NHDES-R-WD-20-19

Extending the Daily Streamflow Period-of-Record at the USGS Gage Site on the Ashuelot River and the USGS Gage Site on the Isinglass River

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1. Introduction and Overview

New Hampshire Department of Environmental Services (NHDES) is responsible for developing and applying the Instream Flow Rules to Designated River basins. NHDES has developed rules in accordance with RSA 483 that describe how protected instream flows (PIFs) will be determined and implemented on the designated rivers. With the assistance of the River Management Advisory Committee, NHDES determined that two river basins of higher priority would be assessed in the near future for the development of watershed-specific PIFs are the Ashuelot River and the Isinglass River watersheds. In preparation, NHDES asked HYSR to extend the period-of-record at gages on these rivers using its QPPQ Transform method.

HYSR demonstrated the QPPQ Transform method in two earlier studies for NHDES. In the first study a key aspect of the QPPQ Transform method was updated, namely a mathematical regional streamflow duration (FDC) model (see Fennessey, 2018a). The second study (Fennessey, 2018b) focused on a special time-series analysis designed to compare daily QPPQ Transform flows with USGS gaged flows at the same location during the summer and early fall. These studies demonstrated that the QPPQ Transform is well suited for developing protected instream flows for ungaged designated rivers and reaches. The third study (Fennessey, 2019) focused on the application of the QPPQ Transform to extend the period-of-record (POR) at two designated instream flow sites, namely the Cold River at Alstead, NH and the Warner River at Davisville, NH.

In this study, the QPPQ Transform method is used to extend the period-of-record of daily flows at two USGS streamgage sites: one on the Ashuelot River near Gilsum and the second on the Isinglass River near Dover. The Ashuelot River near Gilsum gage records began in 1922 and ended in 1980 and then began again in July 2009. The Isinglass River near Dover gage record is shorter and began in December 2002 and ended in December 2006 and then began again in November 2007. With these extensions, the daily streamflow time series at both sites is continuous from October 1, 1950 through September 30, 2017.

The focus of this report is an assessment of how well the method worked by analyzing concurrent observed daily flow and QPPQ Transform estimated daily flow at each site. A complete record using the QPPQ Transform method was developed from October 1, 1950 through September 30, 2017. HYSR conducted assessments comparing the daily stream flows during the most flow-sensitive time of the year. Streamflow records from the QPPQ Transform method and those measured at USGS gages were compared for the years with concurrent flow records. The results demonstrate that the flow records from the QPPQ Transform method compare well for the Ashuelot with the observed data during the most flow-sensitive time of the year and are appropriate for use as daily stream flows for these rivers. The results for the Isinglass compare fairly well with the observed data and additional study is planned.

2. Using the QPPQ Transform to Extend Daily Streamflow Gage Records

In two previous studies for NHDES, Fennessey (2018a, 2018b) described the QPPQ Transform method in detail and demonstrated its application and fitness at five USGS streamgage sites located in New Hampshire. In both studies, QPPQ Transform daily streamflow time series at each test streamgage site was computed and compared with the observed historic streamflow at that site. These studies were tests and so the observed streamflows at these sites were not used to develop the daily time series while testing the QPPQ Transform method. In the third study for NHDES, Fennessey (2019) applied the method to extend the streamgage records at the Cold River at Alstead and the Warner River at Davisville USGS gage sites.

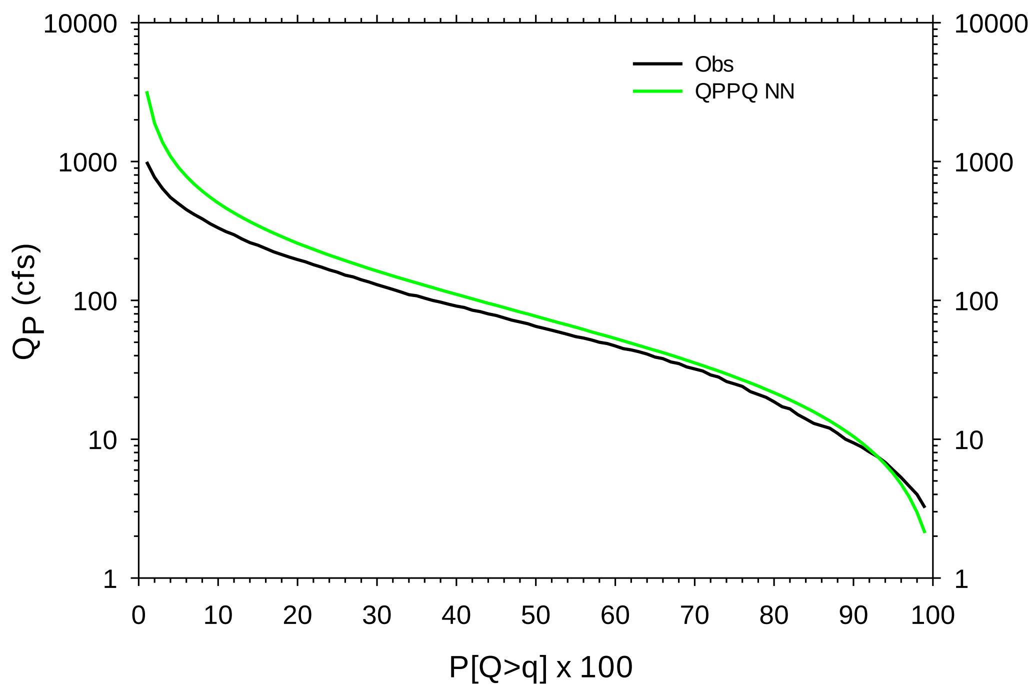
When used to estimate daily flows at an ungaged site, a FDC is constructed using GIS-based, watershed specific climate, soil and topography factors.[1] The FDC describes the range and frequency of daily streamflows. Development of the FDC is a key step towards estimating daily streamflows in the QPPQ Transform method. Because observed historic streamflow records exist at both the Ashuelot River and Isinglass River USGS gage sites, for the present study it is not necessary to use the GIS-based watershed factors to construct a FDC. The observed POR daily data are sampled to determine the parameters needed for the FDC math model.

To construct a long, continuous POR of daily flows at the ungaged or partial record site, it is important to choose a good Index streamgage to drive the QPPQ Transform. Fennessey 2018a determined that the best choice was the nearest neighbor HCDN streamgage. As will be shown

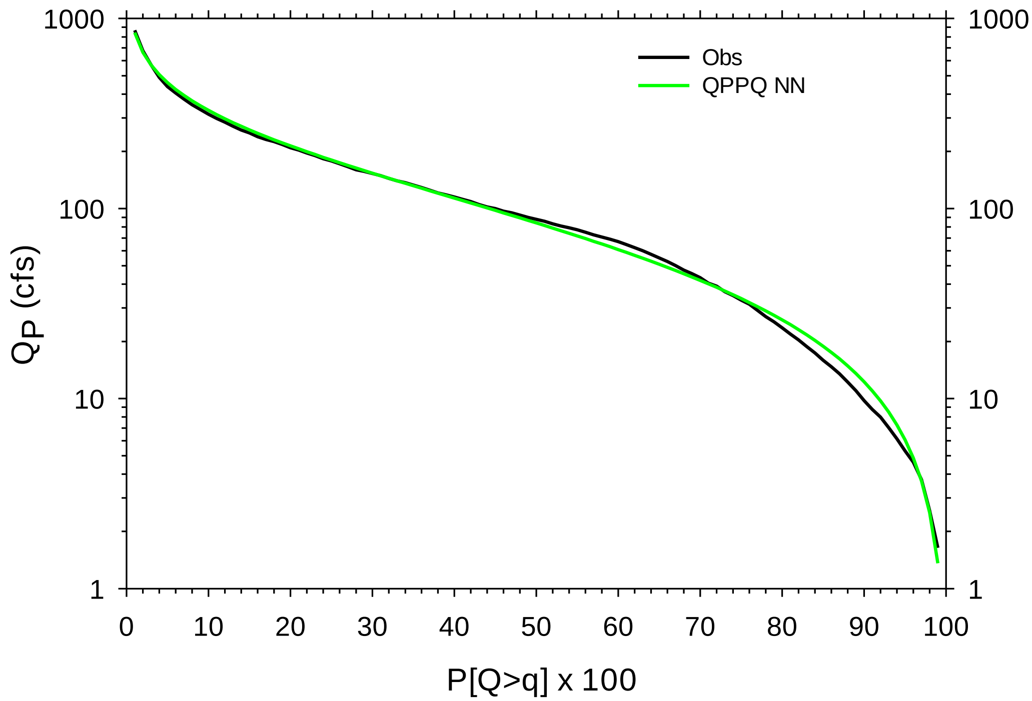
[1] Those watershed factors were discussed previously by Fennessey (2018a). The GIS data layers were described by Falcone et al. (2010), and were tabulated for thousands of watersheds throughout the US and compiled as GAGES-II (see Falcone, 2011).

in the present report, in the case of the Isinglass River, the nearest neighbor HCDN might not be the best choice.

To assess how well the fitted math model compares with the observed FDC, POR FDCs of daily data were constructed for the Ashuelot River and Isinglass River streamgage sites. These results are shown in Figures 2-1a and 2-1b.



Fig, 2-1a. Ashuelot River POR FDCs



Fig, 2-1b. Isinglass River POR FDCs

Figure 2-1a, indicates that over the POR, the QPPQ Transform generated flows will be a bit higher than might have been observed for flows above the daily average which in the Northeast US, are approximately equal to Q_{27}. Figure 2-1b, indicates that over the POR, the QPPQ Transform generated flows match the observed flows very well over the entire flow regime.

3. Extending the Ashuelot River and Isinglass River Records

The Ashuelot River near Gilsum, NH (01157000) was gaged by the USGS from 1922-1980 and then again from 2009 to present. At this time there are approximately 41 years of record for the Ashuelot gage from 1950 to 2019. The watershed area of this site is estimated to be 71.1 mi^2.

HYSR extended the period-of-record (POR) of the Ashuelot River at the Gilsum site using the QPPQ Transform method to fill the POR gap from October 1980 through July 2009. This was accomplished by using the observed POR of 1950-1980 and 2009-2019 daily data to generate the QPPQ Transform's math model parameters. The USGS gage, Smith River near Bristol, NH

(01078000), was selected as the nearest-neighbor (NN) index gage from the Hydro-Climatic Data Network (HCDN), (see Slack and Landwher, 1992). The watershed area of the Smith River index gage site is estimated to be 85.8 mi^2. The QPPQ Transform method applied daily stream flows from this index gage to estimate daily flows for October 1950 – September 2019.

The extended time series of October 1, 1950 – September 30, 2019 daily flows of the Ashuelot River near Gilsum, NH (01157000) gage site consists of observed daily flows (October 1950 – September 1980), QPPQ Transform estimated daily flows (October 1980 –early July 2009), and observed daily flows (later July 2009 – September 2019).

The Isinglass River near Dover, NH (01072870) was gaged by the USGS from early December 2002 to early December 2006, taken off-line and then put back on-line in November 2007. At this time there is approximately 17 years of record for the Isinglass gage. The watershed area of this site is 73.6 mi^2.

HYSR extended the Isinglass River near the Dover site using the QPPQ Transform method to fill in the POR gap from October 1950-early December 2002 and from early December 2006 - early November 2007. The QPPQ Transform's math model parameters were developed from the observed Isinglass River daily records, in this case from early December 2002 – early December 2006 and from early November 2007 - September 2019. The USGS gage, Oyster River near Durham, NH (01073000), was selected for the Isinglass site as the nearest-neighbor HCDN index gage. The watershed area of the Oyster River index gage site is estimated to be 12.1 mi^2. The QPPQ Transform method applied daily stream flows from this index gage to estimate daily flows for October 1950 – September 2019.

The extended time series of October 1, 1950 – September 30, 2019 daily flows of the Isinglass River near Dover, NH (01072870) consists of QPPQ Transform estimated daily flows (October 1950 – early December 2002), observed daily flows (early December 2002 – early December 2006, QPPQ Transform estimated daily flows (early December 2006 – early November 2007), and observed daily flows (early November 2007 – September 2019).

4. Assessing the Extended Ashuelot River and Isinglass River Records

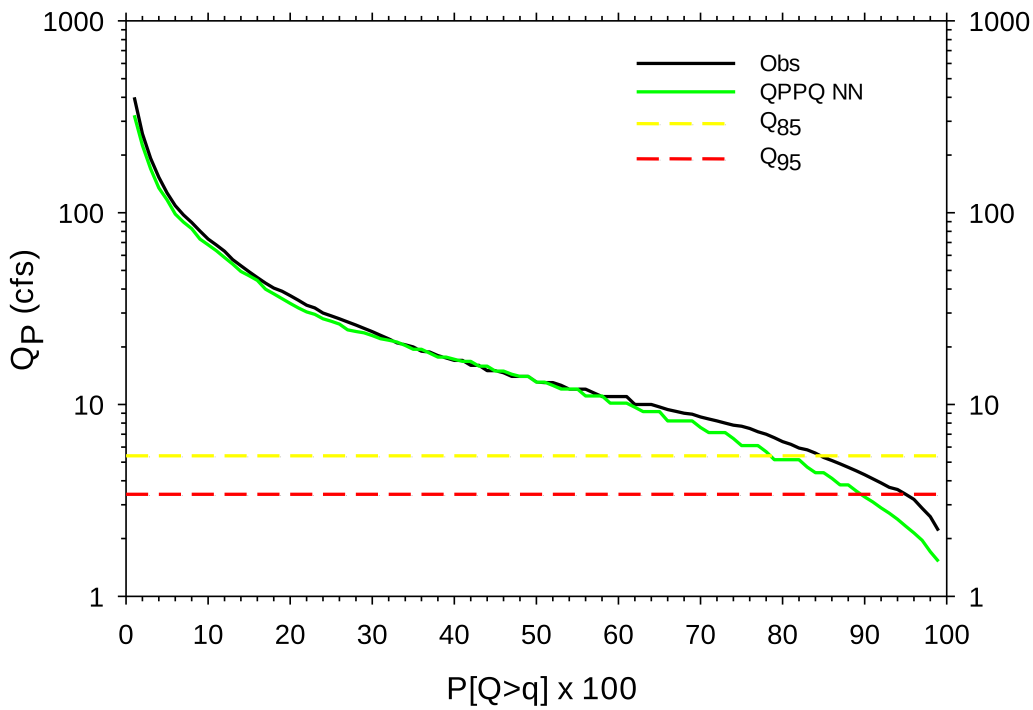
Because historic gage records exist at both sites, HYSR examined and compared the observed data at each site with the concurrent QPPQ Transform data. The following assessment methods apply to the concurrent periods of observed daily streamflow data and QPPQ data for the Ashuelot and Isinglass Rivers. For this assessment, only complete Water Years (October 1 – September 30) are used to reduce statistical bias. These assessments apply to a test season focusing on the summer low flows. The assessments apply selected low-flow thresholds, Q85 and Q95, as thresholds for comparisons.

As described by Fennessey (2018a, 2018b and 2019), NHDES and HYSR both believe that the period of particular concern to fishery specialists is during summer into early fall when stream flows are typically low. Fennessey (2018a, 2018b and 2019) used the July 15 – September 30 summer flow season that was used by the University of New Hampshire et al. (2007). In those same Fennessey studies, two season-specific flow quantiles, Q_{85} and Q_{95}, were used as assessment thresholds. For the present study, HYSR again uses this season and these flow quantiles to assess the effectiveness of using the QPPQ Transform to extend the Ashuelot and Isinglass River gage records.

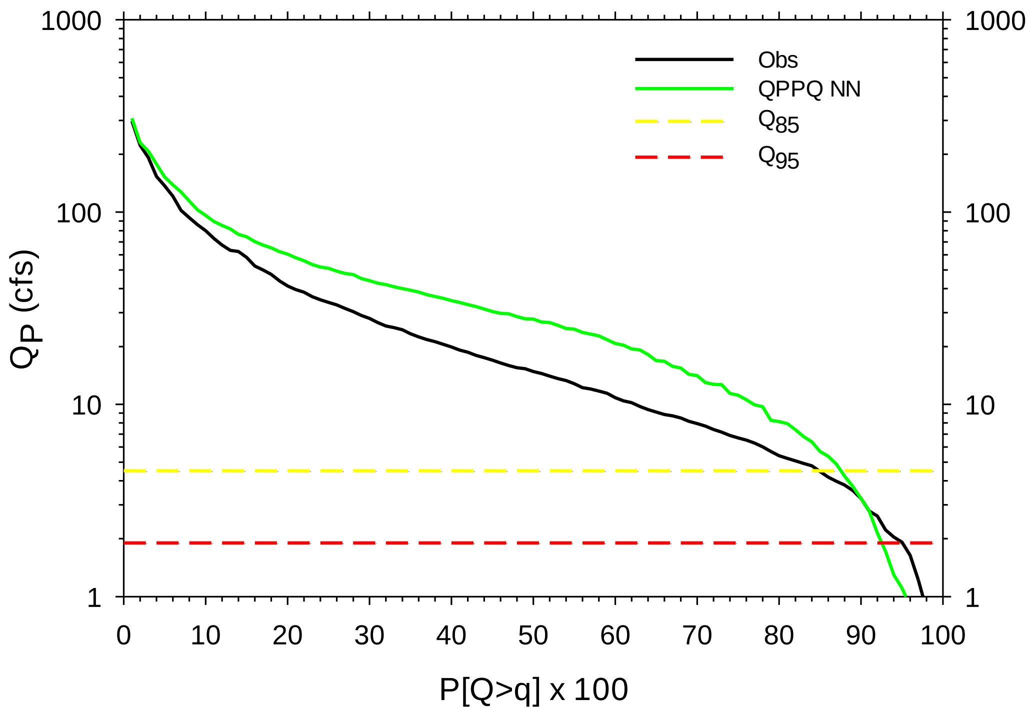
The first assessment is the comparison of streamflow duration curves or FDCs as was described by Fennessey (2018a, 2018b and 2019). As shown in Figures 4-1a and 4-1b, the observed FDC (black line) is compared with the QPPQ Transform FDC (green line) for concurrent POR summer flow seasons. The summer season Q_{95} and Q_{85} flow rates indicated on each graph are estimated using the concurrent observed gaged flow data.

The concurrent POR used to construct the FDC for the Ashuelot River is October 1950 – September 1980 and October 2009 – September 2019. The Ashuelot River QPPQ Transform flows, as shown by Figured 4-1a, are nearly identical to the concurrent observed flows high flows down to about Q_{55}. However, those flows diverge down to a maximum difference of about 40% at Q_{99}. Relative to the observed threshold management flows, Figure 4-1a indicates that the Ashuelot River observed Q_{85} is approximately equal to the QPPQ Transform Q_{79} and the observed Q_{95} is about equal to the QPPQ Transform Q_{88}.

The concurrent POR used to construct the FDC for the Isinglass River is October 2002 – September 2006 and October 2008 – September 2019. As shown by Figured 4-1b, the QPPQ Transform estimated flows are higher starting about Q_3 down to Q_{90}. The maximum difference is about 45%. For flows below Q_{90}, the QPPQ Transform estimated flows are less that the concurrent observed flows. Figure 4-1b also indicates that the Isinglass River observed Q_{85} is approximately equal to the QPPQ Transform Q_{79} and the observed Q_{95} is about equal to the QPPQ Transform Q_{91}. Relative to these thresholds, estimated flows between about Q_{10} and Q_{80} are not as good but they are still quite acceptable.



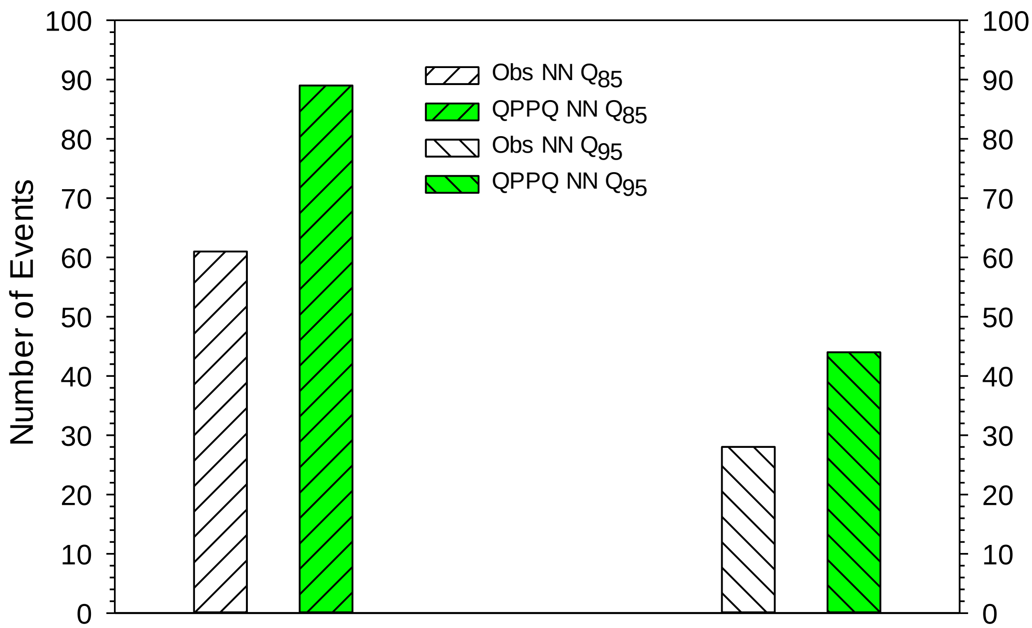
Fig, 4-1a. Ashuelot River Summer Season FDCs



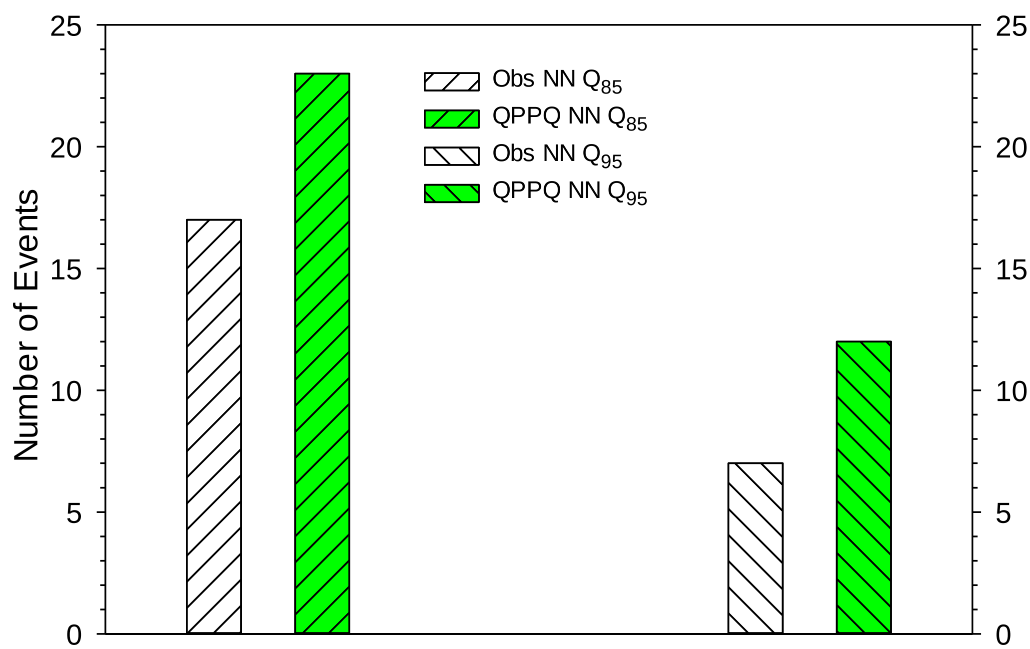
Fig, 4-1b. Isinglass River Summer Season FDCs

For the second assessment, HYSR undertook an extensive negative run-length analysis as described by Fennessey (2018b and 2019). In addition to summer season specific FDCs, this is another way to compare observed historic flows to QPPQ Transform estimated flows. A negative run-length event is a period of continuous days when flows fall below a threshold streamflow rate and then recover and rise above that threshold, which signals the end of the event. The two test management thresholds used are the summer season Q_{95} and Q_{85} gaged flow rates estimated using the concurrent observed flows for this analysis.

Figures 4-2a and 4-2b below illustrate the first negative run-length event assessment. These results show the difference between the total number of sub-Q_{85} and sub-Q_{95} negative run-length events that took place during the summer season for the concurrent POR of both the observed and QPPQ Transform estimated flows of the Ashuelot River and Isinglass River respectively.



Fig, 4-2a. Ashuelot River Summer Season Total Number of Negative Run-length Events



Fig, 4-2b. Isinglass River Summer Season Total Number of Negative Run-length Events

The results of this assessment indicate that for the Ashuelot River during the summer season, there are fewer observed time series negative run-length events than QPPQ Transform events for the concurrent POR relative to $Q_{85:}$: 61 versus 89 events. By comparison, relative to Q_{95}, there are fewer total negative run-length events and but proportionally about the same difference between observed time series and QPPQ Transform events: 28 versus 44 events.

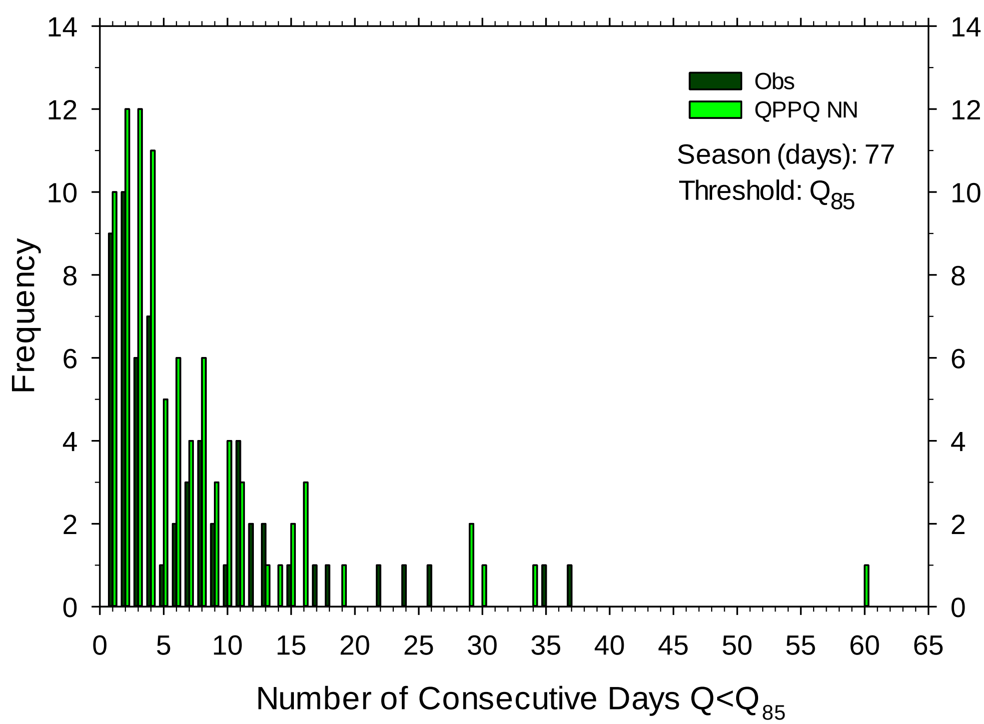
Similarly, there are fewer observed events than predicted events for the Isinglass River summer season concurrent POR. For the Isinglass summer season Q_{85} there are 17 versus 23 events. The same is true of $Q_{95.}$ There are fewer observed negative run-length events than QPPQ Transform time series events relative to the summer season observed Q_{95}: 7 versus 12 events.

These summer season results might be due to the observed Q_{85} and Q_{95} flow rates being greater than the QPPQ Transform time series Q_{85} and Q_{95} flow rates, as shown by the FDCs of Figures 4-1a and 4-1b. Or they may partly be an artifact of parsing the frequency and durations of these low-flow events. For example, if there is one day between a pair of one-day negative run-length events versus a single event that lasted 3 consecutive days? It turns out that a larger portion of the differences occur during one- and two-day events where one expects the greatest variability, as described below.

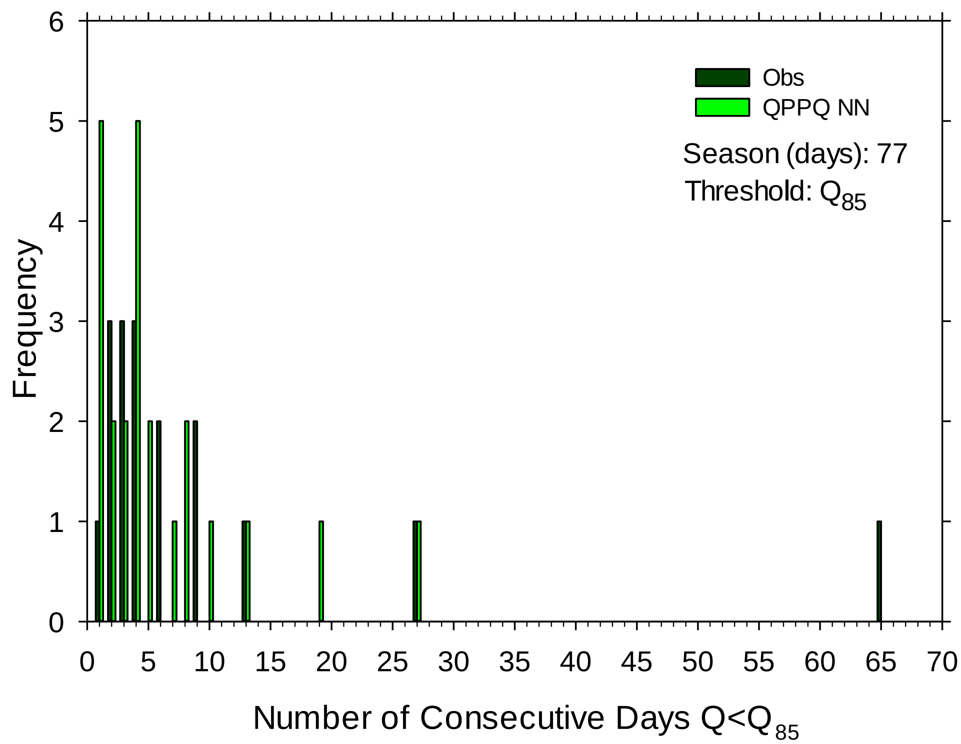
Note that NHDES's protected instream flow criteria for the Lamprey and Souhegan Rivers never applied durations shorter than three days to assessing negative run-length conditions. NHDES also required a two-day period of above a threshold streamflow rate before restarting a negative run-length count of days. In other words, a two-day period was the minimum duration NHDES applied to represent a recovery of stream flows (see NHDES, 2011, 2013) before the next negative run-length began. The considered differences between the number of shorter duration events should be given less weight.

The series of figures below illustrate the third assessment which considers the duration of the negative run-length events. These results are shown as frequency histograms which indicate the difference between the duration frequency of sub-Q_{85} and sub-Q_{95} negative run-length events that took place during the summer season for the concurrent POR of both the observed and QPPQ Transform estimated flows of the Ashuelot River and Isinglass River respectively. As in the previous negative run-length assessment, each site uses the observed summer season Q_{85} and Q_{95} flow rates as test thresholds.

Figures 4-3a and 4-3b respectively show the sub-Q_{85} threshold negative run-length event duration frequency histograms for the Ashuelot River and the Isinglass River. For example, Figure 4-3a indicates that there were 9 observed time series negative run-length events that lasted one day and 10 one-day events from the QPPQ Transform time series. Similarly, the longest single observed time series event lasted 38 days, whereas the longest QPPQ Transform time series event lasted 60 days over the concurrent POR during the 77-day-long July 15 – September 30 summer season used for the assessment. Figure 4-3a also shows that the match is quite good, as indicated by the similar shape and clustering. Figure 4-3b indicates that the clustering of the sub-Q_{85} negative run-length events of both Isinglass River observed and QPPQ Transform time series is good for events lasting more than one day. More negative run-length events do occur using the QPPQ Transform time series, which confirms the results shown on the right of Figure 4-2a, but given that both have one “extreme event” lasting 28 days, despite there being a single 65 day long observed event, the match is good.

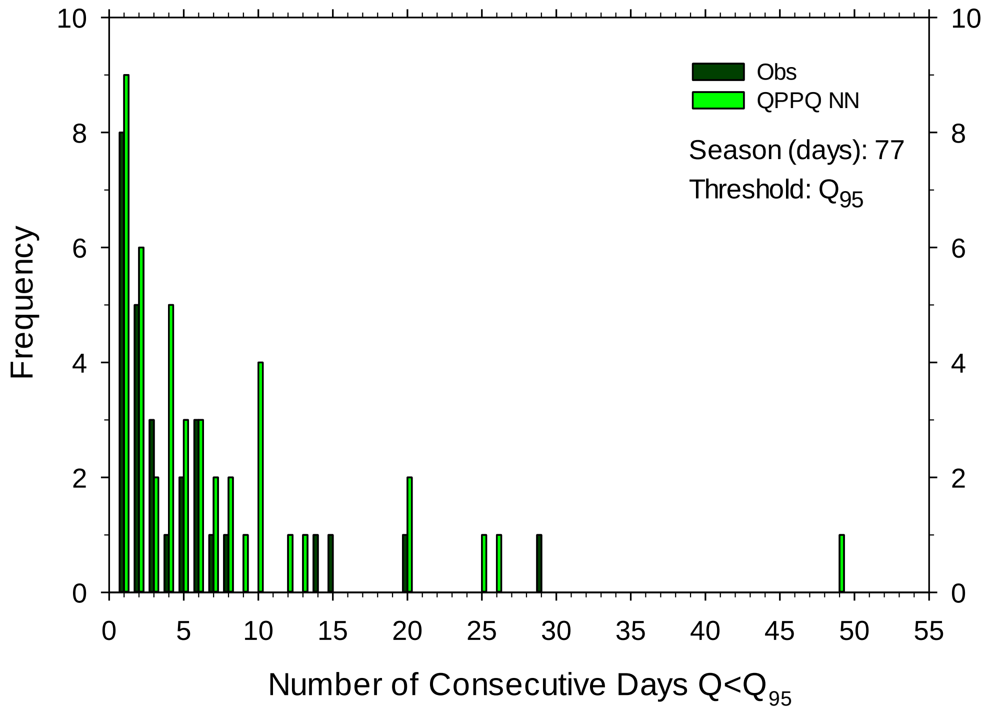


Fig, 4-3a. Ashuelot River Summer Season Frequency of Sub-Q_{85} Event Durations

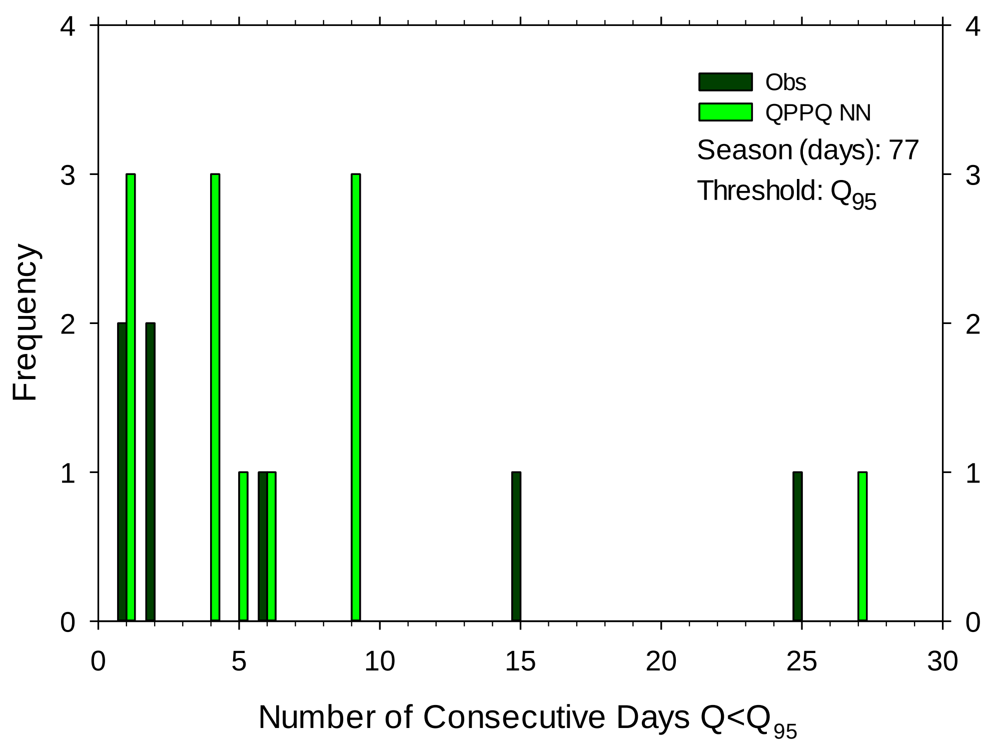


Fig, 4-3b. Isinglass River Summer Season Frequency of Sub-Q_{85} Event Durations

Focusing on Q_{95}, Figure 4-4a indicates that there are 8 observed time series negative run-length events that lasted one day and 9 one-day events from the QPPQ Transform time series for the Ashuelot River. The longest single observed time series event lasted 29 days, whereas the longest QPPQ Transform time series event lasted 50 days over the concurrent summer season POR. Figure 4-4b shows there were 2 observed time series negative run-length events that lasted one day and 3 one-day events from the QPPQ Transform time series for the Isinglass River. Similarly, the longest single observed time series event lasted 25 days, whereas the longest single QPPQ Transform time series negative run-length event lasted 27 days over the concurrent summer season POR. These figures show good match given the small population of negative run-length events due the short POR available to make this comparison for the Isinglass.



Fig, 4-4a. Ashuelot River Summer Season Frequency of Sub-Q_{95} Event Durations



Fig, 4-4b. Isinglass River Summer Season Frequency of Sub-Q_{95} Event Durations

5. Summary and Conclusions

With the assistance of the River Management Advisory Committee, NHDES determined that protected instream flows (PIFs) will be developed for two priority designated watersheds, the Ashuelot River and Isinglass River watersheds. To assist with that analysis, HYSR was retained to extend historic streamgage records for a U.S. Geological Survey stream gage located in each watershed. These gage sites are the Ashuelot River near Gilsum, NH (01157000) and the Isinglass River near Dover, NH (01072870).

The daily streamflow time series for each gage site were extended to a 68-year continuous period-of record beginning October 1, 1950 and ending September 30, 2019. Within that, the historic record for the Ashuelot River near Gilsum is quite long: October 1, 1950 to the end of September, 1980 and then from July 2009 to present. The Isinglass River near Durham is shorter having been gaged from early December 2002 to the end of December 2006 and from early November 2007 to the present. The extended Ashuelot River – Dover, NH (01157000) gage site time series consists of observed daily flows from October 1950 – September 1980, QPPQ Transform estimated daily flows (October 1980 – September 2009), and observed daily flows (October 2009 – September 2019). The extended time series for the Isinglass River near Durham, NH (01072870) consists of QPPQ Transformed estimated daily flows (October 1950 – early December 2002), observed daily flows (early December 2002-end of December 2006), QPPQ Transform estimated daily flows (end of December 2006-early November 2007) and observed daily flows (early November 2007 - present). These two time series were prepared and provided to NHDES August 2020.

Because both gage sites had periods of historic record, it is possible to determine how well the corresponding QPPQ Transform time series compared with the historic record. For this assessment, only complete Water Years (October 1 – September 30) are used to reduce statistical bias. In the case of the Ashuelot, that concurrent POR was October 1950 – September 1980 and October 2009 – September 2019. For the Isinglass River, the concurrent POR was October 2003 – September 2006 and October 2008 – September 2019.

HYSR conducted an assessment of the QPPQ Transform and the observed flows for the most flow-sensitive period of the year from July 15 and September 30. Between summer and early fall, daily stream flows tend to fall within their narrowest and lowest range. Five assessments were made at each site. The first, a comparative assessment between concurrent observed summer season daily flows and QPPQ Transform estimated daily flow FDCs compare well for the Ashuelot and the Isinglass. Four other tests, which focus on sub-threshold event duration analysis, indicate comparative results that are very similar. Particularly, if one considers the minimum negative run-length event duration of concern as being 2 or more days, the results between the two time series is even better. Given these results, HYSR concludes that the QPPQ Transform flow record extensions for the Ashuelot gage site are very good approximations of the stream flow conditions and are appropriate and suitable for developing stream flow protections on this river. HYSR concludes that for the Isinglass River gage site, the record extension is a good approximation of the stream flow conditions but not nearly as suitable for developing stream flow protections on this river as those for the Ashuelot.

6. Supplemental and Recommended Future Study

The study results for the Isinglass River described above warrant further examination. Despite the excellent agreement between the POR observed and QPPQ FDCs shown in the early part of the study, the dissimilarity between the summer season FDCs was surprising. HYSR believes that one of the reasons might be due to choosing the Oyster River, the nearest neighbor HCDN streamgage as the Isinglass' Index Gage. It was chosen because of the nearest HCDN neighbor Index Gage rule developed by Fennessey (2018a). For this reason, HYSR will conduct an analysis of the Isinglass and an alternative Index Gage site and compare those results with those presented in this report.

The present study results and likely those of the planned HYSR supplemental Isinglass study suggest than an in-depth study of Index Gage site choice is warranted. HYSR believes that it is important that NHDES be assured that the very best Index Gage site is being used for record extension. Because one of the future applications of the QPPQ is to develop long periods of daily data at ungaged sites, understanding how best to choose the appropriate Index Gage is vitally important because there is nothing to compare the QPPQ Transform flows with.

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