Appendix 13

Part 2 Hydrology Appendix

1.1 Hydrology

Daily streamflow data for the Lamprey River at Packers Falls are available from the United States Geological Survey (USGS). This streamflow gage is located towards the end of the designated reach. The Oyster River, which is an adjacent watershed, also has a USGS streamflow gage. The Durham NOAA precipitation gage provided daily precipitation values from 1939 to present. This is the longest, continuously operating NOAA station in the region. Table 1 summarizes stations characteristics.

Table 1: Available streamflow and precipitation data

Station Number	Station Name	Latitude NAD27	Longitude NAD27	Drainage Area (mi^2)	Period of Record
USGS 01073500	Lamprey River near Newmarket, NH	43°06´09´´	70°57´11´´ W	183	7/24/1934 to present
USGS 01073000	Oyster River near Durham, NH	43°08´55´´	70°57´56´´ W	12.1	12/15/1934 to present
COOP 272174	Durham	43°09´	71°57´ W	N/A	12/1/1939 to present

1.2 Historical Analysis

The study included a historical trend analysis using average discharge, precipitation, and watershed yield (the ratio of precipitation to discharge), and Indicators of Hydrologic Alteration (Richter et al., 1996). Richter et al.'s (1996) *Indicators of Hydrologic Alteration* (IHA) characterizes trends in streamflow variability with respect to timing, duration, frequency, and rate of change. IHA statistics were initially calculated for water years 1934 to 2007. IHA uses linear regression analyses to identify trends.

For the period of record, significant trends were identified for average and low flow conditions in many fall months, using a 95% significance level ($\alpha = 0.05$). A comparison of the

Lamprey River and Oyster River mean flow values for August shows a distinct change in the flow regime in early 1950s (Figure X). These differences were also noted by previous researchers including Stephen Roy, Brandon Kernen, Tom Mack, and Rob Flynn.

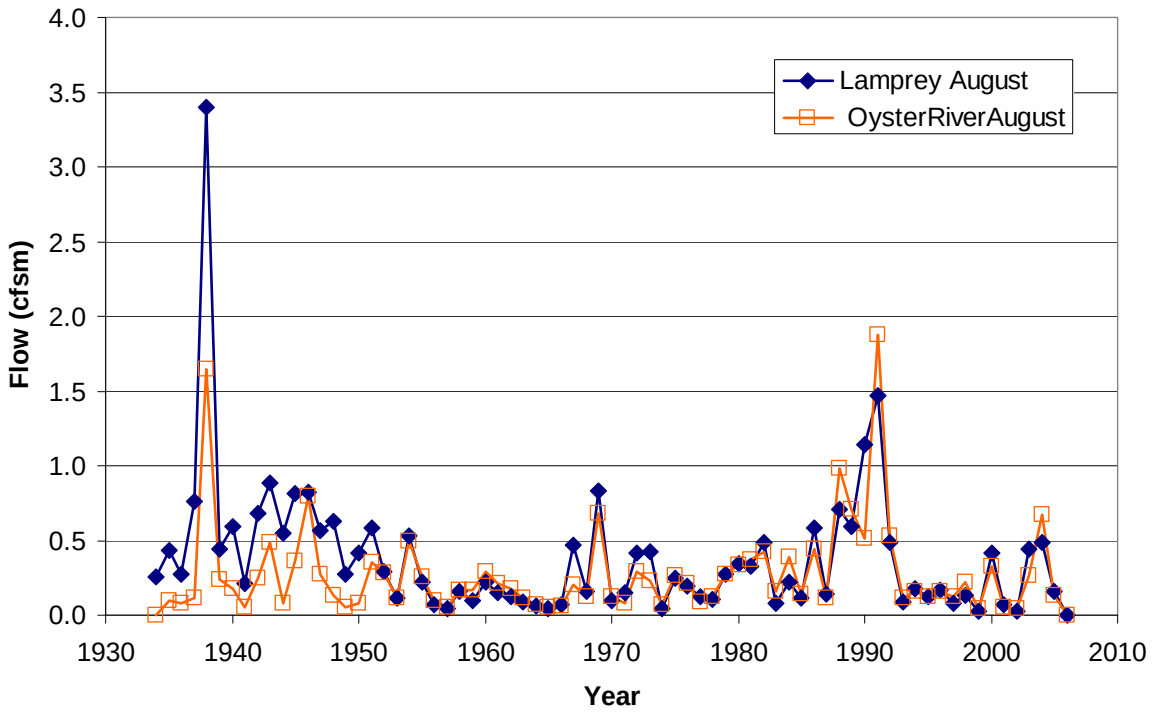

Figure X. Mean August streamflow values (cfsm) for the Lamprey River and the Oyster River from 1934 to 2006.

R. Flynn, USGS, investigated the historical record and found:

"Beginning in the early to mid-1950's, there is a downward shift in the hydrograph at the USGS Lamprey River gage for the months of July and August and an upward shift in the hydrograph for the months of October and November. The downward shift of the hydrograph for July and August and the reversal of this shift in the hydrograph for October and November, indicates that the Lamprey River flow may be impacted by impoundment and management of that impoundment. Last week, I stopped by the NHDES Dam bureau and took a look at the files for the Dolloff Dam on Pawtuckaway Lake in Nottingham, NH as Pawtuckaway Lake flows into the North River which empties into the Lamprey River above Wadleigh Falls (and the USGS gage at Packers Falls). The Pawtuckaway drainage area is 20.66 sq. mi. The New Hampshire Resources Board took over operation of the Dolloff Dam in 1955. Prior to this, the structure was operated by New Hampshire Electric as a storage reservoir for power generation. On August 14, 1950, an agreement was made between the State of NH and NH Electric to maintain the lake at 10 feet in the winter and 18 feet in the summer with summer defined as the period of June 1 to October 1. Prior to this agreement, New Hampshire Electric would draw down the lake all summer. After

this agreement, drawdown occurred in the fall (beginning October 1) and a constant level was maintained throughout the summer. I believe that the management practices of New Hampshire Electric beginning in 1951 and of the New Hampshire Resources board beginning in 1955 are the cause of the shift in the hydrograph for the Lamprey River. In addition, it was noted in the file that the Dollof Dam was repaired and the gate was repaired and closed in 1950 and that prior to this repair, there was "excess leakage" at the gate." (personal communication from R. Flynn, USGS to T. Mack, USGS, November 27, 2006).

Based on these findings, the period prior to 1955 was not considered when identifying 3-year periods having wet, dry, and average conditions as well as the representative 30-yr period.

1.3 Concurrent Flow Analysis

Concurrent flow measurements were conducted over a range of flows at two locations upstream of the USGS gage (downstream of Wadleigh Falls and upstream of Lee Hook Road). These measurements were conducted for flows ranging from 7.4 to 300 cfs (0.04 to 1.64 cfsm) as measured at the USGS gage. Table X gives the two linear regression relationships developed from the concurrent flows measurement at the two locations. The results indicate that while the area downstream of Lee Hook Road is fairly well represented by an area weighting approach, the Wadleigh Falls flow is slightly greater than that characteristic of an area weighting approach.

Table X. Concurrent flow results for locations upstream of the Lamprey River USGS gage using the relationship $Q_{upstream} = a . Q_{USGS}$. Concurrent flows were measured from 7.4 to 300 cfs. Accuracy of relationships decrease outside the measured range.

Site Description	Area (mi^2)	Ratio to USGS gage	Num. of Measures	a	R^2
Wadleigh Falls	135	0.738	16	0.7849	0.998
Lee Hook Road	161	0.880	16	0.8813	0.9902
USGS Gage	183	1.000	N/A	N/A	N/A

1.4 Streamflow Time Series

The streamflow record for water years 1934 to 2007 was examined to identify 3-year periods following 1955 having wet, dry, and average conditions. In addition, streamflow values for the last five years and a typical 30-yr period were identified. 3-yr average streamflow values were determined using a 3-yr moving window. When available, the annual precipitation record was examined to support the selection of 3-yr periods. The maximum annual average flow (452.6 cfs) occurred from 2005 to 2007 and had a correspondingly high precipitation value of 54.2 in. The second highest annual average flow (394.2 cfs) occurred from 1982 to 1984. The minimum average flow (179.5 cfs) occurred from 1964 to 1966 with a very low average annual precipitation (35.7 in). Average conditions for streamflow (286.4 cfs) and precipitation (43.5 in) were found from 1990 to 1992. Over the last 5 years (2003 to 2007), the average streamflow (386.2 cfs) was well above the long-term average conditions. The selected 30-yr period is 1976 to 2005. This period includes historically wet and dry periods and has an average flow (287.0 cfs) that is close to the long-term average. An IHA analysis performed on the 30-yr period showed no trends for any month's average, maximum or minimum values.

A "pre-Colonial" hydrograph for 1976 to 2005 was estimated by removing the AWU net withdrawals net of return flow and historical dam operation at the Dolloff Dam on Pawtuckaway Lake in Nottingham, NH. To consider the impact of AWU withdrawals, a monthly record of net withdrawals was created for each year that water records were available. All long term water use data records from AWUs, not just those having direct and induced recharge, were considered. The withdrawal records were developed from the quarterly water use reports submitted to the NHDES from the fourth quarter, 1988 through 2005. Prior to quarterly reporting, the 1976 to 1988 period, monthly withdrawals were estimated from historical data with input from AWUs.

AWUs having permitted withdrawals in 1988 and 1989 were contacted regarding historic water use location and quantity. The historic groundwater and surface water withdrawals are documented in AnnualWaterUse.xls modified from W. Ives', NHDES, Lamprey Annual Report Calculations spreadsheet. Net water use (equivalently consumptive water use) was estimated by multiplying the gross use by a consumptive loss rate.

The University of New Hampshire (Water Use ID 20066) aperiodically transfers water out of the Lamprey River watershed (and upstream of the Lamprey USGS gage, but downstream of the Oyster River USGS gage) to the Oyster River watershed. The transfer is considered to be 100% consumptive and therefore yields no return flow. In contrast to most other AWUs, this water use is intermittent and using monthly average values to estimate daily water use is not reasonable. Instead, a daily time series for the 30-yr period was created from daily records obtained from W. East, Durham Drinking Water Plant (available for all but 4 of the years). Periodic differences were identified between the monthly totals from the plant's daily records and the NHDES quarterly report values. Additional records were reviewed with W. East prior to establishing the daily values for this study. For 1997, 1999, 2000, and 2001, only monthly records were available. Based on input from W. East, a pumpage rate of 800,000 gpd was applied to the number of days necessary to match the monthly totals. An odd pumpage rate was used on one day each month, as necessary, to match the reported monthly values. The streamflow records were reviewed and work days (Monday to Saturday) having the lowest flow values were assumed to be the dates on which pumping occurred. The remaining days had no withdrawal.

Values are summarized by stream location and used to create a daily time series for each location (Time Series Worksheet in AnnualWaterUse.xls). The resulting consumptive

withdrawal rates should be added to the daily flows in the measured 30-year hydrograph to generate streamflow records without the impact of AWUs withdrawals.

The pre-Colonial hydrograph should also be corrected for the historical dam operation at the Dolloff Dam on Pawtuckaway Lake in Nottingham, NH. Historic operation records for the Dolloff Dam were obtained from the NHDES Dam Bureau. The dam levels are routinely raised seven feet in the spring and lowered seven feet in the fall. The levels are controlled by a series of stop logs that may be inserted or removed. Typically, the dam levels are lowered by incrementally removing stop logs from October to December. Levels are typically raised in February and March to within 2 to 3 feet of the recreational pool. The remainder of the pool is filled by early May.

Sixteen years of historic operation records for the Dolloff dam were reviewed to determine typical operations including fill and release start and end dates and fill and release volume. The median drawdown period begins on October 12 and ends on December 19, a 67.5 day period, during which the Pawtuckaway Lake levels typically drop from 24.73 ft to 19.35 ft (staff gage height). The volume released from storage was estimated, using a storage area relationship, to be 3,938 acre-ft over the 67.5 day release period or equivalently 29.29 cfs. 1,535 acre-ft of this release volume is typically refilled at a rate of 20.8 cfs from February 21st to March 29th. The remaining 2,403 acre-ft is filled from March 30th to May 5th at a rate of 33 cfs. Note: while the stop logs are typically removed by December 19th, additional outflow continues to lower lake levels somewhat during the remainder of January and February. In early February the first stop logs are placed to begin to the refill process.

Dam operations will result in somewhat augmented flows in the fall during the release and reduced flows in the spring during the filling period. In light of this management scenario,

the historical time series can be adjusted by subtracting the releases in the fall and adding the fill rates in the spring. A daily time series was created to adjust for dam operation where negative values correspond to corrections for the fall release and positive values to corrections for the spring fill. The resulting time series were added to the daily flows in the measured 30-year hydrograph to generate streamflow records without the dam management.