Appendix C: Flow Estimation and Measurement Techniques of the Scenic Rivers Monitoring Program

Eric Wentz and Robert Limbeck

Ungaged Stream Flow Estimation

Two USGS computer applications were used by DRBC to assign estimates of stream flow to our ungaged, unregulated streams. These estimates were used to classify each of our water quality samples by their flow conditions. Using a combination of StreamStats and BaSE from USGS, we were able, with acceptable confidence, to associate a stream flow on a specific date to an ungaged stream in the Delaware River Basin. StreamStats is a Web-based Geographic Information System (GIS) that provides users with access to an assortment of analytical tools that are useful for water-resources planning and management as well as allows users to easily obtain streamflow statistics, drainage-basin characteristics, and other information for user-selected sites on streams (http://water.usgs.gov/osw/streamstats/). Daily mean streamflow is estimated in BaSE using a methodology that equates streamflow as a percentile from a flow duration curve for a particular day at an ungaged location with streamflow as a percentile from the flow duration curve for the same day at a reference stream gage that is considered to be hydrologically similar to the ungaged location (Stuckey, M.H., Koerkle, E.H., and Ulrich, J.E., 2012, Estimation of baseline daily mean streamflows for ungaged locations on Pennsylvania streams, water years 1960–2008: U.S. Geological Survey Scientific Investigations Report 2012–5142, 61 p.). We made use of a beta-version of BaSE specifically adapted to the Delaware River Basin.

Using these two programs, estimation of streamflow has multiple steps. The first step was to identify the stream to have its flow estimated. Our sample sites were GPS located and coordinates were input into StreamStats using the Zoom to Latitude/Longitude function. This puts a crosshair onto the map at the precise location to use the Delineation Tool in StreamStats. This delineates the selected watershed upstream from the selected GPS coordinates. Once the delineation was complete the basin characteristic statistics were populated in StreamStats. These statistics were then downloaded as a Microsoft Database file (.mdb).

Switching over to the BaSE program, the database file is directly imported into the BaSE application to compute baseline stream flow. By default we let the BaSE application choose the reference gage of the most hydrologically similar to the ungaged site. However, these needed to be closely checked for geographic proximity. Often the best reference gages are located far from the ungaged location, meaning that localized summer thunderstorms are missed. It is frequently possible to select a different reference gage that is closer to and gets the same local weather conditions as the ungaged location.

BaSE creates an excel report that includes streamflow data, exceedance probabilities, basin characteristics, and hydrographs for the ungaged site. The data output from BaSE estimates baseline streamflow at a daily time scale for ungaged streams in the Delaware River Basin using data collected during water years 1960– 2008. However, for data outside these water years (2009-Current), we looked at the daily flow from the reference gage and compared that flow to the flow of the ungaged stream for the previous water years and used the associated flow.

With sample dates and the flow associated with the dates we were able to plot the points along the flow duration curve generated by BaSE. We did this in order to see if our sampling occurred throughout the entire flow duration curve or if we unintentionally targeted high or low flow. This was useful also for identifying regulated streams such as the Mongaup River, Paulins Kill, and Bushkill Creek – it appeared as if our sampling did not cover the low end of the flow duration curve, but only because flow was almost always supplemented by reservoir releases or flow augmentation. This situation occurred on the Mongaup River in New York, where three reservoirs control flow for electric hydropower generation. Also, Bushkill Creek in Northampton County, PA is regulated by a large quarry operation that captures the stream and pumps it back out using a series of large quarry dewatering pumps (see Figure 1 & 2). On these streams, BaSE estimates of low flow do not apply because their flow is artificially supported by augmentation measures. For the Mongaup we could not use BaSE. For the Bushkill we could shift the flow duration curve by the constant 65 cfs supplied by the quarry dewatering pumps.

Gaged Stream Flow Estimation

For streams that have a USGS continuously monitored flow gage, we accessed the flow of the specific date and time that was sampled and record that flow for the sample. This flow is used where the stream gage was in close proximity to our sample site. Where instantaneous flow was captured some distance above or below the sample site we used Drainage Area Weighting (DAW) to estimate the stream flow at the sample site. This required using the USGS program StreamStats again to delineate the watershed at the point where the gage was located and at the sample point. In most instances where we used DAW, the sample location was further down the watershed than the stream gage but not so far down as to not be useful in estimating the stream flow (i.e. within 20% of drainage area size). If the difference in drainage area between the gage location and the sample site exceeded 20%, DAW was either not used to estimate flow, or checked against the BaSE method for agreement (see Figure 3).

To check continuity of this method and the BaSE method, flow duration curves were produced from the gaged data with DAW applied and the BaSE data that was generated. To minimize discrepancies between the two sets of data, the same period of record was used along with average daily flow, which is a standard in the BaSE generated file. These two flow duration curves by different methods were placed on the same excel graph and showed exceptional agreement when the period of record from BaSE and USGS were identical (see example in Figure 4). Some disparity was seen on streams with regulated flows, a sample site that encompassed twice as much watershed as the gage, or on sites where the period of record was not similar.

Stream Flow from Gage Height / Discharge Relationship

This was our long practice of many years, setting up sites with gage height benchmarks and creating gage/discharge relationships using USGS field methods. Whenever we sampled water quality a measurement was taken from the benchmark to the top of the water. These streams were separately visited periodically through the year to take discharge measurements along with the water level height from the gage height marker. Using many measurements at the full range of flows, it was possible to assign a stream flow to a sample event by creating a site specific gage height / discharge relationship. We generated site specific stream flow equations (best fit linear, power or exponential regressions) to calculate the sample stream flow.

In using this method for the past 20 years, we found that in streams with stable channels we could retain the rating from year to year with minimal adjustments by taking a few stream discharge measurements and adding a correction value. Unfortunately, for the majority of the streams we monitored, we had to completely recreate the rating curve every year (and sometimes after every big storm). The stream channels were too unstable, and we could not create stabilization structures to maintain the gages. We also could not afford the staff time it took to create new rating curves so often. Due to the expense in field time that it takes to maintain gages, this method was abandoned at problematic monitoring sites in favor of a BaSE or DAW approach. The BaSE and DAW estimation methods are somewhat less accurate, but are sufficient for our requirement of classifying water quality samples to determine flow relationships. So we sacrificed some accuracy for the savings of thousands of hours of staff time, yet still were able to achieve our data quality objectives. We also gained valuable insight about the heroic efforts required by the U.S. Geological Survey to maintain our stream gage network.

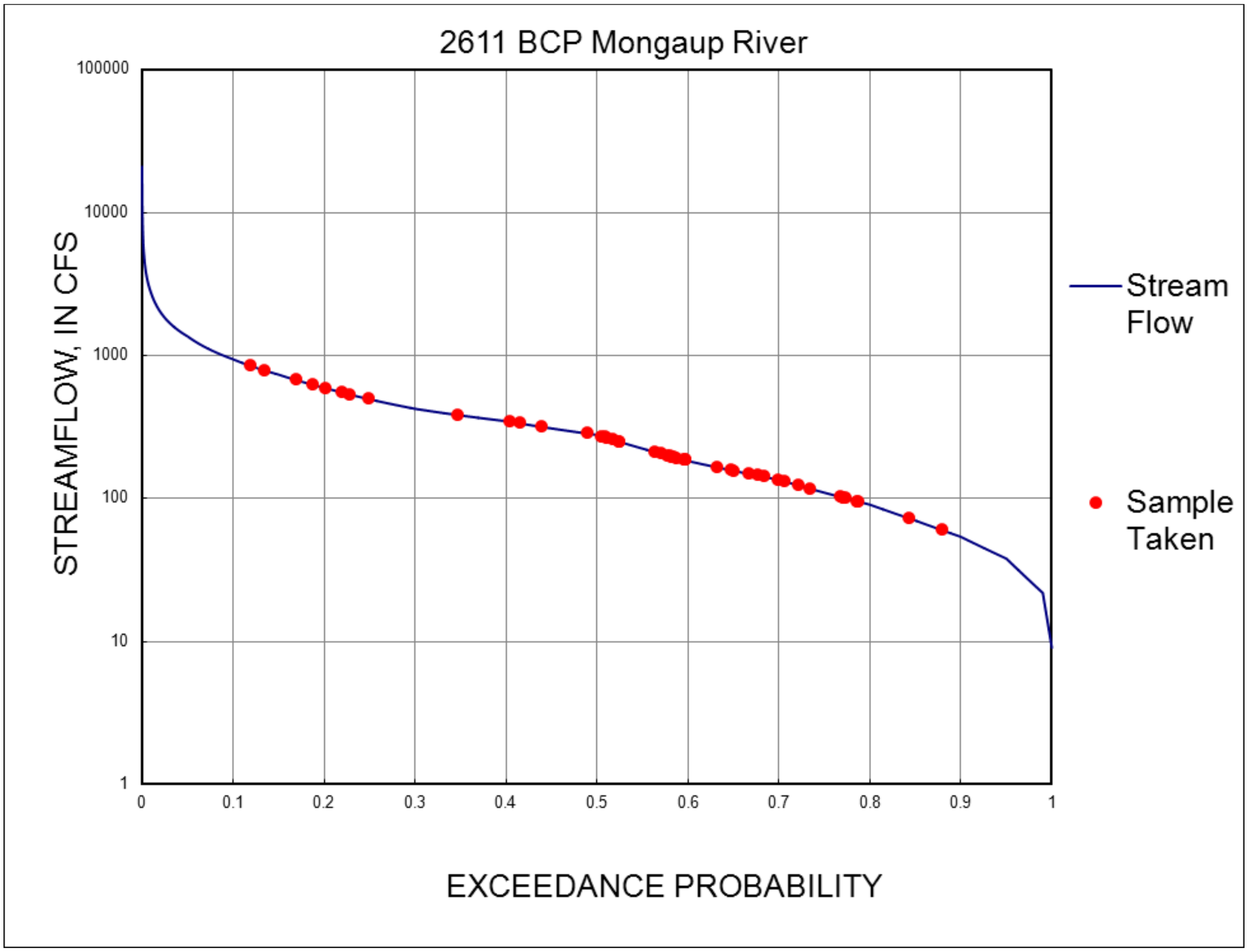
Special Circumstance: Mongaup Stream Flow Estimation

This streamflow was difficult or impossible to estimate using previous methods. We could not use BaSE as the Mongaup is controlled upstream by a hydropower dam, the Rio system. We could not use DAW on the Mongaup from the upstream gage for the same reason. A gage discharge relationship was not reliable because high flows would not be measureable due to dangerous conditions.

We used a combination of methods to estimate flow. We looked at reports from the Delaware River Master to see what the daily release was from the Rio system. We also looked at the flow above and below the influence of the Mongaup with DAW and tried to calculate the Mongaup influence. We also knew that the Mongaup has a minimum flow of 100 cfs, 60 cfs in drought conditions, required for their operations and agreement with NYSDEC. Finally, we looked at notes supplied by our sampling team as to the visual assessment of the stream flow conditions. Using these multiple sources we could crosscheck and determine if the sample was taken during the releases reported to the river master or at the minimum flow.

Luckily for future assessment there is a USGS stream flow gage on the Mongaup River below the Rio system which will provide stream flow reporting without the use of any flow estimation tools.

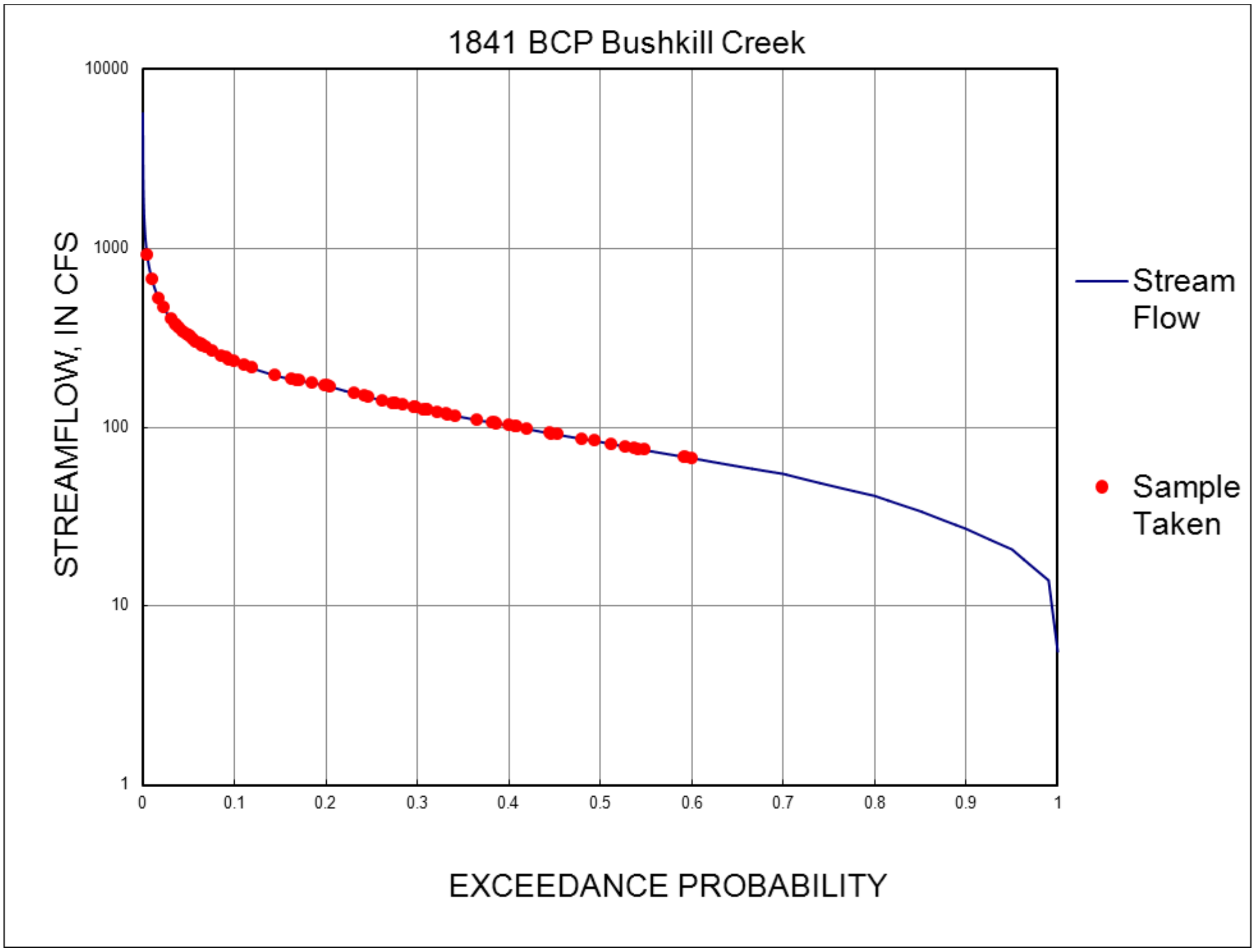
Figure 1



As stipulated by the Rio hydroelectric power plant operating license, a minimum flow must be passed in the reach of the Mongaup River between the Rio Dam and the Rio Powerhouse to maintain aquatic habitat. The minimum flow is 100 cfs unless it can be shown that inflow to the reservoir is less in which case the flow may be reduced but not below 60 cfs per FERC license requirements and agreement with the New York State Department of Environmental Conservation (NYSDEC). The existing Rio Project utilizes 870 cfs and has a capacity to generate 10 MW. The minimum flow unit will utilize 100 cfs (12% increase) and the installed generating capacity will be increased by 600-900 kW (DOCKET NO. D-2011-020 CP-1).

Hydropower flow downstream at our BCP site should be around 970 cfs at maximum power discharge.

Figure 2

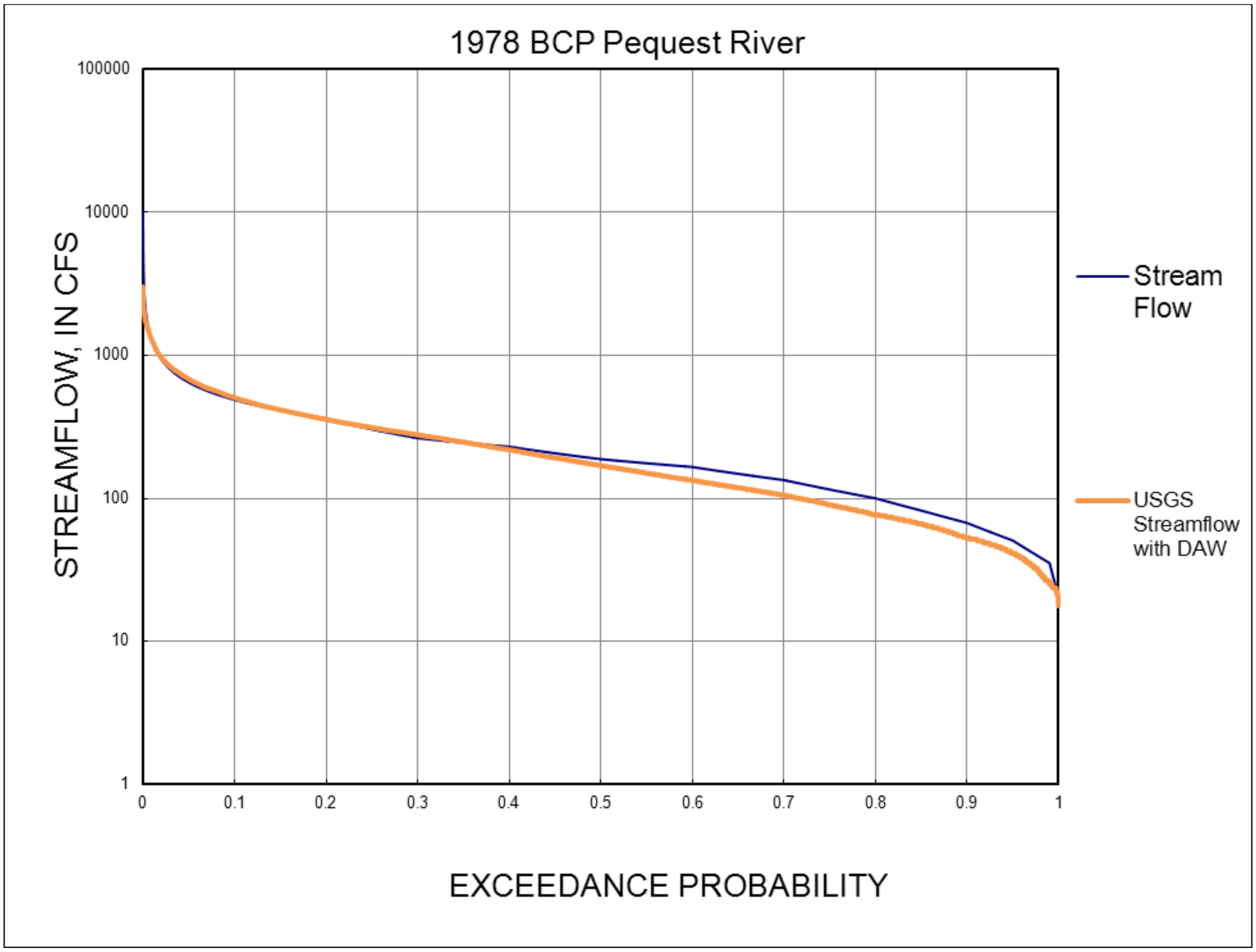


Hercules Cement Plant is located in the mid-reaches of the Bushkill Creek watershed and changes flow of the Bushkill Creek downstream of its location.

John Michael Paz, president of Godwin Pumps comments, "One of the real benefits we brought to Hercules is our diligence. For instance, Godwin mechanics make each client feel that their project is a top priority. Our chief road mechanic, Paul Natalino, provided regular service on the pumps at Hercules every other week, and as a result everything ran smoothly. When a client needs to pump 40 to 45 mgd to keep their operation going, like Hercules does, they can't tolerate a lack of service or delays in delivery of equipment." (Case History GODWIN PUMPS OF AMERICA, INC. Vol. 4 No. 2 http://www.pacificpumpandpower.com/pdf/HerculesCH.pdf)

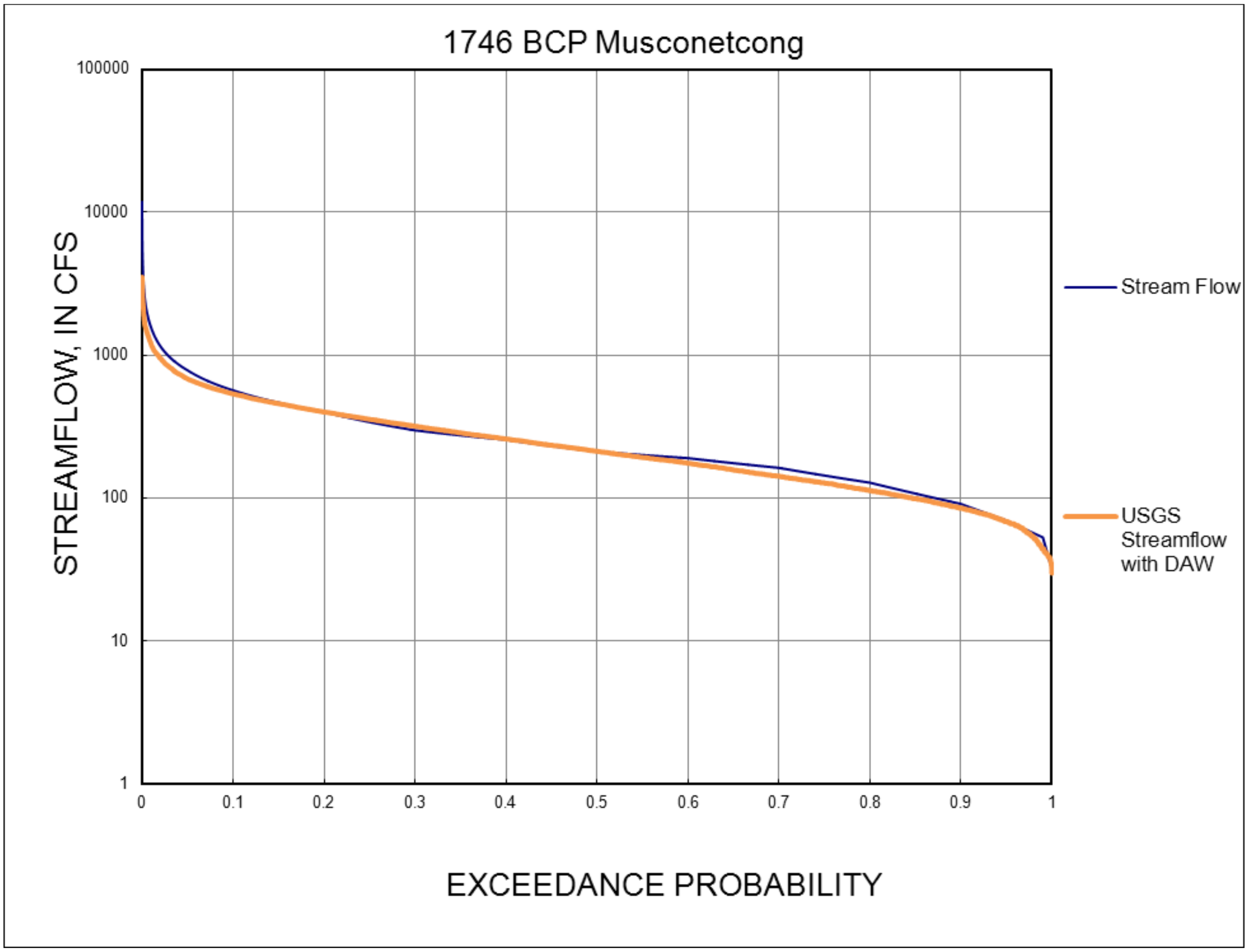
We converted 40-45 mgd to 62-70 cfs - the bottom limit of flow that our sampling has captured, which is almost entirely quarry dewatering discharge. If those pumps fail then Bushkill Creek goes dry from Tatamy to Easton, PA.

Figure 3



The DRBC sample site on the Pequest River has a drainage area of 157 square miles, and the USGS gage has a drainage area of 106 square miles. This difference is 32.5% which is greater than our 20% cutoff for DAW but when comparing with BaSE we see excellent agreement among the higher flow events and sufficient agreement for our data quality needs in the lower flow events. In this case, BaSE had less standard error of prediction at lower flow than other watersheds where gages are far from sites.

Figure 4



The sample site on the Musconetcong has a drainage area of 156 square miles, and the USGS gage has a drainage area of 141 square miles. This difference of 10% is within our 20% cutoff for use of DAW estimation technique, and shows excellent agreement between BaSE and DAW throughout the flow duration curve.