User Guide

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Domain: www.erams.com/flowanalysis

Comprehensive Flow Analysis

CATENA ANALYTICS

One Water Solutions Institute

Colorado State University

CONTENTS

EXECUTIVE MESSAGE

Catena Analytics offers powerful platforms for building accessible and scalable analytical tools and simulation models that can be accessed via desktop or mobile devices. Our team has spent that last decade developing the Environmental Resource Assessment and Management System (eRAMS), an open source technology that provides cloud-based geospatially-enabled software solutions as online services and a platform for collaboration, development, and deployment of online tools. Our services are used to assist with strategic and tactical decision making for sustainable management of land, water and energy resources. Thank you for choosing Catena Analytics and the eRAMS platform to meet your data, modeling, analysis and geospatial needs.

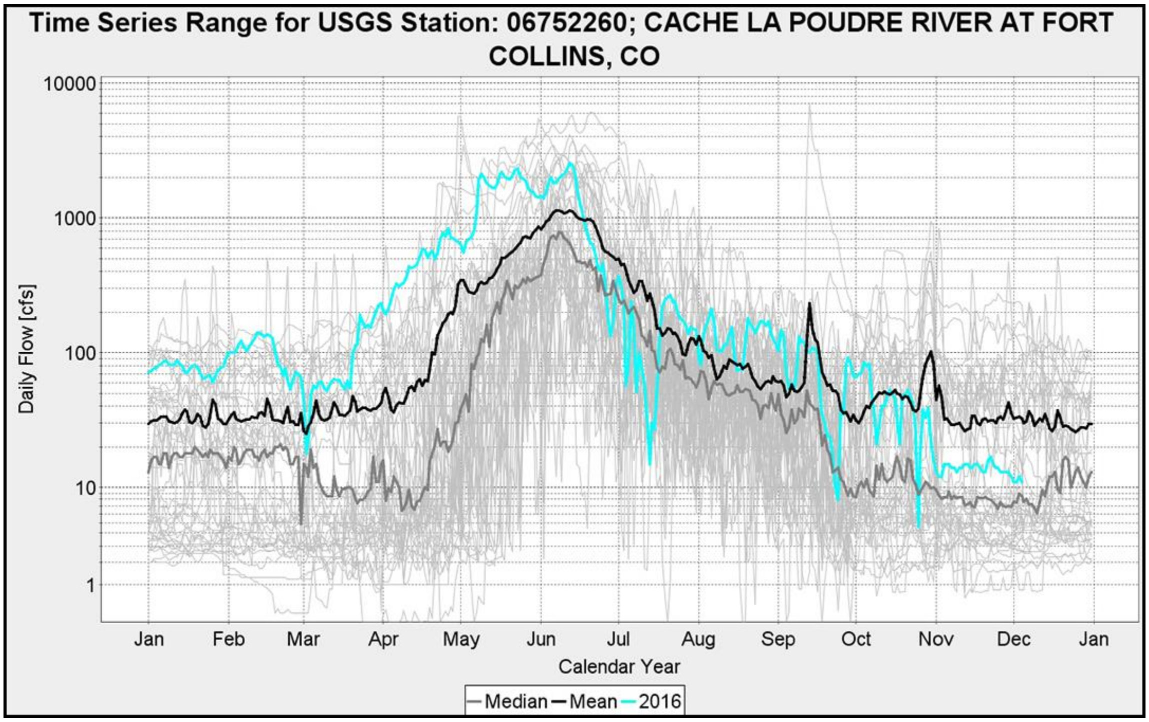
WHO SHOULD USE THIS GUIDE

This guide is a tutorial to get you started using eRAMS Comprehensive Flow Analysis. The guide provides instructions for commonly performed tasks and uses of the tool. This tool is intended for use by urban planners and water managers, academic groups, regulatory officials, consultants as well as state, local and federal agencies planning for the future of water resources.

NEED HELP?

After reviewing the guide if you need additional assistance we are here to help! This guide is designed to provide instruction on commonly performed operations and answers to many frequently asked questions. If you find any aspect of the tool challenging or missing information from this guide, please engage an eRAMS expert to guide you through any hurdles. Contact us at: eramsinfo@gmail.com

INTRODUCTION



Purpose

Comprehensive Flow Analysis allows users to explore statistical properties of river discharge and water quality using either publicly available data or user supplied data.

Description

Our suite of comprehensive water quality assessment tools allows users to analyze various aspects of streamflow data including statistical analysis and regression, flood frequency, base flow separation, flow duration curves, and load estimation. Use the Comprehensive Flow Analysis tools to examine:

- River discharge and water conditions
- Ambient water quality
- Drought duration and intensity
- Water quality load estimation
- Flood frequency

Stream monitoring stations from the USGS National Water Information System (NWIS) and EPA's Water Quality eXchange (WQX) via the Water Quality Portal (WQP) databases are available for selection and analysis. Our tools can also be used to download stream flow (daily average or 15-minute), water quality, and annual peak discharge data.

Users can view results and model outputs in a variety of options including:

- Time series graphs
- Envelope plots
- Histograms
- Cumulative distribution function (CDF) graphs
- Flood and drought magnitude-frequency plots
- Duration curves

Software Availability

Domain

www.erams.com/flowanalysis

Documentation URL

https://erams.com/catena/tools/water-quality/

Publication/Citation

Wible, T., W. Lloyd, O. David, M. Arabi. 2014. Cyberinfrastructure for Scalable Access to Stream Flow Analysis. In: Ames, D.P., Quinn, N.W.T., Rizzoli, A.E. (Eds.), Proceedings of the 7th International Congress on Environmental Modelling and Software, June 15-19, San Diego, California, USA. ISBN: 978-88-9035-744-2

Wible, Tyler and Arabi, Mazdak. 2013. Comprehensive Flow Analysis Using Cloud-Based Cyberinfrastructure. Colorado Water. 30(5): 15-17.

Authorized Use Permission

GETTING STARTED

Quick Start

Follow the simple workflow below to get started:

1. Select Stream Monitoring Station
2. Select Analysis Method
3. Provide Inputs
4. Review Results

System Requirements

A modern web-browser is required to connect and run CFA. Browser options include: Google Chrome v.69, Mozilla Firefox v.62, Safari v.11.1, and Microsoft Edge v.17.

USING THE TOOL

ACCESS THE TOOL

Public Access

Comprehensive Flow Analysis (CFA) can be accessed without registering an eRAMS account. In the public-facing version the data and analysis will only be available for the duration of the browser session. Once the browser is closed the project will no longer be available (i.e. users cannot save their work or share their project).

If a user prefers to save their project, share it with collaborators or revisit their analysis, an account is required. Follow the instructions below to create your free account and save your projects or visit our website to get started: https://erams.com/account/

Create an eRAMS Account

1. From the eRAMS Registration page, enter a username, password, your first and last name, and your email address. Click on the "Create Account"
   - eRAMS will display a popup box alerting you that an email confirmation has been sent to the provided email address
2. Open the email account provided in the registration form from either a new browser window or from your local email application.
   - Search for an email from eRAMS with the subject line "eRAMS Email Check"
3. Open this email and click on the provided link to confirm your email address.
   - ***Note**: If you do not see the confirmation email appear in your email inbox immediately, check your spam or junk email folder to ensure that the confirmation message wasn't automatically discarded. You may also need to wait a few moments to ensure the email is delivered successfully.*
4. Once you click on the provided email link, you should be redirected to eRAMS, where you'll be automatically logged in

Registered User Access

1. Login to your eRAMS account here: https://erams.com/account/
2. Select the "Projects" tab from the left panel (Figure 1)
   - ***Hint**: You must be logged into your eRAMS account*
3. Select "Create Project" from the top toolbar
4. Enter a Project Name
   - Alternatively, select a project from the list to access previous projects
5. Select "Flow Analysis" from the Project Type drop down
   - Optional: Select layers from previously saved project under the "Include Layers from Project" drop down
6. Click "OK"
7. Locate the name of the project you have created in the project list, click the link
   - The link will redirect you to the CFA interface where you can conduct analysis and save work to your account

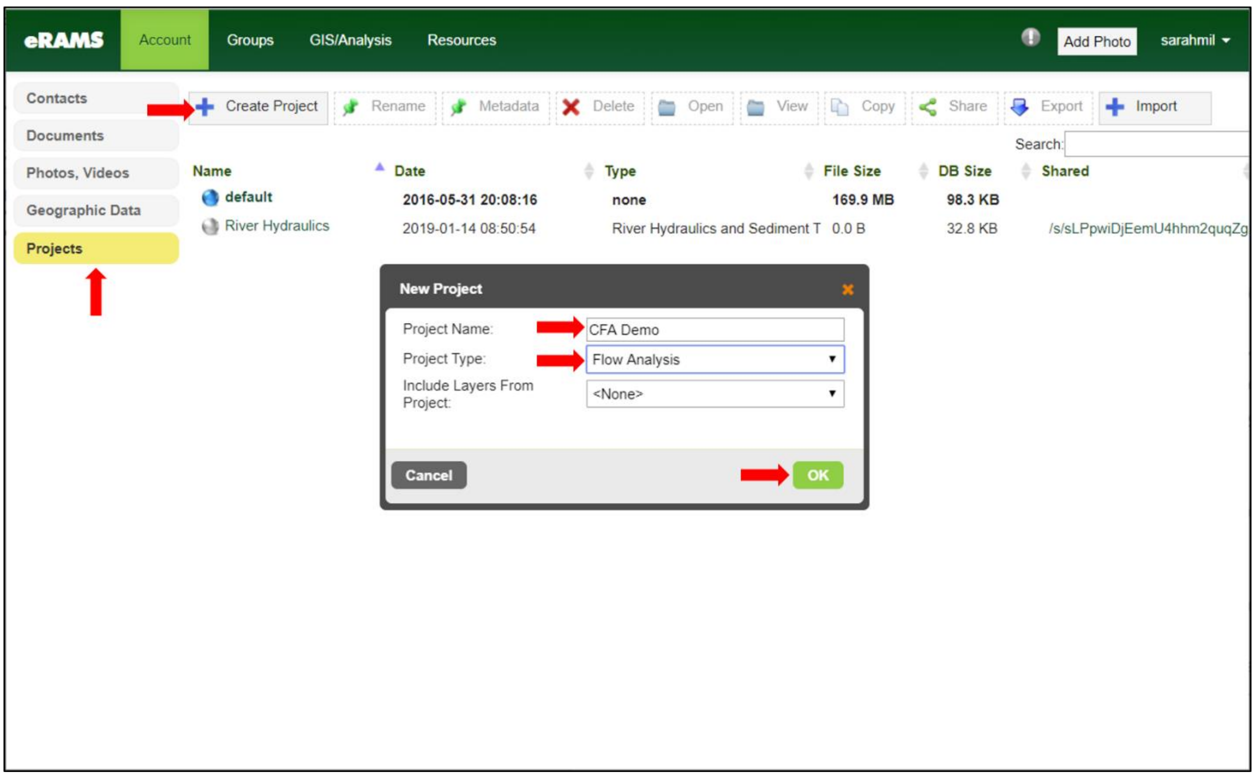


Figure 1: Registered user process for creating a Flow Analysis project in eRAMS

Step 1 – Select Stream Monitoring Station

Select Base Layer (optional)

With the CFA interface open, click the "Map" tab on the left dashboard

1. Select the "Base Layers" drop-down
2. Select the desired base layer
    - Options include: Google, Bing, USGS National Map, None

Locate Stations

The CFA Interface provides several methods to search and identify stream monitoring stations. Users can search for a station using keywords (e.g. name) or by where it is located on the map. In addition, you can select a buffer radius and search around an area, shape or line.

The "Help" button in the Flow Analysis tab provides detailed instructions for performing a search (Figure 2).

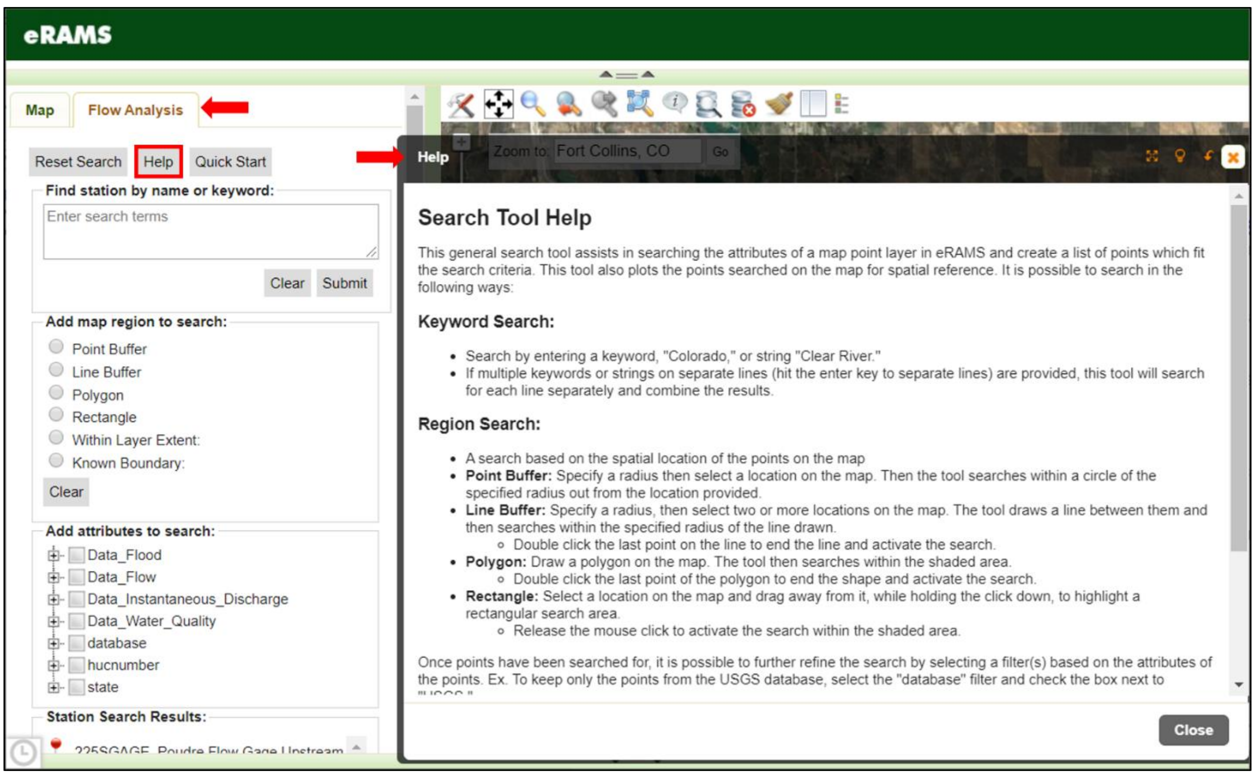


Figure 2: Additional (in-line) station search information

1. Enter search criteria to locate stations and click "Submit" to return stations
2. Results will appear on the left dashboard under "Station Search Results" and corresponding station markers will appear on the map
    - USGS NWIS stations
    - EPA WQX stations

- Colorado Division of Water Resource (CDWR) stations
- stations created by the user
    - i. ***Note:*** *this feature is only available to registered account users – click "add station" and select a point on the map. Once the station is created, you can provide additional information about the station (e.g name or station id)*

3. Select the desired station from the results list to open the CFA interface and station summary information
4. Select "Flow Analysis Model to launch the CFA interface

Step 2 – Select Analysis Method

Once the CFA interface is launched, users can select from several analytical tools. Additional details for each tool including technical information and model descriptions are provided as in-line information by clicking the corresponding hyperlink (Figure 3). A brief summary of each tool is provided below.

Note*: To upload your own data select the link on the "Station" tab*

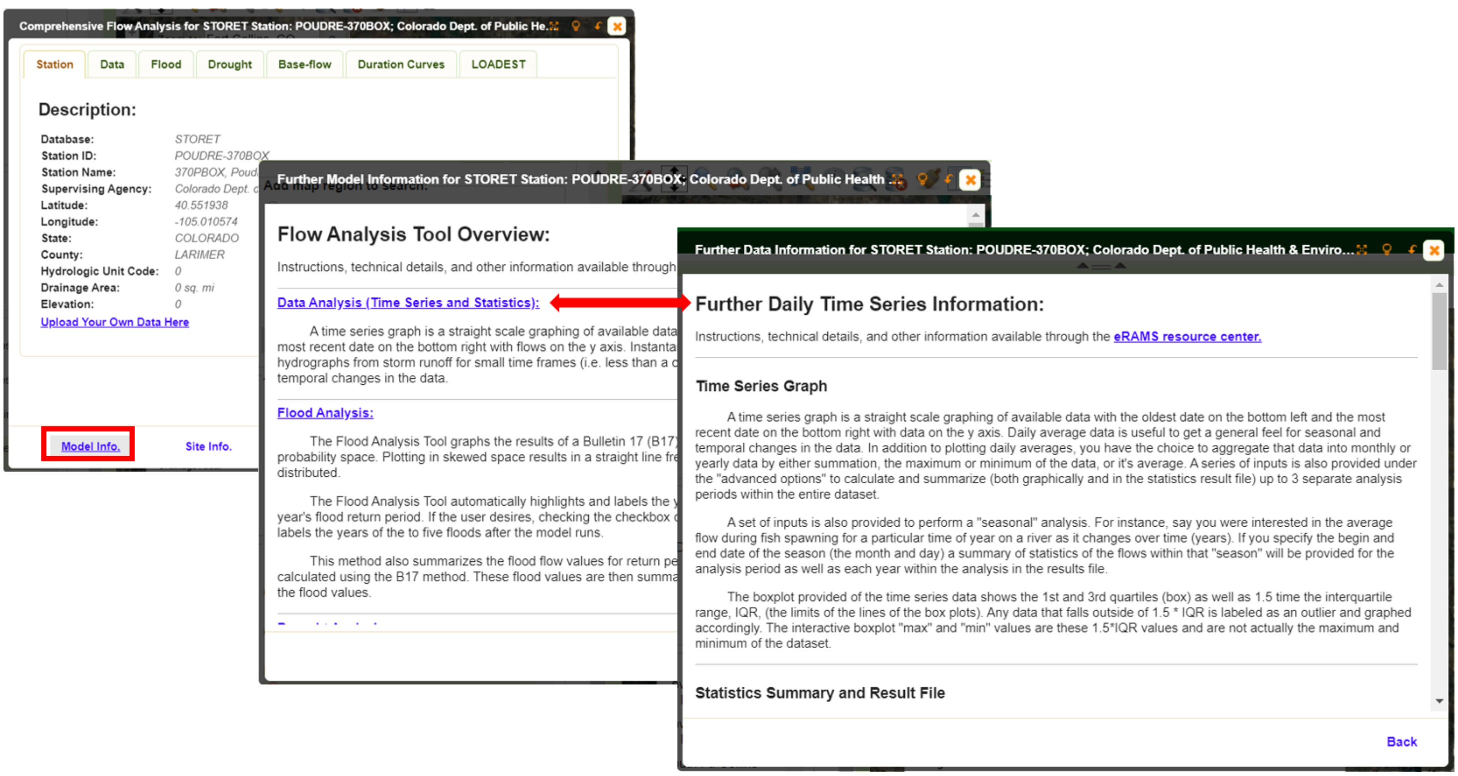


Figure 3: Analytical details and technical information is available in the CFA interface

Data Analysis

The first model included in CFA is a simple time series analysis. The Time Series Analysis Tool graphs temporal changes in available flow or water quality data for any given station within the specified time period of interest. Time series also provides a summary of the statistics of the graphed data, including its min, max, median, mean, upper and lower quartiles, and standard deviation.

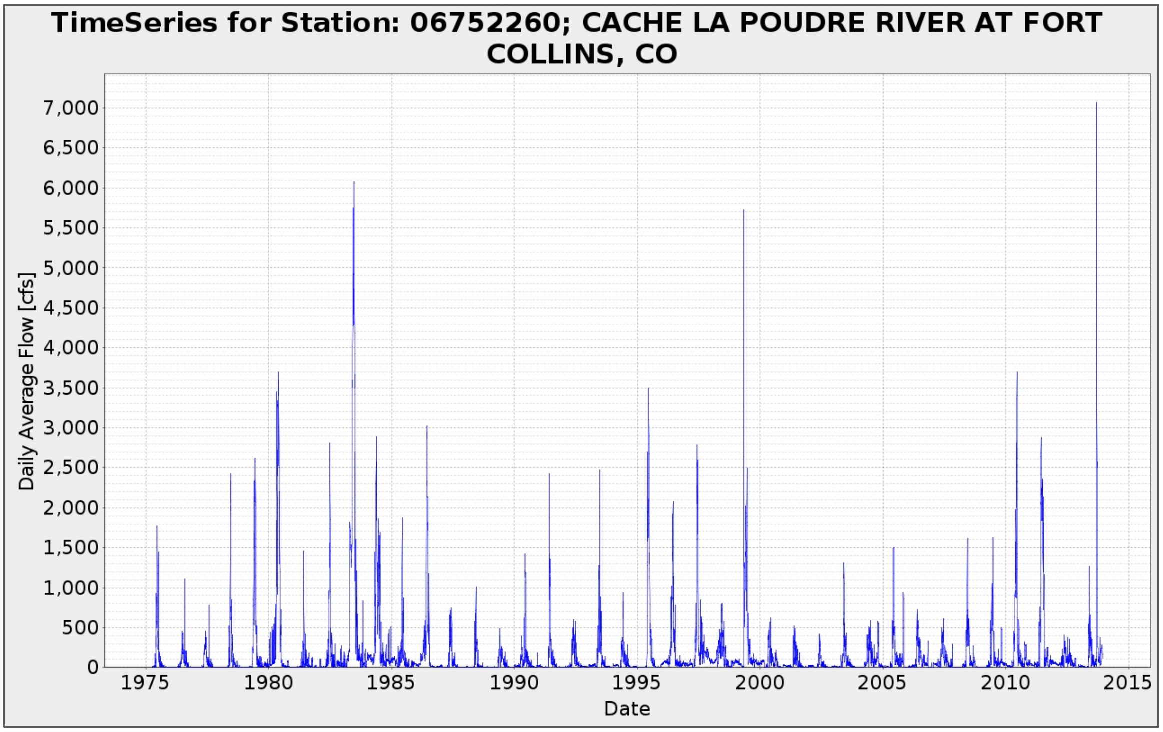


Figure 4: CFA time series analysis results

Flood Analysis

Of greater benefit than a simple time series of stream flows, CFA also includes a flood analysis model. The Flood Analysis Tool follows the USGS Bulletin 17B approach (IACWD 1982) for flood flow frequency analysis of unregulated streams and graphs the results of a Bulletin 17 (B17) flood analysis of the current station, in skewed probability space. Plotting in skewed space results in a straight-line frequency curve, even if the data is not normally distributed.

This tool automatically highlights and labels the year of the largest flood and the most recent year's flood return period. This method also summarizes the flood flow values for return periods such as the 25, 50, 100 and 200-year floods calculated using the B17 method. These flood values are then summarized in a table with the confidence intervals for the flood values (Figure 5).

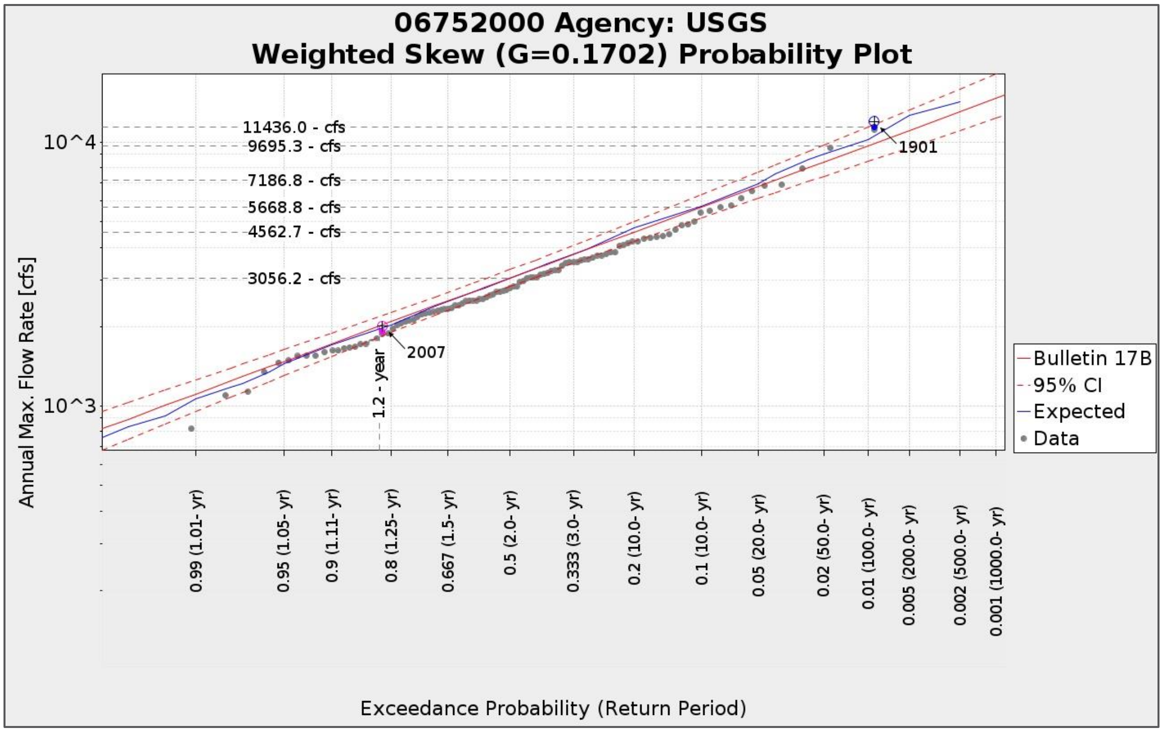


Figure 5: CFA flood analysis results

Drought Analysis

An opposite, but equally important, aspect of stream flows is the consideration and analysis of droughts from stream flow records.

The drought analysis calculates annual flow data and then fits a regression model, AR(p) or ARMA(p, q), to the annual data in order to project if forward 100,000 years to create a sufficiently large sample size. Then projected data is analyzed to determine the average occurrence interval of various 1-year, 2-year, etc. droughts. The projected data drought lengths are then graphed against their average recurrence interval along with the recurrence interval of the historic data (Figure 6).

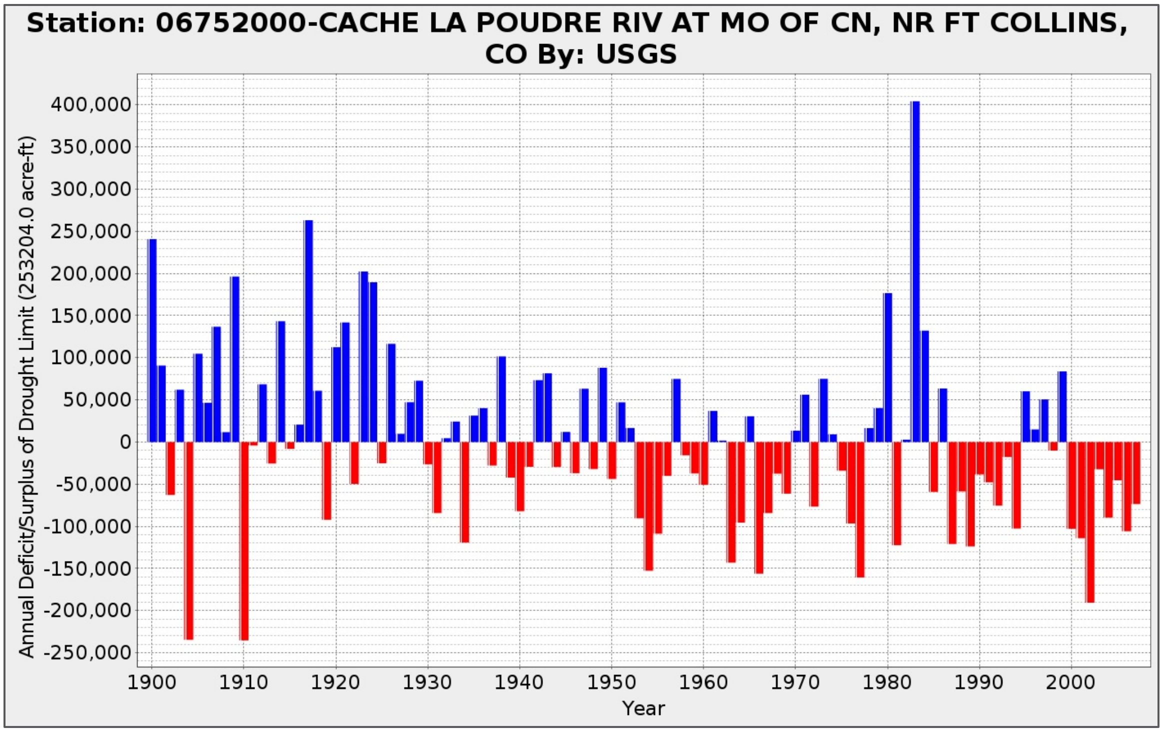


Figure 6: CFA drought analysis results

Baseflow Analysis

Another useful aspect of stream flow analysis and hydrologic modeling of river basins is river base-flow. Rather than write a numerical hydrograph separation tool, CFA has incorporated the numerical base-flow separation program "BFLOW," developed by the by Arnold et al. (1995; Arnold and Allen 1999). BFLOW is an automated digital filter base-flow separation tool which performs a multi-pass separation of base-flow from total stream flow. The results are graphed on a time series. The base-flow of a river is useful when identifying the runoff contribution from a storm to streamflow.

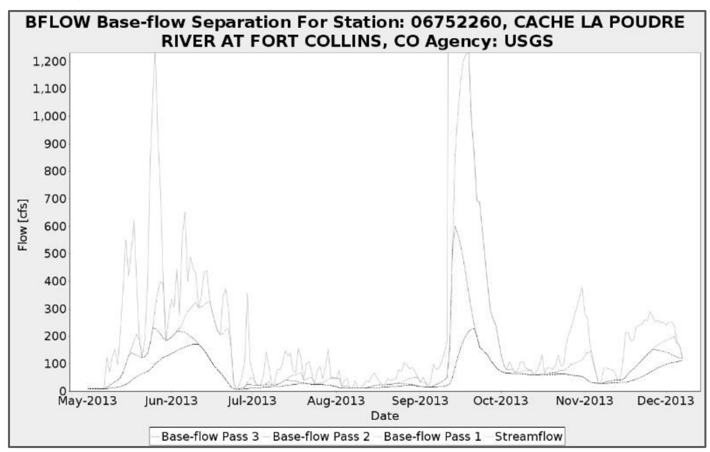


Figure 7: CFA baseflow analysis

Duration Curve Analysis

Another approach to stream flow data is the application of duration curves; which statistically rank and graph available flow data. The Flow Duration Curve (FDC) tool in CFA graphs Weibull plotting position ranks of stream flows on a scale of percent exceedance. Graphing flow values in this way allows for a quick visualization of the variability of flow under the different flow regimes and is useful numerically for thresholds such as the flow rate only exceeded 10% of the time in the historical record.

A Flood Duration Curve (FDC) is the ranked graphing of river flows on a scale of percent exceedance. For example, a flow value associated with the flow interval of 15% means that particular flow value is met or exceeded only 15% of the time. This graph provides a quick overview of the flow ranges, variability and probability of flows of a river segment during different flow periods of a river.

A Load Duration Curve (LDC) is a flow duration curve multiplied by the users chosen target pollutant concentration that should not be exceeded. The LDC is graphed along with points of observed pollution concentrations and box plots of the observed points within their respective flow intervals (Figure 8). If the observed points are below the LDC line there is no excess, however, if the observed points lie above the LDC line this indicates observations which exceed the maximum specific target pollution concentration. A more in-depth study of the watershed should be completed to identify proper pollution sources and remediation solutions.

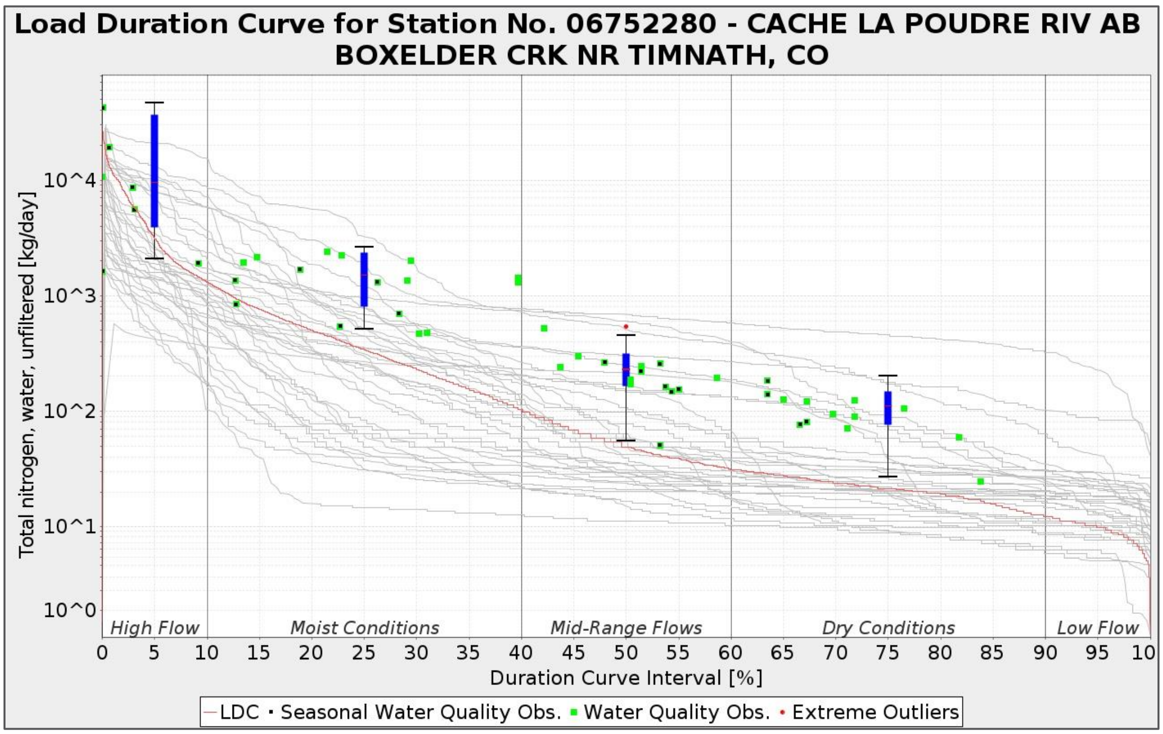


Figure 8: CFA load duration curve analysis results

LOADEST Analysis

LOADEST (LOAD ESTimator) is a FORTRAN executable developed by the U.S. Geological Survey that estimates the amount of constituent loads in streams and rivers given a times series of stream flows and constituent concentration. Estimation of constituent loads occurs in two steps, the calibration procedure and the estimation procedure, both of which are based on three statistical estimation methods; the Adjusted Maximum Likelihood Estimation (AMLE), Maximum Likelihood Estimation (MLE) and Least Absolute Deviation (LAD).

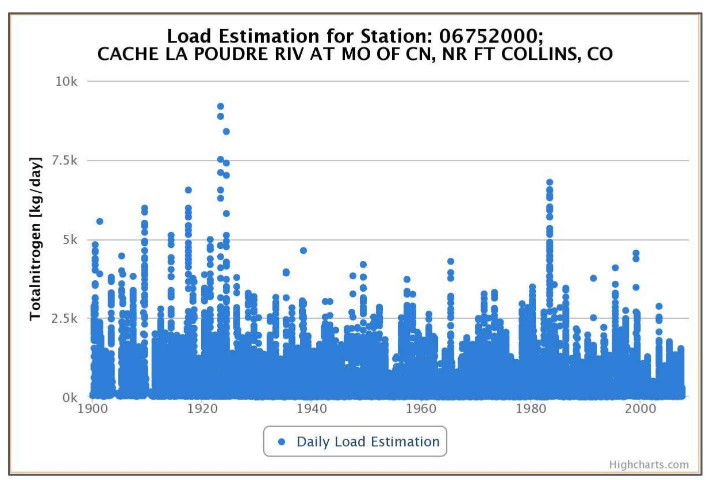


Figure 9: CFA LOADEST analysis results

Step 3 – Provide Inputs

Each of the corresponding analysis tools provides user input options, including the ability to upload your own data (Figure 10). In addition, users are able to download the existing data for that station (if available).

1. Specify inputs or upload data
2. Click "Run Model" to generate a report

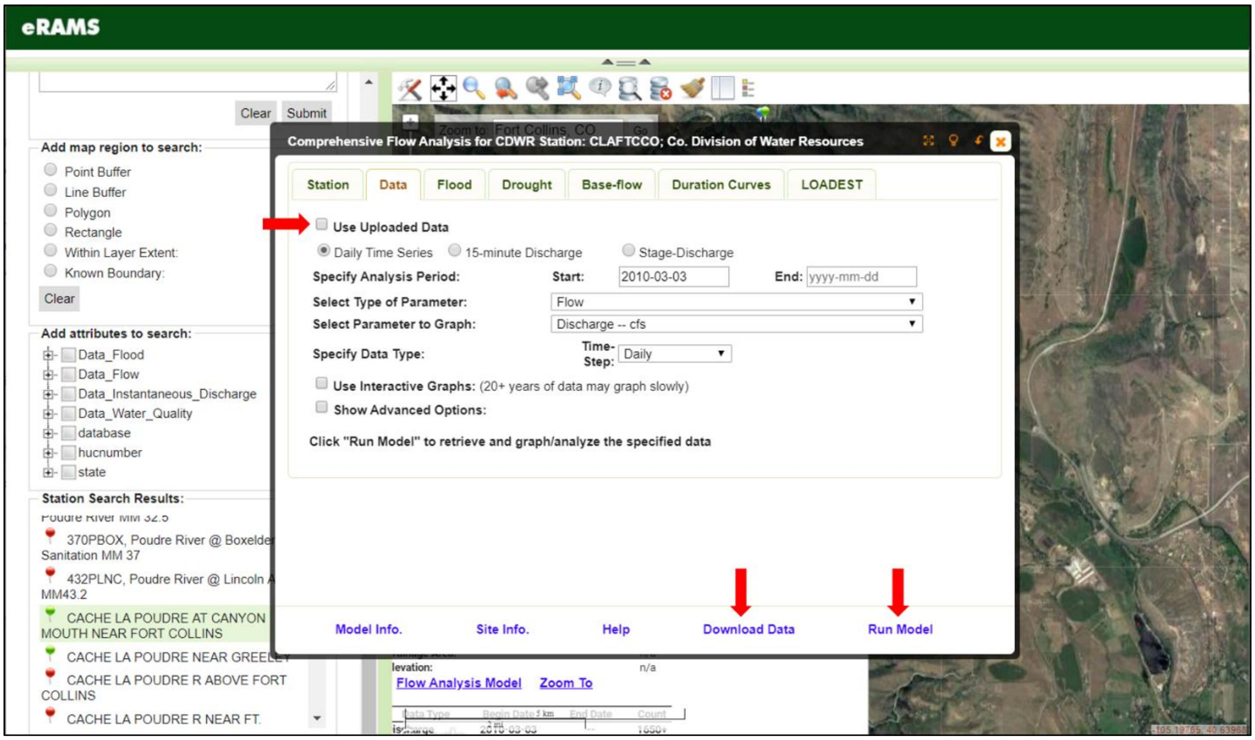


Figure 10: CFA user input options

Step 4 – Review Results

Once required information is provided the CFA will run the requisite models and produce a results summary report. The report can be printed, and the results can be downloaded as an excel file. In addition, users can add comments to the report. The results will also include a list of relevant references.

Model details and technical information can be accessed from the "Further Model Info" link (Figure 11).

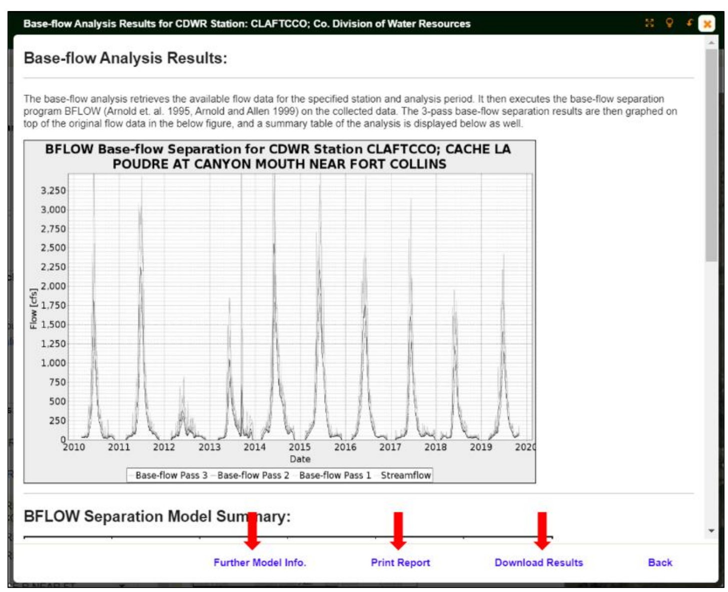


Figure 11: CFA Base-flow results and relevant links

DATA

Geospatial Information

The base layer for the CFA tool is a GIS point layer of stream flow and water quality monitoring locations historically or actively maintained by the Colorado Division of Water Resources (http://www.dwr.state.co.us/), U.S. Geological Survey (http://waterdata.usgs.gov/nwis), or the EPA's WQX database (https://www.waterqualitydata.us/).

Public Access Data

The data used in the CFA tool is either auto-extracted from the Colorado Division of Water Resources (http://www.dwr.state.co.us/), U.S. Geological Survey (http://waterdata.usgs.gov/nwis), or the EPA's WQX database via the Water Quality Portal (WQP) (https://www.waterqualitydata.us/).

User Provided Data

The user is also able to upload and use their data alone or in combination with the public database data. If you wish to use your own data combined with the available USGS or EPA data, upload your file and then check the "Use Uploaded Data" box on the analysis interface and choose whether you desire to analyze your data only or merge it with available USGS/EPA data and then analyze it.

User Data Requirements

The user uploaded data must be in a comma separated value (CSV) file. The first row must contain a label for the columns, for example "date, flow, 00600". The first column must contain dates, in any of the following formats:

yyyy-mm-dd	yyyy-m-dd	yyyy/mm/dd	yyyy/m/dd
yyyy-mm-d	yyyy-m-d	yyyy/mm/d	yyyy/m/d

The remaining columns of the file are to be different datasets, with corresponding labels in the first row:

- If flow data is provided, the label must be "flow" (with units of cfs).
- If water quality data is provided:
    - The label must be the 5-digit USGS code (including zeros) for that type of water quality data
    - The water quality data must be in the units of that USGS code
- If there are dates with no data for one or more columns, please put "null" or "n/a" in the column

FAQS

Frequently Asked Questions

Q: Can you compare flow data between two different monitoring stations, or do you need to run two different analyses and compare them?

A1: You can select more than one station (hold "ctrl" or "shift" and select another station in the "Station Search Results" list on the left panel) and a button for "Multiple Site Comparison" will appear below the list. Clicking this button will open a different interface to compare daily or instantaneous discharge and flow duration curves for multiple monitoring stations side by side in graphs and summary tables.

A2: You can also simply select a station, open the flow analysis interface and run an analysis. Then select a different station, open another flow analysis interface and run and analysis. Then compare the results windows to each other.

Q: Why can't I see anything when I go to the map on www.erams.com/flowanalysis?

A: Some internet browsers have issues displaying the maps of eRAMS. eRAMS has been optimized for Mozilla Firefox and Google Chrome and switching to this web browser should correct map display issues.

Q: How do I use data from two different stations in one analysis?

A: Some stream monitoring stations are present in multiple databases due to shifts in responsibility from agencies like the USGS to groups like the Colorado Division of Water Resources (CDWR). Therefore, it is necessary to pull data from multiple databases to get a complete dataset for one stream monitoring station. To address this issue follow the steps below:

1. Select the second station and download the desired data
2. Format this data to the specifications for a user uploaded file for the flow analysis tool
3. Select the first station and upload this file as user data
4. Check the box to "Use Uploaded Data" on the analysis input page
5. Select "Merge Uploaded Data with Public Data" and specify what to use for dates that are included in both datasets

Q: How do I save an interactive graph?

A: The interactive graphs contain a menu (three grey lines) on the top right of the figure which opens an option to save the graph as any of the provided file types.

Q: Why do the static graphs stop at January 1st, 1900?

A: A limitation of the graphing software used to produce the static graph images is that it cannot handle dates prior to 1900-01-01, so these dates are not included in the graph. However, these dates are still included in all statistics and interactive graphs.

Q: How do the “seasonal” dates work?

A: When a season begin and end dates are specified, any data that is after, or equal to, the “begin date” and before, or equal to, the “end date” is included in the season.

For example, if a season is specified to be July 1st through August 20th, July 1st data will be included in the “seasonal” data statistics, but June 30th data will not be included. Additionally, if the “season” is specified as November 1st through March 1st, it will still function properly.

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TECHNICAL DISCUSSION

INTRODUCTION

Stream flow data has become an increasingly important tool for assessing current stream conditions and as a predictor for future conditions. However, there are numerous aspects of stream flow to analyze as well as methods to do so:

- Stream flow variability and availability for water rights and allocations
- Extent and use of flood plains
- Amount of return flows from groundwater to streams, mostly for modeling purposes
- Impact and extent of droughts on municipal water supply

The foundation of all of these analyses is the stream flow record itself, but there is not currently a uniform approach to each of these topics combined into a single comprehensive tool. The manner and implementation of a new tool is importance to its acceptance and usage.

Current stream flow analysis tools and numerical techniques like base-flow separation BFLOW (Arnold et al. 1995; Arnold and Allen 1999), hydrograph separation HYSEP (Sloto and Michele 1996), the Bulletin 17B flood analysis method (IACWD 1982), Web-based Hydrograph Analysis Tool WHAT (Lim et al. 2005), drought analysis (Salas et al. 2005; Mishra and Singh 2011), and others require installation and use of a software package on a single computer or manual data manipulation and calculations. Numerical automation of data analysis can streamline data processing and remove inherent uncertainties in manual data manipulation techniques. Additionally, the benefit of a web-based tool is that it requires no software installation and is platform independent. For these reasons, web-based software is much easier to deploy as well as simpler for people to use. A further complication of web-modeling development is the scaling of usage to meet user demands. The utilization of cloud infrastructure allows the intensive calculations to be moved from a single server to one or many cloud-based virtual machines, as needed based on current demand/usage.

With the above features in mind the Comprehensive Flow Analysis (CFA) tool was designed for the Environmental Risk Assessment and Management System, eRAMS. eRAMS is a web-based geospatial analysis tool to facilitate open-source environmental modeling. The web-deployment of eRAMS satisfies the design criteria for no software installation necessary for users. Additionally, eRAMS' utilizes the cloud-based modeling services provided by the Cloud Services Innovation Platform, CSIP (David et al. 2012). The cloud services reached by eRAMS, through CSIP, satisfies the second criteria to utilize virtual machine computation. CSIP provides an open web interface to the models integrated with it, utilizing a Representational State Transfer, REST, web service to facilitate initiating, interacting, and retrieving results from modeling runs.

CURRENT INFRASTRUCTURE

The Environmental Risk Assessment and Management System (eRAMS) website was developed by Dr. Mazdak Arabi at Colorado State University to facilitate geospatial manipulation of data for environmental modeling. eRAMS works on a web-based geospatial analyst, similar to ArcGIS, to manipulate, model, and share geospatial information. Additionally, several models have been linked into eRAMS including watershed delineation, the Soil and Water Analysis Tool (SWAT), a multi-criteria decision analysis tool, data extraction tools and the High Country Solar Platform (HCSP) for determining solar panel feasibility. The CFA tool is accessible on eRAMS through a scalable cloud-based framework called the Cloud Service Infrastructure Platform (CSIP) developed by Olaf David and Wes Lloyd (2013).

The Comprehensive Flow Analysis (CFA) tool was developed by creating and integrating a series of flow analysis methods into a single web tool and interface. CFA includes six flow models: a time series and statistical analysis, a flood analysis, a drought analysis, a base-flow separation tool, a flow and load duration curve tool, and a load estimator tool. The combination of these models into a single program on an open-source-cloud-based platform allows for multiple independent analyses on the same dataset using the same tool without the need to switch programs or re-format input data for a different flow analysis. Beyond simply saving time, CFA creates a standardized approach to the different aspects of flow analysis allowing site to site comparisons of results.

Behind the scenes, a model run of CFA is accomplished by taking the inputs, including: which model is requested (flood, time series, base-flow, etc.), station ID, begin and end dates, and other information. This is then passed them from eRAMS to CSIP via a representational state transfer, REST using a JavaScript Object Notation (JSON) to list the inputs of the desired CFA run. After receiving the REST request, CSIP initializes a model run of CFA, waits for it to finish executing, then returns the result from CFA back to eRAMS. An outline of this interaction is shown below in Figure 12.

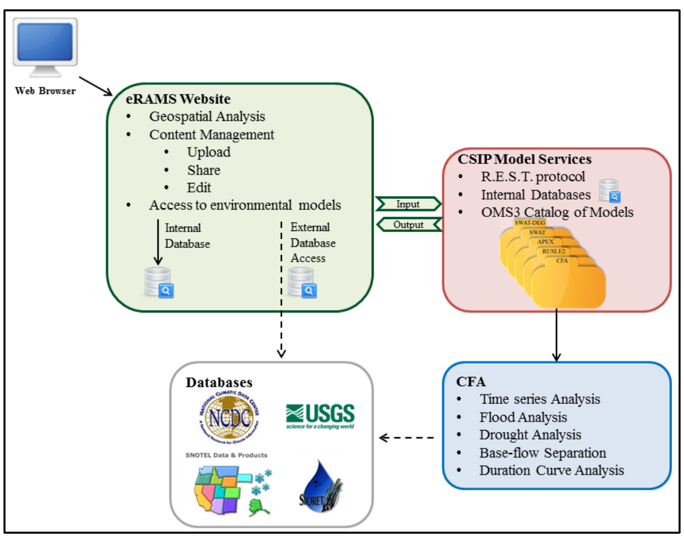

Figure 12: Current eRAMS/CFA Infrastructure Interaction

Comprehensive Flow Analysis Models

Each of the analysis methods included in CFA is summarized below including an explanation of method-specific inputs and outputs. The database, organization, station id, and station name need to correspond to that of a stream monitoring station in the Colorado Division of Water Resources (CDWR), EPA's WQX, or USGS' National Water Information System (NWIS) database.

4.1. Data Analysis

4.1.1. Time Series Analysis

The first model included in CFA is a simple time series analysis. The Time Series Analysis Tool graphs temporal changes in available flow or water quality data for any given station within the specified time period of interest. Time series also provides a summary of the statistics of the graphed data, including its min, max, median, mean, upper and lower quartiles, and standard deviation. An example of the output from the Time Series Analysis Tool is shown below in Figure 13.

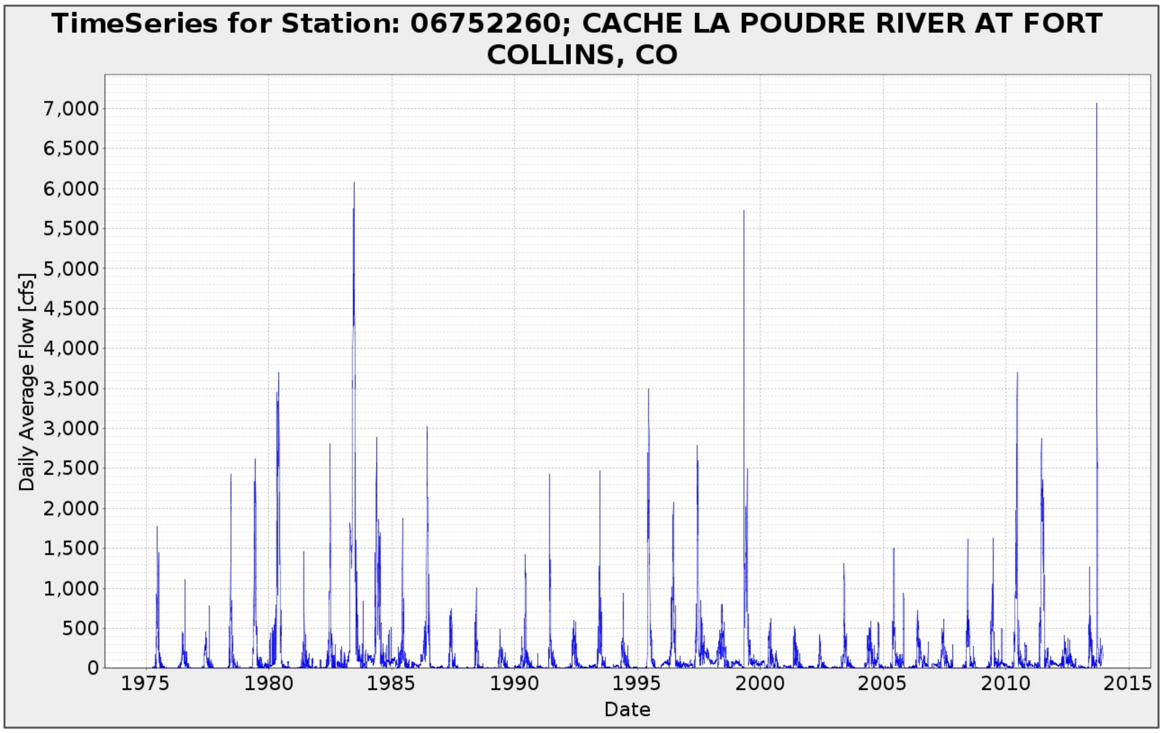

Figure 13: CFA's Time Series Analysis Tool Result Graph

4.1.2. 15-Minute Discharge Analysis

In addition to daily time series data extraction and analysis the CFA tool includes a data extractor and graphing routine for 15-minute flow data. This feature is available for USGS stations through the NWIS database. However, the USGS is currently in the process of transitioning its 15-minute discharge data from the Instantaneous Data Archive, IDA, (not accessed by this tool) to the National Water Information System, NWIS, (accessed by this tool). As a result, instantaneous flow data prior to October 1st, 2007 is not yet available through the NWIS database and thus not available through this tool for analysis. 15-minute flow data is also extracted from the CDWR database for active stations within the past 5 years and any additional data has to be specially requested from CDWR. 15-minute flow data is much better at analyzing flow events from storm runoff and better estimates true peak flow values than daily averages.

4.1.3. Stage-Discharge (Rating-Curve) Data

In addition to time series data extraction, the CFA tool includes a data extractor and graphing routine for stage-discharge (rating curve) data for active 15-minute flow stations. This data is available for the most recent survey of USGS stations through the NWIS database. Additional rating curve data is available for stations from the CDWR database.

4.2. Flood Analysis

Of greater benefit than a simple time series of stream flows, CFA also includes a flood analysis model. The Flood Analysis Tool in CFA follows the USGS Bulletin 17B approach (IACWD 1982) for flood flow frequency analysis of unregulated streams. However, CFA is unable to verify whether the stream gauging stations are unregulated or not. For this reason, as with all models, users should have some prior knowledge about the model and its limitations as well as knowledge of the area of interest. The USGS Bulletin 17B method follows the recommendations of Bulleting 15 (WRC-HC 1967) for flood magnitude/frequency study, in which a Log-Pearson Type III distribution is fitted to available flood data. By fitting a distribution to available data, return periods for unobserved and historic floods can be calculated using the parameters of the fitted distribution. This also allows for flood flows of standard return periods, like the 100-year flood, to be interpolated from the fitted distribution.

Due to the sensitivity of the Log-Pearson Type III distribution to its skewness parameter Bulletin 17B published by the Hydrology Subcommittee of the Interagency Advisory Committee on Water Data (IACWD 1982) recommends the use of both a station skew value, derived from available station data, and a generalized regional skew value. The generalized regional skew value can be found from interpolation of the regional skew map included in the Bulletin 17B documentation (IACWD 1982). For greater accuracy of skewnesses, many states have developed similar maps of their states and surrounding areas based on new regression techniques (see Appendix B for flood skewness coefficient references). Within CFA the state skewness maps were digitized and interpolated on as well as the Plate I map (IACWD 1982) and combined allowing the regional skewness value for each station to be auto-extracted. The generalized skewness coefficients used in this particular tool are first attempted to be taken from a state agency generated map; then if no state data is available the skewness is take from the Plate I map (IACWD 1982). As per the recommendation of Bulletin 17B (IACWD 1982) the final skewness used in the flood analysis is an average between the station skewness, calculated from the available flood dataset, and the generalized skewness, found as described above. An example of the result of the Flood Analysis Tool can be seen below in Figure 14. Following the figure is an explanation of the methodology in CFA's flood analysis tool using the Bulletin 17B method.

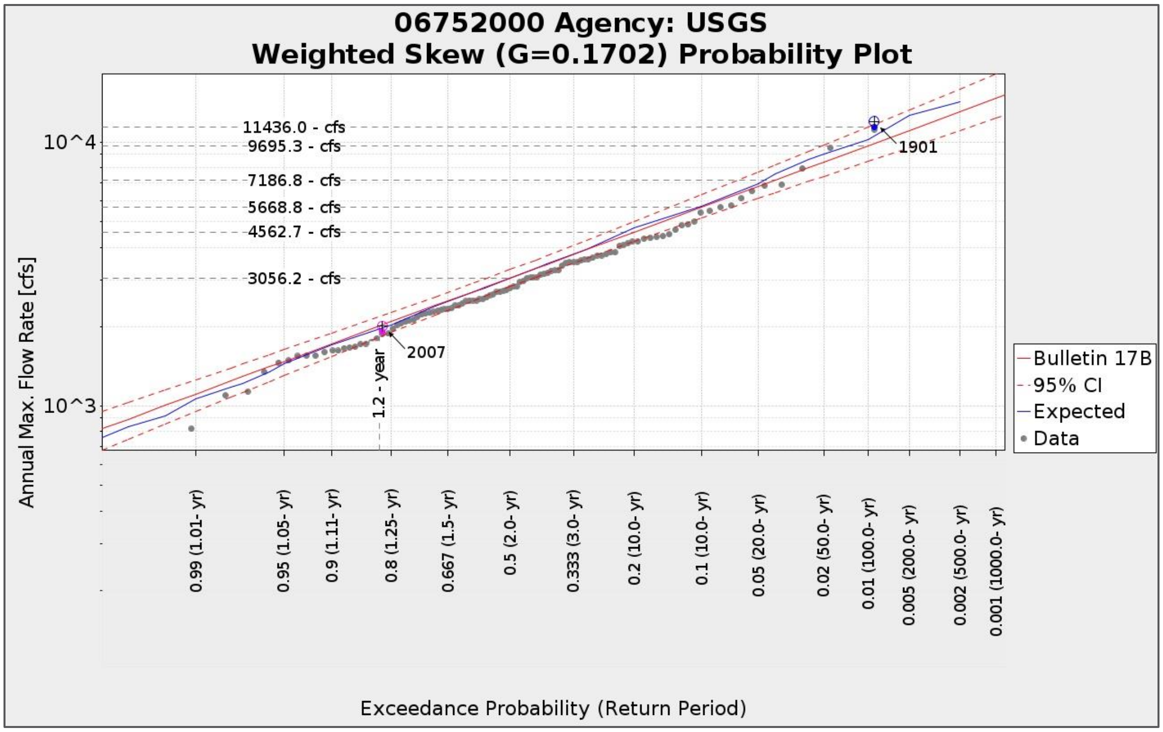

Figure 14: CFA's Flood Analysis Tool Result Graph

- The methodology inside CFA's Bulletin 17B method is to first check if there is sufficient data for the analysis (greater than 10 and less than 149 flood peaks).
- Then the statistics (count, Log10 mean, standard deviation, and skewness) for the base dataset are calculated.
- Based on the skewness value the outliers of the dataset (if any) are determined. The statistics of the dataset are then recalculated with the new outlier-removed dataset. If the skewness changes greatly between these steps a warning flag is conveyed to the user.
- Then the frequency/probabilities for each flood are linearly interpolated from the tables provided in the Bulletin 17B documentation (IACWD 1982). If the flood is outside the dataset for interpolation, those values are extrapolated.
- The frequencies/probabilities are then plotted against flood magnitudes in skewed probability space (aka the spacing between the probabilities is not standard unless skewness equals zero).

4.3. Drought Analysis

An opposite, but equally important, aspect of river flows is the consideration and analysis of droughts from stream flow records. For this reason, a generalized drought analysis tool was included in CFA. The drought analysis method included in CFA fits a regression model to historic annual stream flow data and forecasts it to simulate a larger dataset in order to predict high recurrence interval droughts (Salas, et al. 2005). The following is a step by step explanation of the drought analysis method used and example outputs for each step.

The drought analysis begins by calculating annual flow values from available average daily flow data. Figure 15 contains an annual time series of the flow data with the specified annual drought limit as a reference.

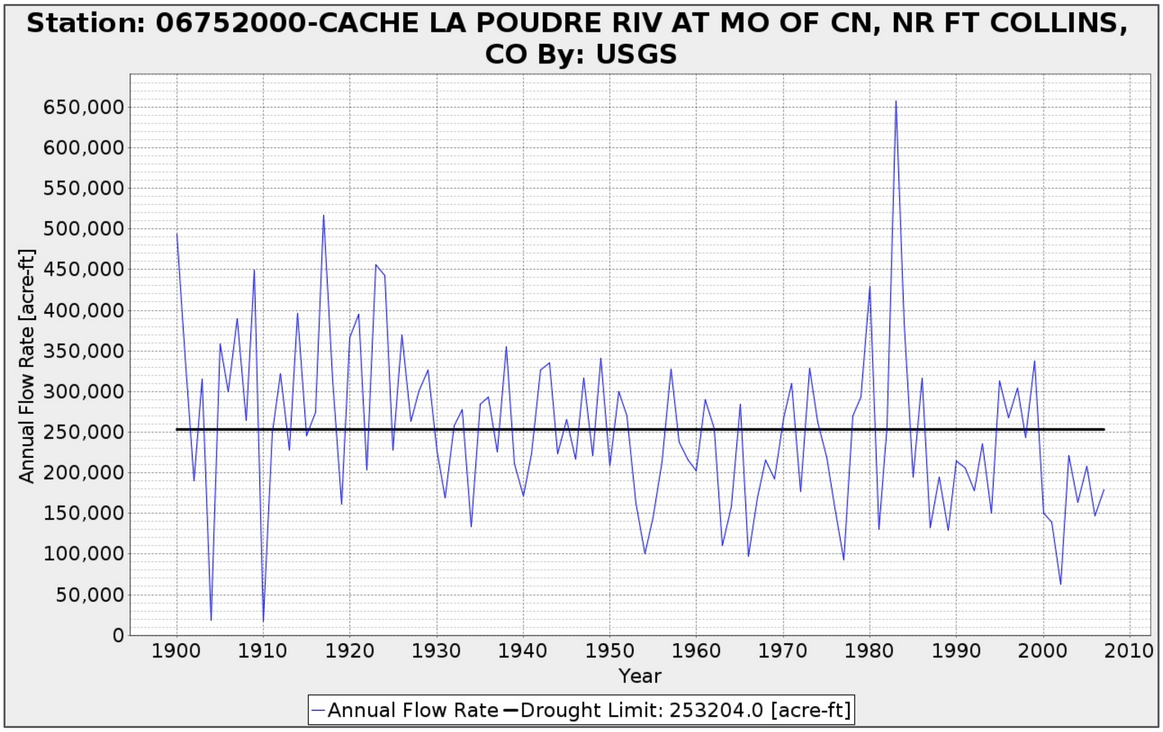

Figure 15: CFA's Drought Analysis Tool Result Graph 1

Figure 16 contains a second time series containing the annual surplus or deficit between the supplied annual flow and the drought demand limit; this is meant to highlight the occurrence of droughts.

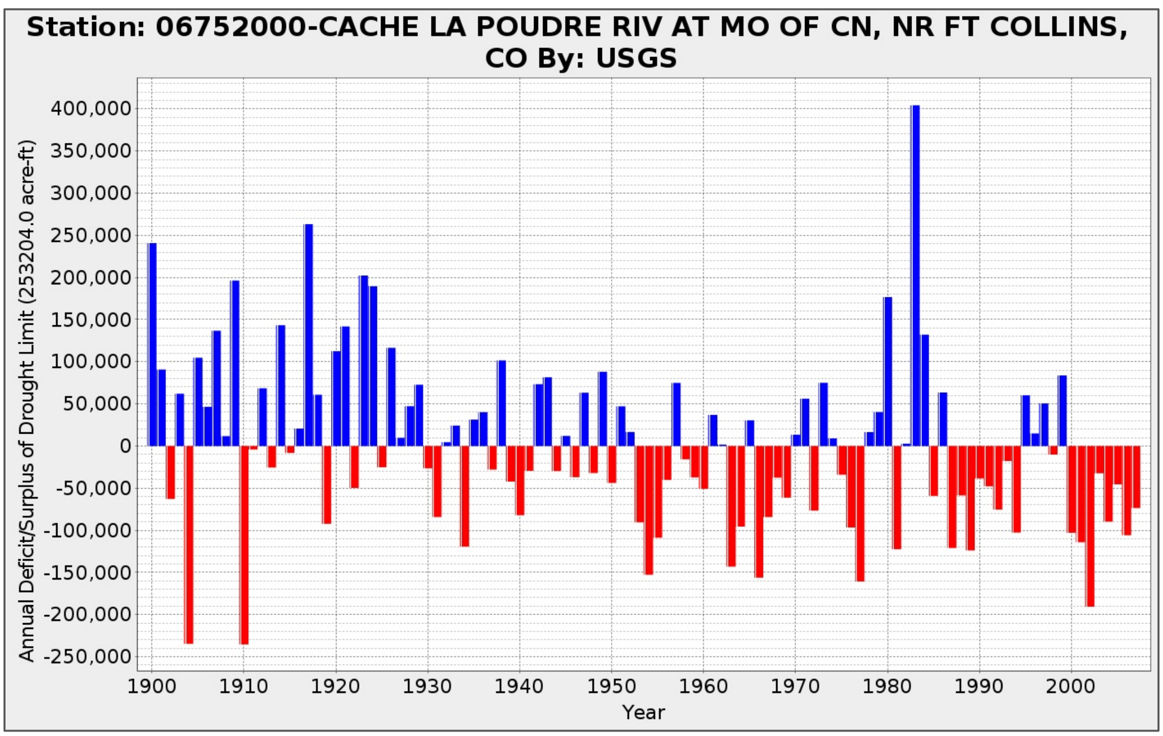

Figure 16: CFA's Drought Analysis Tool Result Graph 2

After calculating the annualized flow data, it is then converted to its stochastic component (the mean is subtracted from the data and then divided by the standard deviation). The stochastic data is then transformed into a normalized dataset using a Box-Cox transformation. Then an Auto-Regressive (AR) or Auto-Regressive-Moving-Average (ARMA) model is fitted to the dataset (Salas 1993). The purpose of fitting the regressive model to the stochastic data is to increase the size of the dataset while maintaining its statistical properties, mean and standard deviation. Figure 17 contains a plot of the original annual data verses the predicted model data to illustrate the correlation between the datasets. If the correlation is poor then further modifications need to be made to the regression model in order to improve the reliability of the drought analysis.

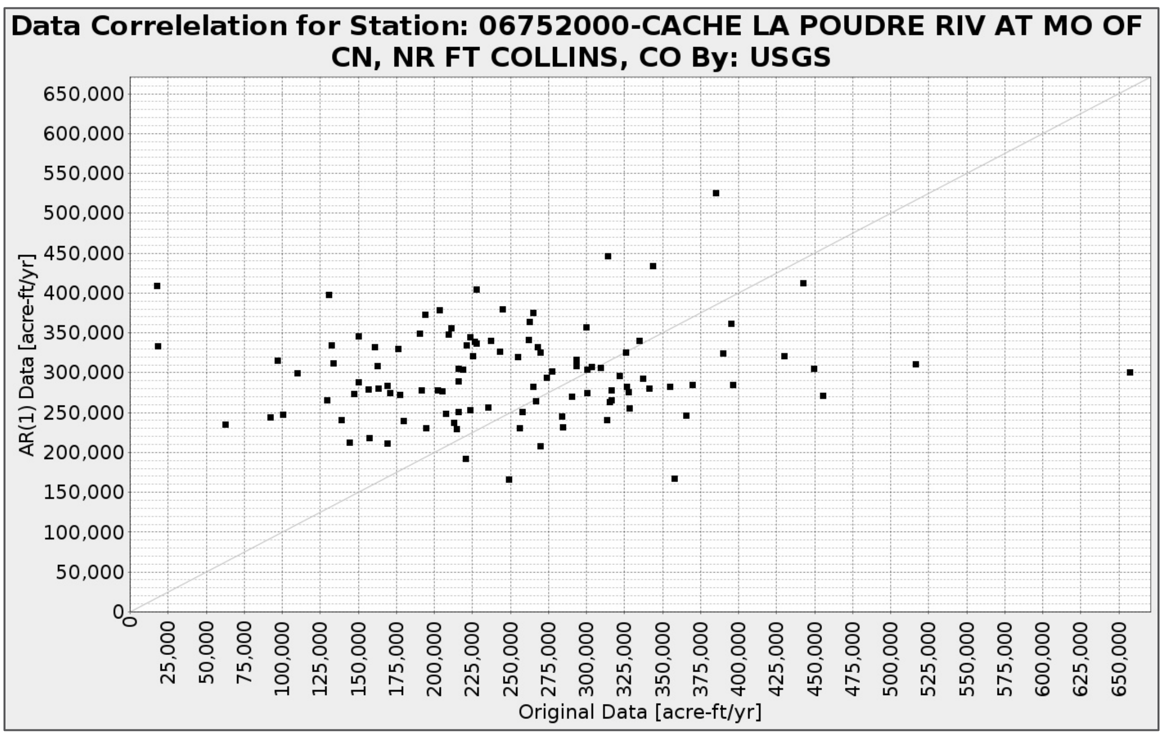

Figure 17: CFA's Drought Analysis Tool Result Graph 3

After fitting the regression model, a 100,000 year forecasting is performed using the fitted model to create a dataset sufficiently large to 'observe' high recurrence interval droughts. Figure 18 contains a plot of the original data and the first portion of the 100,000 year projected dataset used to analyze the drought impacts. This projected dataset is large to allow sufficient 'droughts' to occur illustrating high recurrence interval droughts that cannot be calculated from minimal observed data. The first 100 years of this dataset are not used in the analysis and a dropped as a model warm-up period. This allows for the model to operate independent of initial conditions.

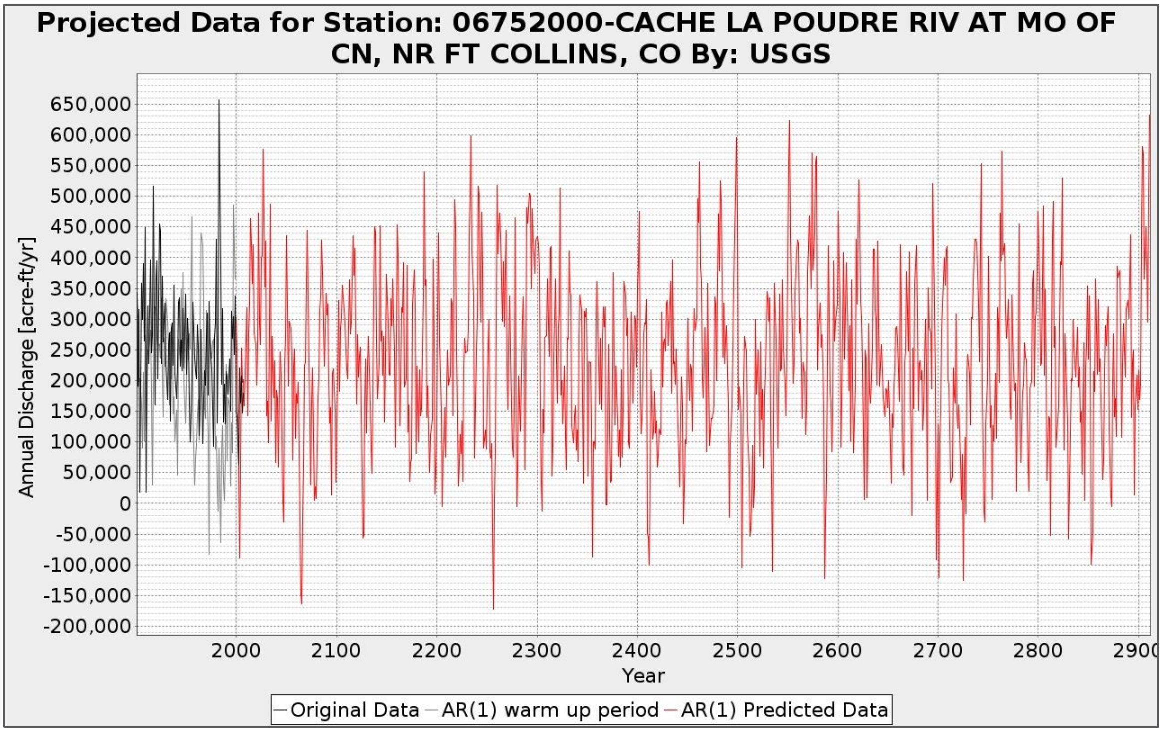

Figure 18: CFA's Drought Analysis Tool Result Graph 4

Next the drought analysis uses the projected dataset to calculate the average recurrence interval of the 1yr, 2yr, 3yr, etc. droughts. These droughts are then categorized by their amount of drought deficit (supplied annual flow - drought demand limit) and illustrated in Figure 19. The original data and its corresponding recurrence intervals are included in Figure 19 as well to illustrate the fit of the predicted data to that of the observed data. If the fit is poor, a better correlation of the regression model will likely improve the fit of the drought recurrence intervals.

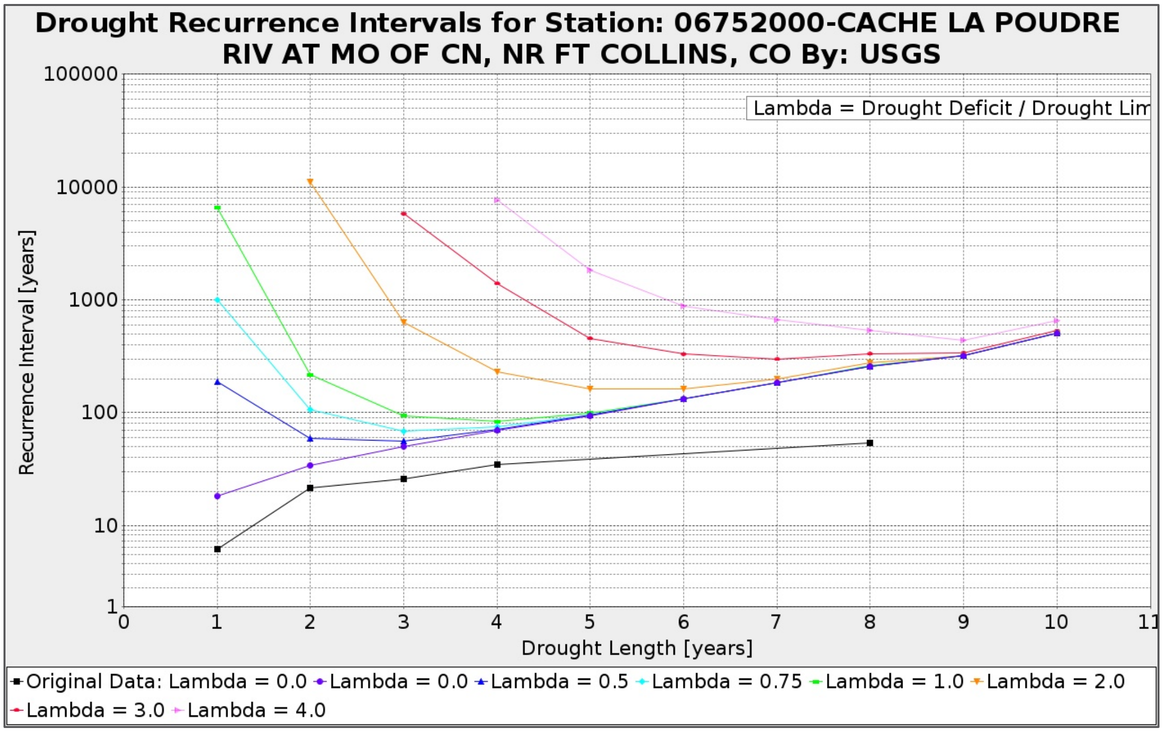

Figure 19: CFA's Drought Analysis Tool Result Graph 5

4.4. Base-flow Separation

Another useful aspect of stream flow analysis and hydrologic modeling of river basins is river base-flow. Rather than write a numerical hydrograph separation tool, CFA has incorporated the numerical base-flow separation program "BFLOW," developed by the by Arnold et al. (1995; Arnold and Allen 1999). BFLOW is an automated digital filter base-flow separation tool which performs a multi-pass separation of base-flow from total stream flow. In order to implement the windows executable BFLOW in CSIP, which uses a Linux platform, the windows emulator WINE (WineHQ 2012) was used within CSIP (Lloyd et al. 2012). For the ease of use, like the rest of the tools in CFA, BFLOW operates on uploaded or auto-extracted data. CFA also automatically generates and formats the data into the necessary input files for the BFLOW executable. Beyond simply performing the analysis and returning the results CFA's base-flow analysis also graphs the outputs of BFLOW's separation overlaid onto total stream-flow for a visual understanding of groundwater contributions to stream flow, see Figure 20. The result file of the BFLOW program is available for download like the other flow analysis modes in CFA.

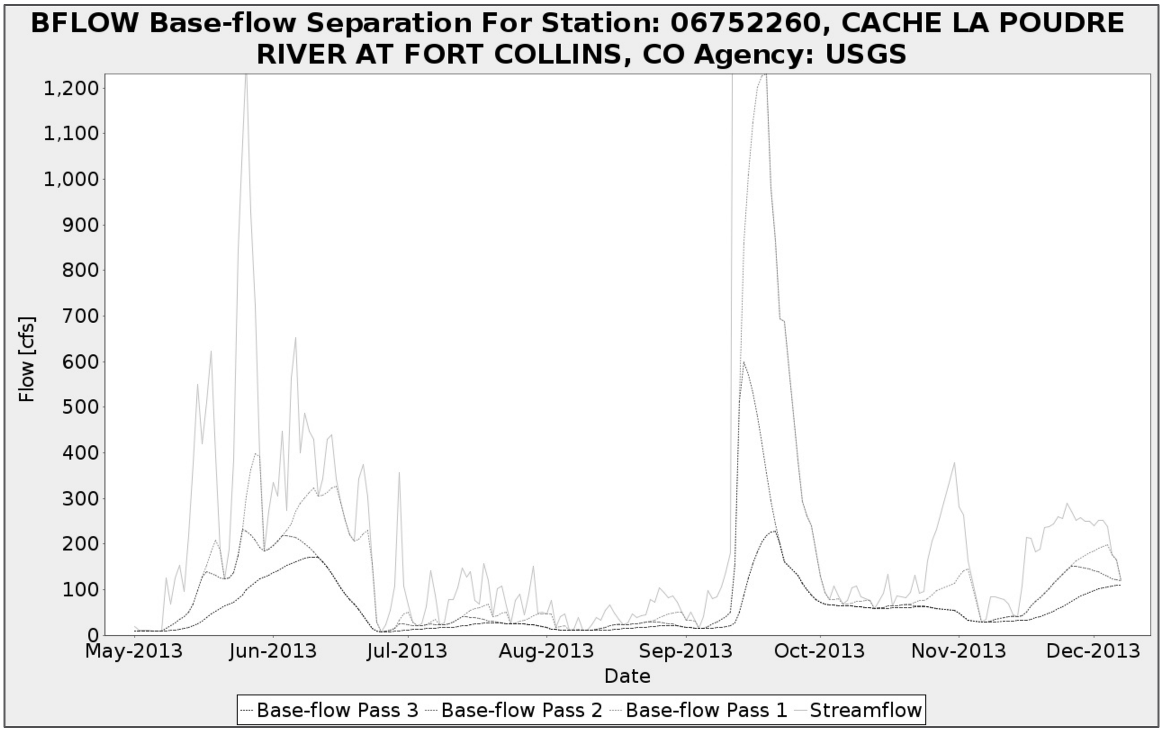

Figure 20: CFA's Base-Flow Separation (BFLOW) Tool Result Graph

4.5. Duration Curve Analysis

Another approach to stream flow data is the application of duration curves; which statistically rank and graph available flow data. The Flow Duration Curve (FDC) tool in CFA graphs Weibull plotting position ranks of river flows on a scale of percent exceedence. Graphing flow values in this way allows for a quick visualization of the variability of flow under the different flow regimes and is useful numerically for thresholds such as the flow rate only exceeded 10% of the time in the historical record. The plotting position used in CFA is a tied-rank max. This means for example if there are 3 observations of a flow value of 30cfs that would normally have ranks 13, 14, and 15 the rank of all three observations is re-set to the maximum rank of the ties, in this case rank 15. An example of the output of CFA's FDC tool is shown below in Figure 21. The black line is the duration curve for the entire period of analysis while there is a light grey line for each annual duration curve in the period of analysis.

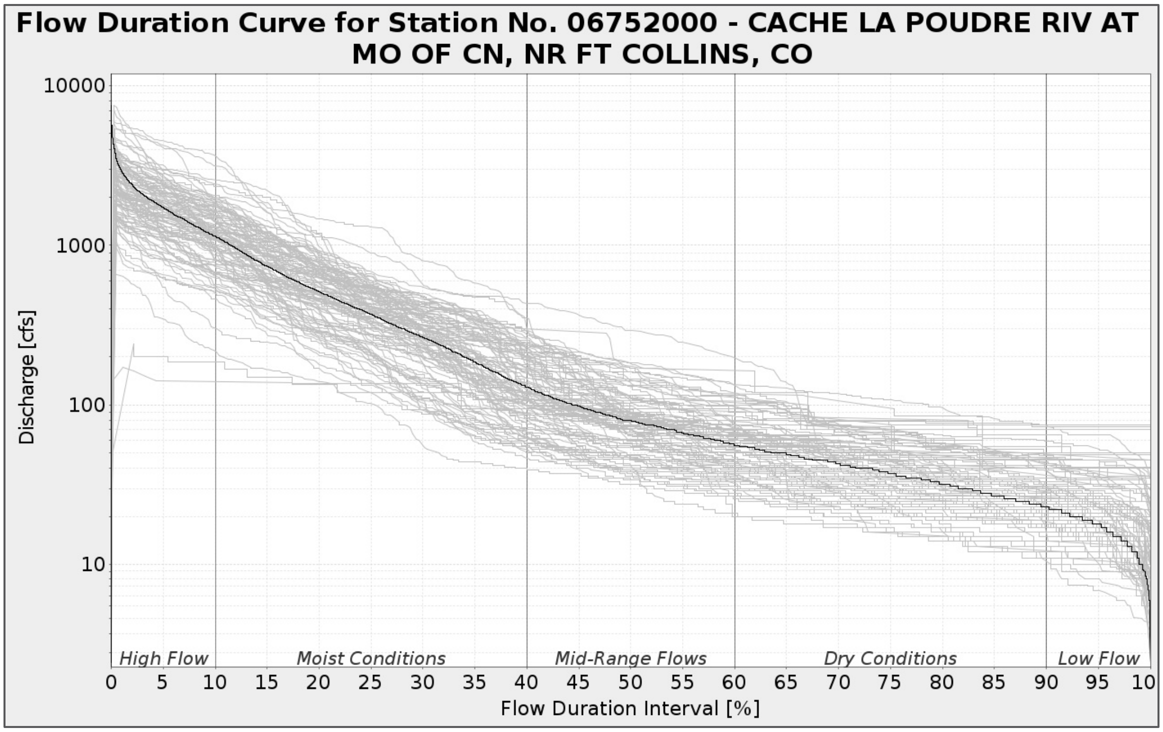

Figure 21: CFA's Flow Duration Curve Analysis Tool Result Graph

An extension of the FDC is the Load Duration Curve (LDC) tool in CFA. A LDC is a FDC multiplied by a target water quality concentration level to achieve a load per day value of a particular water quality nutrient. In addition to the LDC itself, observed water quality samples can be graphed as loads (flow * water quality concentration * conversion factors = load). If the observed loads never occur above the LDC line then there is no indication of a water quality problem for that desired target concentration, as shown in Figure 22.

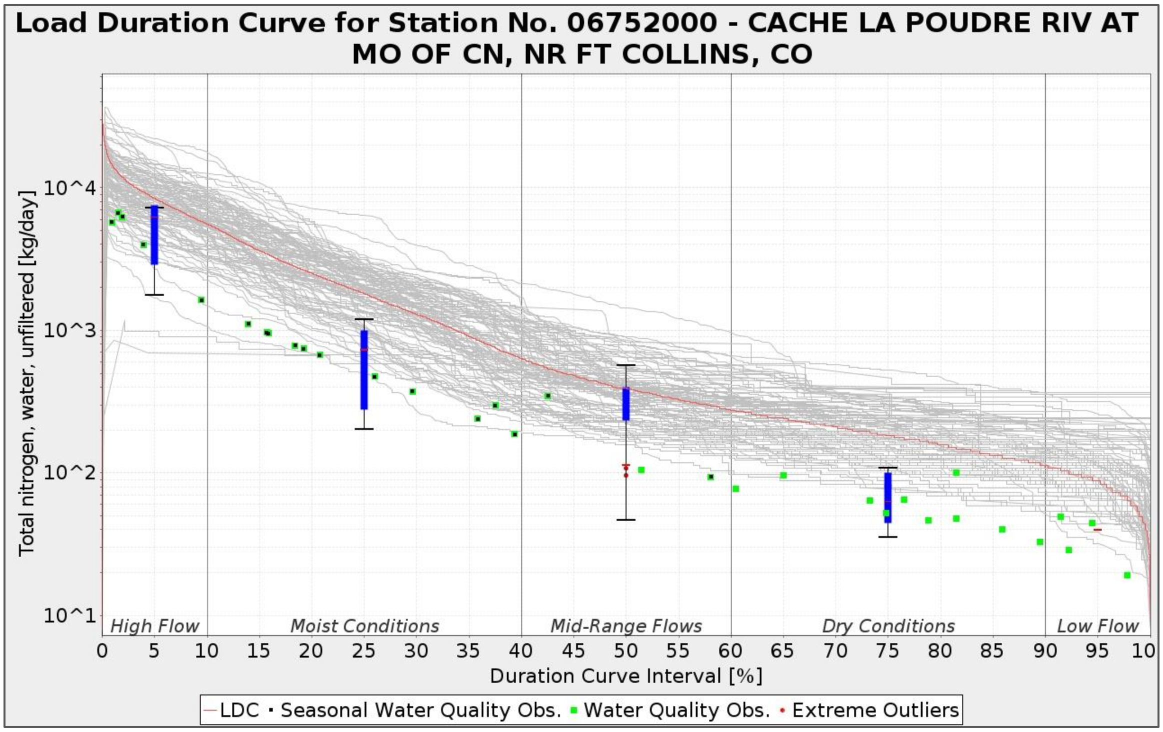

Figure 22: CFA's Load Duration Curve Analysis Tool Result Graph 1

If there are observations which exceed the LDC, shown in Figure 23, it can sometimes help determine, based on where the observations exceed the curve, what pollution sources are probable contributors (Cleland 2007, Cleland 2003 and Cleland 2002). Based on the location of these exceedences and the outline provided in (Cleland 2007, Cleland 2003 and Cleland 2002), CFA's LDC dynamically estimates possible nutrient pollution sources based on the location and magnitude of the exceeded values on the graph and reports this back to the user. In addition to the more complex analysis of identifying pollutant sources, LDCs can also be used to identify Total Maximum Daily Loads (TMDLs) for different flow regimes of a river of interest (Cleland 2007). The value of the LDC at a given exceedence is equal to the TMDL for that river, minus a margin of safety, for the specified pollutant and target water quality concentration.

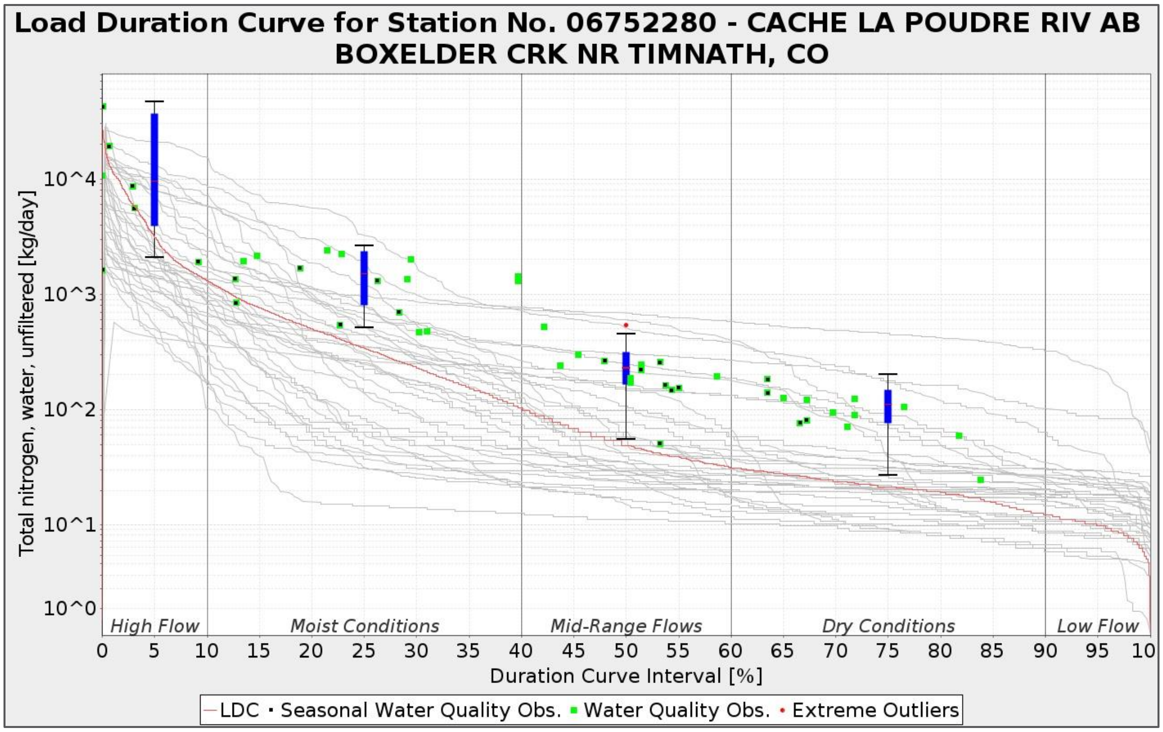

Figure 23: CFA's Load Duration Curve Analysis Tool Result Graph 2

4.6. Load Estimator

Another executable included in CFA is the Load Estimator which is a tool (LOADEST) developed by the U.S. Geological Survey (Runkel et al. 2004). LOADEST is a FORTRAN executable that estimates the amount of constituent loads in streams and rivers given a time series of stream flows and constituent concentrations. Estimation of constituent loads occurs in two steps, the calibration procedure and the estimation procedure, both of which are based on three statistical estimation methods. These methods are Adjusted Maximum Likelihood Estimation (AMLE), Maximum Likelihood Estimation (MLE) and Least Absolute Deviation (LAD). The first two methods are appropriate when the calibration model errors, or residuals, are normally distributed. Of these two, AMLE is best utilized when the calibration data (i.e. stream flow and constituent concentration) are censored. The LAD is an alternative to maximum likelihood estimation when the residuals are not normally distributed.

In the calibration step, known constituent concentrations with corresponding stream flows are used to calibrate LOADEST so that it may be determined which of the preloaded models in LOADEST may best be used for determining the load. Next, in the estimation step, all of the known stream flows are used to estimate loads of constituent for each day. CFA then provides a time series graph, see Figure 24, of the loads estimated by LOADEST. These loads can be determined in either grams, kilograms, pounds or tons. CFA also provides a boxplot and a statistical summary of the estimated loads for the given time period determined by the stream flow data. Finally, if daily stream flow values are available, these daily loads (Figure 24) can be summed in CFA to provide monthly (Figure 25) or even yearly (Figure 25) values of constituent loads in streams and rivers and their corresponding time series and boxplots will be provided.

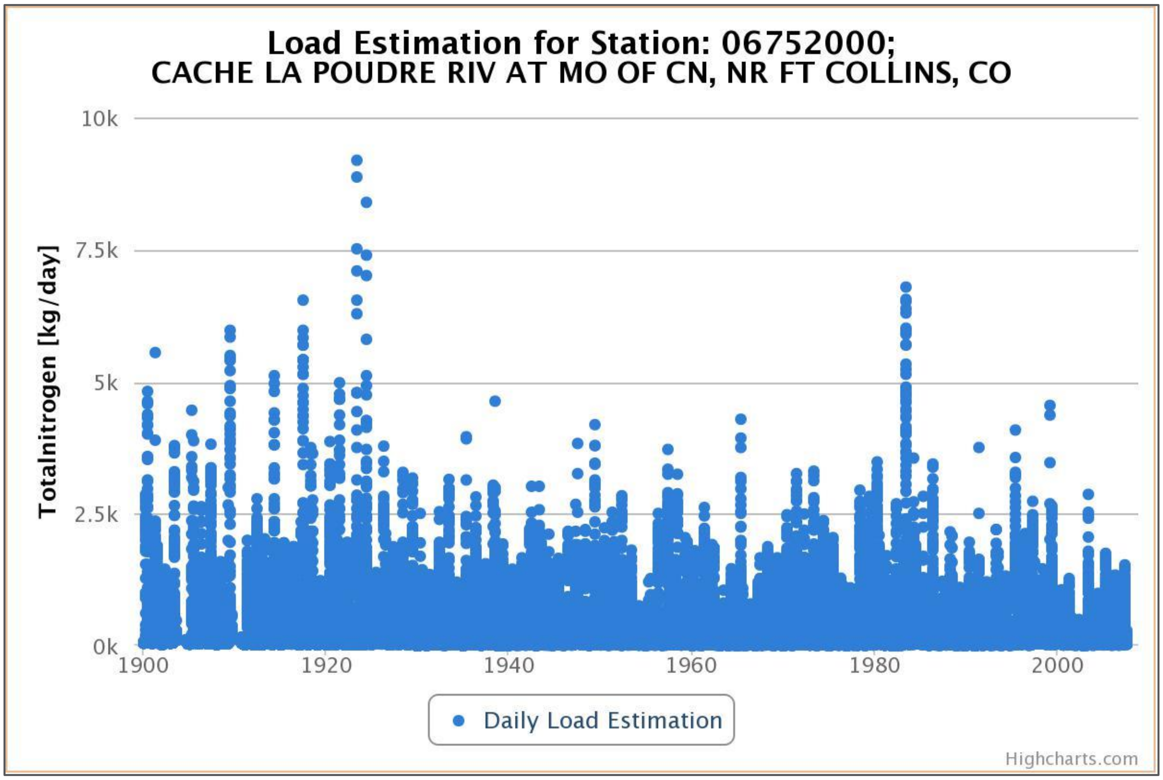

Figure 24: CFA's Load Estimator (LOADEST) Analysis Tool Result Daily Graph

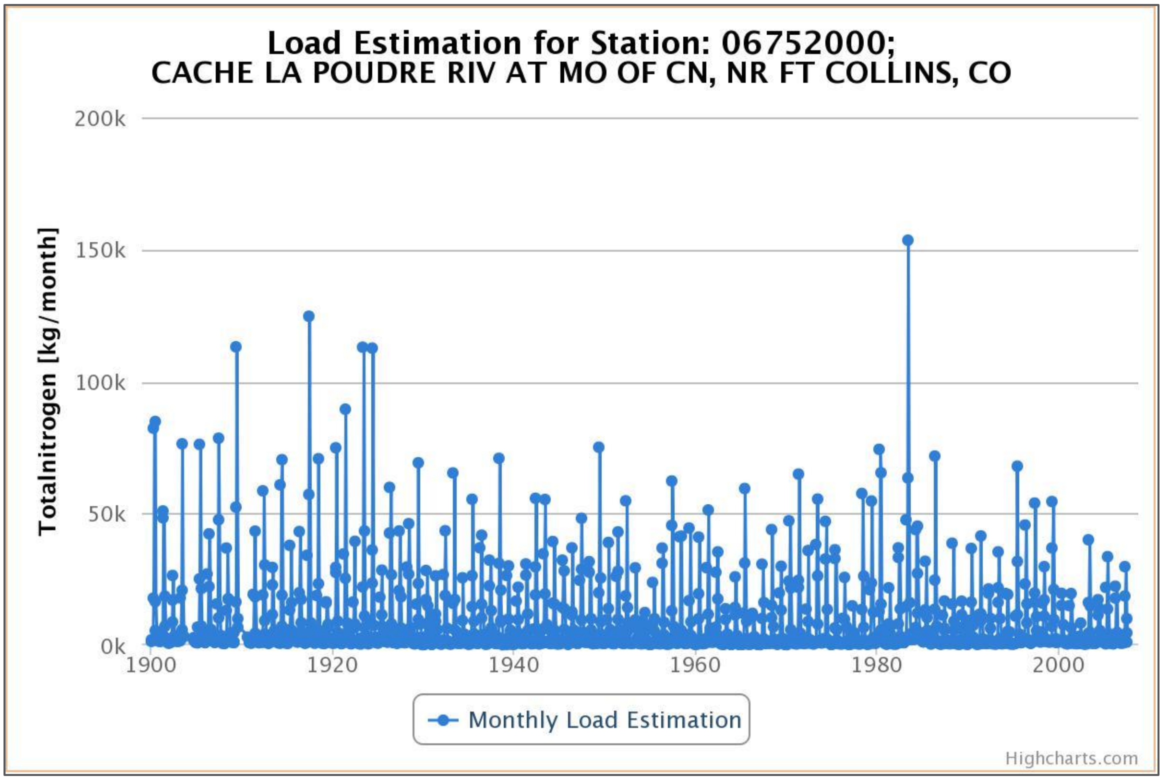

Figure 25: CFA's Load Estimator (LOADEST) Analysis Tool Result Monthly Graph

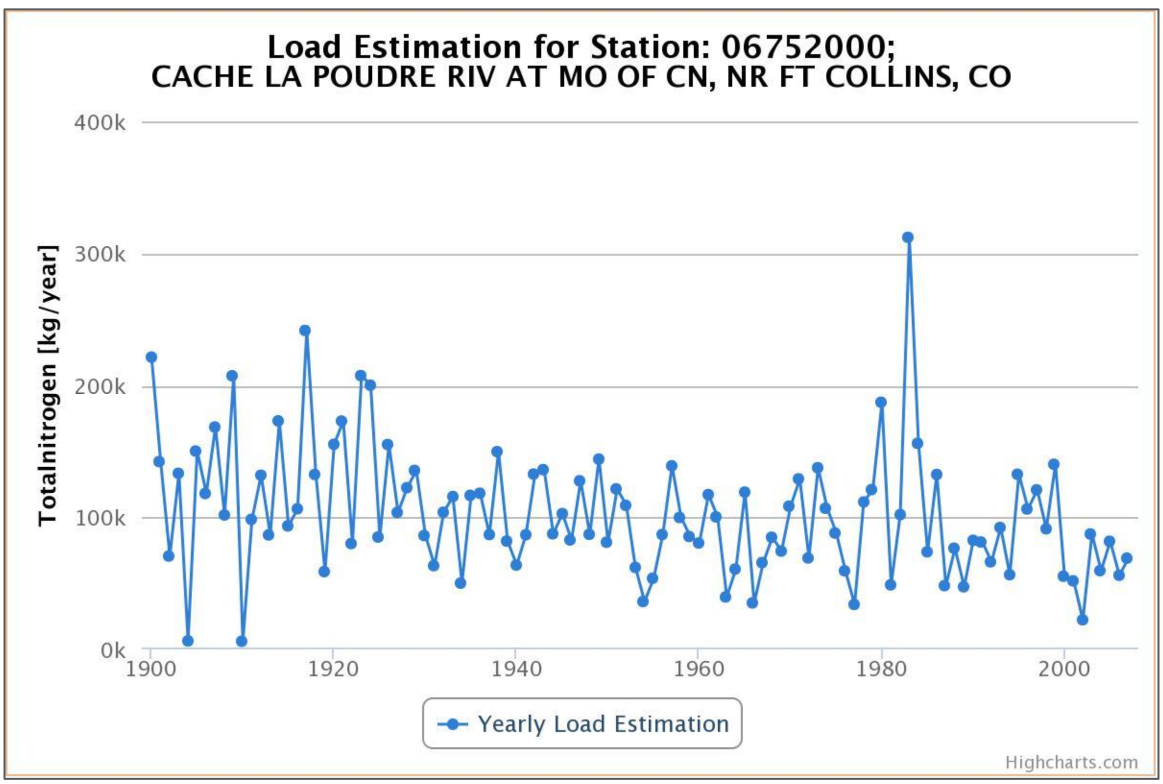

Figure 26: CFA's Load Estimator (LOADEST) Analysis Tool Result Annual Graph

REST Access

The CFA tool is also available through a representational state transfer, REST. A description of an available CFA model is available through a "get" statement to the following URLs for each of the CFA analyses:

CFA Analysis	REST "GET" URL
Time Series	http://csip.engr.colostate.edu:8082/csip/m/cfa/timeseries/1.0
15-Minute Discharge	http://csip.engr.colostate.edu:8082/csip/m/cfa/timeseries15min /1.0
Stage-Discharge (Rating Curve)	http://csip.engr.colostate.edu:8082/csip/m/cfa/stagedischarge/1.0
Flood Analysis	http://csip.engr.colostate.edu:8082/csip/m/cfa/flood/1.0
Drought Analysis	http://csip.engr.colostate.edu:8082/csip/m/cfa/drought/1.0
Base-flow Separation	http://csip.engr.colostate.edu:8082/csip/m/cfa/baseflow/1.0
Flow Duration Curve Load Duration Curve	http://csip.engr.colostate.edu:8082/csip/m/cfa/durationcurve/1.0
Load Estimation	http://csip.engr.colostate.edu:8082/csip/m/cfa/loadest/1.0

The result of the "get" will be an example JavaScript Object Notation (JSON) of the required inputs of the model. Using this JSON as a template, replace the value of each input with the desired inputs for a CDWR, EPA WQX, or USGS station. Then a "post" back to the same URL will call the desired model to execute using the provided inputs. After running a result JSON will be sent back containing the various results for the desired model. Any result files listed in the return JSON can be accessed at the specified location using another REST "get" call.

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WineHQ – Run Windows applications on Linux, BSD, Solaris, and Mac OS X, 2012, http://www.winehq.org/

Appendix A: CFA Web Interface Example

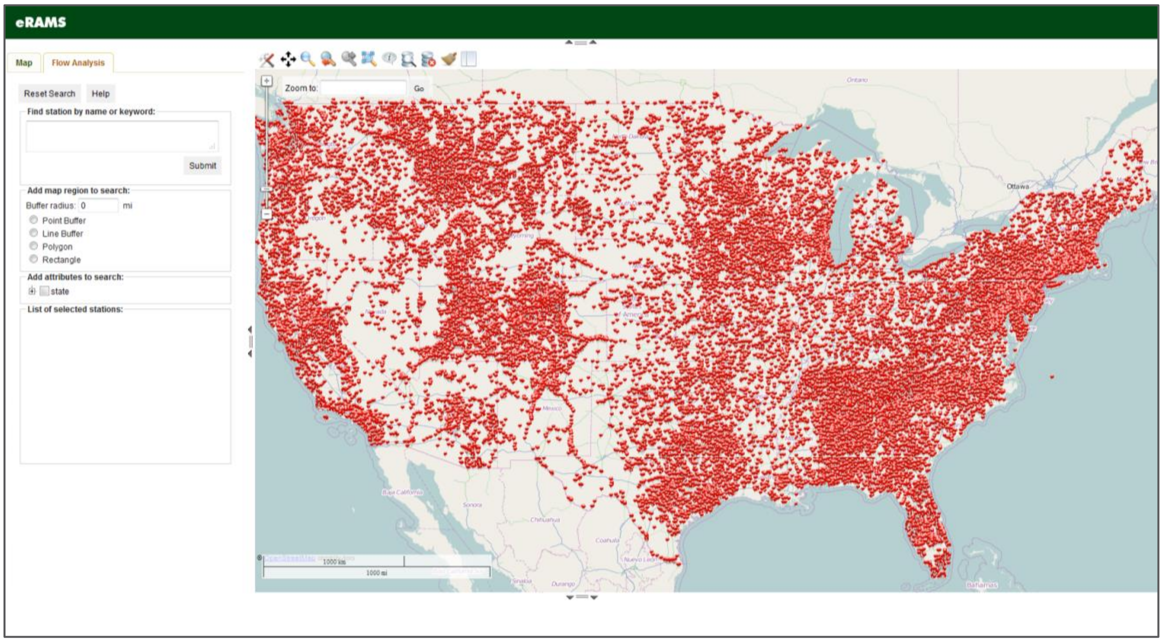

Figure 27: eRAMS Comprehensive Flow Analysis Home Screen

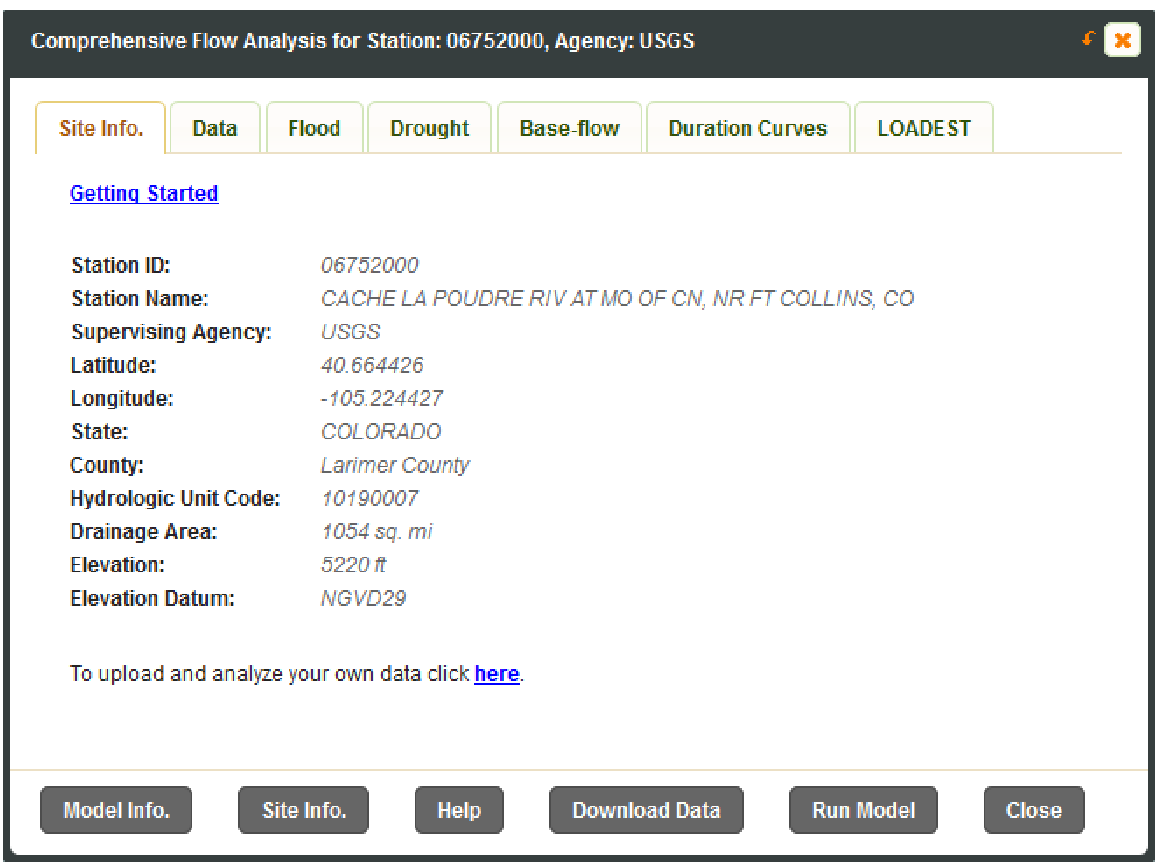

Figure 28: CFA's Interface, Site Information Page

Appendix B: State Regional Flood Skewness Coefficients

Alabama:	Olin, D. A. Magnitude and Frequency of Floods in Alabama. Rep. no. 84-4191. U.S. Geological Survey. Web. 5 July 2012. <http://pubs.usgs.gov/wri/1984/4191/report .pdf>.
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Illinois	Soong, David T., Audrey L. Ishii, Jennifer B. Sharpe, and Charles F. Avery., 2004, Estimating Flood-Peak Discharge Magnitudes and Frequencies for Rural Streams in Illinois. Rep. no. 2004-5103. U.S. Geological Survey. Web. 10 June 2012. <http://il. water.usgs.gov/pubs/sir2004-5103.pdf>.
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