CDM

Memorandum

To: *Barbara Blumeris, USACE*

From: *Ginger Croom and Kirk Westphal, CDM*

Date: *April 14, 2008*

Subject: *Upper Merrimack and Pemigewasset River Study*
Task 9 - Water Supply Evaluation

Executive Summary

Several significant water supply withdrawals from the mainstem of the Merrimack River in Southern New Hampshire are in various stages of development and permitting. From 1986 to 1996, Pennichuck Water Works, which supplies Nashua and other neighboring communities, operated with a permit that allowed withdrawals from the river up to 20 MGD under certain flow conditions. In 1996, this permit was increased to a maximum allowable withdrawal of 30 MGD under favorable flow conditions. The City of Manchester is planning future withdrawals from the Merrimack in Hooksett, phased in increments of 5 – 7 MGD over time up to a maximum of 20 MGD. The prospective withdrawals for Manchester are not currently permitted.

A preliminary investigation of water supply withdrawal scenarios at the two active and proposed locations between Hooksett, New Hampshire and the New Hampshire/Massachusetts state border was conducted as Task 9 of the Upper Merrimack and Pemigewasset River Study. The analysis utilized the existing watershed hydrology and river hydraulics models developed during Phase I of the Merrimack River Watershed Assessment Study, without modification. The models were run under the baseline conditions defined in Phase I for two representative years (dry and average) to test the sensitivity of the river flow to incremental levels of water supply withdrawals. A representative wet year was not included since the focus of this evaluation was on the impact of water withdrawals during low flows. The impacts on water quality were not considered here, but examination of potential water quality impacts is proposed as part of subsequent tasks of the Upper Merrimack and Pemigewasset River Study.

The evaluation showed that the proposed water withdrawal scenarios for Manchester Water Works and the current withdrawal permit for Pennichuck Water Works would have minor hydrologic impacts on the Merrimack River. For Manchester WW, the maximum proposed withdrawal pumping rate of 20 MGD did not cause significant impacts on the river flow. Additionally, the upstream withdrawal of 20 MGD by Manchester WW had very little impact on Pennichuck WW's withdrawal amounts under the current permit conditions. A hypothetical scenario, in which Pennichuck WW was allowed to withdraw at the maximum rate of 30 MGD at all times, had a minor impact on the river, but under both the prior and current permits this rate was only allowed during a short period of the year.

For Manchester WW, the maximum withdrawal scenario (20 MGD) resulted in a maximum flow reduction under low flow conditions (i.e. when the river flow is less than the 7Q10 flow) of 5-6% while the current permit for Pennichuck WW resulted in a reduction of 3%. If Pennichuck WW was allowed to withdraw at the maximum rate of 30 MGD at all times, which is not possible under their current permit and presented only for illustrative purposes, then the low flow reduction was 7%. Under the worst case scenario with both Manchester WW withdrawing at 20 MGD and Pennichuck WW operating under the current permit at 12 MGD under low flow conditions, the low flow reduction was about 7-8% downstream of the Pennichuck WW withdrawal intake.

1.0 Objectives

Two objectives framed this analysis:

- Develop a preliminary understanding of the magnitude of the impacts of the specified mainstem withdrawals on the flow regimes in the river;

- Estimate the frequency at which the prospective withdrawals would be available to the water purveyors, as governed by known conditions on withdrawal permits.

2.0 Models and Methodology

For Phase I of the Merrimack River Watershed Assessment, CDM developed a series of models to simulate watershed runoff and loading, river hydraulics, and in-stream water quality conditions of the Lower Merrimack River beginning at the Hooksett Dam just north of Manchester, NH and extending to the Atlantic Ocean (see CDM (2006) for more details on the model development for Phase I). These models included combined sewer overflow (CSO) models for five municipalities along the river using SWMM and MOUSE, a watershed runoff and loading model using HSPF, a river hydraulics model using SWMM, and an in-stream water quality model using WASP. The models were calibrated to a wide range of flow regimes and water quality conditions.

For this preliminary water withdrawal evaluation, the existing CSO discharge models (SWMM and MOUSE), the watershed loading model (HSPF), and the river hydraulics model (SWMM) were used without any additional modification. The WASP water quality model was not used for this evaluation since the focus was solely on the impacts on river flow and not water quality. The models were configured to represent current conditions for basin hydrology and drainage infrastructure.

Simulations were run for the representative dry and average years (1993 and 1994, respectively) over the same 185 day period (May 1 - November 1) that was used in Phase I. Runoff from each subcatchment was estimated with the HSPF model, and the river flow (with no withdrawals at the two sites under investigation) was simulated with SWMM. This established a baseline for comparison to the withdrawal scenarios, which were simulated with the current and proposed withdrawal thresholds and restrictions.

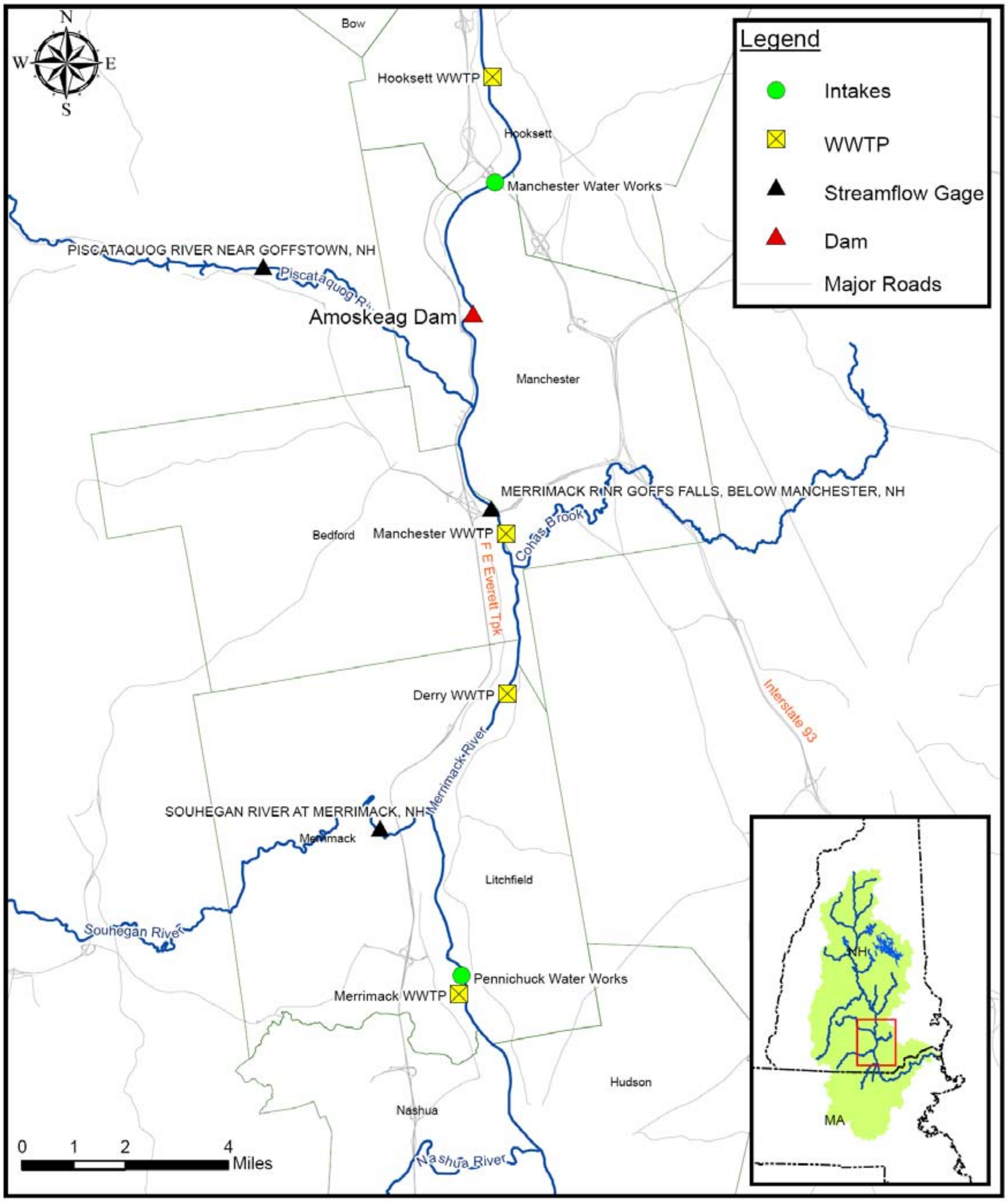
Withdrawals were evaluated at one location for the Manchester Water Works in Hooksett, NH and a second location for Pennichuck Water Works in Merrimack, NH. The Manchester Water Works withdrawal location is downstream of the I-93 bridge near Exit 10. The Pennichuck Water Works withdrawal location is on the west side of the river, approximately 1 mile upstream of the Merrimack/Nashua town line. The water withdrawal locations, wastewater treatment facility discharges, streamflow gages, and dams between Hooksett and Nashua are shown in Figure 1.

The withdrawal scenarios were evaluated by subtracting the rate of withdrawal from the simulated flows at each withdrawal location. While existing return flows from the watershed, including from the Manchester Wastewater Treatment Facility (WWTF), were included in the model, they were not altered in response to changes in the withdrawal rates since the focus of this analysis was on the flow conditions just downstream of the withdrawal locations. While increases in river withdrawals would result in increases in WWTF discharges, the 8-mile reach between the withdrawal intake and the discharge location would be unaffected by this return flow. For the scenario with both Manchester WW and Pennichuck WW withdrawing, the return flow from the Manchester WWTF, which is 9.5 miles upstream of the Pennichuck WW intake location, was not increased in order to provide conservative (i.e. minimum) estimates of flow conditions at the Pennichuck WW. Other return flows from the watershed (such as from groundwater via septic system leaching) also enter the river at various points but these flows are difficult to quantify and were not changed in this analysis to again provide conservative flow estimates. The impacts of water withdrawal rates on watershed return flows will be considered in subsequent proposed tasks of this study.

The resulting downstream flows were compared to the estimated 7Q10 flow at each withdrawal location. The NH DES Dam Bureau reported a 7Q10 flow of 644 cfs at the USGS streamflow gage near Goff's Falls below Manchester, NH (Gage ID: 01092000) (NH DES, 2007). While the 7Q10 flow may differ depending on the period of record used in the calculation, this value was assumed to be representative for the purpose of this analysis. As shown in Figure 1, the Goff's Falls gage is located about midway between the two withdrawal locations. To estimate the 7Q10 at each withdrawal location, the ratio of simulated flows between the withdrawal location and Goff's Falls was calculated for low flows that were near the 7Q10 of 644 cfs at Goff's Falls. For the Manchester WW withdrawal location, the average ratio of the withdrawal location flows to Goff's Falls flows was 0.91. For the Pennichuck WW, the average ratio of Goff's Falls flows to the withdrawal location flows was 0.87. Using these ratios, the estimated 7Q10 flows were 586 cfs at the Manchester WW withdrawal location and 740 cfs at the Pennichuck WW withdrawal location.

Time series and flow duration curves were generated based on the resulting downstream flows. For the water withdrawal scenarios at Pennichuck Water Works, where the rate of withdrawal depended on water surface elevation and downstream flow, operational logic was included to evaluate specific elevation and flow criteria (see below for more details). Time series plots of water withdrawal rates were also generated for the Pennichuck withdrawal scenarios. Summary statistics of total water withdrawal volumes and the distributions of water withdrawal rates were calculated for each scenario.

Figure 1 – Map of Water Withdrawal Locations, WWTPs, Streamflow Gages and Dams



3.0 Manchester Water Works

Four water withdrawal scenarios were evaluated for Manchester Water Works. Each scenario included a constant rate of water withdrawal ranging from 0 to 20 MGD. The specific withdrawal rates and total withdrawal volumes over the 185 day simulation period are shown in Table 1. These withdrawal scenarios are in addition to the existing Manchester Water Works withdrawal from Lake Massabesic, which is included in the model.

Table 1 - Water Supply Withdrawal Scenarios for Manchester Water Works

Withdrawal Rate (MGD)	Total Withdrawal* (MG)
0 (Baseline)	0
7	1,295
14	2,590
20	3,700

* Total withdrawal over 185-day simulation period.

Since these scenarios do not depend on water surface elevation or downstream flow requirements, each withdrawal rate was simply subtracted from the simulated flows generated by SWMM at the withdrawal location. The water withdrawal permit may condition withdrawals on downstream residual flow, but absent that information, the withdrawals were simulated as constant, and the associated impacts and volumes should be viewed as an upper limit. Because the rates of withdrawal were considerably smaller than the flow rate in the river, the time series of downstream flows only include the two scenarios with the minimum (0 MGD) and maximum (20 MGD) withdrawal rates. These two scenarios provide lower and upper bounds to the downstream flows resulting from the other two scenarios (7 and 14 MGD).

Time series of downstream flows during the dry year (1993) and average year (1994) are presented in Figures 2 and 3, respectively. The percent change in daily flow between the baseline and maximum withdrawal scenarios are shown in Figure 4 for both years. The flow duration curves for the two years are shown in Figures 5 and 6. Low-flow conditions are indicated on these graphs by the estimated 7Q10 flow of 586 cfs at the Manchester WW withdrawal location. For the baseline simulation (no withdrawals) the flow was less than the 7Q10 about 8% of the time for 1993 (dry) and about 3% of the time for 1994 (average) (Figures 5 and 6).

Figure 2 - Time Series for Manchester WW Scenarios during 1993 (Dry)

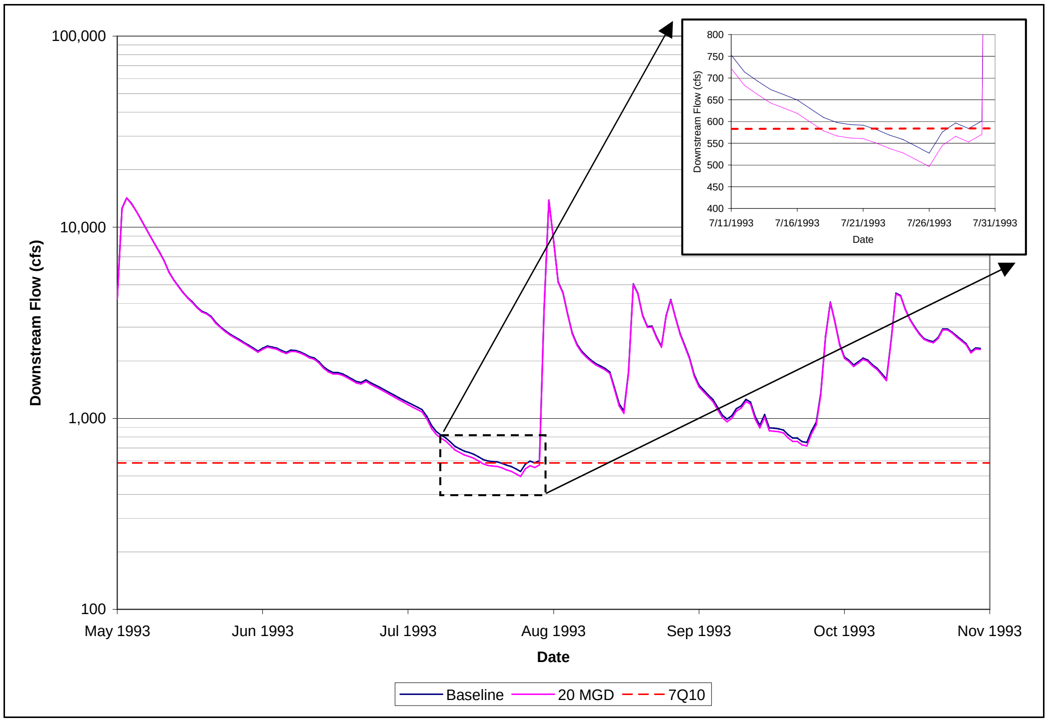


Figure 3 - Time Series for Manchester WW Scenarios during 1994 (Average)

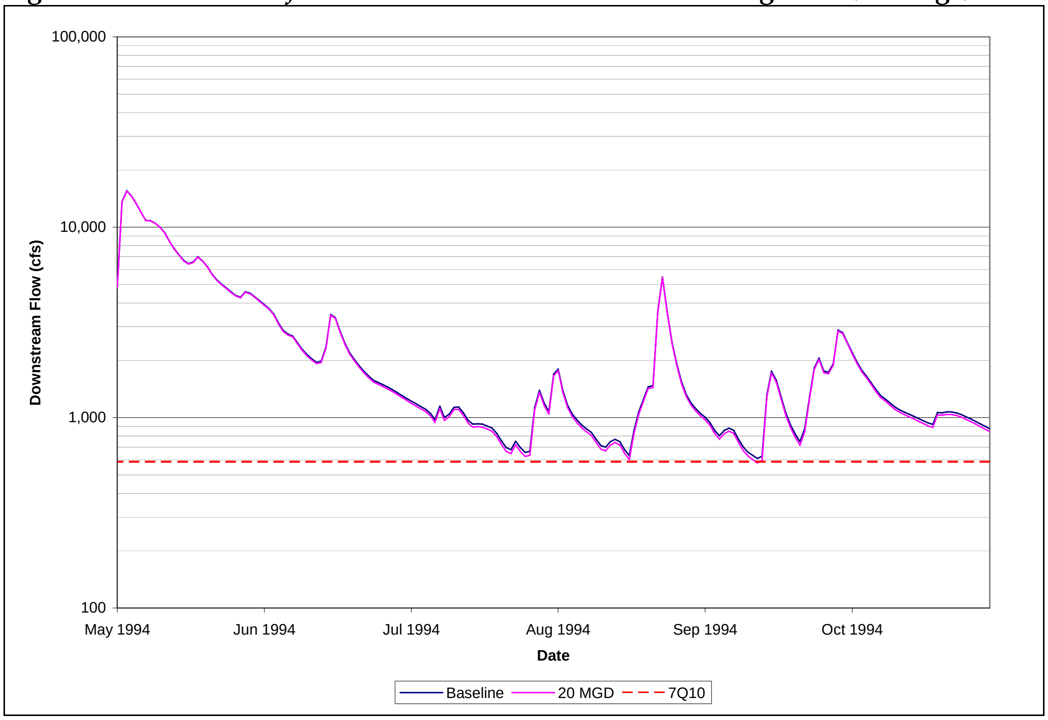


Figure 4 – Change in Flow from Baseline to Maximum (20 MGD) Withdrawal for Manchester WW during 1993 (Dry) and 1994 (Average)

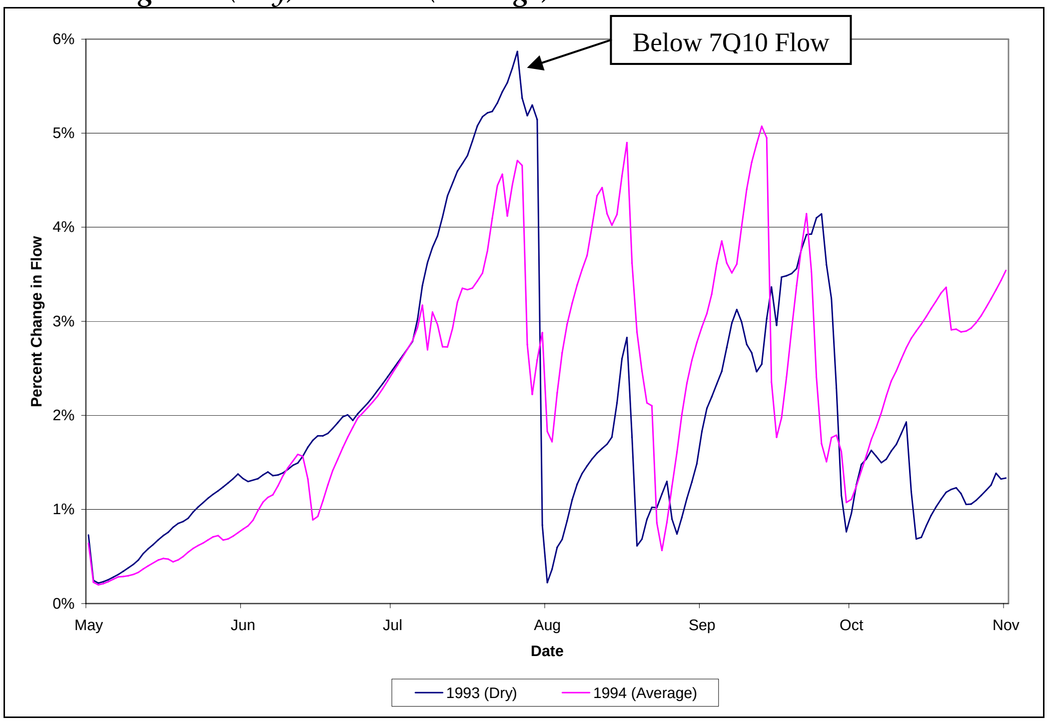


Figure 5 - Flow Duration Curves for the Minimum and Maximum Manchester WW Withdrawal Scenarios during 1993 (Dry)

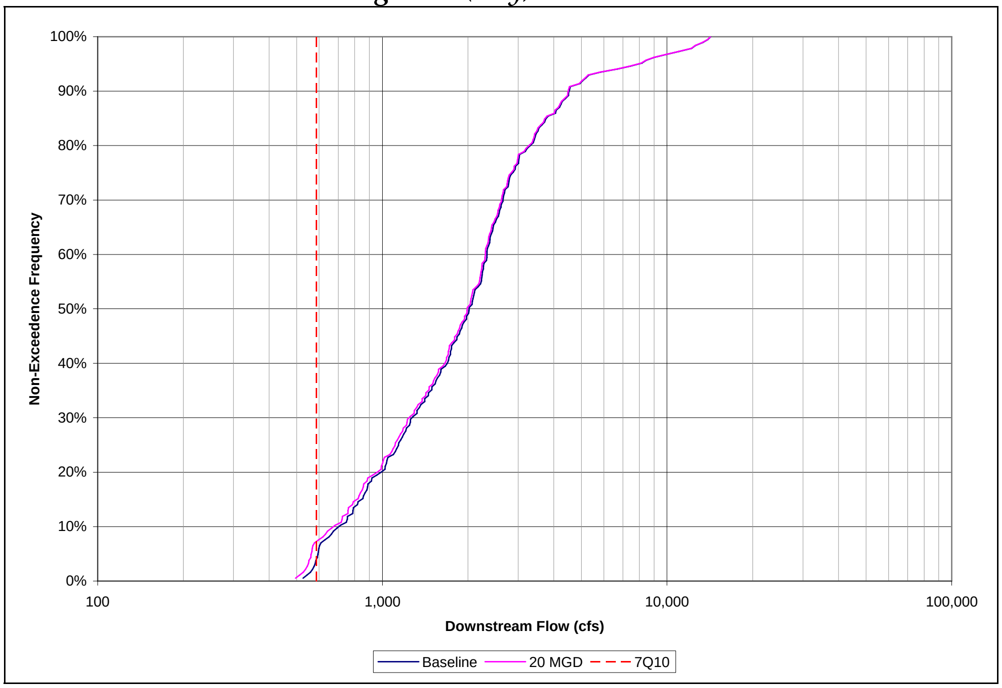
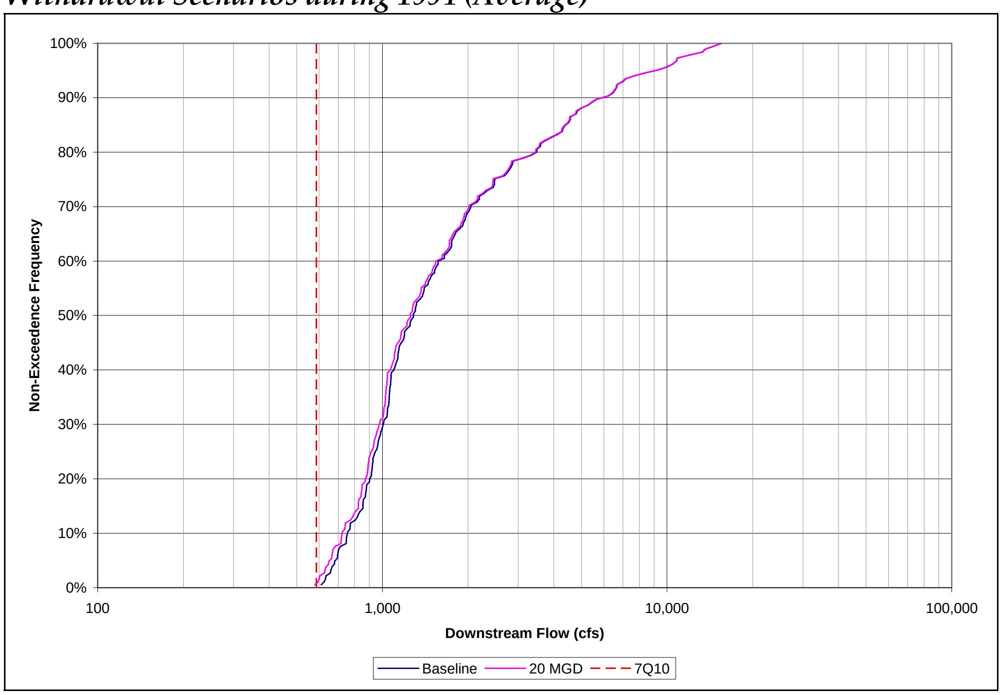


Figure 6 - Flow Duration Curves for the Minimum and Maximum Manchester WW Withdrawal Scenarios during 1994 (Average)



Both the time series and the flow duration curves indicate that the maximum rate of water withdrawal for Manchester Water Works would have a small impact on the flow of the river, even at low flows when the river flow is less than the 7Q10 flow. The average flows during the month of August, the summer, and the overall simulation period for the dry year (1993) are compared to the 7Q10 flow in Table 2. The percent change in average flow from the baseline scenario to the maximum 20 MGD scenario for each period is also presented in Table 2. For the lowest simulated flow of 527 cfs, which occurred during July 1993, the maximum withdrawal of 20 MGD (31 cfs) would result in a 5.9% reduction to a flow of 496 cfs.

Table 2 – Summary of Average Flows in 1993 (Dry) for Manchester Water Works Withdrawals

Scenario	7Q10 (cfs)	August Average (cfs)	Summer Average* (cfs)	Overall Average** (cfs)
Baseline	586	3,306	1,772	2,608
7 MGD	586	3,295	1,761	2,597
14 MGD	586	3,284	1,751	2,586
20 MGD	586	3,275 (0.9%)†	1,741 (1.7%)†	2,577 (1.2%)†

* June 21 – September 23
** May 1 – November 1
† Percent change in flow from Baseline scenario

4.0 Pennichuck Water Works

The following five water withdrawal scenarios were evaluated for Pennichuck Water Works.

- Baseline (0 MGD)
- Prior Withdrawal Permit (12-20 MGD)
- Current Withdrawal Permit (12-30 MGD)
- Maximum Withdrawal (30 MGD)
- Combined Maximum Withdrawal including Manchester WW (30 MGD + 20 MGD upstream)

The allowable withdrawal rates and permit requirements for each of these scenarios are summarized in Table 3. For the prior withdrawal permit, the rate of withdrawal depends on the water surface elevation at the point of withdrawal. If the water surface elevation is greater than 91.2 ft MSL, then the elevation criterion is met and the rate of withdrawal is set to 20 MGD. If the elevation is below 91.2 ft MSL and the criterion is not met then the rate of withdrawal is set to 12 MGD.

Under the current withdrawal permit, the withdrawal rate depends on the same elevation requirement as the prior permit in addition to a downstream flow requirement and a greater maximum withdrawal rate of 30 MGD. The downstream flow requirement is satisfied if the flow after withdrawal is greater than 4,460 cfs during May and June or greater than 1,715 cfs during the other months. If both the elevation and the flow criteria are met then the allowable withdrawal rate is 30 MGD, but if only the flow criterion is met then the allowable withdrawal rate is 20 MGD. If the flow requirement is not met then the current permit reverts to the flow rates under the prior permit with 20 MGD if the elevation criterion is met and 12 MGD otherwise.

For the no withdrawal and maximum withdrawal scenarios, the withdrawal rates are simulated as constant in order to provide an upper bound. In these cases, the withdrawals do not depend on the water surface elevation or downstream flow requirements. Although the current permit does not allow Pennichuck to withdraw at 30 MGD during low flows, the maximum withdrawal scenario was included for illustrative purposes in this analysis. The combined maximum withdrawal scenario was included to consider the impact on the river of having both utilities withdrawing water at the maximum allowable rates, which again is not allowed under the current Pennichuck permit during low flows and is included solely for illustrative purposes.

Table 3 - Water Withdrawal Scenarios for Pennichuck Water Works

Scenario	Elevation Criterion Satisfied?	Flow Criterion Satisfied?	Withdrawal Rate (MGD)
No Withdrawal:	--	--	0
Prior Permit:	Yes	--	20
	No	--	12
Current Permit:	Yes	Yes	30
	Yes	No	20
	No	Yes	20
	No	No	12
Maximum (Pennichuck Only)*:	--	--	30
Combined Maximum**:	--	--	30

* Included for illustrative purposes only and not allowed under current permit
** After Manchester has withdrawn 20 MGD upstream, and also included for illustrative purposes only and not allowed under current permit.

4.1 Alternative Elevation Criteria

During Phase I of the Merrimack River Watershed Assessment, the river hydraulics model was calibrated using measurements of flow. Water surface elevation was not a specific calibration criterion, due to lack of available data, except for locations in the estuary. As a result, the ability of the model to accurately and consistently evaluate the elevation criterion for Pennichuck withdrawals was uncertain, especially because the withdrawal location can be influenced by backwater from the Pawtucket Dam in Lowell.

To reduce the impacts of this uncertainty on this evaluation, withdrawal scenarios were assessed by:

- Substituting a flow-based criterion for the elevation criterion, to provide a likely range of impacts;

- Assuming maximum constant withdrawal, to provide an upper bound on the impacts.

A relationship between flow and elevation was constructed using the SWMM output at the Pennichuck withdrawal location. The flow corresponding to an elevation of 91.2 ft MSL was then used as a substitute for the elevation criterion. In general, the relationship between flow and elevation is expected to be one-to-one with one flow rate corresponding to one elevation. However, due to the influence of backwater from the Pawtucket Dam, the flows corresponding to an elevation of 91.2 ft MSL ranged from 3,210 to 4,240 cfs. These two flows were used as surrogates for elevation, in order to effectively estimate a range of potential impacts. The current permit scenarios were thus evaluated using three versions of the elevation criterion:

- Elevation of 91.2 ft MSL (Original)

- Flow of 3,210 cfs (Upper Bound – least restrictive)

- Flow of 4,240 cfs (Lower Bound – most restrictive)

Comparison of these three versions of the elevation criterion show that the resulting water withdrawal rates and volumes are not significantly different among the three versions of the elevation criterion (see below). For simplicity, only the results of the original elevation criteria are presented in the time series and flow duration curves (Figures 7 – 11). All three forms of the elevation criterion are included in the final summary charts and statistics to show the differences between them (Table 5 and Figures 12 – 14). However, since all three types of simulated thresholds result in somewhat restrictive withdrawal allowances, the relationship between flow and water surface elevation at the withdrawal location should be examined more thoroughly in subsequent phases of this study (e.g. during the field work, or through daily operational record-keeping at the intake facility).

4.2 Impact on River Flow

Similar to the results for Manchester Water Works withdrawal scenarios, the Pennichuck Water Works scenarios have minor impacts on the downstream river flow. Time series plots of downstream flows for each of the five scenarios are shown in Figures 7 and 8 for 1993 (dry year) and 1994 (average year), respectively. The percent change in daily flow for both years between the baseline and maximum (Pennichuck Only) scenarios are shown in Figure 9. The flow duration curves are shown in Figures 10 and 11. The estimated 7Q10 flow of 740 cfs at the Pennichuck WW withdrawal location is also included in these graphs. The simulated flows under baseline conditions (no withdrawals) were less than the estimated 7Q10 flow about 4% of time during 1993 and less than 1% during 1994. In general, the differences between the prior permit and current permit scenarios are very small such that the lines for these two scenarios overlap frequently in each plot.

Figure 7 - Time Series for Pennichuck Withdrawal Scenarios during 1993 (Dry)

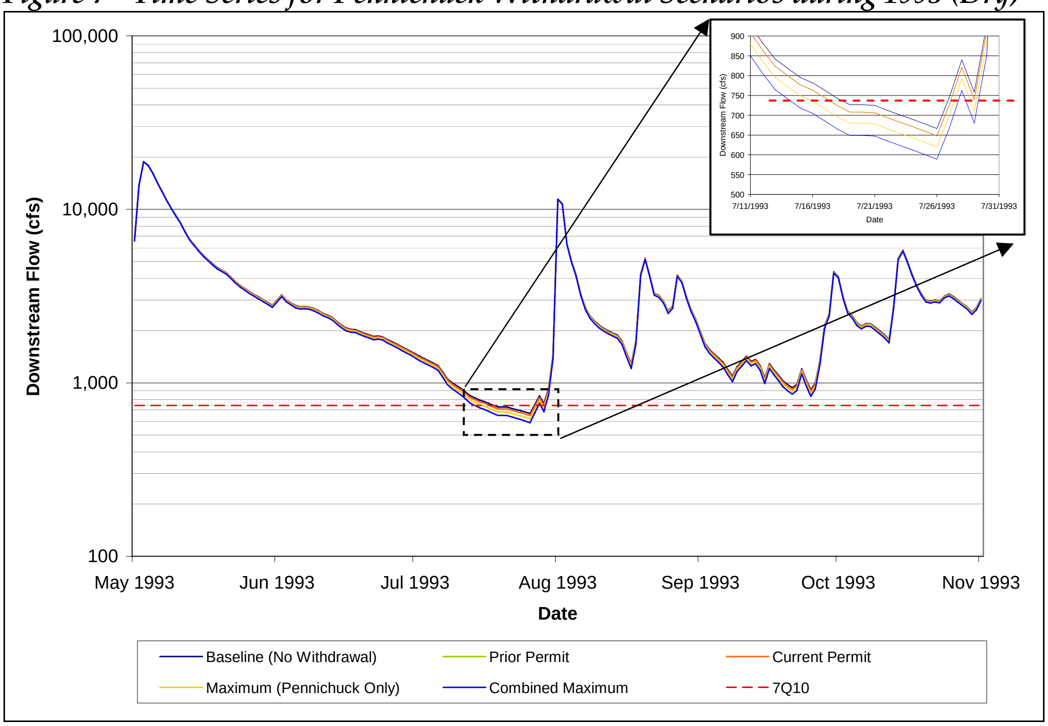


Figure 8 - Time Series for Pennichuck Withdrawal Scenarios during 1994 (Average)

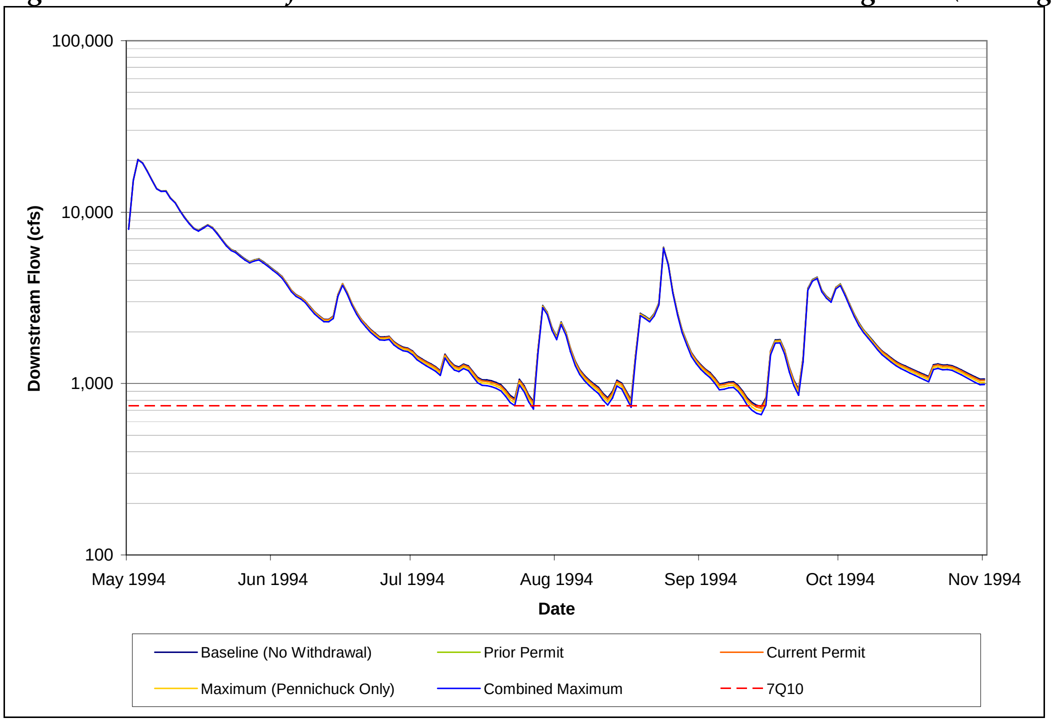


Figure 9 - Change in Flow from Baseline to Maximum Withdrawal Scenario for Pennichuck WW during 1993 (Dry) and 1994 (Average)

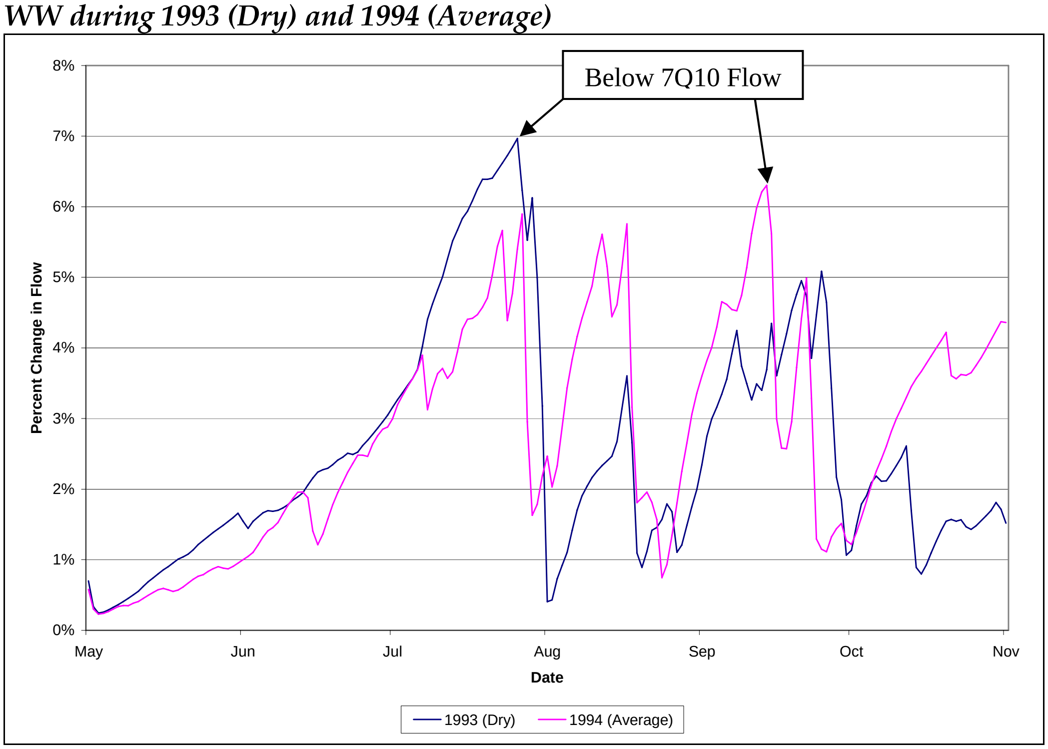


Figure 10 - Flow Duration Curves for Pennichuck Withdrawal Scenarios during 1993 (Dry)

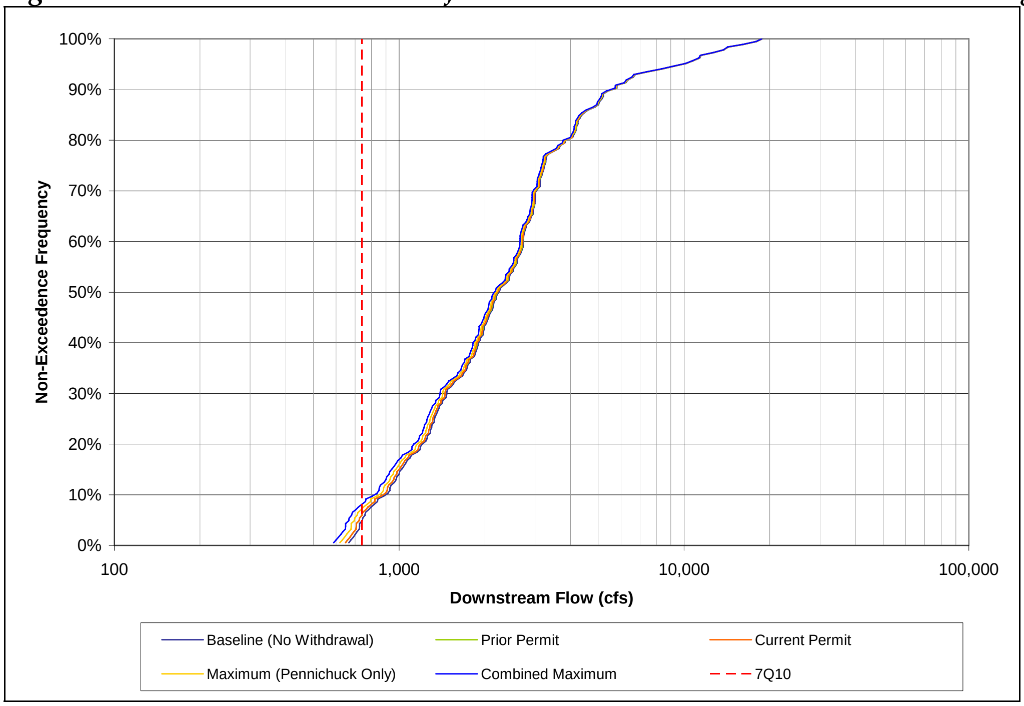
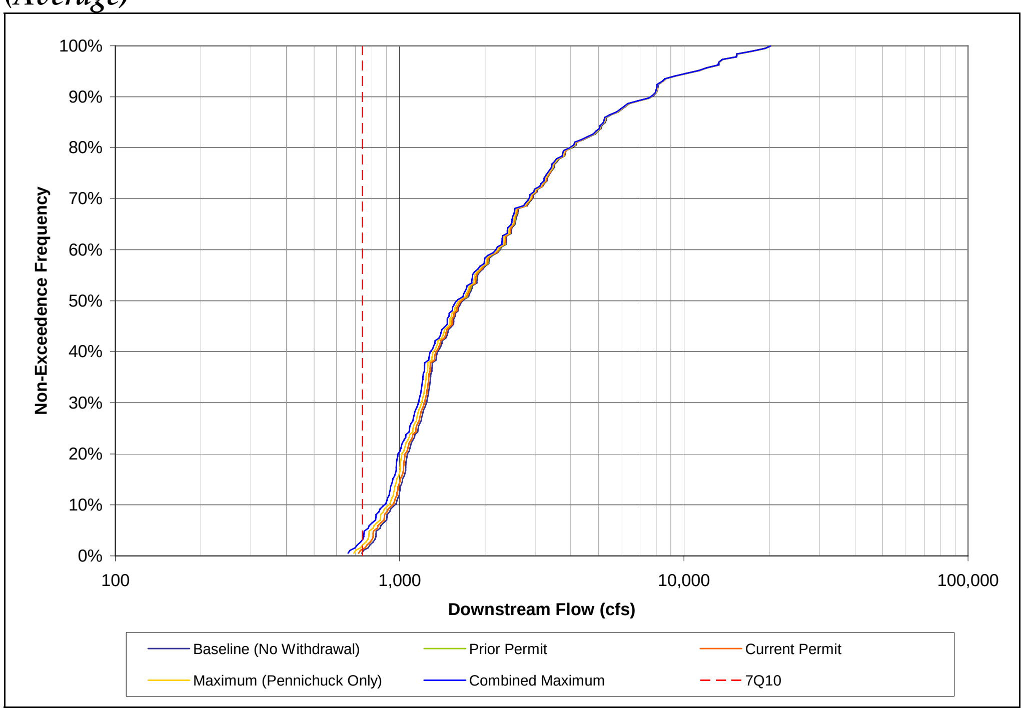


Figure 11 - Flow Duration Curves for Pennichuck Withdrawal Scenarios during 1994 (Average)



The Pennichuck Water Works withdrawal scenarios again resulted in minor impacts on the downstream river flow. The minimum flow in July of 1993 was reduced by 7.0% from 666 cfs to 620 cfs for the maximum withdrawal rate of 30 MGD (without Manchester withdrawals). Although the current permit would not allow Pennichuck to withdraw at 30 MGD, this result shows that it would still have a minor impact on the river flows. In Table 4, the average flows during the month of August, the summer, and the overall simulation period are compared to the estimated 7Q10 flow for the dry year (1993). For the maximum and maximum combined scenarios, the percent change in average flow from the baseline scenario for each period is also included in Table 4.

Table 4 – Summary of Average Flows in 1993 (Dry) for Pennichuck Water Works Withdrawals

Scenario	7Q10 (cfs)	August Average (cfs)	Summer Average* (cfs)	Overall Average** (cfs)
Baseline	740	3,529	1,951	3,104
Prior Permit	740	3,508	1,932	3,084
Current Permit	740	3,496	1,928	3,078
Maximum	740	3,482 (1.3%)†	1,904 (2.4%)†	3,058 (1.5%)†
Maximum Combined††	740	3,451 (2.2%)†	1,874 (3.9%)†	3,027 (2.5%)†

* June 21 – September 23
** May 1 – November 1
† Percent change in average flow from Baseline scenario
†† Maximum withdrawals by both Manchester WW (20 MGD) and Pennichuck WW (30 MGD)

4.3 Water Withdrawal Totals and Distributions

In addition to the impacts on the river flow, the total amounts and distribution of water withdrawals were evaluated for the Pennichuck Water Works scenarios. (This was not done for the Manchester Water Works withdrawals, since those were simulated as unconditional withdrawals in the absence of defined permit conditions). For each scenario (excluding the no withdrawal scenario), the percent of the total 185-day period that each withdrawal rate was applied was calculated. As discussed above, the current permit scenario was evaluated using three versions of the elevation criterion (Original, Lower Bound, and Upper Bound), all of which are included in this section. Also included is the current permit scenario (using the original elevation criterion) with maximum withdrawal (20 MGD) upstream by Manchester Water Works. For this scenario, the upstream flows at the Pennichuck withdrawal location were reduced by 20 MGD before calculating the allowed water withdrawals for Pennichuck under the future permit conditions.

For each scenario and each year, the total volumes of permitted withdrawals over the 185 day period are presented in Table 5 and Figure 12. The distribution of withdrawal rates as percent of the simulation period are also included in Table 5 and shown in Figures 13 and 14 for each year.

Between the dry (1993) and average (1994) years, the differences in total withdrawal volumes were minor. In some cases, the withdrawal volumes were less for the average year (1994) than for the dry year (1993); although these differences are not significant and are due mainly to the distribution of low flows during the two years.

The amount of water withdrawals allowed under the current permit requirements (~ 3,200 MG) was about 30% greater than the amount allowed under the prior permit (~ 2,500 MG). When the maximum withdrawal rate was used for the entire period, the total volume of water (5,550 MG) was more than twice that withdrawn under the prior permit.

Table 5 - Totals and Distributions of Water Withdrawals for Pennichuck Water Works

	1993 (Dry Year)				**1994 (Average Year)**			
	Total*	**% Time Pumping at:**			**Total***	**% Time Pumping at:**		
Pennichuck WW Scenario	*(MG)*	*12 MGD*	*20 MGD*	*30 MGD*	*(MG)*	*12 MGD*	*20 MGD*	*30 MGD*
No Withdrawals	0	--	--	--	0	--	--	--
Prior Permit	2,460	84	16	0	2,532	79	21	0
Current Permit (Original)	3,184	55	29	16	3,136	64	16	20
Current Permit (Upper Bound)	3,356	50	28	22	3,242	60	17	23
Current Permit (Lower Bound)	3,190	54	30	16	3,096	64	18	18
Current Permit w/ Max. Manchester	3,172	55	30	15	3,088	64	17	19
Maximum Withdrawal**	5,550	0	0	100	5,550	0	0	100

* Over 185-day Period (May 1 – November 1)
** Included for illustrative purposes only and not allowed under current permit

Figure 12 - Total Withdrawals for Pennichuck Water Works

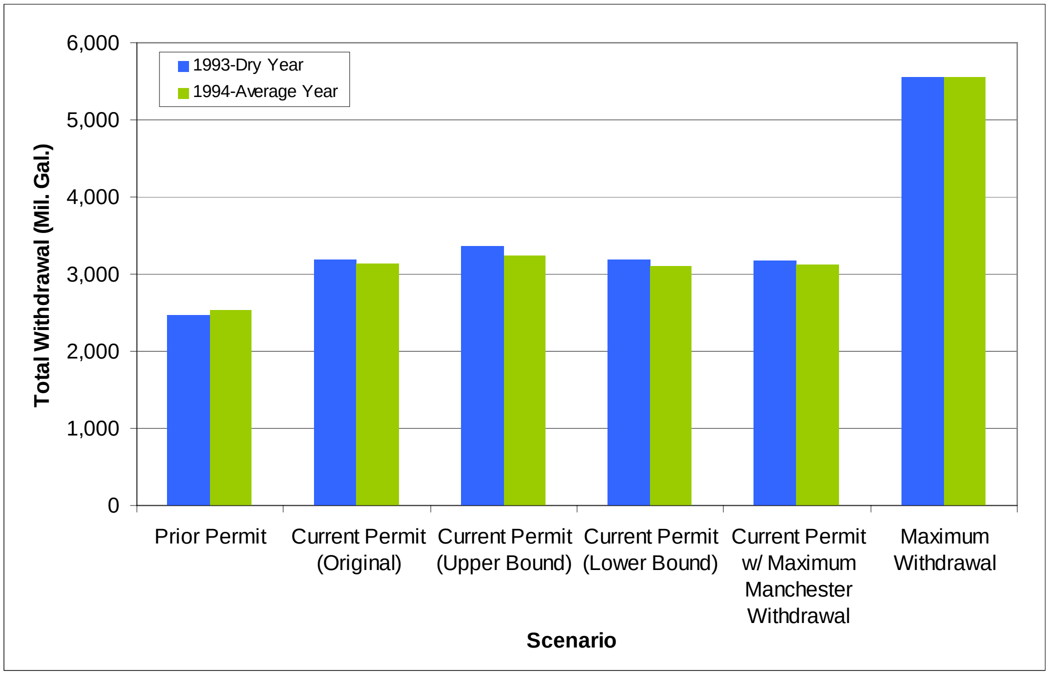


Figure 13 - Distributions of Withdrawal Rates for Pennichuck Water Works during 1993 (Dry)

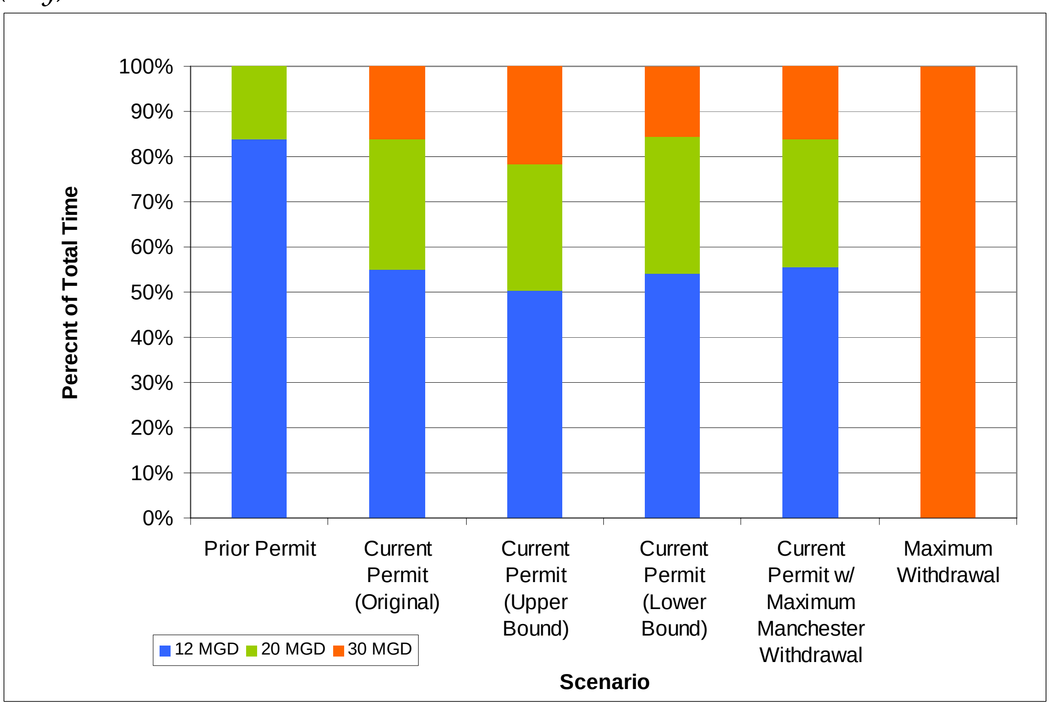
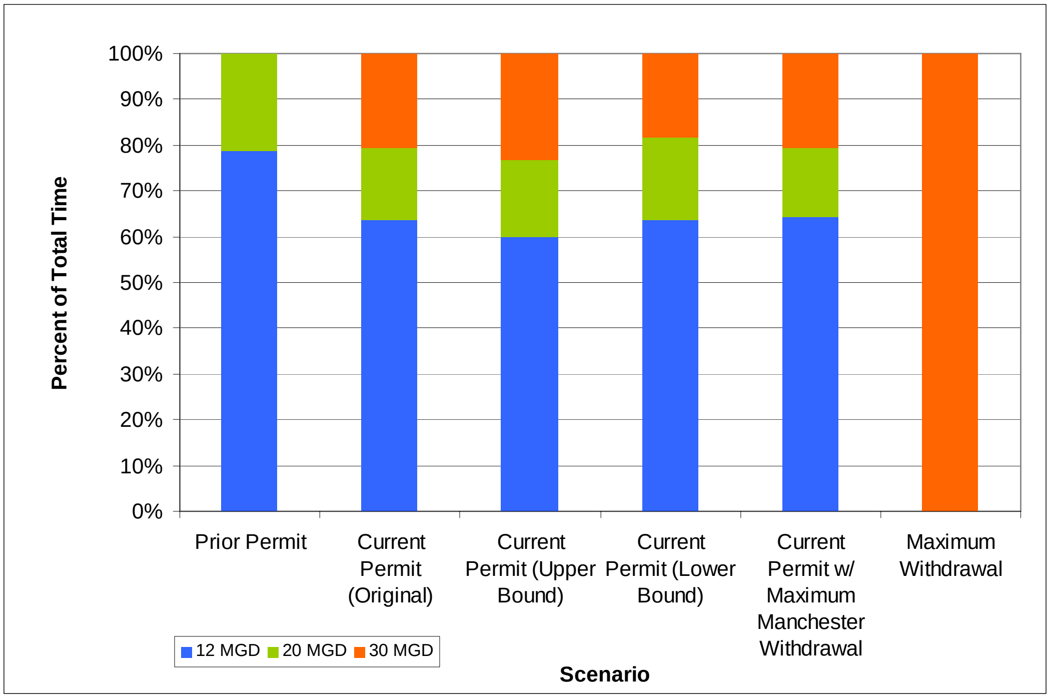


Figure 14 - Distributions of Withdrawal Rates for Pennichuck Water Works during 1994 (Average)



Time series of the withdrawal rates under the prior permit, the current permit (using the original elevation criterion), and the current permit with maximum withdrawals upstream by Manchester WW are shown in Figures 15 and 16 for each year. For all three scenarios, the maximum withdrawal rate was not allowed for extended periods of time except during the wet spring season. During the remainder of the year, the maximum withdrawal rate was only allowed for short periods coinciding with major storm events.

Figure 15 - Time Series of Withdrawal Pumping Rates for Pennichuck Water Works during 1993 (Dry)

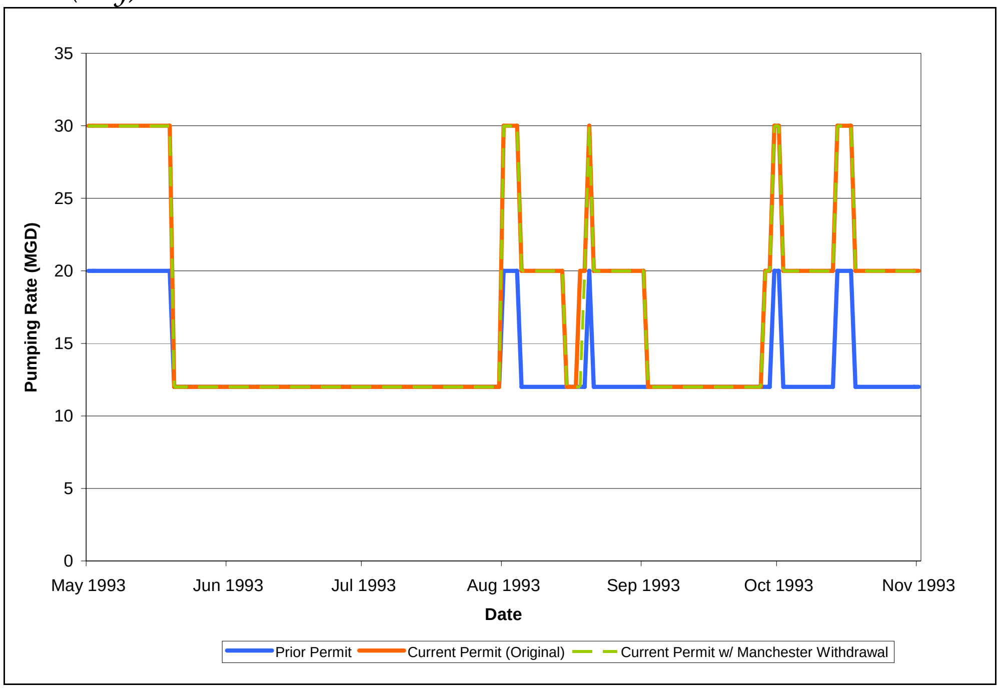
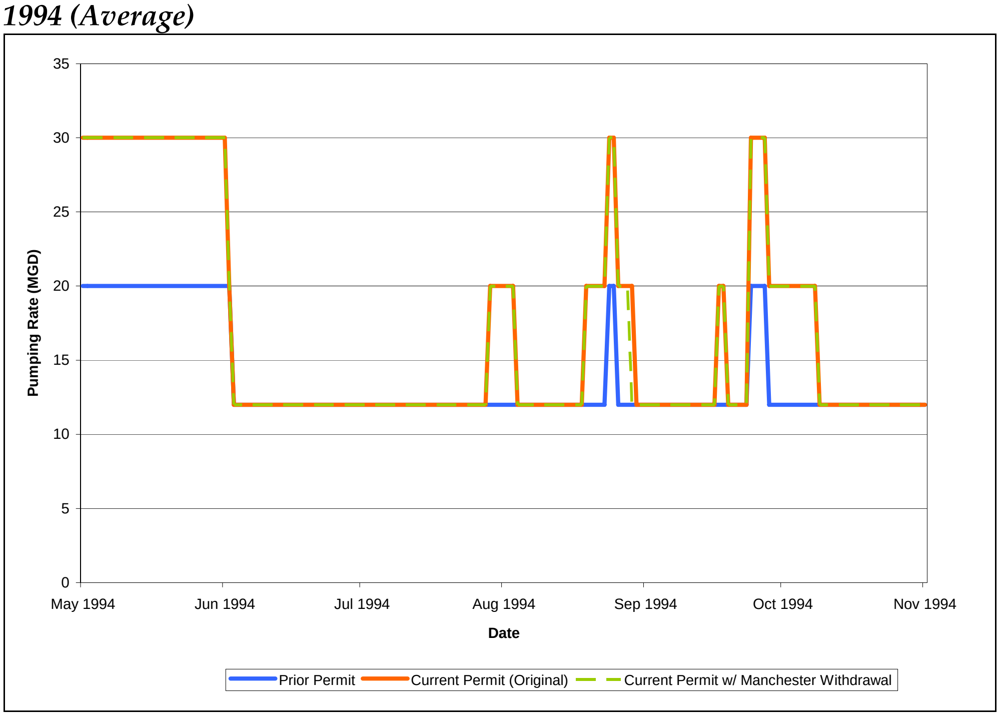


Figure 16 - Time Series of Withdrawal Pumping Rates for Pennichuck Water Works during 1994 (Average)



5.0 Conclusions and Recommendations

This preliminary evaluation indicates that the proposed water withdrawal scenarios for both Manchester Water Works and Pennichuck Water Works would have minor hydrologic impacts on the Merrimack River. For Manchester WW, the maximum withdrawal pumping rate of 20 MGD does not cause significant impacts on the river flow. Additionally, the upstream withdrawal of 20 MGD by Manchester WW has very little impact on Pennichuck WW's withdrawal amounts under the future permit conditions. In a hypothetical scenario where Pennichuck WW was allowed to withdraw at the maximum rate of 30 MGD, the impact on the river would be minor even during low flows, but under both the prior and current permits this rate is only allowed during a short period of the year.

For Manchester WW, the maximum withdrawal scenario (20 MGD) resulted in a reduction of 5-6% under low flow conditions (i.e. when the river flow is less than the 7Q10 flow) while the current permit for Pennichuck WW resulted in a reduction of 3%. If Pennichuck WW was allowed to withdraw at the maximum rate of 30 MGD at all times, which is a hypothetical scenario included only for illustrative purposes, then the low flow reduction would be 7%. Under the worst case scenario with both Manchester WW withdrawing at 20 MGD and Pennichuck WW operating under the current permit at 12 MGD under low flow conditions, the reduction is about 7-8% downstream of the Pennichuck WW withdrawal intake.

Due to the uncertainty in the correlation between flow and water surface elevation at the Pennichuck intake (flow is not measured here, and no measured data exist on the correlation between water level and flow at this location), it is advisable to examine this correlation more carefully in subsequent phases of this study. Continuous daily monitoring of staff gage height and streamflow at the Pennichuck WW intake location would be needed to improve this correlation. A monitoring period of at least one year is recommended in order to capture the full range of low to high flow conditions since the correlation is not likely to be constant across this range. This period would also include times when the relationship between water level and flow is impacted by dam operations downstream of the intake location. All three types of simulated threshold conditions (based solely on hydraulic model relationships that are inferred, but not calibrated at this specific site due to lack of data) result in somewhat restrictive withdrawal allowances, and it is difficult to ascertain the realism of such restrictions without more substantive data on flows and water levels at this site.

Despite the minor hydrologic impacts on the river flows, the impacts on water quality may be significant and will be assessed under subsequent tasks of the Upper Merrimack and Pemigewasset River Study.

6.0 References

CDM (2003). *Merrimack River Watershed Assessment Study: Description of Existing Conditions.* Prepared for New England District US Army Corps of Engineers. (Sponsor Communities: Manchester, NH; Nashua, NH; Lowell, MA; GLSD, MA; and Haverhill, MA)

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