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Town of Exeter, NH
WSE 2070533

March 2, 2010

Ms. Jennifer R. Perry, PE - Public Works Director
Town of Exeter
13 Newfields Road
Exeter, NH 03833

Re: Exeter River Drawdown Observations

Dear Ms. Perry:

In November 2009, the Town of Exeter conducted a month-long "drawdown" of the impoundment behind the Great Dam to assess the impacts of a potential dam removal on public water supplies and other water withdrawals from the river. This effort was performed as an additional task of the Water Supply Alternatives Study undertaken by the Town through funding from the New Hampshire Coastal Program and performed by Weston & Sampson. The drawdown phase sought to gain insight regarding the following questions:

- Is there a natural impoundment without the Great Dam?
- What effect would lower water levels have on the Town's ability to withdraw water at the Exeter River Pumping Station?
- What effect would a lower impoundment have on nearby groundwater levels and the proposed reactivation of the Town's Stadium and Gilman wells?

<u>Background</u>

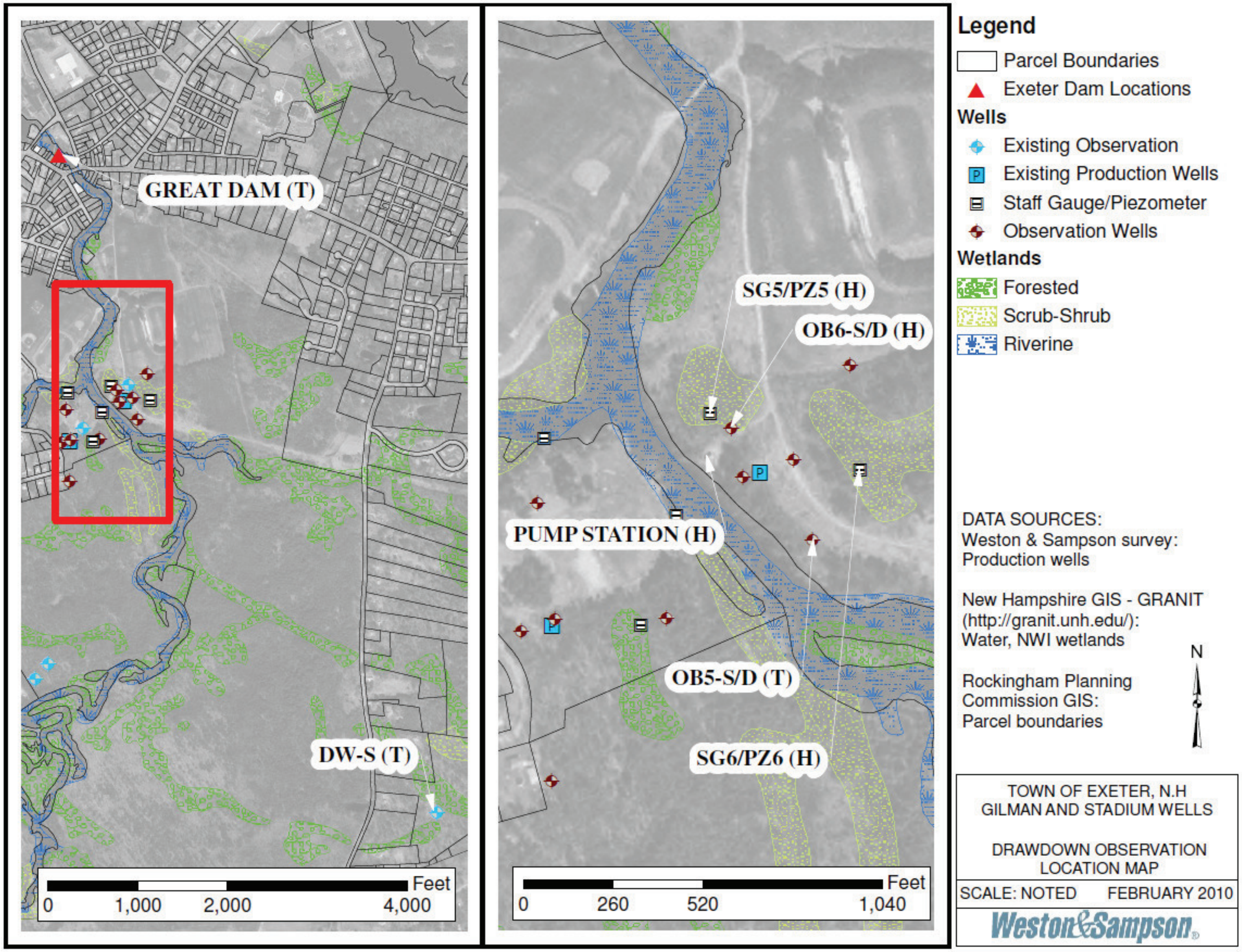
As pointed out in the Water Supply Alternatives Report completed by Weston & Sampson, previous studies and reports about the Exeter River suggest that the potential removal of Great Dam would not completely eliminate the impounded area behind the Dam. These reports estimated that the natural bedrock ledge that the Dam was constructed on would maintain an impoundment at approximately El. 15.0' NGVD29. While the impoundment would be retained to some degree, this drop would represent a significant change from the current average pond level of approximately El. 23.75' NGVD29. This drop of almost eight feet may impact the water level upstream at the Town's River Intake, which serves as a primary surface water supply source for the Town during the summer months.

By simulating a potential dam removal with the drawdown, Weston & Sampson sought to assess the Town's ability to continue to withdraw water with a lower impoundment as well as any impacts to other surface water withdrawals referenced in the Water Supply Alternatives Study. In addition, if the water level in the River were to drop from its current impounded level with the Great Dam in place, nearby groundwater levels might also be expected to drop to some degree. The drawdown allowed Weston & Sampson to observe and estimate the magnitude of those changes and their corresponding impact to the water availability at the Gilman and Stadium Wells.

Work Completed / Data Collection

In an effort to assess the impacts from a lowered River level, a variety of water level data was collected during the month-long drawdown performed at the Great Dam. This drawdown began on November 2nd at 8:00am when the low level outlet gate in Great Dam (3-foot wide by 4-ft high) was fully opened by the Town. Weston & Sampson installed a pressure transducer adjacent to Great Dam to record hourly water levels within the impoundment. Two additional transducers were deployed in monitoring wells OB5-S/D, located near the Stadium well, approximately 3,200 feet upstream of the Great Dam. The purpose was to measure water levels in both the shallow and deep aquifers respectively in an area identified during a July 2009 pumping test on the Stadium and Gilman wells as potentially containing some degree of hydraulic connection between the two aquifers. Two additional transducers were deployed in observation wells DW-S and DW-D, located in the Drinkwater Road area, to measure ambient water level trends in the shallow and deep aquifers respectively. In addition to recording water levels hourly with pressure transducers, water levels were also recorded at least daily at the River Intake pump station and other surrounding monitoring wells by Town personnel using an electronic water level meter. These additional locations included Great Dam itself in order to corroborate data from the pressure transducer at the Dam; inside the River Pump Station; two piezometer/staff gage couplets in wetlands near the Stadium Well site, PZ5/SG5 and PZ6/SG6; and two observation wells, OB6-S and OB6-D, located in the shallow and deep aquifers respectively between two wetland sites. The locations of each observation point are shown in Figure 1 while the specifications of each observation well are provided in Table 1.

Figure 1: Drawdown Observation Location Map



Note: (T) Transducer measurement, (H) Electronic water level meter measurement

Table 1: Observation Well Details

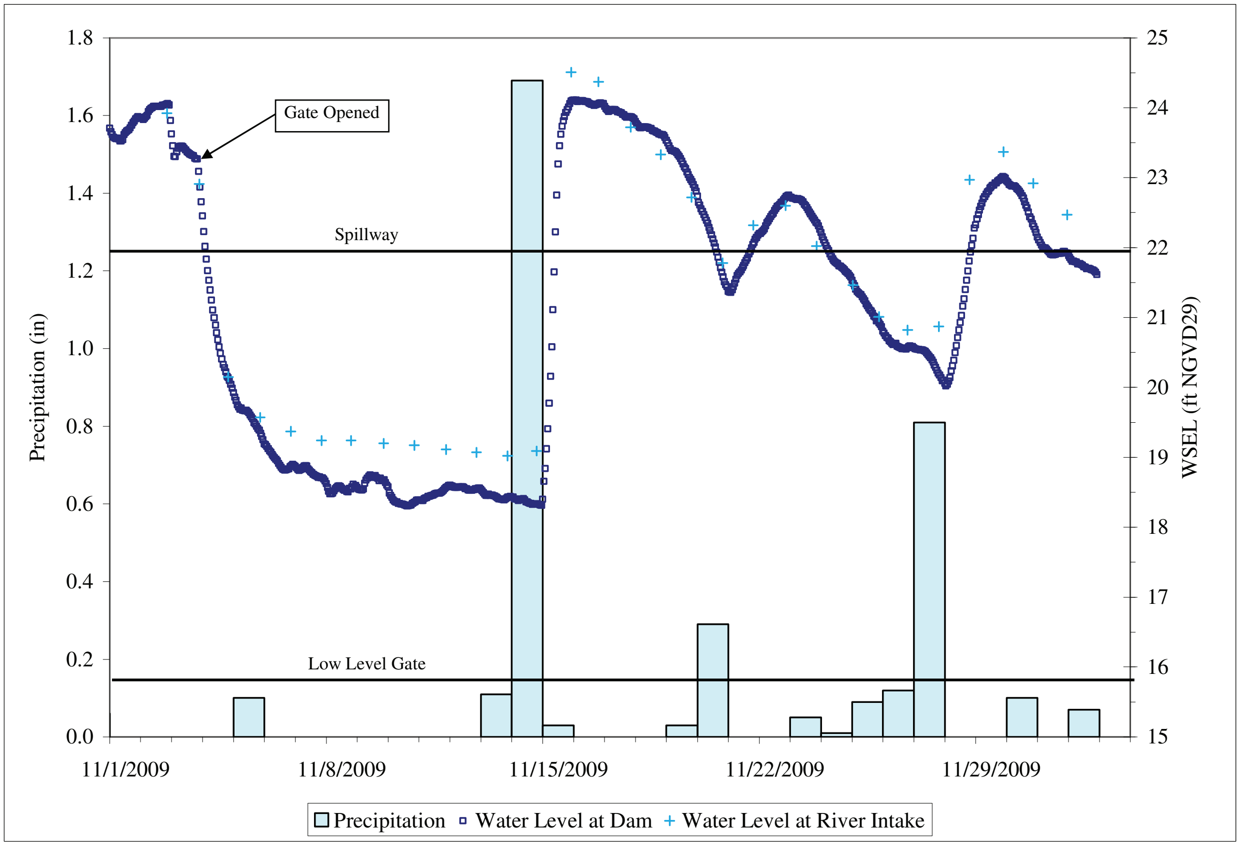
Well ID	X-Coordinate (Easting)[1]	Y-Coordinate (Northing)[1]	Z-Coordinate (Elevation)[2]	Well Diameter	Screen Interval[2]		
				(in)	*(ft)*		*(ft)*
OB5-S	1178315.98	173294.40	29.32	1.25	19.32	-	24.32
OB5-D	1178317.85	173295.00	29.36	1.25	-7.64	-	-4.64
OB6-S	1178114.07	173619.53	30.11	1.25	18.11	-	23.11
OB6-D	1178113.26	173617.99	30.23	1.25	-16.77	-	-14.77
DW-D	1181660.04	168910.78	33.56	2.5	-94.44	-	-106.44
DW-S	1181635.45	168930.89	32.71	2.5	20.71	-	15.71
PZ5/SG5	1178083.16	173609.59	26.79	1.25	19.79	-	17.79
PZ6/SG6	1178326.63	173574.33	27.84	1.25	20.84	-	18.84

Notes: 1. NH State Plane Coordinate System, NAD83 feet.
2. Feet above MSL NGVD29 (measured from top of casing).

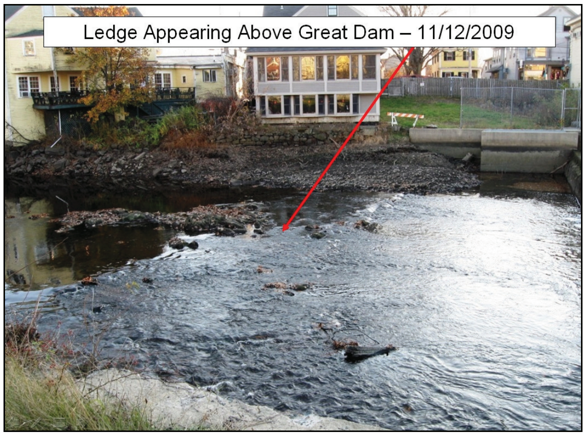
<u>Surface Water Observations</u>

The commencement of the drawdown roughly coincided with an approximately two-week period of little to no precipitation within the Exeter River watershed and correspondingly low river discharge. Discharge from the dam's gate, roughly 180 cfs, coupled with low inflow (between 30 and 50 cfs during that two-week period) resulted in a measurable drop in water level within the impoundment. As shown in Figure 2, a water level of approximately El. 18.25' NGVD29 was sustained at Great Dam from November 7th to November 14th, representing a drop of 4.5 feet from the Dam's average pond level of El. 22.75' NGVD29. Data derived from the drawdown was then analyzed to estimate the magnitude of impact to local water resources by the potential removal of Great Dam.

Figure 2: River Water Levels during November 2009 Drawdown



The drawdown largely confirmed the presence of a natural bedrock ledge immediately upstream of Great Dam. While the ledge was partially obscured by the continued flow of the river as well as rocks, bricks, logs, leaves, and other debris, it is clear that the ledge extends the width of the River.

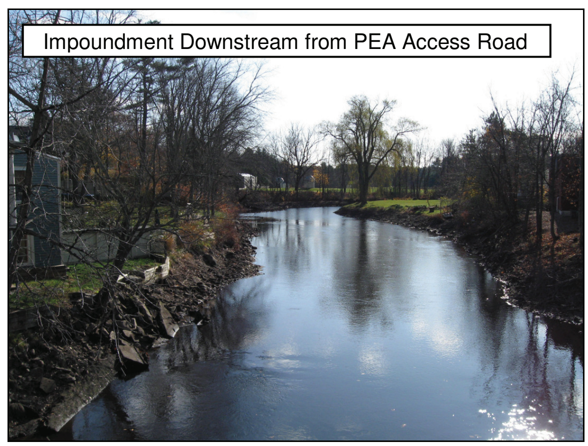



Exposed Bedrock Ledge Above Great Dam – 11/12/2009

Observed bedrock (or ledge) was evident at a somewhat higher elevation than estimated in previous studies. Based on observations from the drawdown, the bedrock ledge forming the natural impoundment is likely to appear between El. 16.0’ and 18.0’ NGVD29 at the Great Dam location. An elevation survey of the ledge is recommended to confirm this visual observation

The drawdown confirmed earlier estimates as shown in the following photos. Generally, the River was slightly narrower and consequently faster. Overbank areas were significantly more distinguished from the river channel and floodplain. These changes were most obvious near the confluences of the many tributaries, such as the Little River, the Cove, and Great Brook.

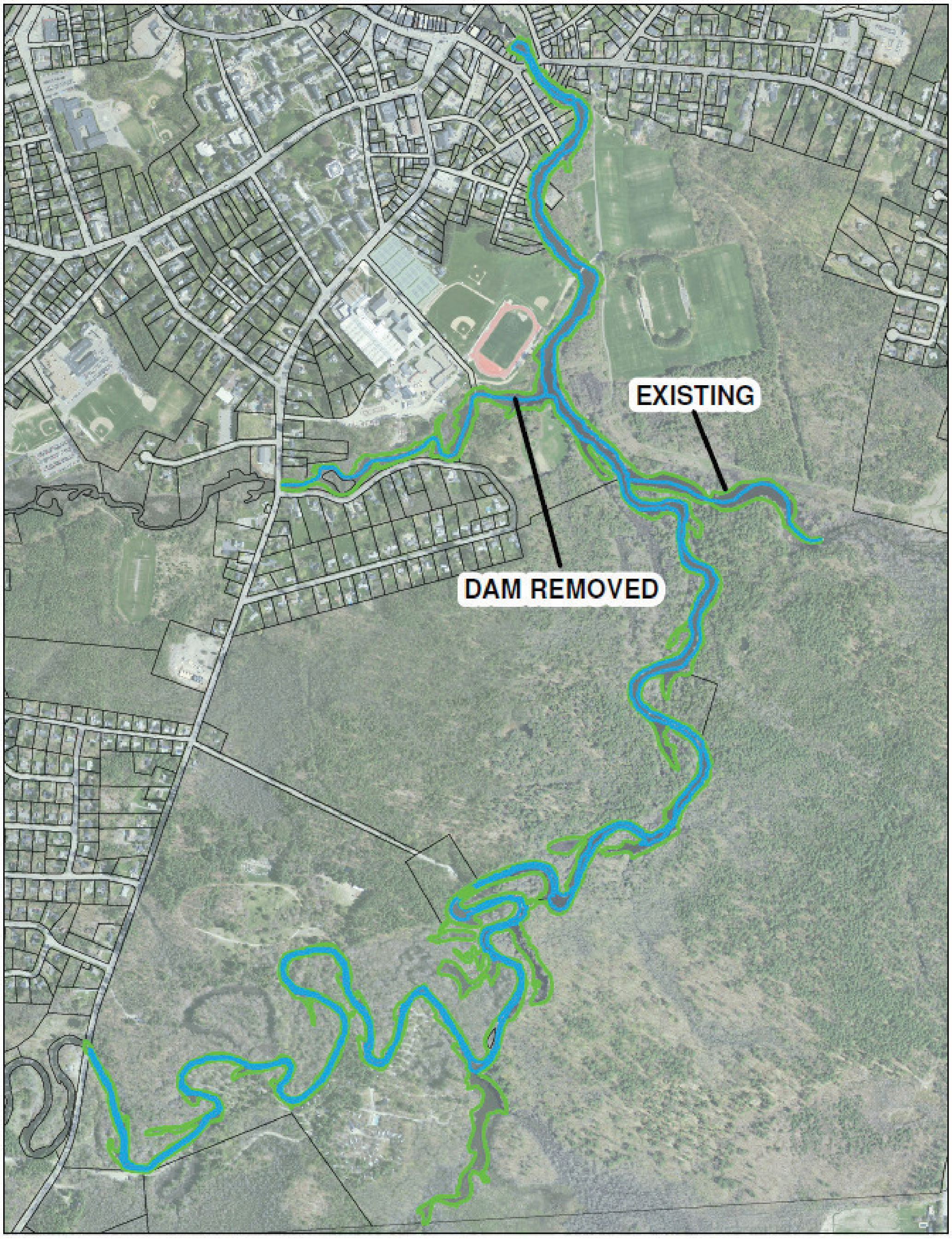

Little River Looking Upstream from PEA Footbridge


Impoundment Downstream from PEA Access Road

Throughout the course of the drawdown, Weston & Sampson performed site visits to observe these and many other areas within the impoundment. A number of additional photos are attached to this letter to highlight the riverine nature of the impoundment experienced during the drawdown.

In addition to confirming the presence of a natural impoundment, the drawdown also simulated what changes might look like for the effected river corridor with a lower water level. Prior to the drawdown, the natural impoundment was estimated to be significantly more riverine than the current impoundment. Figure 3 shows an estimate of the aerial extent of natural impoundment.

Figure 3: Hypothetical Areal Extent of Natural Impoundment



The more riverine nature of the Exeter River was also reflected in the impoundment's hydraulic grade line. Typically, the Great Dam impoundment creates a flat hydraulic grade line or ponded water level from the dam to the River Intake. During the drawdown, however, this relationship changed. When the water level at Great Dam was sustained at approximately El. 18.25', the water level at the River Intake was approximately one foot higher. This is shown in Figure 2. Combined with the higher-than-expected bedrock ledge, this increased hydraulic slope yielded promising results regarding the Town's ability to withdraw water at the River Intake pump station with a lower impounded water level.

Previous studies indicated that maintenance of sufficient withdrawal capability at the River Intake would require a minimum water surface elevation of approximately El. 16.0 feet. These studies also suggested that a natural impoundment might have an average pond level of only El. 15.94' suggesting a potential problem for water withdrawals during low flow periods via the existing River Intake location and depth.

The results, however, indicate this issue may not be as severe as previously hypothesized. The observations during the drawdown show that (1) the bedrock ledge currently above the Great Dam would likely form a natural impoundment one to three feet higher than anticipated at the Dam location and (2) the shift in the hydraulic grade line without Great Dam would likely cause water levels to be approximately one foot higher at the River Intake. These two factors, revealed during the drawdown, suggest that while modifications to the River Intake might be required if Great Dam were removed, these modifications may not be as substantial as previously thought. It is very likely that average water withdrawals, between 1.0 and 1.3 million gallons per day, would still be possible for much of the year even without any modifications to the River Intake. In fact, the Town pumped between 1.0 and 1.3 million gallons per day from the River throughout the entire drawdown.

Observations performed during this drawdown confirmed that other surface water withdrawals from the Exeter River would also be impacted by a lower impoundment level. These water withdrawals, noted in Weston & Sampson's 2009 "Exeter River Study," include withdrawals for irrigation at Phillips Exeter Academy, irrigation and cooling at the Exeter Mills Apartments, and the Founders Park dry fire hydrant. During the drawdown, the water level of the impoundment dropped below the intakes of all three of these withdrawals. If Great Dam were to be removed, these surface water withdrawals would require additional design and construction to modify their intakes and allow for continued withdrawals.

Groundwater Observations

Water level data derived from the drawdown also allowed for analysis of potential impacts to groundwater levels. As previously mentioned, groundwater levels were tracked throughout the month-long drawdown at several locations in the Gilman and Stadium Well area. Those datasets were then analyzed to determine the magnitude and timing of the influence of Exeter River levels on groundwater levels in that area. This analysis, including data collections, trends and preliminary findings are discussed in the following section of this letter.

Water Level Data Corrections

Barometric Pressure:

Weston & Sampson first corrected the water level datasets recorded by pressure transducers for changes in barometric pressure. When using non-vented pressure transducers, a correction for the barometric pressure must be made to compensate for changes in atmospheric pressure. An increase in atmospheric pressure causes the water level to decline and a decrease causes water levels to rise. The barometric data was obtained using a Solinst® Barologger installed above the water table in OB-5. The data from the Barologger was applied as a correction to all water level readings obtained with the transducers.

The barometric efficiency is the ratio of water level changes in a well to the changes in barometric pressure that produces them. An estimate of barometric efficiency was also calculated and applied as a correction to the data sets. This relationship, the barometric efficiency, was consistently shown to be approximately 0.18, namely that for every foot of barometric pressure placed on the observation wells, the water level measurement was artificially increased 0.18 feet.

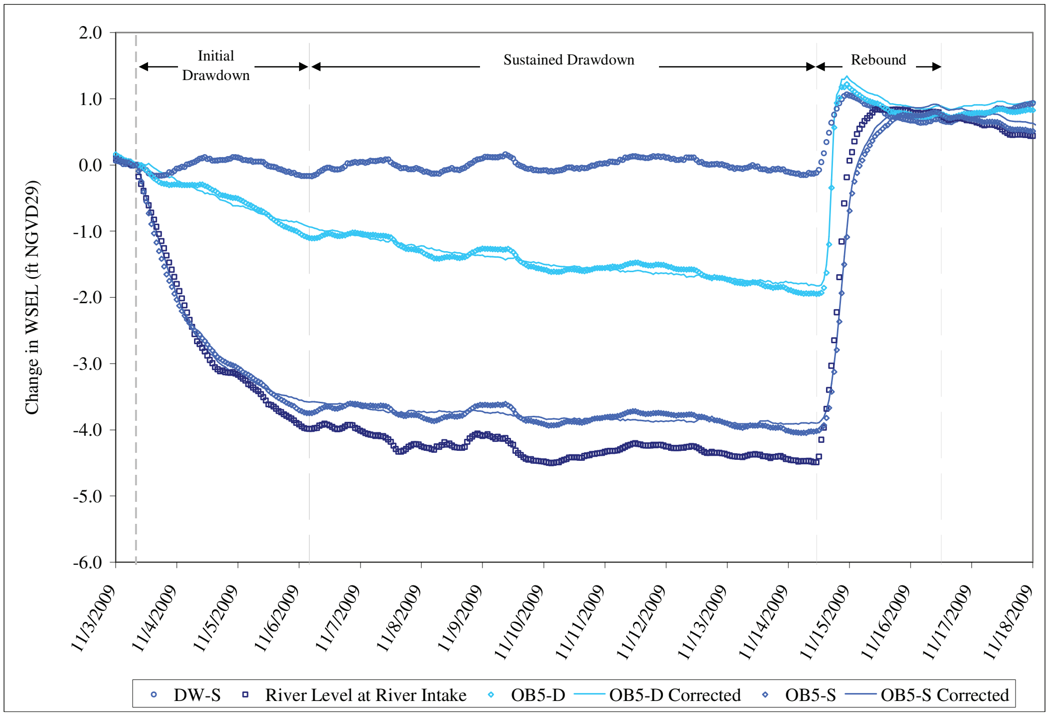
Measurements taken with the electric water level meter were not corrected for barometric pressure fluctuations as they are a true measure of the groundwater elevation.

Ambient Groundwater Level Trend:

Pressure transducers were also employed in two observation wells (DW-S and DW-D), located outside the area expected to be impacted by the drawdown. The purpose of these two data sets was to measure ambient water level trends in both the shallow and deep aquifer systems from September 3rd to December 2nd, 2009. The goal of the ambient groundwater monitoring was to create hydrographs that reflect the overall response of the aquifers in areas as close to natural conditions as possible. This information was used to correct or cancel out the effects of ambient groundwater level trends as a function of recharge events or lack thereof.

As shown by water level trends at DW-S and OB5-S in Figure 4, the shallow aquifer being monitored by both of the aforementioned shallow observation wells did respond to several small precipitation events during the drawdown. As expected, water levels at DW-S did not respond to changes in river level, only to the ambient groundwater trends in the shallow aquifer. In an effort to understand the effects on the shallow aquifer from the river drawdown event, ambient groundwater trends were removed from the datasets for all shallow aquifer observation points. This trend removal would then reveal the impact of the river drawdown on the shallow aquifer groundwater levels. The resultant raw and corrected datasets are shown in Figure 4. Unfortunately, because the transducer in DW-D appeared to have been tampered with, ambient water level monitoring data were not available for the deep aquifer. Previous monitoring efforts however, afforded an understanding of the relationship between the shallow and deep aquifer trends, thus allowing for use of the shallow trend to be used for the deep aquifer corrections as well. Further discussion and analysis of this relationship was discussed in Weston & Sampson's 2009 Stadium and Gilman Well Pumping Test Report. Based on the previously established relationship, water level records from the deep aquifer were corrected with the DW-S hydrograph as well, as shown in Figure 4.

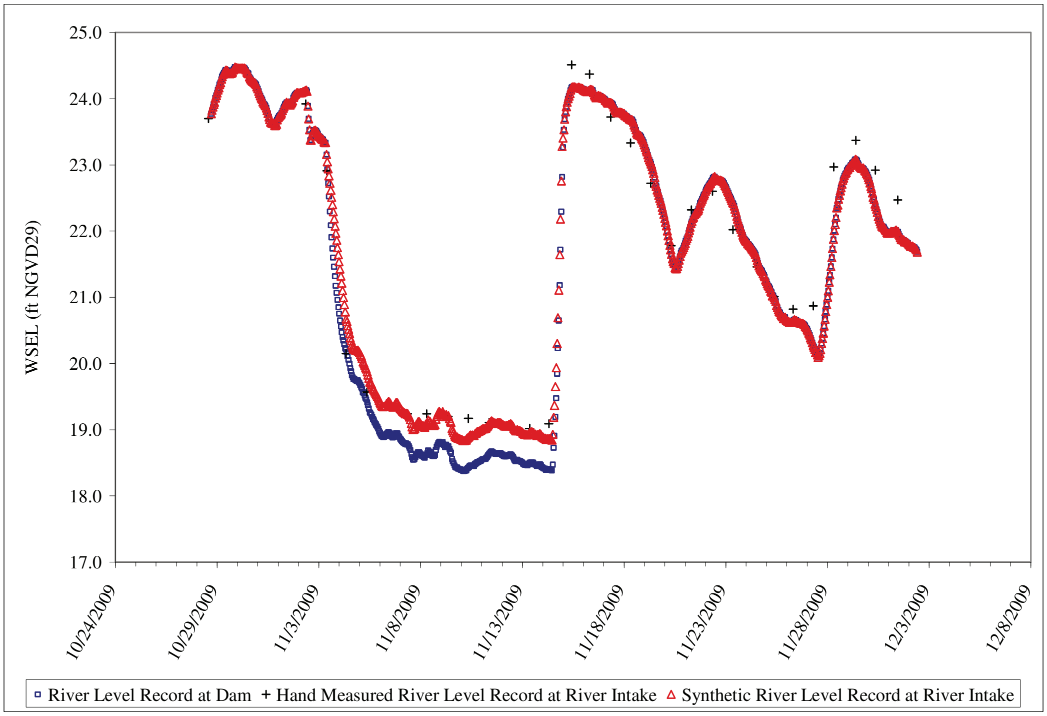
Figure 4: Water Levels Corrected for Ambient Groundwater Trends



Synthetic River Level Development:

In examining the reaction of the groundwater table to the falling river level at the aforementioned locations, it was important to recognize the steepening of the hydraulic grade line (slope) between the Town's River Pump Station and Great Dam during the drawdown. Combining the water levels taken hourly at the River Pump Station with the water levels taken every minute at the Dam, a synthetic River level was developed for the River Pump Station. As shown in Figure 5, this new finer resolution synthetic dataset could then be used to develop an understanding of both the magnitude and timing of a response at the River Pump Station to changes in river level at the Great Dam. In turn, this new synthetic dataset could now be used to understand the magnitude and timing of changes to nearby groundwater levels that were observed each minute as a result of changes to the river level at the River Pump Station (now temporally quantified each minute).

Figure 5: Synthetic River Level Record at the River Intake



Hydrographs of the synthetic River level at the River Intake compared to the shallow and deep groundwater levels at the aforementioned observation wells are presented as Figure 6 and 7 respectively. Using the synthetic River Intake record, Weston & Sampson analyzed the reaction of nearby groundwater levels. Estimates of the magnitude and the time lag of the observed groundwater reactions were quantified and then presented in Table 2. These estimates were differentiated into three time periods as shown in the figures below; the <u>initial drawdown</u> from 8:00am on 11/3 to 4:00am on 11/6 during which the river level dropped quickly, the <u>sustained drawdown</u> from 4:00am on 11/6 to 11:00am on 11/14 when inflow and outflow to the impoundment were approximately equal, and the <u>rebound period</u> from 11:00am on 11/14 to 12:00pm on 11/16m, when a 2-inch rain event refilled the impoundment.

Table 2: Summary of Groundwater Reactions to the River Drawdown

Location		Initial Magnitude *(ft)*	Initial Lag *(hrs)*	Sustained Magnitude *(ft)*	Rebound Magnitude *(ft)*	Rebound Lag *(hrs)*	Rebound Total Time *(hrs)*	Dam Removal Magnitude *(ft)*
River	Intake	-3.99	0	-4.49	5.25	0	12.5	-7.75
Shallow Aquifer	OB5-S	-3.58	<1	-3.9	4.78	1	16	-6.73
	OB6-S	-3.25	**	-3.87	4.12	**	**	-6.68
	DW-S	*	*	*	*	*	*	*
Deep Aquifer	OB5-D	-0.94	2	-1.83	2.72	2	6.5	-3.15
	OB6-D	-0.21	**	-0.26	0.54	**	**	-0.45
Wetlands	SG5	-0.09	**	-0.39	0.51	**	**	-0.67
	PZ5	-0.05	**	-0.25	0.09	**	**	-0.43
	SG6	-0.03	**	-0.33	0.68	**	**	-0.57
	PZ6	*	*	*	*	*	*	*

Notes: * No significant trend was identified at this location.
** No lag time was identified at this location due to the temporal resolution of the data.

As expected, water levels in the shallow aquifer located adjacent to the Exeter River generally tracked the Exeter River closely. Water levels at DW-S, located approximately one mile from the River Intake/Gilman and Stadium Well area, showed no significant reaction to the drawdown and was used to understand the ambient aquifer trends absent any river manipulations. Water levels at OB5-S and OB6-S, located close to the Exeter River showed a sustained response equivalent to 87% and 86% of the drop in river level respectively. Additionally, shallow aquifer observation points showed extremely short lag times, generally within one hour of a change in river level. This short lag time is clearly visible in Figure 7 as the water level in both OB5-S and OB6-S changed relatively little after the initial drawdown period.

Figure 6: Groundwater Reaction to Drawdown in the Shallow Aquifer

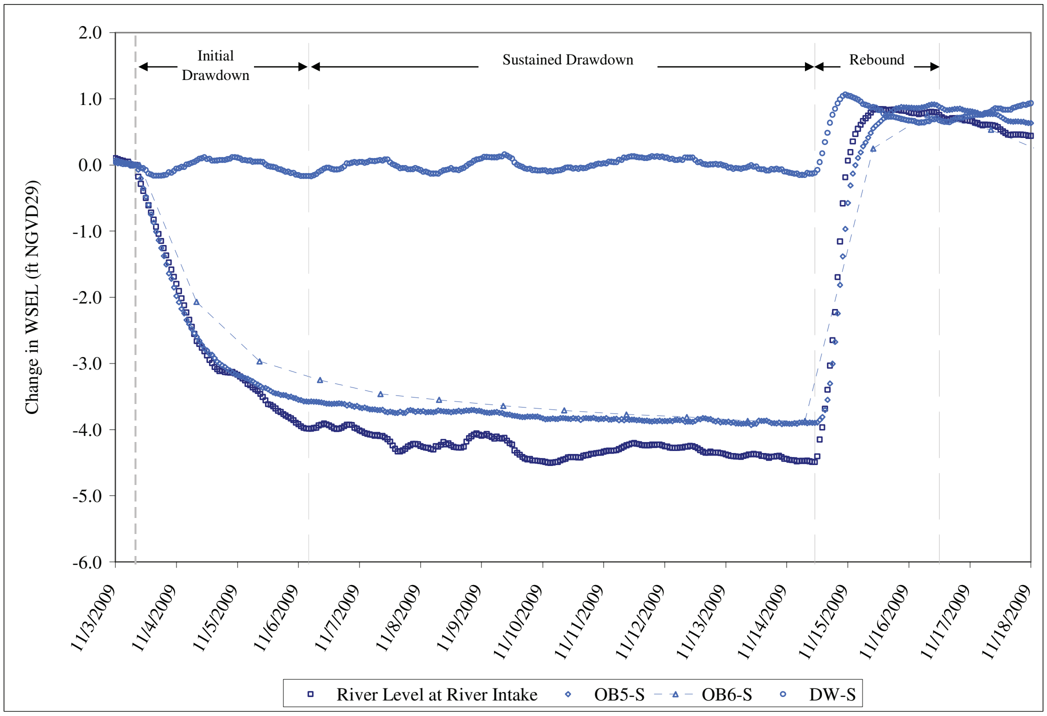
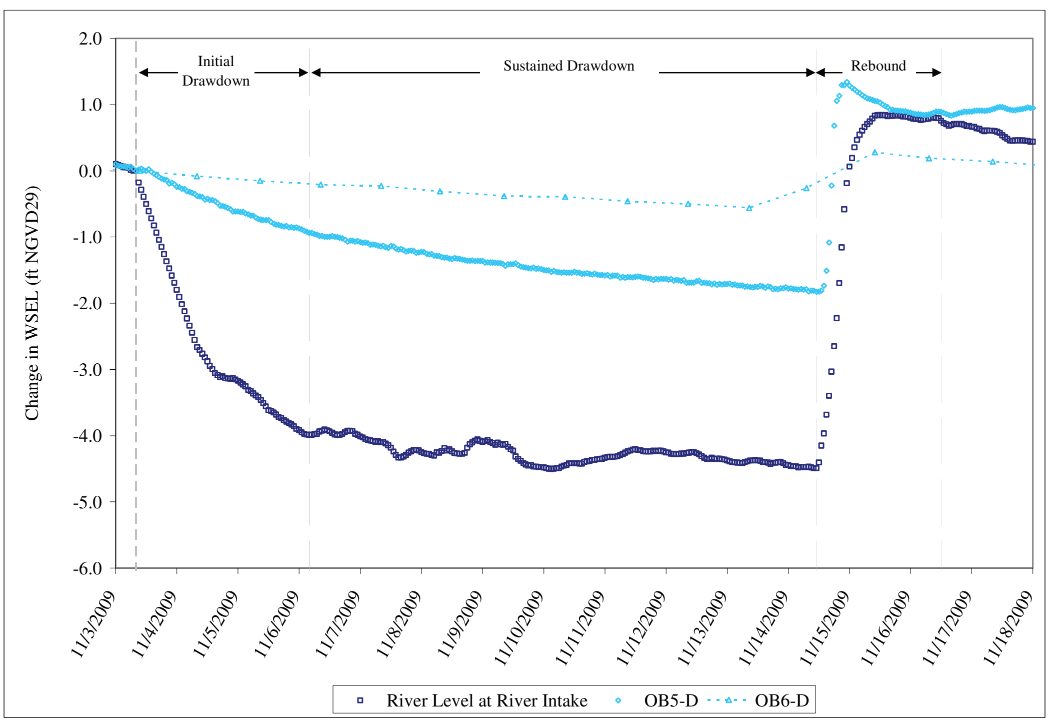


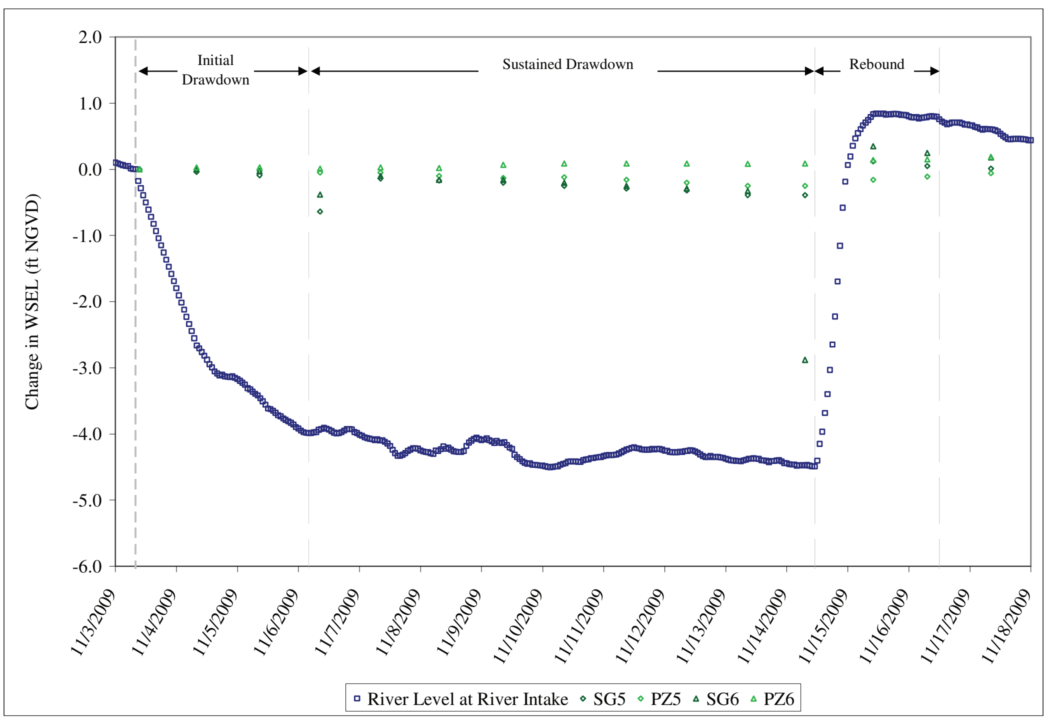
Figure 7: Groundwater Reaction to Drawdown in the Deep Aquifer



Water levels in the deep aquifer also tracked those of the Exeter River, though significantly less so than their shallow counterparts. Water levels at OB5-D and OB6-D showed initial responses equivalent to 23% and 5% of the drop in river level respectively and sustained responses of 41% and 6%. Water levels began to change in OB5-D within two hours of the drawdown; however the full magnitude of that change took several days as shown in Figure 76.

Surface and shallow groundwater levels measured in two wetlands near Stadium Well showed relatively little movement in response to changing river levels. Water level response in each wetland did not exceed 0.5 feet or more than 10% of the change in river level. Any response that was observed showed a significant lag time and occurred over many days.

Figure 8: Groundwater Reaction to Drawdown in Sensitive Receptors



A safe yield analysis was performed on the Gilman and Stadium production wells as individual sources as well as a combined source during a 2009 pumping test of the wells. The analysis was conducted using the specifications of the production wells, the pumping test data, as well as projections of drawdown and specific capacity over a time period of 180 days of pumping without recharge. The projections of drawdown utilized data from a 5-day pumping test and extended that data under conditions of no recharge. This in turn gave a level of certainty that the well will provide a constant source of water now and into the future (180 days) regardless of a rainfall event to recharge the aquifer. Both the drawdown and specific capacity projections were made to provide a conservative estimate of safe yield for the two pumping wells. As shown in Table 3. Gilman and Stadium Wells were originally estimated to yield a combined 820 gallons per minute or 1.1 to 1.2 million gallons per day.

Table 3: Safe Yield Summary Table – Current Conditions with Great Dam

Summary Table - With Dam		
Individual Safe Yields	gpm	gpd
Gilman	580	835,200
Stadium	840	1,209,600
Combined Safe Yields		
Gilman	330	475,200
Stadium	490	705,600
TOTAL	**820**	**1,180,800**

These original safe yield estimates were adjusted to account for the drop in groundwater level due to the potential removal of Great Dam. As noted in Table 2, the greatest anticipated drop in static water level in the deep aquifer due to the potential dam removal is approximately 3.15 feet. Lowering the static water level ultimately lowers the availability of water to the pumping wells and, in turn, changes the estimated safe yield to approximately 740 gpm or 1.1 mgd (Table 4).

Table 4: Safe Yield Summary Table – Without Dam

Summary Table - No Dam		
Individual Safe Yields	gpm	gpd
Gilman	540	777,600
Stadium	760	1,094,400
Combined Safe Yields		
Gilman	300	432,000
Stadium	440	633,600
TOTAL	**740**	**1,065,600**

Shown in Table 5, this change represents an 80 gpm or 0.12 mgd reduction in the estimated safe yield of Gilman and Stadium production wells due to the potential removal of Great Dam, or a drop of approximately 11%.

Table 5: Safe Yield Summary Table

Summary Table - Change		
Individual Safe Yields	gpm	gpd
Gilman	40	57,600
Stadium	80	115,200
Combined Safe Yields		
Gilman	30	43,200
Stadium	50	72,000
TOTAL	**80**	**115,200**

<u>Findings</u>

The analysis of water level data collected during the drawdown revealed the potential impacts of a Great Dam removal on groundwater levels in Exeter. Visual observations made during the drawdown also provide a preliminary assessment of the impacts of potential dam removal on the impoundment itself and on the Town's ability to physically withdraw water from the River nearby groundwater resources.

Great Dam Impoundment

The month-long drawdown lowered the water surface at Great Dam to a minimum elevation of approximately El. 18.25' NGVD29. Based on the visual observations of bedrock ledge at Great Dam and the steepening of the hydraulic slope between the Dam and River Intake during the drawdown, it appears that a potential removal of Great Dam would yield an average pond elevation of no less than 16.0' NGVD29. This pond level would represent a 7.34' drop in water level from existing conditions, or 1.73 times the drop in river level experienced during the drawdown. By multiplying the sustained relative reaction (percent) of groundwater levels experienced during the drawdown by 1.73, the potential dam removal-induced change in groundwater levels was estimated for the River Intake/Gilman and Stadium Well area. Those estimated changes ranged in value between 6.5 and 7.0 feet in the local shallow aquifer;

approximately 3.15 feet at OB5 and 0.45 at OB6; and ranging between 0.4 and 0.7 feet in the Stadium wetlands (Table 2).

Gilman and Stadium Wells

Temporarily lowering the Great Dam impoundment provided a short-term simulation of impacts to groundwater levels in the area of two proposed reactivated pumping wells (Gilman and Stadium) under post-dam removal conditions. The impact of lowered groundwater levels on the safe yield of these production wells was estimated using this data and was found to represent an 80 gpm or 0.12 mgd reduction in the estimated safe yield of Gilman and Stadium production wells due to the potential removal of Great Dam, or a drop of approximately 11%. Combined, the two wells are still projected to produce approximately 1.06 million gallons-per-day of safe yield under post-dam removal conditions.

Exeter River Withdrawals:

The results of the drawdown indicate a bedrock ledge would form a natural impoundment therefore shifting the hydraulic grade line in the River. This shift would cause water levels to be an additional one to two feet higher than expected at the River Intake. These two factors suggest that while modifications to the River Intake will be required if Great Dam were removed, these modifications would not be as substantial as previously thought. It is very likely that average water withdrawals, between 1.0 and 1.3 million gallons per day, will still be possible for some of the year even without any modifications.

Sensitive Receptors:

A cursory review of the data derived from the wetlands indicates that the vertical hydraulic gradient in the wetlands is negative (upward), indicating that the wetlands receive recharge from both precipitation and the shallow aquifer (below the peat layer of the wetland). In a no dam condition, the shallow aquifer water level is predicted to drop close to seven feet and presumably slowly reverse this vertical hydraulic gradient, thus causing water to leak downward into the shallow aquifer system. Data observed throughout this drawdown period, however, revealed water levels both in the standing water within the wetland (SG) and the shallow aquifer (PZ) decreasing. Due to the fact that the standing water decreased at a greater rate than the shallow aquifer, higher negative (upward) vertical hydraulic gradients were produced. Based on these observed conditions, estimates of time to reverse this gradient and subsequently start to desiccate the wetland observed cannot be made during this short observation period. To fully understand the hydrology of the complex wetland environments, a minimum of a year long study would be recommended to assess the seasonal nature of the wetland system.

Summary and Recommendations

This relatively short glimpse at various conditions and responses to a lower river level condition at the Town of Exeter's Great Dam provided valuable planning level findings regarding dam removal or alteration. Although additional work is needed to assess the potential long-term impacts from a number of other perspectives, these findings provide a baseline of understanding of the Great Dam and its effect on the local hydrology. The following items are recommended for further refinement of this analysis:

- Perform a follow-up drawdown, preferably during a lower flow period and for a longer duration to assess potential effects of a lowered impoundment.
- Perform a site bathymetric survey of the river channel where the bedrock ledge appears in front of the Great Dam to confirm its presence and depth.
- Install data logging transducers in the monitoring wells and at the river to gather data for longer-term analysis of water levels.

We are very pleased to have worked with you on this project. We look forward to our continued work with the Town in assessing the most viable and cost effective solutions to the Town's water resource issues.

Please feel free to contact the undersigned if you need additional information or follow-up. We would be more than happy to present these findings at a public forum or before the Town's Board of Selectmen if needed.

Very truly yours,

WESTON & SAMPSON ENGINEERS, INC.

Kevin MacKinnon, P.G.
Technical Leader, Hydrogeology

Brian Goetz
Technical Leader, Water Resources

Attachments/Enclosures

cc: Ted Diers, NH Coastal Program
Russ Dean, Exeter Town Manager

KAM/aw

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