection.Borders(xlInsideHorizontal)
    .LineStyle = xlContinuous
    .Weight = xlThin
```

```
    .ColorIndex = 48
End With

'cell borders
Call MediumBorderOuter(r_output, rStop + 3, 1, 2 * bincount + 5)          'entire table
Call ThinBorderOuter(rstart, rStop, 4, 3 + bincount)              'existing condition data
Call ThinBorderOuter(rstart, rStop, 5 + bincount, 5 + 2 * bincount)          'proposed condition data
Call MediumBorderOuter(rstart - 1, rStop, 2, 3 + bincount)            'existing conditions
Call MediumBorderOuter(rstart - 1, rStop, 4 + bincount, 5 + 2 * bincount) ' proposed conditions

'cell fill color
Range(Cells(r_output, 1), Cells(rStop + 3, 5 + 2 * bincount)).Select
Selection.Interior.ColorIndex = 36

Range(Cells(rstart, 4), Cells(rStop, 3 + bincount)).Select
Selection.Interior.ColorIndex = 2

Range(Cells(rstart, 5 + bincount), Cells(rStop, 5 + 2 * bincount)).Select
Selection.Interior.ColorIndex = 2

Range(Cells(rstart, 3), Cells(rStop, 3)).Select
Selection.Interior.ColorIndex = 4

Range(Cells(rstart, 5 + bincount), Cells(rStop, 5 + bincount)).Select
Selection.Interior.ColorIndex = 4

Range(Cells(rStop + 1, 4), Cells(rStop + 1, 3 + bincount)).Select
Selection.Interior.ColorIndex = 4

Range(Cells(rStop + 1, 6 + bincount), Cells(rStop + 1, 5 + bincount * 2)).Select
Selection.Interior.ColorIndex = 4

Call ThinBorderOuter(rstart, rStop, 3, 3)
Call ThinBorderOuter(rstart, rStop, 5 + bincount, 5 + bincount)
Call ThinBorderOuter(rStop + 1, rStop + 1, 4, 3 + bincount)
Call ThinBorderOuter(rStop + 1, rStop + 1, 6 + bincount, 5 + bincount * 2)

'set row for next table
r_output = rStop + 7

End Sub
Sub FillConfirmForm()

'*****************************************************************************
'fill frmConfirm with summary of input parameters for concentration routine
'*****************************************************************************

Dim iCol As Integer
Dim r As Integer
Dim sIndent As String
Dim atot As Single

sIndent = "      "
```

```
iCol = iSub + 4

With frmConfirm
   tSubBasin = iSub
   .lblOutfall.Caption = "   Outfall ID: " & Sheets(1).tOutfall
   .lblGauge.Caption = "   Rain Gauge: " & Sheets(1).cmbGauge

   If Sheets(1).listWQ.Selected(0) = True Then
      .lblWQ.Caption = "Water Quality Parameters: All"
   Else
      sCaption = " Water Quality Parameters"
      For itm = 1 To Sheets(1).listWQ.ListCount - 1
         If Sheets(1).listWQ.Selected(itm) = True Then
            sCaption = sCaption & vbCrLf & sIndent & Sheets(1).listWQ.Column(1, itm)
         End If
      Next itm
      .lblWQ.Caption = sCaption
   End If

   If Sheets(1).lstMonth.Selected(0) = True Then
      .lblMonth.Caption = "   Months: All"
   Else
      sCaption = "   Months: "
      For itm = 1 To Sheets(1).lstMonth.ListCount - 1
         If Sheets(1).lstMonth.Selected(itm) = True Then
            sCaption = sCaption & Left(Sheets(1).lstMonth.Column(1, itm), 3) & ", "
         End If
      Next itm
      .lblMonth.Caption = sCaption
   End If

   'existing conditions
   sCaption = "    Existing Conditions" & vbCrLf
   For iTreat = 0 To 2
      Select Case iTreat
         Case 0
            sTreat = "No"
         Case 1
            sTreat = "Basic"
         Case 2
            sTreat = "Enhanced"
      End Select

      atot = 0
      sCaption = sCaption & sIndent & sTreat & " Treatment" & vbCrLf

      For r = 1 To UBound(Existing, 1)
         If Existing(r, 1) = iTreat Then
            atot = atot + Existing(r, 3)
            sCaption = sCaption & sIndent & sIndent & Existing(r, 2) & "% - " & Existing(r, 3) & vbCrLf
         End If
      Next r
      If atot = 0 Then
         sCaption = sCaption & sIndent & sIndent & "no drainage area" & vbCrLf
```

```
        End If

        sCaption = sCaption & vbCrLf
    Next iTreat

    sCaption = sCaption & vbCrLf & sIndent & "Total Area: " & E_tot
    .lblExisting = sCaption

    'proposed conditions
    sCaption = "    Proposed Conditions" & vbCrLf
    For iTreat = 0 To 2
        Select Case iTreat
            Case 0
                sTreat = "No"
            Case 1
                sTreat = "Basic"
            Case 2
                sTreat = "Enhanced"
        End Select

        atot = 0
        sCaption = sCaption & sIndent & sTreat & " Treatment" & vbCrLf

        For r = 1 To UBound(Proposed, 1)
            If Proposed(r, 1) = iTreat Then
                atot = atot + Proposed(r, 3)
                sCaption = sCaption & sIndent & sIndent & Proposed(r, 2) & "% - " & Proposed(r, 3)

                If Proposed(r, 4) = 1 Then
                    sCaption = sCaption & " with detention"
                End If
                sCaption = sCaption & vbCrLf
            End If
        Next r

         If atot = 0 Then
            sCaption = sCaption & sIndent & sIndent & "no drainage area" & vbCrLf
        End If

        sCaption = sCaption & vbCrLf
    Next iTreat

    sCaption = sCaption & vbCrLf & sIndent & "Total Area: " & P_tot
    .lblProposed = sCaption

    .tDesc = ""
    .Show
End With

End Sub

Sub ScaleConcentrations()

Dim r As Long
```

```
'calculate scaled concentrations for existing and proposed conditions
For r = 1 To iterations

   'existing conditions
   C_Scaled(r, 1) = ConcScalingFactors(1, 1) * C(r, 1) + ConcScalingFactors(2, 1) * C(r, 2) +
ConcScalingFactors(3, 1) * C(r, 3)

   'proposed conditions
   C_Scaled(r, 2) = ConcScalingFactors(1, 2) * C(r, 1) + ConcScalingFactors(2, 2) * C(r, 2) +
ConcScalingFactors(3, 2) * C(r, 3)

Next r

End Sub

Sub RunConcStart()

iRunType = 1
SelectSub

End Sub
Sub CalcDilutionMain()

'***************************************************************************
'calculate receiving water concentration
'***************************************************************************

Dim i As Integer
Dim StormMax As Integer
Dim iMon As Integer
Dim count As Integer
Dim C_amb() As Single
Dim Camb As Single
Dim row As Integer
Dim sResult As String
Dim Param_Name As String
Dim col_out As Integer
Dim ramb As Integer
Dim iParameter As Integer
Dim C_avg As Single
Dim C_sd As Single
Dim sDesc As String

If Sheets(1).chk1 = -1 Then
   Sheets("Test").Visible = True
   Sheets("Test").Activate
   Cells.Select
   Selection.ClearContents
Else
   Sheets("Test").Visible = False
End If

col_out = 1
```

```
'clear results sheet
Sheets("Results").Visible = True
Sheets("Results").Activate
Cells.Select
Selection.Clear
With Selection.Interior
   .ColorIndex = 2
   .Pattern = xlSolid
End With

Range("A1:A2000").Select
Selection.RowHeight = 12.75
row = Sheets("Ref").Cells(iSub + 1, 3)
frmConfirm.tDesc = Sheets("Dilution_Inputs").Cells(row, 9)

'fill input arrays and existing and proposed conditions
FillInputArrays
FillConditions

'put input parameters in results sheet
ListInputParameters

'get input parameters
iterations = Sheets("Ref").Cells(2, 13)

'redimensionalize arrays
ReDim StormDurations(1 To iterations, 1 To 2)        'column 1 - existing, column 2 - proposed
ReDim C_mix(1 To iterations, 1 To 2)                 'column 1 - existing, column 2 - proposed
ReDim DF(1 To iterations, 1 To 2)                    'column 1 - existing, column 2 - proposed
ReDim Q_comb(1 To iterations, 1 To 2)
ReDim C_amb(1 To iterations)

sGauge = Sheets(1).cmbGauge
sheet = Trim(Left(sGauge, Len(sGauge) - 2))

'fill in storm duration bin array
Sheets("Bin Settings").Activate
row = 2
count = 0
Do Until Cells(row, 6) = ""
   row = row + 1
   count = count + 1
Loop

lastrow = row - 1
StormDurationBins = Sheets("Bin Settings").Range("F2:F" & lastrow).Value
count = UBound(StormDurationBins)
StormMax = StormDurationBins(count, 1)
ReDim StormCounts(1 To count + 1, 1 To 2)

'calculate area-weighted scaling factors for concentration data for existing conditions
ReDim ConcScalingFactors(1 To 3, 1 To 2)
Call CalcScalingFactors(Existing, 1)
```

```
Call CalcScalingFactors(Proposed, 2)

'loop through WQ parameters
For i = 1 To UBound(Parameters)
   iParameter = Parameters(i)

   For row = 2 To 6
      If Sheets("Bin Settings").Cells(row, 1) = iParameter Then
         Param_Name = Sheets("Bin Settings").Cells(row, 2)
      End If
   Next row

   'clear concentration arrays
   ReDim C(1 To iterations, 1 To 3)              ' 1- no treatment, 2 - basic, 3 - enhanced
   ReDim C_Scaled(1 To iterations, 1 To 2)       ' 1 - existing conditions, 2- proposed

   'fill concentration array for selected analyte
   FillConcArray (iParameter)

   'scale concentrations
   ScaleConcentrations

   'get average and std dev ambient concentration for RivPlum
   ramb = Sheets("Ref").Cells(1 + iSub, 3) + iParameter - 1

   If iRunType = 2 Then
      Camb = Sheets("Dilution_Inputs").Cells(ramb, 6)
   ElseIf iRunType = 3 Then
      C_avg = Sheets("Dilution_Inputs").Cells(ramb, 6)
      C_sd = Sheets("Dilution_Inputs").Cells(ramb, 7)

      'fill ambient concentration array using log normal distribution
      For row = 1 To iterations
         C_amb(row) = GenRand(C_avg, C_sd, 0, 1)
      Next row
   End If

   'loop through selected months
   For iMon = 1 To UBound(Months)
      'call sub procedure to calculate combined flow
      Call CalcQ(Months(iMon), "Existing")
      Call CalcQ(Months(iMon), "Proposed")

      'get other RivPlum inputs
      GetRivPlumInputs (Months(iMon))

      'fill dilution factor array by calling RivPlum 1000 times
      'for existing and proposed conditions
      For row = 1 To iterations
         DF(row, 1) = RivPlum(Q_comb(row, 1))
         DF(row, 2) = RivPlum(Q_comb(row, 2))
      Next row

      'calculate mixed concentration for existing and proposed conditions
```

```
        If iRunType = 2 Then
            For row = 1 To iterations
                C_mix(row, 1) = (C_Scaled(row, 1) - Camb) / DF(row, 1) + Camb
                C_mix(row, 2) = (C_Scaled(row, 2) - Camb) / DF(row, 1) + Camb
            Next row
        ElseIf iRunType = 3 Then
            For row = 1 To iterations
                C_mix(row, 1) = (C_Scaled(row, 1) - C_amb(row)) / DF(row, 1) + C_amb(row)
                C_mix(row, 2) = (C_Scaled(row, 2) - C_amb(row)) / DF(row, 1) + C_amb(row)
            Next row
        End If

        'call sub to determine concentration bin increments
        If iRunType = 2 Then
            Call BinMixedConcentration(Camb, iParameter)
        ElseIf iRunType = 3 Then
            Call BinMixedConcentration(C_avg, iParameter)
        End If

        'fill storm duration array for existing and proposed conditions
        sResult = FillStormDurationArray("Existing", iMon)
        If sResult <> "OK" Then
            MsgBox sResult
            Exit Sub
        End If

        sResult = FillStormDurationArray("Proposed", iMon)
        If sResult <> "OK" Then
            MsgBox sResult
            Exit Sub
        End If

        'bin storm data
        BinStormData

        'calculate probabilities
        CalcProbability

        'output results
        Call OutputResults(Param_Name, MonthName(Months(iMon)))
        DoEvents
    Next iMon

Next i

'output arrays if checked
If Sheets(1).chk1 = -1 Then
    Sheets("Test").Cells(1, col_out) = "Scaled Concentration Existing"
    Sheets("Test").Cells(1, col_out + 1) = "Scaled Concentration Proposed"
    Sheets("Test").Cells(1, col_out + 2) = "Q Combined Existing"
    Sheets("Test").Cells(1, col_out + 3) = "Q Combined Proposed"
    Sheets("Test").Cells(1, col_out + 4) = "DF Existing"
    Sheets("Test").Cells(1, col_out + 5) = "DF Proposed"
    Sheets("Test").Cells(1, col_out + 6) = "Cmix Existing"
```

```
    Sheets("Test").Cells(1, col_out + 7) = "Cmix Proposed"

    For row = 1 To iterations
        Sheets("Test").Cells(row + 1, col_out) = CStr(Round(C_Scaled(row, 1), 5))
        Sheets("Test").Cells(row + 1, col_out + 1) = CStr(Round(C_Scaled(row, 2), 5))
        Sheets("Test").Cells(row + 1, col_out + 2) = CStr(Round(Q_comb(row, 1), 5))
        Sheets("Test").Cells(row + 1, col_out + 3) = CStr(Round(Q_comb(row, 2), 5))
        Sheets("Test").Cells(row + 1, col_out + 4) = CStr(Round(DF(row, 1), 3))
        Sheets("Test").Cells(row + 1, col_out + 5) = CStr(Round(DF(row, 2), 3))
        Sheets("Test").Cells(row + 1, col_out + 6) = CStr(Round(C_mix(row, 1), 6))
        Sheets("Test").Cells(row + 1, col_out + 7) = CStr(Round(C_mix(row, 2), 6))
    Next row
End If

'transfer results to new spreadsheet
TransferResults ("Dilution")

End Sub
Sub CalcQ(iMonth As Integer, sType As String)

'****************************************************************************
'calculate combined discharge for existing and proposed outfall conditions
'****************************************************************************

Dim row_Q As Long
Dim row_Temp As Integer
Dim count As Integer
Dim iCol As Integer
Dim arrTemp() As Single
Dim area As Single
Dim FC As Integer
Dim inf As Integer
Dim row_find As Long
Dim Q_mean As Single
Dim Q_SD As Single
Dim QTemp() As Single
Dim sName As String
Dim rain As Integer
Dim iDist As Integer

sName = Trim(Left(sGauge, Len(sGauge) - 2))
rain = Right(sGauge, 2)

Select Case sType
    Case "Existing"
        arrTemp = Existing
        iCol = 1
    Case "Proposed"
        arrTemp = Proposed
        iCol = 2
End Select

count = UBound(arrTemp, 1)
ReDim QTemp(1 To iterations, 1 To count)
```

```
For rTemp = 1 To count
   inf = arrTemp(rTemp, 2)
   area = arrTemp(rTemp, 3)
   FC = arrTemp(rTemp, 4)

   'call function to find row that contains mean and standard deviation flow
   row_find = FindRow(sName, rain, inf, FC, iMonth)
   Q_mean = Sheets(sName).Cells(row_find, 7)
   Q_SD = Sheets(sName).Cells(row_find, 8)
   iDist = Sheets(sName).Cells(row_find, 10)

   For row_Q = 1 To iterations
      QTemp(row_Q, rTemp) = GenRand(Q_mean, Q_SD, 0, iDist)
   Next row_Q
Next rTemp

'calculate combined discharge based upon area
For row_Q = 1 To iterations
   Q = 0
   For row_Temp = 1 To count
      area = arrTemp(row_Temp, 3)
      Q = Q + area * QTemp(row_Q, row_Temp)
   Next row_Temp
   Q_comb(row_Q, iCol) = Q
Next row_Q

End Sub
Function RivPlum(Q As Single) As Single

'*****************************************************************************
'calculate dilution factor based upon dilution input settings
'*****************************************************************************

'receiving water inputs
Dim depth As Double        'stream depth (ft)
Dim v As Double            'stream velocity (fps)
Dim w As Double            'channel width (ft)
Dim factor As Double       'slope or manning's roughness
Dim iType As Integer
Dim d As Double            'Discharge Distance From Nearest Shoreline (ft)
Dim d_Down As Double       'Distance Downstream to Point of Interest (ft):
Dim d_Shore As Double      'distance from nearest shore
Dim mix_coeff As Double    'transverse mixing coefficient
Dim ConcPer As Double      'Concentration of Conservative Substance (%)
Dim m_in As Double         'mass input rate (cfs x %)
Dim v_shear As Double      'shear velocity
Dim f As Double            'Darcy Weibach friction factor
Dim iMethod As Integer     'Original Fischer Method =0 or Effective Origin Modification =1
Dim pi As Double

'plume characteristic
Dim Co As Double
Dim x As Double
```

```
Dim x_add As Double
Dim y_o As Double
Dim y As Double            'y at point of interest
Dim Cratio As Double
Dim C As Double
Dim DF As Double

pi = 3.14159265358979
depth = RivPlumInputs(1, 1)
v = RivPlumInputs(2, 1)
w = RivPlumInputs(3, 1)
factor = RivPlumInputs(4, 1)
iType = RivPlumInputs(5, 1)
d = RivPlumInputs(6, 1)
d_Down = RivPlumInputs(7, 1)
d_Shore = RivPlumInputs(8, 1)
mix_coeff = RivPlumInputs(9, 1)
iMethod = RivPlumInputs(10, 1)
ConcPer = 100

'calculate Source Conservative Mass Input Rate (cfs*%)
m_in = Q * ConcPer

'calculate shear velocity
If iType = 0 Then
   'based on slope
   v_shear = Sqr(32.2 * depth * factor)
Else
   'based on mannings roughness
   f = ((factor * Sqr(257.6)) / (1.49 * depth)) ^ 2
   v_shear = v * Sqr(f / 8)
End If

mix_coeff = depth * mix_coeff * v_shear

Co = m_in / (depth * v * w)
x = (d_Down * mix_coeff) / (v * w ^ 2)
y_o = d / w
y = d_Shore / w

'solution using supersition equation
Dim n As Integer
Dim n_sum As Double

For n = -2 To 2
   n_sum = n_sum + Exp(-((y - 2 * n - y_o) ^ 2 / (4 * x))) + Exp(-((y - 2 * n + y_o) ^ 2 / (4 * x)))
Next n


If iMethod = 1 Then
   'effective origin method
   'Upstream Distance from Outfall to Effective Origin of Effluent Source (ft)
   d_eff_up = ((n_sum * Q) / depth) ^ 2 / (v * pi * 4 * mix_coeff)
End If
```

```
'Effective Distance Downstream from Effluent to Point of Interest (ft)
If iMethod = 0 Then
   d_eff_down = d_Down
Else
   d_eff_down = d_Down + d_eff_up
End If

'x Adjusted for Effective Origin
x_adj = (d_eff_down * mix_coeff) / (v * w ^ 2)


Cratio = n_sum * (1 / Sqr(4 * pi * x_adj))

'Concentration at Point of Interest (Fischer Eqn 5.9)
If Cratio * Co <= ConcPer Or iMethod = 0 Then
   C = Cratio * Co
Else
   C = ConcPer
End If

'Unbounded Plume Half-Width at Point of Interest (ft)
plume_w = Sqr(mix_coeff * d_eff_down / v)

' Plume width bounded by shoreline (ft)
If d > plume_w Then
   plume_w2 = d
Else
   plume_w2 = plume_w
End If


If plume_w < w - d Then
   plume_w2 = plume_w2 + plume_w
Else
   plume_w2 = plume_w2 + (w - d)
End If

'Approximate Downstream Distance to Complete Mix (ft):
d_approx = 0.1 * v * ((2 - 2 * yo) * w) ^ 2 / mix_coeff


'Calculated Flux-Average Dilution Factor Across Entire Plume Width:
flux = (plume_w2 * depth * v) / Q
If flux < 1 Then
   flux = 1
End If

'calculate dilution factor
DF = ConcPer / C

If DF < 1 Then
   DF = 1
End If
```

```
RivPlum = DF

'Debug.Print v_shear
'Debug.Print mix_coeff
'Debug.Print Co
'Debug.Print x
'Debug.Print yo
'Debug.Print y
'Debug.Print n_sum
'Debug.Print x_adj
'Debug.Print d_eff_down
'Debug.Print Cratio
'Debug.Print plume_w
'Debug.Print plume_w2
'Debug.Print DF

End Function
Function GetRivPlumInputs(MonthNum As Integer)

'****************************************************************************
'fill RivPlum array with corresponding inputs for month
'****************************************************************************

Dim col As Integer
Dim r1 As Integer
Dim r2 As Integer
Dim r As Integer

r1 = Sheets("Ref").Cells(1 + iSub, 4)
r2 = r1 + 9
col = 7 + MonthNum
scol = Chr(64 + col)

RivPlumInputs = Sheets("Dilution_Inputs").Range(scol & r1 & ":" & scol & r2).Value

End Function

Sub RunDilution1()

iRunType = 2
SelectSub

End Sub
Sub RunDilution2()

iRunType = 3
SelectSub

End Sub

Sub BinMixedConcentration(C_a As Single, iP As Integer)
'****************************************************************************
'bin mixed concentration results using 0 to ambient concentration as 1st bin
```

```
'and subsequent 1 ug/l bins up to 10 bins
'1st column is the maximum concentration for the bin
'2nd column is bin count for existing conditions
'3rd column is bin count for proposed conditions
'***************************************************************************

Dim bininc As Single
Dim rbin As Integer
Dim rArr As Long
Dim col As Integer
Dim bincount As Long
Dim Cmax As Single
Dim Ctemp() As Single
Dim iDec As Integer

ConcCount = 11
If iP = 1 Then
   'for TSS determine bin increments based upon maximum value
   'sort existing mixed concentration
   ReDim Ctemp(1 To iterations)
   For rArr = 1 To iterations
      Ctemp(rArr) = C_mix(rArr, 1)
   Next rArr

   Call QuickSort(Ctemp)
   Cmax = Ctemp(CLng(0.95 * iterations))

   C_a = Round(C_a, 0)
   Select Case Cmax - C_a
      Case Is < 1
         bininc = 0.1
      Case Is < 5
         bininc = 0.5
      Case Is < 10
         bininc = 1
      Case Is < 20
         bininc = 2
      Case Is < 50
         bininc = 5
      Case Is < 100
         bininc = 10
      Case Else
         bininc = 20
   End Select
   iDec = 1
Else
   bininc = 0.001
   C_a = Round(C_a, 3)
   iDec = 3
End If

ReDim ConcBin(1 To 11, 1 To 3)
```

```
ConcBin(1, 1) = C_a
ConcBin(1, 2) = 0
ConcBin(1, 3) = 0

For rbin = 2 To 10
   ConcBin(rbin, 1) = Round(C_a + (rbin - 1) * bininc, iDec)
   ConcBin(rbin, 2) = 0
   ConcBin(rbin, 3) = 0
Next rbin

'last bin everything else
ConcBin(11, 1) = C_a * 1000
ConcBin(11, 2) = 0
ConcBin(11, 3) = 0

'bin concentration data
For rArr = 1 To iterations
   For col = 1 To 2
      Cm = Round(C_mix(rArr, col), iDec)
      For rbin = 1 To 11
          If Cm < Round(ConcBin(rbin, 1), iDec) Then
            bincount = ConcBin(rbin, col + 1)
            ConcBin(rbin, col + 1) = bincount + 1
            Exit For
          End If
      Next rbin
   Next col
Next rArr

End Sub
Function CheckDilutionInputs(iType As Integer) As String

'******************************************************************************
'check if selected sub basin has complete input settings
'******************************************************************************

Dim r1 As Integer
Dim r2 As Integer
Dim r As Integer
Dim i As Integer
Dim row As Integer
Dim val As Variant
Dim sCheck As String
Dim col As Integer
Dim iM As Integer

sCheck = "OK"

FillInputArrays
Sheets("Dilution_Inputs").Activate

r1 = Sheets("Ref").Cells(1 + iSub, 3)
r2 = Sheets("Ref").Cells(1 + iSub, 4)
```

```
'check that all selected WQ parameters have concentration values entered
For i = 1 To UBound(Parameters)
   iP = Parameters(i)
   row = r1 + iP - 1
   val = Cells(row, 6)
   If IsNumeric(val) = False Then
      sCheck = "concentration value for " & Cells(row, 4) & " is not a valid number"
      GoTo ExitFunc
   ElseIf val = vbNullString Then
      sCheck = "No concentration value for " & Cells(row, 4)
      GoTo ExitFunc
   End If

   If iRunType = 3 Then
      val = Cells(row, 7)

      If IsNumeric(val) = False Then
         sCheck = "standard deviation value for " & Cells(row, 4) & " is not a valid number"
         GoTo ExitFunc
      ElseIf val = vbNullString Then
         sCheck = "No standard deviation value for " & Cells(row, 4)
         GoTo ExitFunc
      End If
   End If
Next i

'check that all selected months have values entered
For i = 1 To UBound(Months)
   iM = Months(i)
   col = 7 + iM

   For r = r2 To r2 + 9
      val = Cells(r, col)
      If IsNumeric(val) = False Then
         sCheck = Cells(r, 4) & " value for " & MonthName(iM) & " is not a valid number"
         GoTo ExitFunc
      ElseIf val = vbNullString Then
         sCheck = Cells(r, 4) & " value for " & MonthName(iM) & " is blank"
         GoTo ExitFunc
      End If

      Select Case r - r2
         Case 0, 1, 2, 3, 6
            If Cells(r, col) = 0 Then
               sCheck = Cells(r, 4) & " value for " & MonthName(iM) & " must be greater than 0"
               Cells(r, col).Select
               GoTo ExitFunc
            End If
      End Select
   Next r
Next i

ExitFunc:
   CheckDilutionInputs = sCheck
```

```
End Function


Function GetMax(sngArr() As Single) As Single

Dim Arow As Long
Dim x As Single
Dim Xmax

Xmax = 0
For Arow = 1 To UBound(sngArr)
   x = sngArr(Arow, 1)
   If x > Xmax Then
      Xmax = x
   End If
Next Arow

GetMax = Xmax

End Function

Sub LoadCalculation_Main()

'*****************************************************************************
'load calculation main program
'*****************************************************************************

Dim iParameter As Integer
Dim Cmin As Single
Dim Cmax As Single
Dim row As Long
Dim Fconv As Single        'conversion factor
Dim sParameter As String
Dim BinVal As Single
Dim Lmin As Single
Dim Lmax As Single
Dim Lstats(1 To 5, 1 To 2) As Single
Dim ExceedCount As Long
Dim PerExceed As Single
Dim val As Single
Dim iRound As Integer
Dim col_out As Integer
Dim rstart As Integer
Dim col As Integer
Dim blnOutput As Boolean
Dim TempArray() As Single
Dim i As Integer

'On Error GoTo EH

If Sheets(1).chk1 = -1 Then
   Sheets("Test").Activate
   Cells.Select
   Selection.ClearContents
```

```
    blnOutput = True
    col_out = 4
Else
    blnOutput = False
End If


Sheets("Results").Visible = True

FillInputArrays

'clear load results sheet
Sheets("Results").Activate
Columns("A:Z").Select
Selection.Clear
With Selection.Interior
    .ColorIndex = 2
    .Pattern = xlSolid
End With

iterations = Sheets("Ref").Cells(2, 13)
Fconv = 0.00006243
sGauge = Sheets(1).cmbGauge

'dimensionalize load arrays
ReDim Load_E(1 To iterations)
ReDim Load_P(1 To iterations)

'fill annual runoff volume array
FillAnnualRunoffVol

'dimensionalize concentration array
ReDim C(1 To iterations, 1 To 3)            ' 1- no treatment, 2 - basic, 3 - enhanced

'get bin settings
ConcSettings = Sheets("Bin Settings").Range("B2:D6").Value

'list input parameters
rstart = ListInputs_Load

'loop through water quality parameters
col_out = 3
For i = 1 To UBound(Parameters)
    iParameter = Parameters(i)
    ExceedCount = 0
    sParameter = ConcSettings(iParameter, 1)
    Cmin = ConcSettings(iParameter, 2) / 2
    Cmax = ConcSettings(iParameter, 3)
    Call FillConcArray(iParameter)

    'calculate scaled annual volumes for each treatment type for existing conditionds
    ReDim Vol_Scaled_E(1 To iterations, 1 To 3)     'column 1 -none, 2- basic, 3 - enhanced
    ReDim Vol_Scaled_P(1 To iterations, 1 To 3)  'column 1 -no treatment, 2- basic, 3 - enhanced
    Call ScaleVolumes("Existing")
```

```
    Call ScaleVolumes("Proposed")

    'calculate pollutant load
    ReDim Existing_Load(1 To iterations)
    ReDim Proposed_Load(1 To iterations)

    For row = 1 To iterations
        Existing_Load(row) = Fconv * (C(row, 1) * Vol_Scaled_E(row, 1) + C(row, 2) * Vol_Scaled_E(row, 2)
+ C(row, 3) * Vol_Scaled_E(row, 3))
        Proposed_Load(row) = Fconv * (C(row, 1) * Vol_Scaled_P(row, 1) + C(row, 2) * Vol_Scaled_P(row,
2) + C(row, 3) * Vol_Scaled_P(row, 3))
    Next row

    'sort load arrays
    Call QuickSort(Existing_Load)
    Call QuickSort(Proposed_Load)

    'get min and max values for existing and proposed conditions
    Lstats(5, 1) = Existing_Load(1)
    Lstats(5, 2) = Proposed_Load(1)
    Lstats(1, 1) = Existing_Load(iterations)
    Lstats(1, 2) = Proposed_Load(iterations)

    'calculate quartiles existing conditions
    Lstats(4, 1) = Existing_Load(CLng(0.25 * iterations))
    Lstats(3, 1) = Existing_Load(CLng(0.5 * iterations))
    Lstats(2, 1) = Existing_Load(CLng(0.75 * iterations))

    'calculate quartiles proposed conditions
    Lstats(4, 2) = Proposed_Load(CLng(0.25 * iterations))
    Lstats(3, 2) = Proposed_Load(CLng(0.5 * iterations))
    Lstats(2, 2) = Proposed_Load(CLng(0.75 * iterations))

    'calculate percent exceedance between proposed and existing conditions
    For row = 1 To iterations
        If Proposed_Load(row) > Existing_Load(row) Then
            ExceedCount = ExceedCount + 1
        End If
    Next row

    PerExceed = ExceedCount / iterations

    'output results
    Sheets("Results").Activate
    r_output = rstart

    Cells(r_output, col_out) = sParameter
    Range(Cells(r_output, col_out), Cells(r_output, col_out + 1)).Select
    Selection.HorizontalAlignment = xlCenterAcrossSelection

    r_output = r_output + 1
    Cells(r_output, col_out) = "Existing"
    Cells(r_output, col_out + 1) = "Proposed"
```

```
    r_output = r_output + 1
    If i = 1 Then
        'labels
        Cells(r_output, 2) = "Max"
        Cells(r_output + 1, 2) = "75th Percentile"
        Cells(r_output + 2, 2) = "Median"
        Cells(r_output + 3, 2) = "25th Percentile"
        Cells(r_output + 4, 2) = "Min"
        Cells(r_output + 5, 2) = "P (exceed)"

    End If

    'results
    For row = 1 To 5
        val = Lstats(row, 1)
        Select Case val
            Case Is < 1
                iRound = 3
            Case Is < 10
                iRound = 2
            Case Is < 100
                iRound = 1
            Case Else
                iRound = 0
        End Select

        Cells(r_output + row - 1, col_out) = CStr(Round(Lstats(row, 1), iRound))

        val = Lstats(row, 2)
        Select Case val
            Case Is < 0.1
                iRound = 3
            Case Is < 1
                iRound = 2
            Case Is < 10
                iRound = 1
            Case Else
                iRound = 0
        End Select

        Cells(r_output + row - 1, col_out + 1) = CStr(Round(Lstats(row, 2), iRound))
    Next row

    Cells(r_output + 5, col_out + 1) = CStr(Round(PerExceed, 3))
    col_out = col_out + 2
Next i

'format table

'bold column and row headers
col_out = col_out - 1
Range(Cells(rstart - 1, 3), Cells(rstart + 1, col_out)).Select
With Selection
    .Font.Bold = True
```

```
   .Interior.ColorIndex = 36
End With

Range(Cells(rstart - 1, 2), Cells(rstart + 7, 2)).Select
With Selection
   .Font.Bold = True
   .Interior.ColorIndex = 36
End With

'center load header
Range(Cells(rstart - 1, 3), Cells(rstart - 1, col_out)).Select
With Selection
   .HorizontalAlignment = xlCenterAcrossSelection
   .VerticalAlignment = xlTop
End With

'draw borders
Call MediumBorderOuter(rstart - 1, rstart + 7, 2, col_out)

For col = 4 To col_out Step 2
   Call MediumBorderOuter(rstart, rstart + 1, 3, col)
   Call MediumBorderOuter(rstart + 2, rstart + 7, 3, col)
Next col

'center load data
Range(Cells(rstart + 1, 3), Cells(rstart + 7, col_out)).Select
Selection.HorizontalAlignment = xlCenter
Cells(1, 1).Select

Columns("B:B").Select
Selection.ColumnWidth = 17
Rows("16:21").Select
Selection.RowHeight = 12.75

TransferResults ("Load")

Exit Sub

EH:
   Sheets("Results").Visible = False
   MsgBox "The following error occurred during calculation: " & Err.Description

End Sub

Function ListInputs_Load() As Integer

'******************************************************************************
'list inputs for load calculation
'******************************************************************************

Dim r As Integer
Dim rOut As Integer
Dim iTreat As Integer
Dim sTreat As String
```

```
Dim blnNoArea As Boolean
Dim col1 As Integer
Dim col2 As Integer

col1 = 4
col2 = 8

Sheets("Results").Activate
Cells(1, 1) = "TDA Pollutant Load Analysis Report"
Range("A1").Select
With Selection
    .Font.Bold = True
    .Font.Size = 20
End With

'list input parameters
Cells(3, 1) = "Date/Time of Run: " & Format(Now, "m/d/yy hh:mm")
Cells(4, 1) = "Outfall ID: " & Sheets(1).tOutfall
Cells(5, 1) = "Rain Gauge:  " & Sheets(1).cmbGauge

Cells(3, 4) = "Existing Conditions"
Cells(3, 8) = "Proposed Conditions"

'format headers
Range(Cells(3, 4), Cells(3, 6)).Select
With Selection
    .Font.Bold = True
    .Interior.ColorIndex = 36
End With
Call MediumBorderOuter(3, 3, 4, 6)

Range(Cells(3, 8), Cells(3, 11)).Select
With Selection
    .Font.Bold = True
    .Interior.ColorIndex = 36
End With
Call MediumBorderOuter(3, 3, 8, 11)

'list existing conditions
rOut = 4
For iTreat = 0 To 2
    Select Case iTreat
        Case 0
            sTreat = "No Treatment"
        Case 1
            sTreat = "Basic Treatment"
        Case 2
            sTreat = "Enhanced Treatment"
    End Select

    Cells(rOut, col1) = sTreat
    rOut = rOut + 1
    blnNoArea = True
```

```
    For r = 1 To UBound(Existing, 1)
        If iTreat = Existing(r, 4) Then
            blnNoArea = False
            area = Round(Existing(r, 3), 2)
            inf = Existing(r, 2)
            Cells(rOut, col1) = "        " & inf & "% Infiltration - " & area & " acres"
            rOut = rOut + 1
        End If
    Next r

    If blnNoArea = True Then
        rOut = rOut - 1
        Cells(rOut, col1) = ""
    End If
Next iTreat

Call MediumBorderOuter(4, rOut + 1, col1, col1 + 2)

rOut = 4

'list proposed conditions

For iTreat = 0 To 2
    Select Case iTreat
        Case 0
            sTreat = "No Treatment"
        Case 1
            sTreat = "Basic Treatment"
        Case 2
            sTreat = "Enhanced Treatment"
    End Select

    Cells(rOut, col2) = sTreat
    rOut = rOut + 1
    blnNoArea = True

    For r = 1 To UBound(Proposed, 1)
        If iTreat = Proposed(r, 1) Then
            blnNoArea = False
            area = Round(Proposed(r, 3), 2)
            inf = Proposed(r, 2)
            iDet = Proposed(r, 4)
            If iDet = 0 Then
                Cells(rOut, col2) = "        " & inf & "% Infiltration - " & area & " acres"
            Else
                Cells(rOut, col2) = "        " & inf & "% Infiltration - " & area & " acres with detention"
            End If
            rOut = rOut + 1
        End If
    Next r

    If blnNoArea = True Then
        rOut = rOut - 1
        Cells(rOut, col2) = ""
```

```
   End If
Next iTreat

Call MediumBorderOuter(4, rOut + 1, col2, col2 + 3)

rOut = rOut + 3

'pollutant header
Cells(rOut, 3) = "Load (lb/yr)"
ListInputs_Load = rOut + 1

End Function

Sub FillAnnualRunoffVol()

'******************************************************************************
'fill annual runoff volume array with random volumes for infiltration rates 0 to 80
'******************************************************************************

Dim r As Long
Dim col As Integer
Dim inf As Integer
Dim Avg_Vol As Single
Dim SD_Vol As Single
Dim lookuprow As Integer

ReDim Vol(1 To iterations, 1 To 5)

For col = 1 To 5
   inf = (col - 1) * 20
   lookuprow = AnnualVolumeRow(sGauge, inf)
   Avg_Vol = Sheets("Annual_Runoff_Volume").Cells(lookuprow, 3)
   SD_Vol = Sheets("Annual_Runoff_Volume").Cells(lookuprow, 4)

   For r = 1 To iterations
      Vol(r, col) = GenRand(Avg_Vol, SD_Vol, 0, 0)
   Next r
Next col

If Sheets(1).chk1 = -1 Then
   Sheets("Test").Activate


   Cells(1, 1) = "Volume_0"
   Cells(1, 2) = "Volume_20"
   Cells(1, 3) = "Volume_40"
   Cells(1, 4) = "Volume_60"
   Cells(1, 5) = "Volume_80"

   For r = 1 To iterations
      Sheets("Test").Cells(r + 1, 1) = Vol(r, 1)
      Sheets("Test").Cells(r + 1, 2) = Vol(r, 2)
      Sheets("Test").Cells(r + 1, 3) = Vol(r, 3)
      Sheets("Test").Cells(r + 1, 4) = Vol(r, 4)
```

```
        Sheets("Test").Cells(r + 1, 5) = Vol(r, 5)
    Next r
End If

End Sub
Function AnnualVolumeRow(RainGauge As String, Infiltration As Integer) As Integer

'******************************************************************************
'find row containing annual volume data for selected rain gauge and infiltration value
'******************************************************************************

Dim row As Integer
Dim inf As Long

Sheets("Annual_Runoff_Volume").Activate
row = 2
Do Until Cells(row, 1) = ""
    If Cells(row, 1) = RainGauge And Cells(row, 2) = Infiltration Then
        Exit Do
    End If
    row = row + 1
Loop

AnnualVolumeRow = row

End Function
Sub ScaleVolumes(sType As String)

'**********************************************************************************
'Calculate scaled annual volumes for each treatment type based upon infiltration scaling factors
'**********************************************************************************

Dim V_i As Long         'annual volume for a given infiltration value
Dim v As Long
Dim V_n As Long         'scaled volumen no treatment
Dim V_b As Long         'scaled volume basic treatment
Dim V_e As Long         'scaled volume enhanced treatment
Dim V_s() As Long       'array to hold calculated scaled volumes
Dim r1 As Long
Dim r2 As Integer
Dim inf As Integer
Dim iTreat As Integer
Dim col As Integer
Dim count As Integer
Dim area As Single
Dim InputArray() As Single

Select Case sType
    Case "Existing"
        InputArray = Existing
    Case "Proposed"
        InputArray = Proposed
End Select
```

```
ReDim V_s(1 To iterations, 1 To 3)

count = UBound(InputArray, 1)
For r1 = 1 To iterations
   V_n = 0
   V_b = 0
   V_e = 0

   'loop through drainage areas
   For r2 = 1 To count
      iTreat = InputArray(r2, 1)      'treatment type 0 - no, 1 - basic, 2 - enhanced
      inf = InputArray(r2, 2)         'infiltration
      area = InputArray(r2, 3)        'area
      col = inf / 20 + 1
      V_i = Vol(r1, col)              'annual volume per acre for given infiltration
      v = V_i * area * (100 - inf) / 100       'scaled volume

      'add new scaled volume to scaled volume total for the corresponding treatment type
       Select Case iTreat
         Case 0
            V_n = V_n + v
         Case 1
            V_b = V_b + v
         Case 2
            V_e = V_e + v
      End Select
   Next r2

   'set combined value
   V_s(r1, 1) = V_n
   V_s(r1, 2) = V_b
   V_s(r1, 3) = V_e

Next r1

Select Case sType
   Case "Existing"
      Vol_Scaled_E = V_s
   Case "Proposed"
      Vol_Scaled_P = V_s
End Select

If Sheets(1).chk1 = -1 Then
   Select Case sType
      Case "Existing"
         col = 9
      Case "Proposed"
         col = 12
   End Select


   Sheets("Test").Cells(1, col) = sType & " scaled volumes none"
   Sheets("Test").Cells(1, col + 1) = sType & " scaled volumes basic"
   Sheets("Test").Cells(1, col + 2) = sType & " scaled volumes enhanced"
```

```
   For r1 = 1 To iterations
      Sheets("Test").Cells(r1 + 1, col) = V_s(r1, 1)
      Sheets("Test").Cells(r1 + 1, col + 1) = V_s(r1, 2)
      Sheets("Test").Cells(r1 + 1, col + 1) = V_s(r1, 3)
   Next r1
End If

End Sub





Sub RunLoadCalcStart()

Dim sCheck As String
Dim itm As Integer
Dim sCaption As String

iRunType = 3
iSub = 6
s = CheckInputs("Load")
If s <> "OK" Then
   MsgBox s
   Exit Sub
End If

FillConditions
LoadCalculation_Main

End Sub

Function SaveOutfallSettings(iType As Integer) As String

'*******************************************************************
'save outfall settings
'*******************************************************************

Dim sUser As String
Dim sDesc As String
Dim ID As Long
Dim row As Long
Dim col As Integer
Dim row2 As Integer
Dim sAnalyte As String
Dim WQ_row As Integer
Dim s As String
Dim rLook As Integer
Dim iParameter As Integer
Dim iMon As Integer
Dim i As Integer

sUser = InputBox("Enter user initials or name", "User name")
```

```
sDesc = InputBox("Enter a short description of the settings for future reference", "Enter Description")

Sheets("Outfall_Runs").Activate

'find last row
row = 1
Do Until Cells(row, 1) = ""
   If row = 65536 Then
      s = "The maximum of outfalls that can be saved in an Excel sheet has been reached"
      GoTo ExitFunc
   End If
   row = row + 1
Loop

ID = Cells(1, 11) + 1

'add new outfall run
Cells(row, 1) = ID
Cells(row, 2) = sUser
Cells(row, 3) = Sheets(1).tOutfall
Cells(row, 4) = Sheets(1).cmbGauge
Cells(row, 5) = FormatDateTime(Now, vbShortDate)
Cells(row, 6) = sDesc
Cells(row, 7) = iType

'add sub-basin settings
Sheets("Outfall_Settings").Activate
'find last row
row = 1
Do Until Cells(row, 1) = ""
   If row = 65536 Then
      s = "The maximum number of outfalls that can be saved in an Excel sheet has been reached"
      GoTo ExitFunc
   End If
   row = row + 1
Loop

blnDetention = False
For iSub = 1 To 5
   col = iSub + 4

   If Sheets(1).Cells(38, col) > 0 Then
      FillConditions

      For row2 = 1 To UBound(Existing)
         Cells(row, 1) = ID
         Cells(row, 2) = iSub
         Cells(row, 3) = "Existing"
         Cells(row, 4) = Existing(row2, 1)
         Cells(row, 5) = Existing(row2, 2)
         Cells(row, 6) = Existing(row2, 3)
         row = row + 1
      Next row2
```

```
        For row2 = 1 To UBound(Proposed)
            Cells(row, 1) = ID
            Cells(row, 2) = iSub
            Cells(row, 3) = "Proposed"
            Cells(row, 4) = Proposed(row2, 1)
            Cells(row, 5) = Proposed(row2, 2)
            Cells(row, 6) = Proposed(row2, 3)
            row = row + 1
        Next row2
    End If
Next iSub

'add dilution settings
If iType = 1 Then
    FillInputArrays

    row = 2
    Sheets("Concentration_Inputs").Activate
    Do Until Cells(row, 1) = ""
        If row = 65536 Then
            s = "The maximum of outfalls that can be saved in an Excel sheet has been reached"
            GoTo ExitFunc
        End If
        row = row + 1
    Loop

    'add concentration inputs
    For i = 1 To UBound(Parameters)
        iParameter = Parameters(i)

        For iSub = 1 To 5
            rLook = Sheets("Ref").Cells(iSub + 1, 3) + iParameter - 1
            If Sheets("Dilution_Inputs").Cells(rLook, 6) > 0 Then
                Sheets("Concentration_Inputs").Cells(row, 1) = ID
                Sheets("Concentration_Inputs").Cells(row, 2) = iSub
                Sheets("Concentration_Inputs").Cells(row, 3) = iParameter
                Sheets("Concentration_Inputs").Cells(row, 4) = Sheets("Dilution_Inputs").Cells(rLook, 6)
                Sheets("Concentration_Inputs").Cells(row, 5) = Sheets("Dilution_Inputs").Cells(rLook, 7)
                row = row + 1
            End If
        Next iSub
    Next i

    'add rivplum settings
    'find next row available
    row = 8
    Sheets("RivPlum_Inputs").Activate
    Do Until Cells(row, 1) = ""
        If row = 65536 Then
            s = "The maximum of outfalls that can be saved in an Excel sheet has been reached"
            GoTo ExitFunc
        End If
        row = row + 1
    Loop
```

```
   For iSub = 1 To 5
      rLook = Sheets("Ref").Cells(iSub + 1, 4)

      For iMon = 1 To 12
         col = 7 + iMon
         If Sheets("Dilution_Inputs").Cells(rLook, col) > 0 Then
            Sheets("RivPlum_Inputs").Cells(row, 1) = ID
            Sheets("RivPlum_Inputs").Cells(row, 2) = iSub
            Sheets("RivPlum_Inputs").Cells(row, 3) = iMon
            Sheets("RivPlum_Inputs").Cells(row, 4) = Sheets("Dilution_Inputs").Cells(rLook, col)
            Sheets("RivPlum_Inputs").Cells(row, 5) = Sheets("Dilution_Inputs").Cells(rLook + 1, col)
            Sheets("RivPlum_Inputs").Cells(row, 6) = Sheets("Dilution_Inputs").Cells(rLook + 2, col)
            Sheets("RivPlum_Inputs").Cells(row, 7) = Sheets("Dilution_Inputs").Cells(rLook + 3, col)
            Sheets("RivPlum_Inputs").Cells(row, 8) = Sheets("Dilution_Inputs").Cells(rLook + 4, col)
            Sheets("RivPlum_Inputs").Cells(row, 9) = Sheets("Dilution_Inputs").Cells(rLook + 5, col)
            Sheets("RivPlum_Inputs").Cells(row, 10) = Sheets("Dilution_Inputs").Cells(rLook + 6, col)
            Sheets("RivPlum_Inputs").Cells(row, 11) = Sheets("Dilution_Inputs").Cells(rLook + 7, col)
            row = row + 1
         End If
      Next iMon
   Next iSub
End If

s = "Settings Saved"
ActiveWorkbook.Save

ExitFunc:

   SaveOutfallSettings = s
End Function

Sub SelectOutfall()

If Sheets("Outfall_Runs").Cells(1, 11) = 0 Then
   MsgBox "There are no previous outfall settings to load"
   Exit Sub
End If

frmSelectRun.Show

End Sub

Sub LoadOutfallSettings(ID As Long)

'*******************************************************************
'load previous outfall settings into input sheets
'*******************************************************************

Dim row As Long
Dim area As Single
Dim inf As Single
Dim iTreat As Integer
Dim iBasin As Integer
```

```
Dim sType As String
Dim inputrow As Integer
Dim col As Integer

'find setting row
frmSelectRun.Hide

'clear current outfall settings
Sheets(1).Activate
Range("E27:I37").Select
Selection.ClearContents
Range("E42:I52").Select
Selection.ClearContents

'fill with sub basin areas with zeroes
Application.ScreenUpdating = False
   For col = 5 To 9
      For row = 27 To 37
         Cells(row, col) = 0
      Next row

      For row = 42 To 52
         Cells(row, col) = 0
      Next row
   Next col
Application.ScreenUpdating = True

row = 2
With Sheets("Outfall_Runs")
   .Activate

   Do Until Cells(row, 1) = ID
      row = row + 1
   Loop

   Sheets(1).tOutfall = .Cells(row, 3)
   Sheets(1).cmbGauge = .Cells(row, 4)

End With

row = 2
With Sheets("Outfall_Settings")
   .Activate
   Do Until Cells(row, 1) = ID
      row = row + 1
   Loop

   Do Until Cells(row, 1) <> ID
      iBasin = Cells(row, 2)
      sType = Cells(row, 3)
      iTreat = Cells(row, 4)
      inf = Cells(row, 5)
      area = Cells(row, 6)
```

```
        Select Case sType
            Case "Existing"
                inputrow = 27
            Case "Proposed"
                inputrow = 42
        End Select

        Select Case iTreat
            Case 0
                inputrow = inputrow + 10
            Case 1
                inputrow = inputrow + inf / 20
            Case 2
                inputrow = inputrow + 5 + inf / 20
        End Select

        Sheets(1).Cells(inputrow, iBasin + 4) = CStr(Round(area, 2))
        row = row + 1
    Loop
End With

Sheets(1).Activate
Cells(1, 1).Select


End Sub

Sub SaveOutfallStart()

iResp = MsgBox("Do you want to save the current outfall settings for future reference?", vbYesNo)

If iResp = vbNo Then
    Exit Sub
End If

MsgBox SaveOutfallSettings(0)

End Sub
Sub SaveDilutionStart()

iResp = MsgBox("Do you want to save the current outfall and dilution inputs for future reference?",
vbYesNo)

If iResp = vbNo Then
    Exit Sub
End If

MsgBox SaveOutfallSettings(1)

End Sub

Sub LoadOutfall()

iLoadType = 1
```

```
frmSelectRun.Show

End Sub
Sub LoadDilution()

iLoadType = 2
frmSelectRun.Show

End Sub

Sub LoadDilutionSettings(ID As Long)

'*****************************************************************
'load previous dilution settings into input sheet
'*****************************************************************

Dim row As Long
Dim iParameter As Integer
Dim rPut As Integer
Dim iMonth As Integer
Dim iCol As Integer
Dim rstart As Integer
Dim col_put As Integer
Dim col_data As Integer

ClearDilutionInputs

'get concentration inputs
Sheets("Concentration_Inputs").Activate

row = 1
Do Until Cells(row, 1) = ID
   row = row + 1
Loop

Do Until Cells(row, 1) <> ID
   iSub = Cells(row, 2)
   iParameter = Cells(row, 3)
   rPut = Sheets("Ref").Cells(iSub + 1, 3) + iParameter - 1
   Sheets("Dilution_Inputs").Cells(rPut, 6) = Cells(row, 4)
   Sheets("Dilution_Inputs").Cells(rPut, 7) = Cells(row, 5)
   row = row + 1
Loop

'get dilution inputs
Sheets("RivPlum_Inputs").Activate
row = 1
Do Until Cells(row, 1) = ID
   row = row + 1
Loop

Do Until Cells(row, 1) <> ID
   iSub = Cells(row, 2)
   iMonth = Cells(row, 3)
```

```
   col_put = 7 + iMonth
   rstart = Sheets("Ref").Cells(iSub + 1, 4)

   col_data = 4
   For rPut = rstart To rstart + 7
      Sheets("Dilution_Inputs").Cells(rPut, col_put) = Cells(row, col_data)
      col_data = col_data + 1
   Next rPut

   row = row + 1
Loop
End Sub

Function FindConcRow(i As Integer, t As Integer) As Integer

'********************************************************************************************************
' find row number of avg conc and std dev for a given treatment type and water quality parameter
'***************************************************************************************************
Dim r As Integer

Sheets("Water Quality").Activate

For r = 2 To 16
   If Cells(r, 1) = t Then
      Do Until Cells(r, 2) = i
         r = r + 1
      Loop
      Exit For
   End If
Next r

FindConcRow = r

End Function

Function FindRow(sName As String, iRain As Integer, iInfiltration As Integer, iDetention As Integer,
iMonth As Integer) As Long

'********************************************************************************************************
'find row corresponding to rain gauge, infiltration, detention and month
'********************************************************************************************************

Dim r As Integer
Dim blnFound As Boolean

Sheets(sName).Activate

r = 2
blnFound = False
Do Until Cells(r, 1) = ""
   If Cells(r, 1) = iRain And Cells(r, 2) = iMonth And Cells(r, 3) = iInfiltration And Cells(r, 4) = iDetention
Then
      blnFound = True
      Exit Do
```

```
   End If
   r = r + 1
Loop

If blnFound = True Then
   FindRow = r
Else
   FindRow = -999
End If

End Function

'*********************************************************************
'*  Return random numbers from a Log-Normal Distribution
'*********************************************************************
Function log_normal_var(mean1, var1)

   'Var1 and mean1 are the original sd and mean

   sd = (Log(var1 / mean1 ^ 2 + 1)) ^ 5
   mean = Log(mean1) - sd ^ 2 / 2

   'Raise e to the power of (gauss*sd+mean)
   'gauss returns the random number from a standard normal distribution

   log_normal_var = Exp(gauss * sd + mean)


End Function

'*********************************************************************
'*  Return random numbers from a truncated Log-Normal Distribution
'*********************************************************************

Function truncate_log_normal_old(mean1, var1, leftLim, RightLim)
   Dim x As Double
   Dim randomx As Double
   Dim x_norm As Double

   x = RightLim + 1
   Do Until x >= leftLim And x <= RightLim
      'Var1 and mean1 are the original sd and mean

      sd = (Log(var1 ^ 2 / mean1 ^ 2 + 1)) ^ 0.5
      mean = Log(mean1) - sd ^ 2 / 2

      'Raise e to the power of (gauss*sd+mean)
      'gauss returns the random number from a standard normal distribution
      x = Exp(gauss * sd + mean)
   Loop

   truncate_log_normal = x

End Function
```

```
Sub ThinBorderAll(row1 As Integer, row2 As Integer, col1 As Integer, col2 As Integer)

'*******************************************************************
'places a thin border on the input cell limits
'*******************************************************************

Range(Cells(row1, col1), Cells(row2, col2)).Select

With Selection.Borders(xlEdgeLeft)
   .LineStyle = xlContinuous
   .Weight = xlThin
End With

With Selection.Borders(xlEdgeTop)
   .LineStyle = xlContinuous
   .Weight = xlThin
End With

With Selection.Borders(xlEdgeBottom)
   .LineStyle = xlContinuous
   .Weight = xlThin
End With

With Selection.Borders(xlEdgeRight)
   .LineStyle = xlContinuous
   .Weight = xlThin
End With

With Selection.Borders(xlInsideVertical)
   .LineStyle = xlContinuous
   .Weight = xlThin
   .ColorIndex = xlAutomatic
End With

With Selection.Borders(xlInsideHorizontal)
   .LineStyle = xlContinuous
   .Weight = xlThin
   .ColorIndex = xlAutomatic
End With

End Sub
Sub MediumBorderOuter(row1 As Integer, row2 As Integer, col1 As Integer, col2 As Integer)

'*******************************************************************
'places a medium thick outer border on the input cell limits
'*******************************************************************

Range(Cells(row1, col1), Cells(row2, col2)).Select

With Selection.Borders(xlEdgeTop)
   .LineStyle = xlContinuous
   .Weight = xlMedium
```

```
End With

With Selection.Borders(xlEdgeBottom)
   .LineStyle = xlContinuous
   .Weight = xlMedium
End With

With Selection.Borders(xlEdgeRight)
   .LineStyle = xlContinuous
   .Weight = xlMedium
End With

With Selection.Borders(xlEdgeLeft)
   .LineStyle = xlContinuous
   .Weight = xlMedium
End With
End Sub

Sub ThinBorderOuter(row1 As Integer, row2 As Integer, col1 As Integer, col2 As Integer)

'**********************************************************************
'places a thin outer border on the input cell limits
'**********************************************************************

Range(Cells(row1, col1), Cells(row2, col2)).Select

With Selection.Borders(xlEdgeTop)
   .LineStyle = xlContinuous
   .Weight = xlThin
End With

With Selection.Borders(xlEdgeBottom)
   .LineStyle = xlContinuous
   .Weight = xlThin
End With

With Selection.Borders(xlEdgeRight)
   .LineStyle = xlContinuous
   .Weight = xlThin
End With

With Selection.Borders(xlEdgeLeft)
   .LineStyle = xlContinuous
   .Weight = xlThin
End With

End Sub
Sub TransferResults(sType As String)

'**********************************************************************
'put results sheet into a new workbook
'**********************************************************************

Dim sBookResults As String
```

```
Dim sBookCopy As String
Dim sName As String
Dim sFname_temp As Variant
Dim sFname As String
Dim rcopy As Integer

'On Error GoTo EH

Select Case sType
   Case "Concentration"
      sFname_temp = Sheets(1).cmbGauge & "_Conc_Results_" & Month(Now) & "-" & Day(Now) & "-" &
Year(Now) & ".xls"
   Case "Load"
      sFname_temp = Sheets(1).cmbGauge & "_Load_Results_" & Month(Now) & "-" & Day(Now) & "-" &
Year(Now) & ".xls"
   Case "Dilution"
      sFname_temp = Sheets(1).cmbGauge & "_Receiving_Water_Results_" & Month(Now) & "-" &
Day(Now) & "-" & Year(Now) & ".xls"
End Select

sBookResults = ActiveWorkbook.Name
Workbooks.Add
sBookCopy = ActiveWorkbook.Name

'copy results sheet to new book
Windows(sBookResults).Activate
rcopy = Sheets("Ref").Cells(iSub + 1, 3) - 4
Sheets("Results").Select
Sheets("Results").Visible = False
Sheets("Results").Copy Before:=Workbooks(sBookCopy).Sheets(1)
Windows(sBookResults).Activate
Sheets(1).Activate
Windows(sBookCopy).Activate
Sheets("Results").Visible = True

'delete all other sheets in new workbook
Application.DisplayAlerts = False
Do Until Sheets.count = 1
   i = Sheets.count
   If Sheets(i).Name <> "Results" Then
      Sheets(i).Delete
   End If
Loop
Application.DisplayAlerts = True

'copy dilution inputs to new sheet
If sType = "Dilution" Then
   With Workbooks(sBookCopy)
      .Sheets.Add After:=Sheets(1)
      .Sheets(2).Name = "Dilution_Inputs"
   End With

   Workbooks(sBookResults).Activate
   Sheets("Dilution_Inputs").Activate
```

```
    Range(Cells(rcopy, 1), Cells(rcopy + 22, 21)).Select
    Selection.Copy

    Workbooks(sBookCopy).Activate
    Sheets("Dilution_Inputs").Activate
    Cells(1, 1).Select
    ActiveSheet.Paste
    Application.CutCopyMode = False

    Sheets(1).Activate
End If

sFname = Application.GetSaveAsFilename(sFname_temp, , , "Save Results as")

If sFname = "False" Then
    Exit Sub
Else
    ActiveWorkbook.SaveAs sFname
End If

Exit Sub

EH:
    MsgBox "The following error occurred while trying to transfer the data: " & Err.Description

End Sub
Public Sub QuickSort(ByRef sngArray() As Single)
    Dim iLBound As Long
    Dim iUBound As Long
    Dim iTemp As Single
    Dim iOuter As Long
    Dim iMax As Long

    iMax = 1
    iLBound = LBound(sngArray)
    iUBound = UBound(sngArray)

    'Dont want to sort array with only 1 value
    If (iUBound - iLBound) Then

        'Move the largest value to the rightmost position, otherwise
        'we need to check that iLeftCur does not exceed the bounds of the
        'array on EVERY pass (time consuming)

        For iOuter = iLBound To iUBound
            If sngArray(iOuter) > sngArray(iMax) Then iMax = iOuter
        Next iOuter

        iTemp = sngArray(iMax)
        sngArray(iMax) = sngArray(iUBound)
        sngArray(iUBound) = iTemp

        'Start quicksorting
        InnerQuickSort sngArray, iLBound, iUBound
```

```
    End If
End Sub

Private Sub InnerQuickSort(ByRef sngArray() As Single, ByVal iLeftEnd As Long, ByVal iRightEnd As
Long)
    Dim iLeftCur As Long
    Dim iRightCur As Long
    Dim iPivot As Single
    Dim iTemp As Single

    If iLeftEnd >= iRightEnd Then Exit Sub

    iLeftCur = iLeftEnd
    iRightCur = iRightEnd + 1
    iPivot = sngArray(iLeftEnd)

    'Arrange values so that < pivot are on the left and > pivot are on the right
    Do
        'Find >= value on left side
        Do
            iLeftCur = iLeftCur + 1
        Loop While sngArray(iLeftCur) < iPivot

        'Find <= value on right side
        Do
            iRightCur = iRightCur - 1
        Loop While sngArray(iRightCur) > iPivot

        'No more swapping to do
        If iLeftCur >= iRightCur Then Exit Do

        'Swap
        iTemp = sngArray(iLeftCur)
        sngArray(iLeftCur) = sngArray(iRightCur)
        sngArray(iRightCur) = iTemp
    Loop

    'Call quicksort recursively on left and right subarrays
    sngArray(iLeftEnd) = sngArray(iRightCur)
    sngArray(iRightCur) = iPivot

    InnerQuickSort sngArray, iLeftEnd, iRightCur - 1
    InnerQuickSort sngArray, iRightCur + 1, iRightEnd
End Sub

Sub FillConditions()

'******************************************************************************
'fill arrays with outfall inputs for existing and proposed conditions
'******************************************************************************

Dim row As Integer
Dim Arow As Integer
Dim A_count As Integer
```

```
Dim iType As Integer
Dim inf_high As Single
Dim inf As Single
Dim A_det As Single
Dim Temp() As Single
Dim iTemp As Integer
Dim temp_rows As Integer
Dim row_sort As Integer
Dim A As Single
Dim blnSplit As Boolean

E_tot = 0
P_tot = 0

'existing conditions
For row = 27 To 37
   If Sheets(1).Cells(row, iSub + 4) > 0 Then
      A_count = A_count + 1
     E_tot = E_tot + Sheets(1).Cells(row, iSub + 4)
   End If
Next row

If A_count = 0 Then
   Exit Sub
End If

ReDim Existing(1 To A_count, 1 To 4)

For row = 27 To 37
   If Sheets(1).Cells(row, iSub + 4) > 0 Then
      Arow = Arow + 1
      Select Case row
         Case 27 To 31
            iType = 1
         Case 32 To 36
            iType = 2
         Case 37
            iType = 0
      End Select

      Existing(Arow, 1) = iType
      Existing(Arow, 2) = Sheets(1).Cells(row, 4)
      Existing(Arow, 3) = Sheets(1).Cells(row, iSub + 4)
      Existing(Arow, 4) = 0
   End If
Next row


'proposed conditions
A_count = 0
For row = 42 To 52
   If Sheets(1).Cells(row, iSub + 4) > 0 Then
      A_count = A_count + 1
      P_tot = P_tot + Sheets(1).Cells(row, iSub + 4)
```

```
        inf = Sheets(1).Cells(row, 4)
        If inf > inf_high Then
            inf_high = inf
        End If
    End If
Next row

If A_count = 0 Then
    Exit Sub
End If

ReDim Proposed(1 To A_count, 1 To 4)

Arow = 0
For row = 42 To 52
    If Sheets(1).Cells(row, iSub + 4) > 0 Then
        Arow = Arow + 1

        Select Case row
            Case 42 To 46
                iType = 1
            Case 47 To 51
                iType = 2
            Case 52
                iType = 0
        End Select

        Proposed(Arow, 1) = iType
        Proposed(Arow, 2) = Sheets(1).Cells(row, 4)
        Proposed(Arow, 3) = Sheets(1).Cells(row, iSub + 4)
        Proposed(Arow, 4) = 0
    End If
Next row

'calculate detention area of existing and proposed conditions
A_det = P_tot - E_tot

If A_det > 0 And blnDetention = True Then
    'if total proposed area is greater than existing and user selected detention, apply
    'detention to area of highest infiltration down

    'sort array by infiltration
    ReDim Temp(1 To 3)
    For row = 1 To A_count
        For row_sort = 1 To A_count - 1
            inf = Proposed(row_sort, 2)
            If inf < Proposed(row_sort + 1, 2) Then
                For iTemp = 1 To 3
                    Temp(iTemp) = Proposed(row_sort, iTemp)
                Next iTemp

                Proposed(row_sort, 1) = Proposed(row_sort + 1, 1)
                Proposed(row_sort, 2) = Proposed(row_sort + 1, 2)
                Proposed(row_sort, 3) = Proposed(row_sort + 1, 3)
```

```
            For iTemp = 1 To 3
                Proposed(row_sort + 1, iTemp) = Temp(iTemp)
            Next iTemp
        End If
    Next row_sort
Next row

'determine which areas to apply detention to
row = 1
A = 0
For row = 1 To A_count
    A = A + Proposed(row, 3)
    If A = A_det Then
        blnSplit = False
        Exit For
    ElseIf A > A_det Then
        blnSplit = True
        Exit For
    End If
Next row

If blnSplit = True Then
    'need to split one area so add another row to array
     ReDim Temp(1 To A_count + 1, 1 To 4)
Else
    ReDim Temp(1 To A_count, 1 To 4)
End If

row = 1
A = Proposed(row, 3)
Do Until A > A_det
    For iTemp = 1 To 3
        Temp(row, iTemp) = Proposed(row, iTemp)
    Next iTemp

    Temp(row, 4) = 1    'apply detention to area
    row = row + 1
    A = A + Proposed(row, 3)
Loop

If blnSplit = False Then
    Do Until row > A_count
        For iTemp = 1 To 3
            Temp(row, iTemp) = Proposed(row, iTemp)
        Next iTemp
        Temp(row, 4) = 0
        row = row + 1
    Loop
Else
    'divide area into detention and no detention sections
    Temp(row, 1) = Proposed(row, 1)
    Temp(row, 2) = Proposed(row, 2)
    Temp(row, 3) = Proposed(row, 3) - (A - A_det)
```

```
      Temp(row, 4) = 1

      'no detention
      Temp(row + 1, 1) = Proposed(row, 1)
      Temp(row + 1, 2) = Proposed(row, 2)
      Temp(row + 1, 3) = A - A_det
      Temp(row + 1, 4) = 0
      row = row + 1

      'set remaining areas as no detention
      Do Until row > A_count
         For iTemp = 1 To 3
            Temp(row + 1, iTemp) = Proposed(row, iTemp)
         Next iTemp
         Temp(row + 1, 4) = 0
         row = row + 1
      Loop
   End If
   Proposed = Temp
End If

   'For row = 1 To UBound(Proposed, 1)
      'Debug.Print Proposed(row, 1), Proposed(row, 2), Proposed(row, 3), Proposed(row, 4)
   'Next row
End Sub
Sub FillConcArray(iWQ As Integer)

'*****************************************************************************************************
' fill basic, enhanced, no treatment concentration arrays with 1000 random concentrations
'iWQ - water quality parameter ID
' c1 - minimum concentration
'c2 - max concentration
'*****************************************************************************************************
Dim lookuprow As Integer
Dim C_Mean As Single
Dim C_StdDev As Single
Dim treatment As Integer
Dim ScaleFactor As Single
Dim r As Long

'1st column of concentration array - no treatment
'2nd column of concentration array - basic treatment
'3rd column of concentration array - enhanced treatment

For treatment = 0 To 2
   lookuprow = FindConcRow(iWQ, treatment)
   C_Mean = Sheets("Water Quality").Cells(lookuprow, 4)
   C_StdDev = Sheets("Water Quality").Cells(lookuprow, 5)

   For r = 1 To iterations
     C(r, treatment + 1) = GenRand(C_Mean, C_StdDev, 0, 1)
   Next r
Next treatment
```

```
End Sub
Function CheckInputs(sType As String) As String

'*****************************************************************************
'check if all outfall inputs are filled and valid
'*****************************************************************************

Dim sMessage As String
Dim blnSelected As Boolean
Dim col As Integer
Dim blnFound As Boolean

sGauge = Sheets(1).cmbGauge

If sType = "Concentration" Then
   If Sheets(1).tOutfall = "" Then
      sMessage = "No outfall ID entered"
      GoTo ExitFunction
   End If

   blnFound = False
   'check if rain gauge data sheet exists
   For i = 1 To Application.Worksheets.count
      If Sheets(i).Name = Trim(Left(sGauge, Len(sGauge) - 2)) Then
         blnFound = True
         Exit For
      End If
   Next i

   If blnFound = False Then
      sMessage = "Can't find data for " & sGauge & " rain gauge"
      GoTo ExitFunction
   End If

   'check if at least one water quality parameter is selected
   blnSelected = False
   For i = 0 To Sheets(1).listWQ.ListCount - 1
      If Sheets(1).listWQ.Selected(i) = True Then
         blnSelected = True
         Exit For
      End If
   Next i

   If blnSelected = False Then
      sMessage = "No water quality parameter selected"
      GoTo ExitFunction
   End If

   'check if at least one month
   blnSelected = False
   For i = 0 To Sheets(1).lstMonth.ListCount - 1
      If Sheets(1).lstMonth.Selected(i) = True Then
         blnSelected = True
         Exit For
```

```
        End If
    Next i

    If blnSelected = False Then
        sMessage = "No month selected"
        GoTo ExitFunction
    End If
End If

'check if non-numeric or negative areas entered
col = iSub + 4
For i = 27 To 37
    If Sheets(1).Cells(i, col) <> "" And IsNumeric(Sheets(1).Cells(i, col)) = False Then
        sMessage = "Existing condition contains a non-numeric area value"
        GoTo ExitFunction
    Else
        If Sheets(1).Cells(i, col) < 0 Then
            sMessage = "Existing condition contains a negative area"
            GoTo ExitFunction
        End If
    End If
Next i

For i = 42 To 52
    If Sheets(1).Cells(i, col) <> "" And IsNumeric(Sheets(1).Cells(i, col)) = False Then
        sMessage = "Proposed condition contains a non-numeric area value"
        GoTo ExitFunction
    Else
        If Sheets(1).Cells(i, col) < 0 Then
            sMessage = "Proposed condition contains a negative area"
            GoTo ExitFunction
        End If
    End If
Next i

'check if total area for existing and proposed conditions is > 0
If Sheets(1).Cells(38, iSub + 4) = 0 Then
    sMessage = "No drainage areas entered for existing conditions"
    GoTo ExitFunction
End If

If Sheets(1).Cells(53, iSub + 4) = 0 Then
    sMessage = "No drainage areas entered for proposed conditions"
    GoTo ExitFunction
End If

'all inputs selected
sMessage = "OK"

ExitFunction:

    CheckInputs = sMessage

End Function
```

```
Sub FillInputArrays()

'****************************************************************************
'get selected water quality parameters and months from input sheet
'****************************************************************************

Dim i As Integer
Dim count As Integer

'fill parameter array
If Sheets(1).listWQ.Selected(0) = True Then
   ReDim Parameters(1 To 5)
   For i = 1 To Sheets(1).listWQ.ListCount - 1
      Parameters(i) = Sheets(1).listWQ.Column(0, i)
   Next i
Else
   For i = 1 To Sheets(1).listWQ.ListCount - 1
      If Sheets(1).listWQ.Selected(i) = True Then
         count = count + 1
         ReDim Preserve Parameters(1 To count)
         Parameters(count) = Sheets(1).listWQ.Column(0, i)
      End If
   Next i
End If

'fill month array
count = 0
If Sheets(1).lstMonth.Selected(0) = True Then
   ReDim Months(1 To 12)
   For i = 1 To 12
      Months(i) = i
   Next i
Else
   For i = 1 To Sheets(1).lstMonth.ListCount - 1
      If Sheets(1).lstMonth.Selected(i) = True Then
         count = count + 1
         ReDim Preserve Months(1 To count)
         Months(count) = Sheets(1).lstMonth.Column(0, i)
      End If
   Next i
End If
End Sub

Sub SelectSub()

'****************************************************************************
'shows form for user to select which sub basin # to run
'****************************************************************************

Dim col As Integer

If Sheets(1).Cells(53, 10) = 0 Then
   MsgBox "No sub basin areas defined"
```

```
   Exit Sub
End If

frmSelectSub.cmbSelect.Clear
For col = 5 To 9
   If Sheets(1).Cells(53, col) > 0 Then
      frmSelectSub.cmbSelect.AddItem col - 4
   End If
Next col

frmSelectSub.Show
End Sub

Sub RemoveToolbars()
   On Error Resume Next
      With Application
        .CommandBars("HI-RUN_Toolbar").Enabled = True
        .CommandBars("HI-RUN_Toolbar").Visible = True
        .CommandBars("Formatting").Visible = False
        '.CommandBars("Standard").Visible = False
      End With
   On Error GoTo 0
End Sub
Sub RestoreToolbars()
   On Error Resume Next
      With Application
        .DisplayFullScreen = False
        .CommandBars("HI-RUN_Toolbar").Enabled = False
        .CommandBars("HI-RUN_Toolbar").Visible = False
        .CommandBars("Formatting").Visible = True
        .CommandBars("Standard").Visible = True
      End With
   On Error GoTo 0
End Sub

Sub ClearOutfallData()

'******************************************************************************
'clear outfall data from input sheet
'******************************************************************************

i = MsgBox("Clear current subbasin area data", vbYesNo)

If i = vbNo Then
   Exit Sub
End If

Application.ScreenUpdating = False
Sheets(1).Activate
Range("E27:I37").Select
Selection.ClearContents
Range("E42:I52").Select
Selection.ClearContents
Application.ScreenUpdating = True
```

```
Cells(1, 1).Select

End Sub
Function MonthNum(sMonName As String) As Integer

'******************************************************************************
'convert monthname to number
'******************************************************************************

Dim iM

For iM = 1 To 12
   If InStr(1, Trim(LCase(sMonName)), LCase(Left(MonthName(iM), 3))) > 0 Then
      Exit For
   End If
Next iM

MonthNum = iM

End Function


Sub ShadeCells(sType As String)

'******************************************************************************
'shade selected months and water quality parameters for dilution settings
'******************************************************************************

Dim row As Integer
Dim col As Integer
Dim arr() As Variant
Dim i As Integer
Dim j As Integer
Dim iAdd As Integer

Application.ScreenUpdating = False
Select Case sType
   Case "WQ"
      arr = Sheets("Ref").Range("C2:C6").Value

      If Sheets(1).listWQ.Selected(0) = True Then
         For i = 1 To UBound(arr)
            row = arr(i, 1)
            Sheets("Dilution_Inputs").Activate
            Range(Cells(row, 4), Cells(row + 4, 7)).Select
            Selection.Font.ColorIndex = 0
            Selection.Font.Bold = True
         Next i
      Else
         For i = 1 To Sheets(1).listWQ.ListCount - 1
            iAdd = i - 1
            For j = 1 To UBound(arr)
               row = arr(j, 1) + iAdd
               Sheets("Dilution_Inputs").Activate
```

```
                Range(Cells(row, 4), Cells(row, 7)).Select
                If Sheets(1).listWQ.Selected(i) = True Then
                    Selection.Font.ColorIndex = 0
                    Selection.Font.Bold = True
                Else
                    Selection.Font.ColorIndex = 15
                    Selection.Font.Bold = False
                End If
            Next j
        Next i
    End If

Case "Months"
    arr = Sheets("Ref").Range("D2:D6").Value
    Sheets("Dilution_Inputs").Activate

    If Sheets(1).lstMonth.Selected(0) = True Then
        For i = 1 To UBound(arr)
            row = arr(i, 1) - 1
            Sheets("Dilution_Inputs").Activate
            Range(Cells(row, 8), Cells(row + 11, 19)).Select
            Selection.Font.ColorIndex = 0
        Next i
    Else
        For i = 1 To UBound(arr)
            row = arr(i, 1) - 1
            For j = 1 To Sheets(1).lstMonth.ListCount - 1
                Range(Cells(row, 7 + j), Cells(row + 11, 7 + j)).Select
                If Sheets(1).lstMonth.Selected(j) = False Then
                    Selection.Font.ColorIndex = 15
                    Selection.Font.Bold = False
                Else
                    Selection.Font.ColorIndex = 0
                    Selection.Font.Bold = True
                End If
            Next j
        Next i

    End If
End Select

Sheets(1).Activate

Application.ScreenUpdating = False

End Sub
Sub ClearDilutionInputs()

'*******************************************************************************
'clear dilution settings from input sheet
'*******************************************************************************

Dim r As Integer
```

```
Sheets("Dilution_Inputs").Activate

For iSub = 1 To 5
   'clear concentration values
   r = Sheets("Ref").Cells(iSub + 1, 3)

   Range(Cells(r, 6), Cells(r + 4, 7)).Select
   Selection.ClearContents

   Cells(r, 9) = ""

   'clear rivplum settings
   r = Sheets("ref").Cells(iSub + 1, 4)
   Range(Cells(r, 8), Cells(r + 7, 19)).Select
   Selection.ClearContents

Next iSub

Cells(1, 1).Select

End Sub

Public Function GenRand(mean As Single, var As Single, minVal As Single, iType As Integer) As Single

'*******************************************************************************
'generate random number for different types of distributions based on avg and std dev value
'*******************************************************************************
Dim x As Double
Dim rand_x As Double
Dim s As Double
Dim m As Double
Dim pi As Double

pi = 3.14159265358979

Select Case iType
   Case 0
      'normal distribution
      x = 0
      Do Until x > minVal
         x = gauss * var + mean
      Loop
   Case 1
      'log-normal distribution

      x = 0
      Do Until x > minVal
         'Var1 and mean1 are the original sd and mean

         s = (Log(var ^ 2 / mean ^ 2 + 1)) ^ 0.5
         m = Log(mean) - s ^ 2 / 2

         'Raise e to the power of (gauss*sd+mean)
```

```
        'gauss returns the random number from a standard normal distribution
        x = Exp(gauss * s + m)
    Loop
  Case 2
    'logistic distribution
    x = 0

    'calculate spread
    s = Sqr(3) / pi * var

    Do Until x > minVal
        rand_x = Rnd
        x = Log(rand_x / (1 - rand_x)) * s + mean
    Loop

End Select

GenRand = x

End Function
```

APPENDIX I

RIVPLUM6 Model Documentation

SPREADSHEETS FOR WATER QUALITY-BASED NPDES PERMIT CALCULATIONS

Updated July 2000 by Greg Pelletier

Several spreadsheets were developed by the Washington State Department of Ecology to aid NPDES permit writers. These spreadsheets are referred to in Ecology's Permit Writer's Manual (Department of Ecology Publication Number 92-109). Several of the spreadsheets are in separate Lotus 1-2-3 WK1 files and also have been combined and reformatted into an Excel 5 workbook.

- DOSAG2.WK1: This spreadsheet calculates critical sag of dissolved oxygen downstream from a point source using the Streeter-Phelps equation.
- IDOD2.WK1: This spreadsheet calculates concentrations of dissolved oxygen at a mixing zone boundary accounting for dilution of dissolved oxygen and initial dissolved oxygen demand.
- NH3FRES2.WK1: This spreadsheet calculates freshwater un-ionized and total ammonia criteria from temperature and pH from the formulas modified by EPA which were adopted in the 1995 revision to the state water quality standards.
- NH3SALT.WK1: This spreadsheet calculates saltwater total ammonia criteria from temperature, pH, and salinity to meet the un-ionized ammonia criteria.
- PHMIX2.WK1: This spreadsheet calculates the pH of a mixture of two sources for temperature, pH, and alkalinity.
- RIVPLUM5.WK1: This is a simple dilution model for rivers based on the method in chapter 5 of the book "Mixing in Inland and Coastal Waters" by H.B. Fischer et al. (1979, Academic Press Inc.)
- PWSPREAD.XLS: This Excel 5 file contains the following spreadsheets as described above:
    - dosag2
    - idod2
    - nh3fres2
    - nh3fresh
    - nh3salt
    - phmix2
    - rivplum5

- FARFIELD.XLS *(requires the Analysis ToolPak Add-In under the "Tools/Add-Ins" menu)*: This Excel 5 workbook calculates far-field mixing of a plume using the method of N.H. Brooks (1959, "Diffusion of Sewage Effluent in an Ocean Current," in "Waste Disposal in the Marine Environment", edited by E.A. Pearson, pp, 246-267, Pergamon Press, New York, NY.) This workbook is useful for estimating dilution beyond the range of near-field models such as UDKHDEN or PLUMES/UM using Brook's 4/3-power law, linear diffusivity, and constant diffusivity algorithms.

- TSDCALC9.XLW is a workbook composed of several spreadsheets. It is used for reference and for developing water quality-based permit limits. The individual spreadsheets contained in TSDCALC are:
  - criteria.xls
  - ammoniafw.xls
  - reaspot.xls
  - limit.xls
  - performlim.xls
  - human-h.xls

  The spreadsheets CRITERIA.XLS and AMMONIA.XLS contain or calculate water quality criteria. REASPOT.XLS and LIMIT.XLS determine reasonable potential (to violate the water quality standards) and calculate effluent limits. PERFORMLIM.XLS calculates performance-based effluent limitations and accounts for autocorrelation if known. HUMAN-H.XLS determines reasonable potential and calculates effluent limits for human health pollutants.

3.1 Detailed Descriptions and User Instructions

Spreadsheet DOSAG2.WK1

Revised October 19, 1993

This spreadsheet calculates the critical dissolved oxygen sag and concentration downstream from a point source load of BOD in a river using the Streeter-Phelps equations. The method used is documented in EPA/600/6-85/002a (Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water). This spreadsheet is recommended for use as a screening tool to determine the potential for dissolved oxygen standards to be violated. DOSAG2.WK1 may be overly simplistic for deriving limits for effluent BOD. If DOSAG2.WK1 suggests the dissolved oxygen sag is close to or below the water quality standard, then a more sophisticated model such as QUAL2E or WASP5 should be used to derive appropriate effluent limits. Those water quality models are designed to more accurately simulate water movements, mass transport, and water column processes.

User Instructions for the Input Section

Step 1: Enter the permittees effluent characteristics, including permitted discharge and maximum (e.g, weekly) 5-day BOD (referred to as CBOD5 for "carbonaceous" 5-day BOD). Carbonaceous 5-day BOD is less than the total 5-day BOD if nitrification occurs during the test. The minimum national standards for carbonaceous 5-day BOD in effluent

after secondary treatment are a monthly average of 25 mg/L and weekly average of 40 mg/L (40 CFR Part 133). Guidance for determining if carbonaceous 5-day BOD should be substituted for total 5-day BOD is contained in Ecology's Permit Writer's Manual (section V-3.6).
Nitrogenous BOD (NBOD) should also be estimated if it is significant (*e.g.* if nitrification is not significant during secondary treatment). NBOD can be estimated as:

NBOD = 4.57 * (Ammonia N + Organic N)

where concentrations of NBOD, ammonia N and organic N are expressed in mg/L.
Effluent temperature and dissolved oxygen for the analysis are also entered at this step. The spreadsheet may be used to estimate the maximum permissible effluent CBOD5 and NBOD that will meet the water quality standards for dissolved oxygen. A trial and error solution is necessary for this purpose. Trial values of effluent CBOD5 and NBOD may be entered until the dissolved oxygen at the critical sag meets the water quality standard.

Step 2: Enter receiving water characteristics. These will generally be conditions at the 7Q10 discharge. Upstream CBOD5, NBOD, dissolved oxygen and temperature at the design river flow (*e.g.*, 7Q10) should be entered. The local channel elevation and channel slope (*e.g.*, from USGS topographic maps) downstream from the discharge should also be entered. Downstream average channel depth and velocity at the design flow should be entered also.
If no receiving water data are available, it would be desirable to collect data. Channel cross-sections of depth and velocity can be measured during the critical season. If measurements are not taken near critical conditions, then Manning's equation may be used to estimate velocity and depths from the measurements. Several cross-sections proceeding downstream from the discharge may be needed to characterize the river to the point of critical sag if velocities and depths are not uniform. Dye studies to measure travel time may be useful if velocities are variable. If significant tributaries, groundwater inflows, or other pollutant loads occur before the predicted critical sag point, then a more sophisticated model should be used (*e.g.* QUAL2E).

Measurements of water quality (*e.g.* dissolved oxygen, ammonia, BOD) in the receiving water from upstream and at intervals downstream to the critical sag point are also desirable for model calibration. If the model is applied without sufficient data to demonstrate calibration, then the model should mainly be used to screen for potential violation of standards. If effluent BOD is required to be more restrictive than current technology-based limits, then calibration data are probably needed. Separate calibration and verification data sets taken on different dates may be needed in many cases where the accuracy of the model is in question.

Step 3: Enter the reaeration rate (base e) at 20 degrees C in cell D27. Suggested values using empirical equations referenced in EPA/600/6-85/002a are given below cell D27 for guidance in selecting an appropriate value. If the calculated values are used, select the most appropriate equation based on applicable depth and velocity (*e.g.,* if depth is <1 to 2 feet, then use the value shown from the Tsivoglou-Wallace equation).

Step 4: Enter the BOD decay rate (base e) at 20 degrees C in cell D36. A calculated value based on the Wright and McDonnell equation referenced in EPA/600/6-85/002a is provided and may be entered in cell D36 at Step 4 if desired.

User Instructions for the Output Section

The user does not need to change or enter any values or formulas in the Output Section. The travel time and distance to critical sag, deficit at critical sag, and dissolved oxygen concentration at critical sag are displayed in the Output Section.

Spreadsheet IDOD2.WK1

Revised October 19, 1993

This spreadsheet calculates the dissolved oxygen concentration at a mixing zone boundary from dilution of dissolved oxygen in the effluent and ambient background and immediate dissolved oxygen demand of the effluent. The method used is presented in EPA/600/6-85-002b (Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water - Part II Revised 1985) and EPA/430/9-82-011 (Revised Section 301(h) Technical Support Document).

User Instructions for the Input Section

Step 1: Specify the dilution factor for effluent at the chronic mixing zone boundary. This value should represent dilution at critical conditions if the spreadsheet is being used for developing NPDES permit limits. The dilution factor used should represent the reciprocal of the volume fraction of effluent present at the mixing zone boundary (see Permit Writer's Manual section VI-2.1).

Step 2: Enter the background dissolved oxygen concentration in the receiving water. The 10th percentile during the critical season is recommended as a reasonable worst case. If no data are available it would be desirable to collect data describing background dissolved oxygen concentrations during the critical season (*e.g.* upstream from the discharge to a river).

Step 3: Enter the effluent dissolved oxygen concentration. The 10th percentile during the critical season is recommended as a reasonable worst case.

Step 4: Enter the immediate dissolved oxygen demand (IDOD) of the effluent if known. The IDOD represents the oxygen demand of reduced substances which are rapidly oxidized (*e.g.* sulfides to sulfates). If the effluent contains measurable dissolved oxygen, then the IDOD may be negligible. If IDOD is to be determined experimentally, the procedures in Standard Methods 1979 edition could be followed. However, the method was omitted from Standard Methods in the 1985 edition because of concerns about the accuracy of the test.

User Instructions for the Output Section

The user should not enter or change the value or formula in the output section. The dissolved oxygen at the mixing zone boundary is presented in the output section.

Spreadsheet NH3FRES2.WK1

Revised December 12, 1994 (NH3FRES2.WK1)

NH3FRES2.WK1 contains the formulas modified by EPA that were adopted in the 1995 revision of the state water quality standards. The spreadsheet also calculate the amount of un-ionized ammonia present in a sample if total ammonia, temperature, and pH are known.

User Instructions for the Input Section

Step 1: Specify the temperature (design condition at the mixing zone boundary) for which un-ionized ammonia criteria or concentrations are to be estimated. If the spreadsheet is being used to calculate criteria for a NPDES permit limit, the 90th percentile temperature during the critical season is recommended for a reasonable worst-case condition. If no data are available it may be desirable to collect data during the critical season to describe temperature at the mixing zone boundary.

Step 2: Specify the pH (design condition at the mixing zone boundary) for which un-ionized ammonia criteria or concentrations are to be estimated. If the spreadsheet is being used to calculate criteria for a NPDES permit limit, the 90th percentile pH during the critical season is recommended for a reasonable worst-case condition. If no data are available it may be desirable to collect data during the critical season to describe pH at the mixing zone boundary.

Step 3: Specify the sample total ammonia concentration if known. Entering a value here only affects Output Step 2 (calculation of un-ionized ammonia present in a sample). No input is required at this step if the spreadsheet is being used only to calculate criteria from temperature and pH (*i.e.* values entered at this step do not affect criteria calculations).

Step 4: Specify "Acute TCAP" according to the Gold Book (enter 20 if salmonids are present; 25 if salmonids are absent).

Step 5: Specify "Chronic TCAP" according to the Gold Book (enter 15 if salmonids are present; 20 if salmonids are absent).

User Instructions for the Output Section

The user should not enter or change any values or formulas in the Output Section. The spreadsheet calculates the amount of un-ionized ammonia present in a sample at Output Step 2 if the sample total ammonia was specified at Input Step 3. Output Step 3 provides the acute and chronic criteria for un-ionized ammonia expressed in ug/L as NH3-N. Output Step 4 provides the acute and chronic criteria for total ammonia expressed in ug/L as NH3-N.

Spreadsheet NH3SALT.WK1

Revised October 19, 1993

This spreadsheet calculates water quality criteria for ammonia in saltwater using the method specified in EPA 440/5-88-004 (Ambient Water Quality Criteria for Ammonia (Saltwater)-1989).

User Instructions for the Input Section

Step 1: Specify the temperature (design condition at the mixing zone boundary) for which un-ionized ammonia criteria are to be estimated. If the spreadsheet is being used to calculate criteria for a NPDES permit limit, the 90th percentile temperature during the critical season is recommended for a reasonable worst-case condition. If no data are available it may be desirable to collect data during the critical season to describe temperature at the mixing zone boundary.

Step 2: Specify the pH (design condition at the mixing zone boundary) for which un-ionized ammonia criteria to be estimated. If the spreadsheet is being used to calculate criteria for a NPDES permit limit, the 90th percentile pH during the critical season is recommended for a reasonable worst-case condition. If no data are available it may be desirable to collect data during the critical season to describe pH at the mixing zone boundary.

Step 3: Specify the salinity (design condition at the mixing zone boundary) for which un-ionized ammonia criteria are to be estimated. If the spreadsheet is being used to calculate criteria for a NPDES permit limit, the 10th percentile salinity during the critical season is recommended for a reasonable worst-case condition. If no data are available it may be desirable to collect data during the critical season to describe salinity at the mixing zone boundary.

User Instructions for the Output Section

The user should not enter or change any values or formulas in the output section. The acute and chronic criteria are expressed three ways: 1) as unionized ammonia in mg/L as NH3 at Output Step 5; 2) as total ammonia in mg/L as NH3 at Output Step 6; and 3) as total ammonia in mg/L as NH3-N at Output Step 7. For derivation of total ammonia waste load allocations and comparisons with effluent total ammonia data, it is recommended that the criteria be expressed as total ammonia in mg/L as NH3-N for simplicity. [Note: the criteria in EPA 440/5-88-004 Tables 2 and 3 are for total ammonia as mg/L as NH3, which should be multiplied by 0.822 to convert to mg/L as NH3-N.]

Spreadsheet PHMIX2.WK1

Revised October 19, 1993

This spreadsheet calculates the pH of a mixture of two flows using the procedure in EPA's DESCON program (EPA, 1988. Technical Guidance on Supplementary Stream Design Conditions for Steady State Modeling. EPA Office of Water, Washington DC). The major form of alkalinity is assumed to be carbonate alkalinity. Also, alkalinity and total inorganic carbon are assumed to be conservative.

User Instructions for the Input Section

Step 1: Specify the dilution factor for effluent at the mixing zone boundary. This value should represent dilution at critical conditions if the spreadsheet is being used for developing NPDES permit limits. The dilution factor used should represent the reciprocal of the volume fraction of effluent present at the mixing zone boundary (see Permit Writer's Manual section VI-2.1).

Step 2: Specify the upstream characteristics, including temperature, pH, and alkalinity. For development of NPDES permit limits for ammonia, the 90th percentiles during the critical season are recommended. If no data are available, it is desirable to collect data describing upstream temperature, pH, and alkalinity during the critical season.

Step 3: Specify the effluent characteristics, including temperature, pH, and alkalinity. For NPDES permit limits, a reasonable worst case estimate of each may be estimated from DMR data (*e.g.* for ammonia limits use 90th percentile values from the DMR data during the critical season). If effluent data are not available then data should be collected during the critical season. In many cases, pH in ambient receiving water (at Step 2 above) may be assumed to represent the pH in the mixing zone.

User Instructions for the Output Section

The user does not need to enter or change any values or formulas in the Output Section.

The spreadsheet calculates and displays the pH at the mixing zone boundary at Output Step 4. Some important factors that can influence pH are not included in this calculation. For example, photosynthesis in the receiving water may increase pH downstream from the mixing zone. In many cases where dilution is relatively large (*e.g.* greater than a dilution factor of 20) the pH in the mixing zone will be dominated by ambient conditions. This spreadsheet should be used mainly where effluent dilution is relatively low and effluent pH and alkalinity are much different than in the receiving water.

Spreadsheet RIVPLUM5.WK1

Revised February 22, 1996

This spreadsheet calculates dilution at a specified point of interest downstream from a point discharge to a river. The procedure used is described in Fischer *et al.*, 1979 (Mixing in Inland and Coastal Waters, Academic Press) and referred to in EPA/505/2-90-001 (TSD for WQ-based Toxics Control.) The calculation for dilution factors incorporates the boundary effect of shorelines using the method of superposition (Fischer *et al.*, equation 5.9.)

This spreadsheet is based on the assumption that the discharge: 1) is a single point source, which is most appropriate for single port or short diffusers, or side-bank discharges; and 2) is completely and rapidly mixed vertically, which usually only occurs in shallow rivers. If the diffuser length occupies a substantial portion of the stream width, or the discharge is not vertically mixed over the entire water column within the acute mixing zone, an alternative model should be used such PLUMES or CORMIX.

RIVPLUM5.WK1 is useful for estimating dilution in shallow rivers for side-bank discharges or single-port outfalls. This spreadsheet replaces a previous version called RIVPLUM4.WK1 RIVPLUM5.WK1 was modified to include optional calculation of the effective origin of a wastewater source.

User Instructions for the Input Section

Step 1: Enter the effluent design flow (see Permit Writer's Manual section VI-3.3.2).

Step 2: Specify the receiving water characteristics, including average channel depth, velocity and width downstream from the discharge at the design flow (e.g, at 7Q10. NOTE: The product of depth*width*velocity should equal the receiving water discharge rate downstream from the discharge).

Also enter either the channel slope downstream from the discharge (*e.g.*, as measured from a USGS topographic map) or Manning's "n" coefficient for roughness. Finally, enter either 0 (if slope is entered above) or 1 (if Manning's "n" is entered above).

The slope or Manning's "n" are used to estimate shear velocity and transverse mixing coefficients. Either method may be used, depending on which data are more readily available. It is not necessary to specify both slope and Manning's "n". If comparisons are made between the two methods then care should be taken to be sure that slope and Manning's "n" values are consistent with velocity, depth, and width data since all are related by Manning's equation.

In general, it is not desirable to overestimate Manning's "n" because a lower value will generally be more protective since it will predict a lower transverse mixing coefficient. If the Manning option is used, the following values may be appropriate estimates for Manning's "n" (EPA/600/3-87-007 after Henderson, F.M., Open Channel Flow, Macmillan Co., New York, NY, 1966):

- Artificial channel, earth, smooth, no weeds: 0.020
- Artificial channel, earth, some stones and weeds: 0.025
- Natural channel, clean and straight: 0.025 - 0.030
- Natural channel, winding with pools an shoals: 0.033 - 0.040
- Natural channel, very weedy, winding and overgrown: 0.075 - 0.150

If no receiving water data are available, then data collection would be desirable. Measurements of channel cross-sections of width, depth, and velocity should be collected within the mixing zone at conditions near critical low flow (*e.g.* near 7Q10). If conditions are significantly different than 7Q10 during measurements, then data may need to be adjusted (*e.g.* using Manning's equation).

Step 3: Enter the distance between the diffuser midpoint and the nearest shoreline of the river (*e.g.*, for a side-bank discharge enter 0).

Step 4: Enter the location of the downstream point at which dilution factors will be estimated, including the distance downstream from the diffuser and the distance from the nearest shoreline. The "point of interest" is the location at which dilution factors will be estimated in the Output Section. The highest concentration of effluent downstream from the outfall will be the same distance from shore as the point of discharge. Therefore, the distance from shore for the point of interest should be the same as for the diffuser midpoint in Step 3 for a worst case. However, the dilution at any point downstream may be estimated using any combination of distances downstream and from shore for the "point of interest."

Step 5: Enter the transverse mixing coefficient constant. A value of 0.6 is recommended for most natural channels. Fischer reports that the transverse mixing coefficient can range from 0.1 to 0.2 for straight artificial channels. Curves and sidewall irregularities increase the coefficient such that in natural streams it is rarely less than 0.4. If the stream is slowly meandering and the sidewall irregularities are moderate, then the coefficient is usually in the range of 0.4 to 0.8. Therefore, a value of 0.6 is usually recommended in natural channels. Uncertainty in this constant is usually at least +/- 50 percent.

Step 6: Enter 0 to use the original equations documented in Fischer et al. (1979), or enter 1 to account for the effective origin of the wastewater source in the Fischer et al. equations. Entering 0 will give results identical to the previous version of the spreadsheet (RIVPLUM4).
The optional correction for effective origin is based on discussion in section 5.1.3 of the Fischer *et al.* text. The dilution factors for some discharges may be underestimated without correction for effective origin.

The dilution model is based on considering a rectangular channel of depth (d) into which is discharged M units of mass of effluent per unit time in the form of a vertical line source. A line source of M units into a flow of depth (d) is equivalent to a point source of strength M/d in a two-dimensional flow, for which the concentration (C) is as follows from equation 5.8 and 5.9 of Fischer *et al.* (the nomenclature is as in Fischer *et al.*; Qe=effluent flow (L^3/T); u=velocity (L/T); d=depth (L); Et=transverse mixing coefficient (L^2/T); x=distance downstream (L); y=distance across channel (L); W=channel width (L)):

$$C = k * C0 / (4 * pi * x')^{0.5} \qquad \text{(eqn 1)}$$

where

$$k = \sum_{n=-2}^{2} \{\exp[-(y'-2n-y0')^2/4x'] + \exp[-(y'-2n+y0')^2/4x']\}$$

$$C0 = M / (u*d*W)$$

$$x' = x*Et/(u*W^2)$$

$$y' = y/W$$

y0' = y' at the source location y=y0

If C represents the effluent volume fraction, then the dilution factor is equal to 1/C. In order to apply this equation very close to the effluent outfall, the effective origin may be estimated as follows.

- If M is estimated as the product of effluent flow and concentration, then the effluent source concentration (Ce) is:

$$Ce = M/Qe \qquad \text{(eqn 2)}$$

- The offset or correction (x0) for the effective origin of effluent may be estimated as follows. First, substitute eqn 2 into eqn 1 for instream C=Ce:

M/Qe = k * C0 / (4*pi*x')^0.5 (eqn 3)

- Next, solve eqn 3 for x=x0, which is the distance downstream from the effective origin to the outfall, such that in-stream concentration equals the effluent concentration at the actual outfall location:

x0 = (k*Qe/d)^2 / (u*4*pi*Et) (eqn 4)

- The effective distance downstream (x) in eqn 1 is then replaced by (x+x0) to account for the effective origin of the source.

User Instructions for the Output Section

The user does not need to enter or change any values or formulas in the Output Section. The plume characteristics incorporating the shoreline effect are displayed at Step 5 of the Output Section, including the approximate distance downstream to complete mix, theoretical maximum available dilution at complete mix of effluent with the receiving water, flux-average dilution at the specified downstream distance, and the calculated dilution factor at the specified point of interest downstream from the discharge.

The distance downstream to complete mixing is often overestimated because most natural channels contain sharp bends or changes that increase mixing beyond the processes included in the model. The model is most useful for predicting mixing where the channel is represented over a relatively short distance (*e.g.* to the mixing zone boundary).

Workbook PWSPREAD.XLS

Revised February 22, 1996

This Excel 5 workbook contains the following spreadsheets:

- dosag2
- idod2
- nh3fres2
- nh3salt
- phmix2
- rivplum5

The spreadsheets in PWSPREAD.XLS perform the same calculations as the Lotus 1-2-3

.WK1 files of the same names. The instructions for each of the sheets in PWSPREAD.XLS are the same as for the .WK1 files.

Workbook FARFIELD.XLS

Revised February 22, 1996

[NOTE: This workbook requires the Analysis ToolPak Add-In, which must be configured using the "Tools/Add-Ins" menu in Excel 5.]

This Excel 5 workbook calculates far-field mixing of a plume using the method of N.H. Brooks (1959, "Diffusion of Sewage Effluent in an Ocean Current," in "Waste Disposal in the Marine Environment", edited by E.A. Pearson, pp, 246-267, Pergamon Press, New York, NY.) This workbook is useful for estimating dilution beyond the range of near-field models such as UDKHDEN or PLUMES/UM using Brook's 4/3-power law, linear diffusivity, and constant diffusivity algorithms.

Brooks' model is applied in this workbook using the algorithm of EPA's PLUMES model (1993, "Dilution Models for Effluent Discharges," U.S. Environmental Protection Agency, EPA/600/R-93/139, Washington, DC.) with the addition of a linear diffusivity algorithm as described by R.A. Grace (1978, "Marine Outfall Systems: Planning, Design, and Construction," Prentice-Hall Inc., Englewood Cliffs, NJ.)

FARFIELD.XLS contains the following four spreadsheets:

- PLUMES algorithm
- Brooks' four-thirds power law
- Brooks' linear diffusivity
- Brooks' constant diffusivity

The "PLUMES algorithm" spreadsheet uses the same method as EPA's PLUMES model ("Dilution Models for Effluent Discharges," U.S. Environmental Protection Agency, EPA/600/R-94/086) to implement Brooks' far-field models. The PLUMES algorithm is documented in equations 66-73 of EPA/600/R-94/086. The major difference between the "PLUMES algorithm" and the other spreadsheets is in the treatment of the parameter "alpha" in the following equation:

epsilon(0) = alpha * b ^n

where epsilon(0) is the lateral diffusion coefficient (L^2/T), b is the width of the plume (L), and n is an exponent used to estimate the initial value of epsilon. The PLUMES algorithm assumes that the initial value of epsilon(0) at the start of far-field modeling is based on n=4/3 for both the 4/3 power law and constant diffusivity models. Therefore, the PLUMES algorithm assumes that "alpha" has units of L^(2/3)/T and n=4/3 regardless of which Brooks' model is used.

The "PLUMES algorithm" spreadsheet also includes Brooks' linear diffusivity model and uses n=4/3 for the initial calculation of epsilon(0). The linear diffusivity model used in the spreadsheet is as presented by equation 7-65 of Grace (1978).

The "Brooks' four-thirds power law", "Brooks' linear diffusivity", and "Brooks constant diffusivity" spreadsheets differ from the "PLUMES algorithm" spreadsheet by assuming different units for "alpha" and different values of n depending on the model being used. "Alpha" has units of L^(2/3)/T for the 4/3 power law (n=4/3), L/T for the linear diffusivity model (n=1), and L^2/T for the constant diffusivity model (n=0). Brooks' equations as documented in equations 7-64, 7-65, and 7-66 of Grace (1978) were used to estimate dilution along the plume trajectory.

User Instructions for the Input Section

Step 1: Specify the plume and diffuser characteristics at the start of far-field mixing. The computations at the end of a near-field mixing model such as UDKHDEN or PLUMES/UM is usually used to define the conditions at the start of far-field mixing. The necessary parameters are the flux-average dilution factor at the end of near-field model computations, the estimated initial width at the start of far-field mixing (*e.g.* equation 70 as described in the PLUMES manual (EPA/600/R-94/086), and the horizontal distance that the plume travels during the near-field mixing phase.

Step 2: Specify the horizontal distance from the outfall to the mixing zone boundary along the trajectory of the plume (*e.g.* as defined in WAC 173-201A-100).

Step 3: Specify the parameter "alpha" as described above. The units for "alpha" depend on which spreadsheet is used, as discussed above.

Step 4: Specify the horizontal current speed along the far-field plume trajectory.

Step 5 (optional): Specify the initial pollutant concentration and the first-order decay rate. The initial concentration for far-field mixing should be the final concentration at the end of near-field mixing.

User Instructions for the Output Section

The user does not need to enter or change any values or formulas in the Output Section. The spreadsheets calculate dilution along the trajectory of the plume and at the specified mixing zone boundary. Optional calculation of pollutant concentrations assuming first-order decay rates is also provided.

3.2 GUIDELINES FOR USING TSDCALC 9.XLW

TSDCALC9.XLW is a workbook composed of several spreadsheets. Several are duplicates of those given above. It is used for reference and for developing permit limits. The individual spreadsheets contained in TSDCALC9 are CRITERIA.XLS, AMMONIA.XLS, REASPOT.XLS, LIMIT.XLS, PERFORMLIM.XLS, and HUMAN-H.XLS. The spreadsheets CRITERIA.XLS and AMMONIA.XLS contain or calculate water quality criteria. The spreadsheets REASPOT.XLS, and LIMIT.XLS determine reasonable potential (to violate the aquatic life water quality standards) and calculate effluent limits. The spreadsheet PERFORMLIM.XLS calculates performance-based effluent limitations and accounts for autocorrelation if known. The spreadsheet HUMAN-H.XLS determines reasonable potential and calculates effluent limits for human health pollutants. The process and formulas for determining reasonable potential and effluent limits in these spreadsheets are taken directly from the *Technical Support Document for Water Quality-based Toxics Control*, (EPA 505/2-90-001). The adjustment for autocorrelation is from EPA (1996a), and EPA (1996b)

CRITERIA.XLS

This spreadsheet is split for convenience of the permit writer. The pollutants of concern can be copied from the lower view and pasted in the upper view. The upper view can then be printed with only the pollutants of concern. Documentation text is found in rows 186-193.

Input - Cell B199 is a fill-in cell for receiving water TSS concentration, if known. TSS is used for calculating the partitioning translator for copper and zinc. If no TSS values are placed in this cell, the statewide 95th percentile ratio or the conversion factor is used as the default translator.

Input - Cell B200 is a fill-in cell, which characterizes the TSS data. Place an A in this cell if the TSS data is derived from several seasons. Place an S in this cell if the TSS data is only from the critical period.

Input - Cell B201 is a fill-in cell for hardness of the receiving water. Hardness is used to calculate several of the metal criteria. The hardness value should be the lowest value from the critical period if the data set is less than 20, or the 10th percentile value if the data set is 20 or greater. Column A contains the pollutant name, the CAS number, and where it is found on the table of effluent characteristics in the NPDES permit application.

Column B is labeled “Priority Pollutant?” A Y in this column means the chemical is a priority pollutant (toxic pollutant).

Column C is labeled Carcinogen? A Y in this column means the chemical is a carcinogen.

Columns D through G are the aquatic life water quality criteria for fresh and marine waters.

Columns H and I are the human health criteria for fresh and salt water. These columns are more correctly stated as Criteria for consumption of water and organisms (typically fresh water) and Criteria for the consumption of organisms only (typically salt water).

Column J gives the source of the criteria and any additional comments. A notation of NTR-HH means the human health criteria are from the National Toxics Rule and therefore part of our regulatory requirements. A notation of Gold Book means the criterion is a federal EPA criterion. These values should be treated as guidance. The “Gold Book” has been modified extensively by federal regulations such as the National Toxics Rule and others.

Columns K through N are translators for the metal criteria, which are used for determining reasonable potential. The translators for cadmium, copper, lead, and zinc are based on data presented by Pelletier (1996).

AMMONIA.XLS

This spreadsheet calculates the freshwater ammonia criteria. The **inputs** for this spreadsheet are temperature and pH of the receiving water at the time of critical condition. If the ammonia criteria are being calculated for non-salmonid waters the acute TCAP must be changed to 25 and the chronic TCAP to 20.

REASPOT.XLS

This spreadsheet determines if there is a reasonable potential for violation of the aquatic life water quality standards based on the input values. There is an example for reasonable potential determination for metals in the PWM in Chapter VI.

Input - Column A - enter the pollutant parameter.

Input - Column B and C – These are the metal criteria translator values taken from Criteria.XLS. If there is no value placed here the default value is the metal conversion factor.

Input - Column D is the ambient background concentration. For metals use the dissolved concentration. If you only have ambient total recoverable data, use the translator to convert the total recoverable data to dissolved.

Input - Columns E and F - enter the appropriate acute and chronic water quality criteria for the parameter.

Columns G and H are the calculated expected concentrations at the edge of the acute and chronic mixing zones. They are calculated from expected effluent concentration, ambient concentration, dilution factors and, for metals, the translator.

Column I compares the expected acute and chronic criteria with the concentration at the edge of the appropriate dilution zone. It returns a yes if the expected concentration is higher than the criteria or a no if not. Yes indicates a reasonable potential to violate the water quality criteria.

Column J is the upper percentile estimate of the effluent concentration. The recommended value to enter is 0.95.

Column K is a calculated value

Input -Column L - Enter in the highest measured effluent concentration

Input -Column M - Enter the coefficient of variation of the effluent parameter (standard deviation/mean). The default value is 0.6. If you have more than 10 effluent values this value should be calculated instead of using the default.

Input - Column N **-** Enter the number of data values in the set from which the value entered in Column L was taken.

Column P is the calculated value used as a multiplier. Column L is multiplied by this value to estimate the 95th percentile value of a small data set lognormally distributed. This value is equivalent to the multiplier in Table 3.2 95/95 in the TSD. If the permit writer has 20 or more data points for a parameter in the effluent, the 95th percentile effluent value can be calculated more accurately by transforming the data by log or lognormal, finding the 95th percentile value and then converting the value back by taking antilog or natural antilog. This value is placed in Column L and the number of samples is varied by trial and error until the multiplier in Column P equals 1.0. For example, with a CV of 0.6 column P would have to be 58 for the multiplier to equal 1.

LIMITS.XLS

This spreadsheet calculates effluent limits for aquatic life pollutants by use of formulas given in the Technical Support Document Box 5-2. Limits are required for any parameters that show a reasonable potential in the preceding spreadsheet. If the parameter has an extensive database, the values should be lognormal transformed (see comment in G2 of PERFORMLIM) and then the spreadsheet PERFORMLIM.XLS used to calculate effluent limits.

Input - Column A - enter the parameter

Input - Columns B and C - enter the acute and chronic dilution factors

Input - Columns F, G, and H can be copied from REASPOT.XLS

Column I is the calculated Average Monthly effluent limit

Column J is the calculated Daily Maximum effluent limit

Columns L and M are the calculated wasteload allocations for acute and chronic criteria

Columns N and O are the acute and chronic long term averages necessary to meet the wasteload allocations. The smaller of these two (the limiting LTA) is automatically placed in column R.

Column P is the expected coefficient of variation for the LTA. Use the effluent CV if available or use the default CV of 0.6.

Column Q is the probability the LTA will meet the WLA (expectation that the water quality standards will be met). A value of 0.99 (recommended by EPA) means an expected probability of exceedance of 0.01 or 1%.

Column S is the effluent CV. Use the calculated value if available or a default of 0.6 if an actual value can't be calculated.

Columns T and U are the expected probability of error for the effluent limits. The recommended values are 0.95 for the AML and 0.99 for the MDL (See the PWM pg. VI-28 for a discussion).

Input - Column V - The number of samples which will be required per month for compliance sampling. If sampling will be less than 1 per month use a value of 1 in this column.

PERFORMLIM.XLS

This spreadsheet calculates performance-based effluent limits. It will account for autocorrelation if the autocorrelation factor is known. The permit manager should assume effluent data is non-normally distributed and use EXCEL™ to transform the data using a lognormal transformation. A note in cell G2 explains the procedure for lognormal data transformation. Rows 5 through 8 are **input** cells. The lognormal transformed mean and variance are placed in cell H5 and H6. The number of samples per month that will be required for compliance monitoring is placed in cell H7. The autocorrelation factor is placed in cell H8 if it is known. Cells H9 through H13 are calculated intermediate values. Cells H15 and H16 are the calculated effluent limits.

HUMAN-H.XLS

This spreadsheet calculates reasonable potential and the effluent limits for human health pollutants. Reasonable potential for human health criteria is based on the 50^{th} percentile effluent value. This spreadsheet deals with the effluent values in two ways. In a situation where the permit writer has 10 or more data points for the effluent concentration, the 50^{th} percentile should be calculated by using the statistical calculation in EXCEL or some other software. Place this calculated 50^{th} percentile value in column N. Any number in this column is always used for calculations if present so it must be 0 unless a calculated percentile value is placed here. In a situation with less than 10 data points, the 50^{th} percentile effluent concentration is estimated within the spreadsheet by placing the highest observed effluent concentration in column I. The estimated coefficient of variation is placed in column J and the expected number of compliance monitoring samples is placed in column L. The 50^{th} percentile value is calculated and then is used to calculate the expected concentration at the edge of the mixing zone. The dilution factor is placed in the last column (o). Carcinogens and non-carcinogens have different design criteria for effluent and receiving water flow so the dilution factors may be different for different human health pollutants. The spreadsheet calculates the expected concentration at the edge of the mixing zone, notes whether an effluent limit is required and, if so, calculates the limits using five and one percent error probabilities for average monthly and daily maximum, respectively.

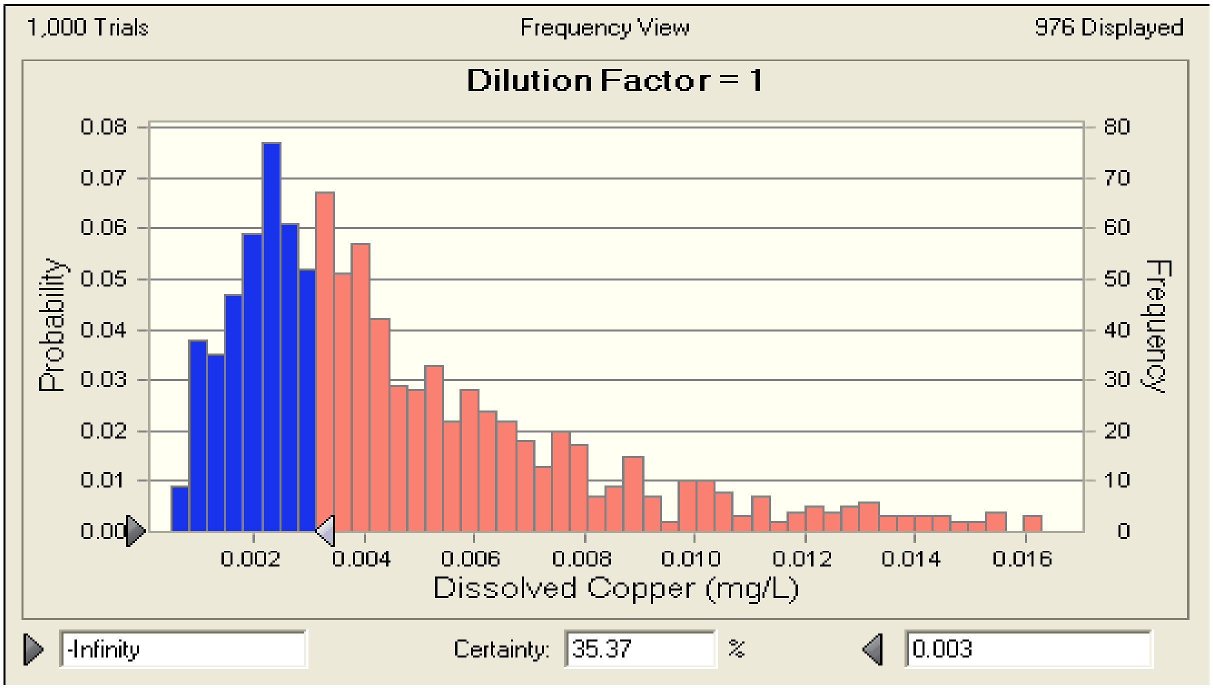
Input -Column A – Enter the pollutant parameter name
Input – Column B – Enter the ambient concentration as the geometric mean of the receiving water values.
Input – Column C – Enter the human health criteria value.
Column D – This column calculates the expected concentration at the edge of the chronic mixing zone.
Column E – This column returns a yes or no as a determination of reasonable potential.
Input - Column F – The number of samples expected to be required in the permit for compliance monitoring.
Columns G and H – the calculated monthly average and daily maximum limits. Note that the monthly average limit equals the WLA adjusted for the background concentration.
Column I – The expected effluent percentile at 95% confidence. The recommended value is 0.5 in this column.
Column J – Internal calculation used to calculate multiplier (Col. O).
Input - Column K – The maximum effluent concentration measured.
Input - Column L – The coefficient of variation. The default value is 0.6 but this should calculated from the effluent data if there are 10 or more data points. The coefficient of variation is the standard deviation ÷ the mean.
Column M – An internal calculation used to calculate the multiplier (Col. O).
Column N – The number of data points in the data set from which value in Column K was taken.
Column O – The calculated value which is used to multiply the value in Column K to estimate the 50^{th} percentile at the 95^{th} percent confidence level. The formula for this multiplier is taken from the EPA TSD.
Input - Column P – The calculated 50^{th} percentile effluent concentration. With 10 or more effluent data points the 50^{th} percentile value should be calculated and placed in this column. A number in this column will take precedence over an estimated value. If the 50^{th} percentile value isn't calculated this column should be 0.
Input - Column Q – The chronic mixing zone dilution factor.

APPENDIX J

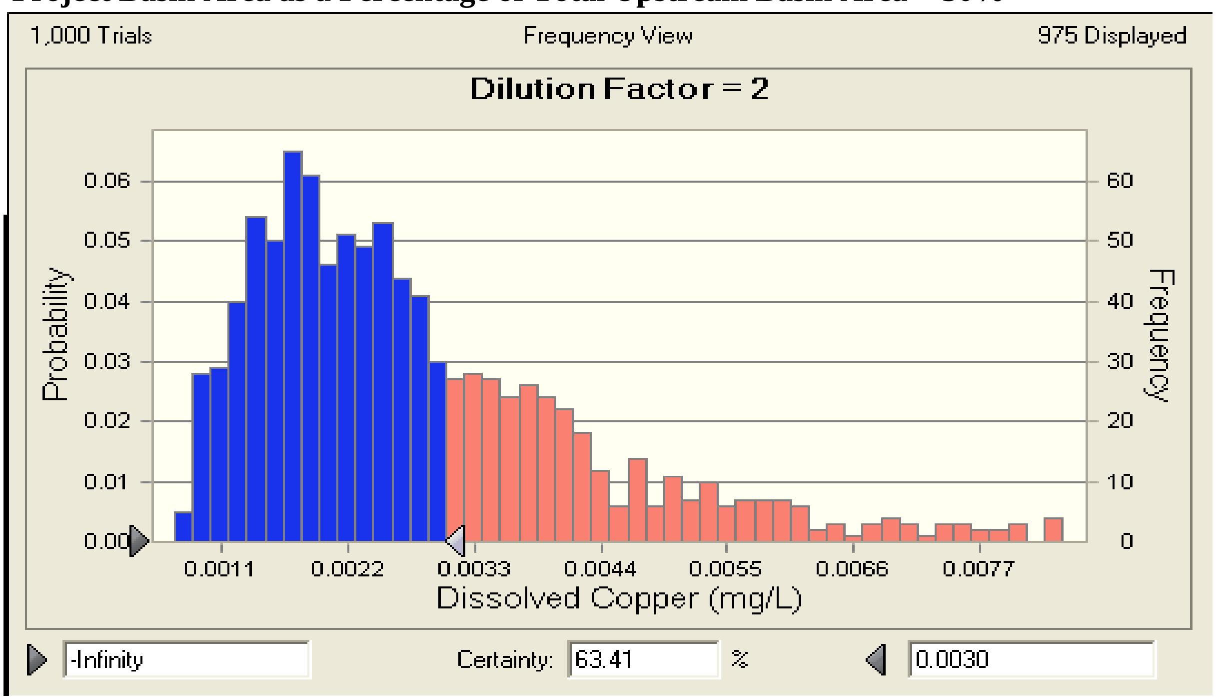
Monte Carlo Simulation Results for Threshold Determination

Monte Carlo Simulation Dilution Analysis for Dissolved Copper

Project Basin Area as a Percentage of Total Upstream Basin Area = 100%

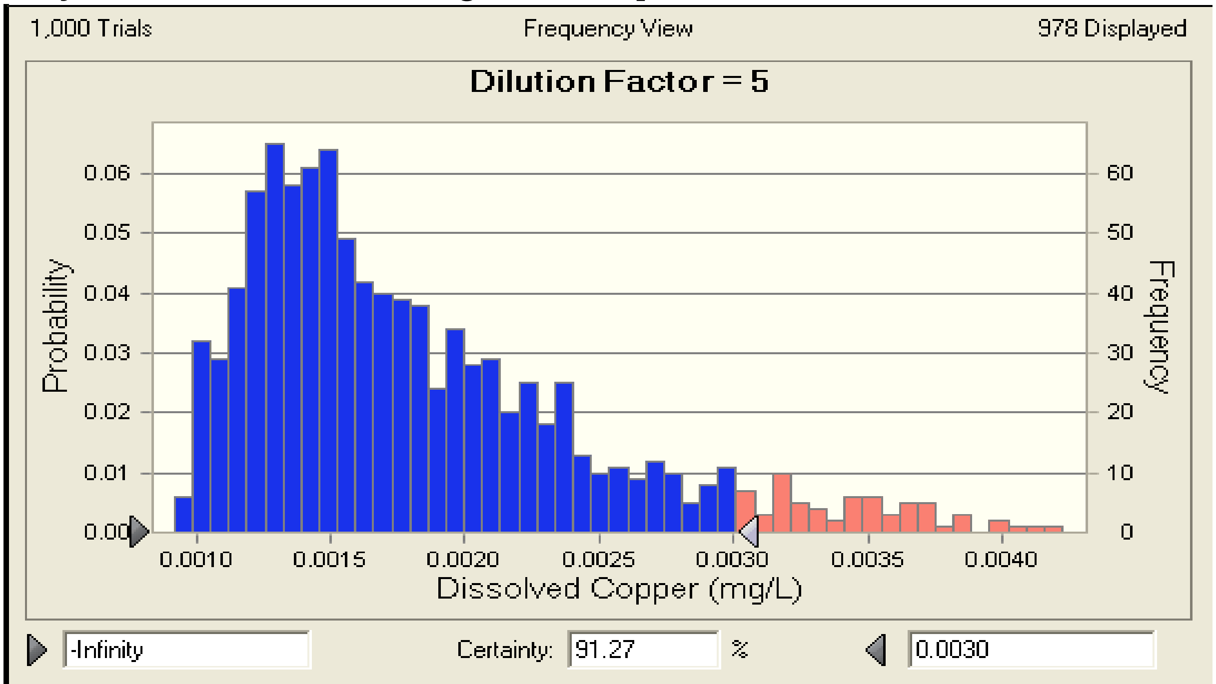


Project Basin Area as a Percentage of Total Upstream Basin Area = 50%

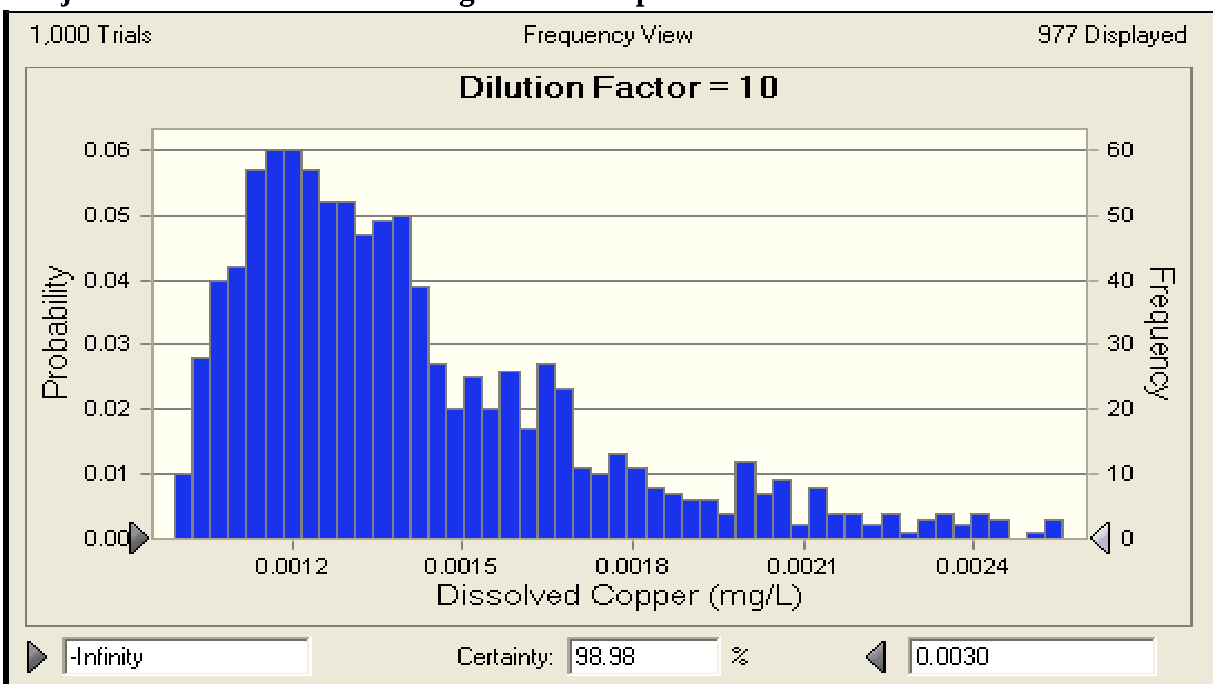


Monte Carlo Simulation Dilution Analysis for Dissolved Copper (continued)

Project Basin Area as a Percentage of Total Upstream Basin Area = 20%

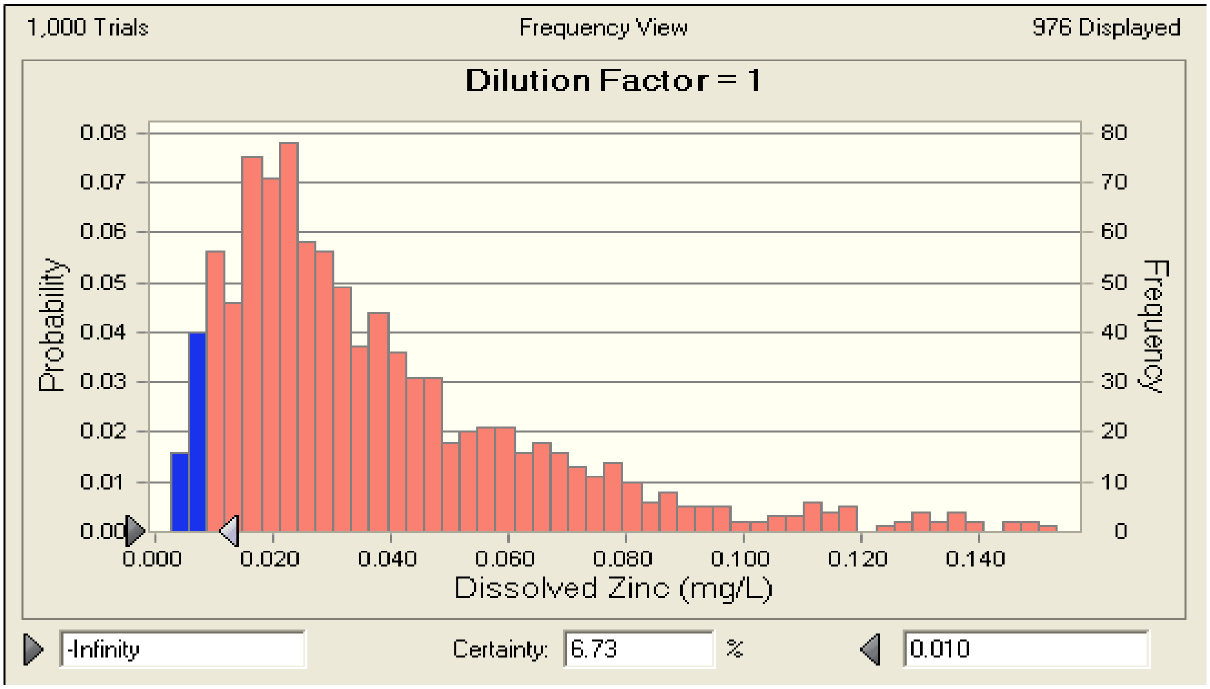


Project Basin Area as a Percentage of Total Upstream Basin Area = 10%

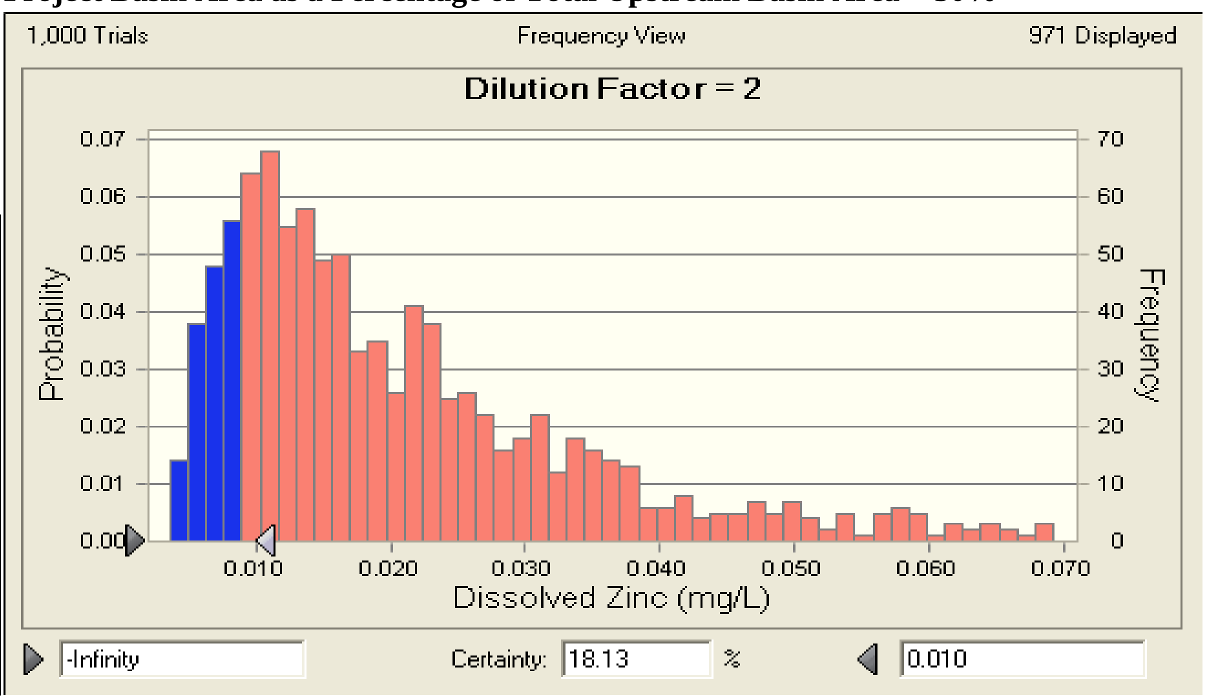


Monte Carlo Dilution Analysis for Dissolved Zinc

Project Basin Area as a Percentage of Total Upstream Basin Area = 100%

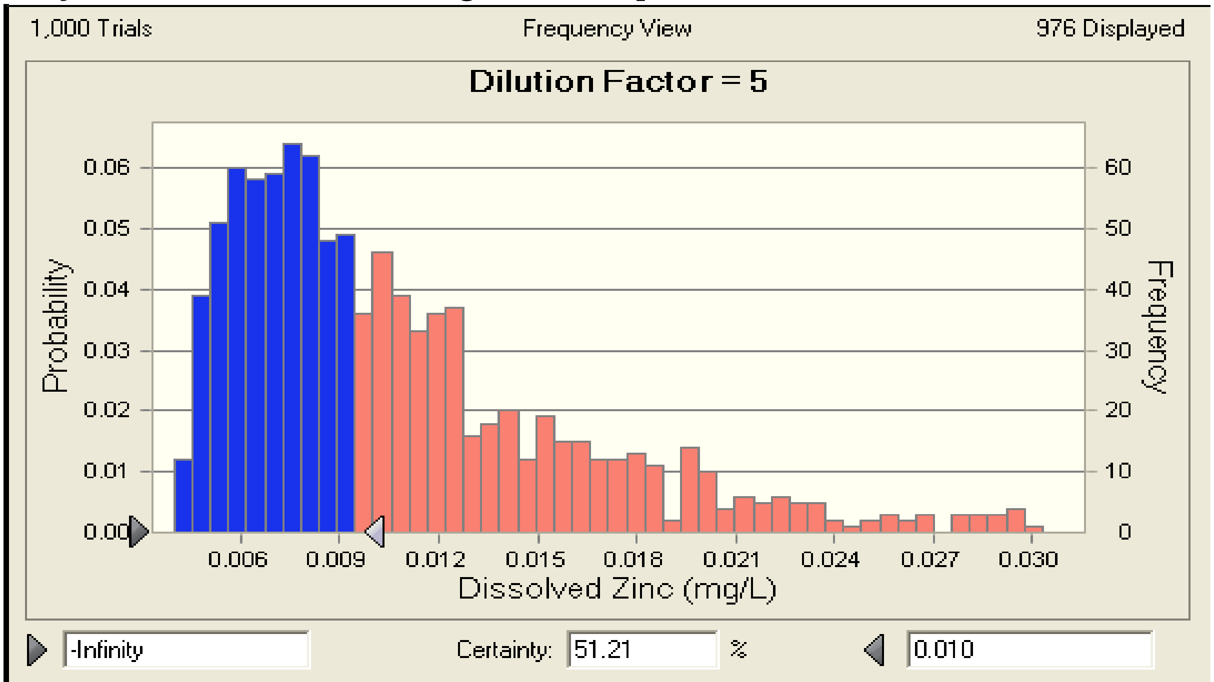


Project Basin Area as a Percentage of Total Upstream Basin Area = 50%

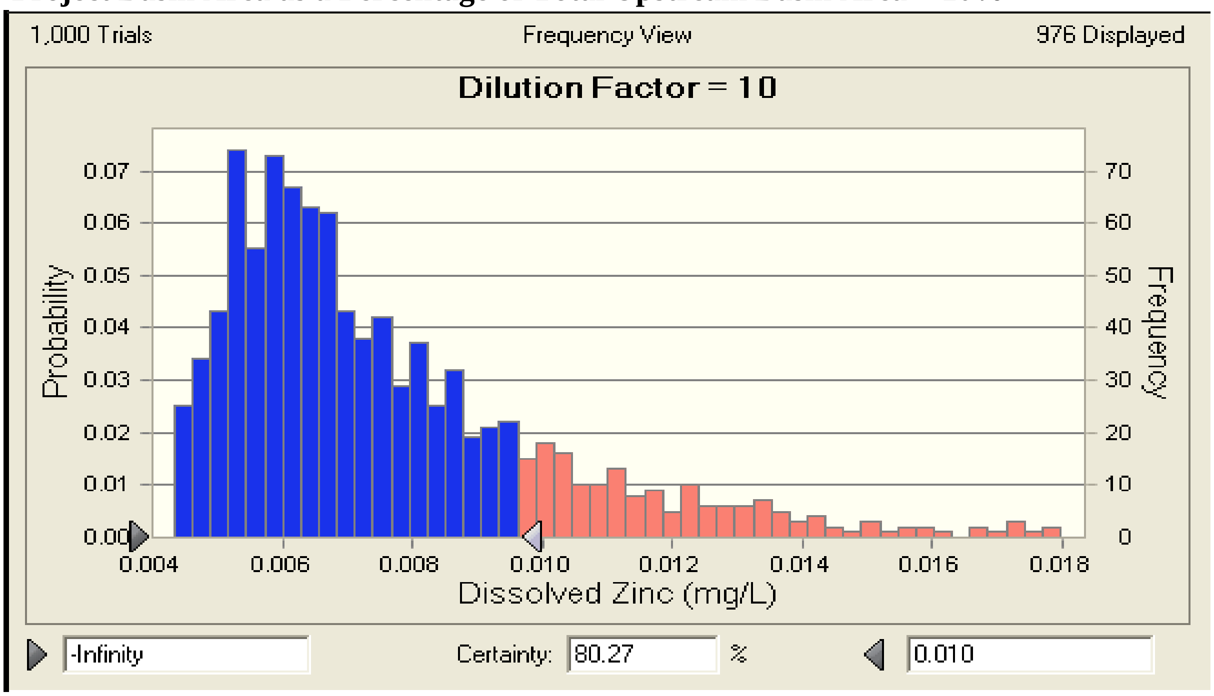


Monte Carlo Dilution Analysis for Dissolved Zinc (continued)

Project Basin Area as a Percentage of Total Upstream Basin Area = 20%

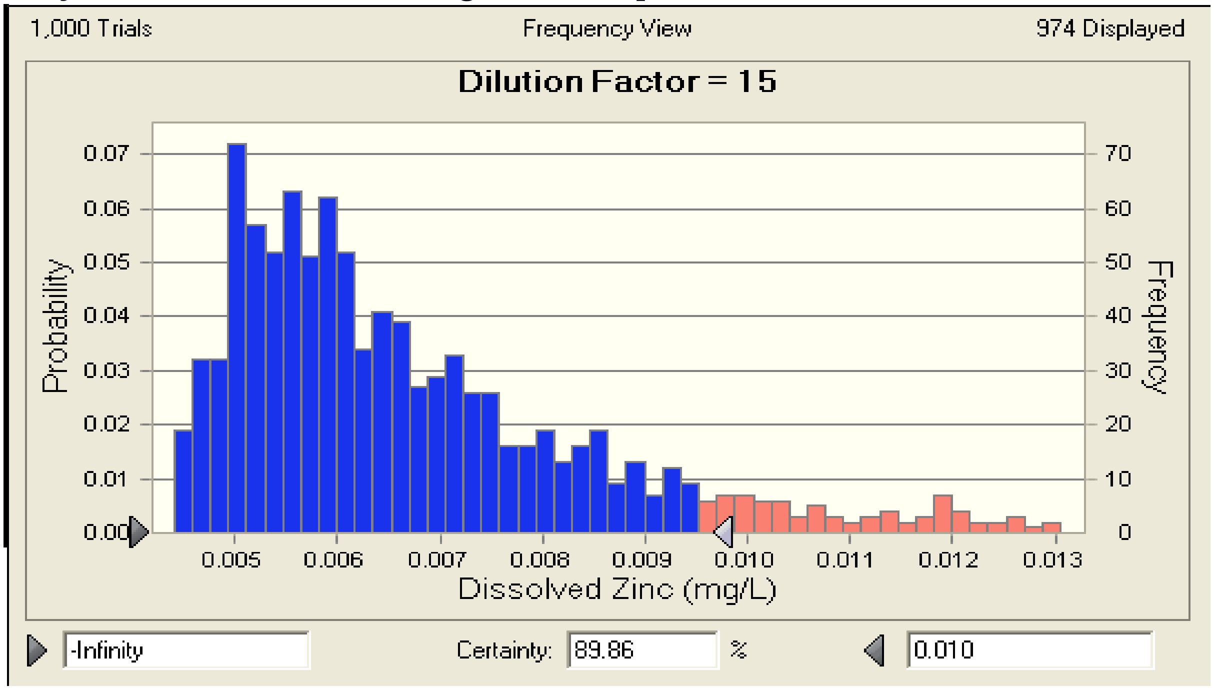


Project Basin Area as a Percentage of Total Upstream Basin Area = 10%



Monte Carlo Dilution Analysis for Dissolved Zinc (continued)

Project Basin Area as a Percentage of Total Upstream Basin Area = 7%



Project Basin Area as a Percentage of Total Upstream Basin Area = 5%