Tighe&Bond
Engineers | Environmental Specialists

L-0700-013
January 3, 2019

Mr. Dexter Legg, Chairman
City of Portsmouth Planning Board
1 Junkins Avenue
Portsmouth, New Hampshire 03801

Re: **Lonza Biologics – Subdivision Application**
Waiver Request from Part 506.01(c) Cul-de-Sac Length and Diameter

Dear Mr. Legg:

On behalf of Lonza Biologics, we respectfully request a recommendation for approval to the Pease Development Authority (PDA) to grant the following waiver related to a PDA Subdivision Application for a proposed industrial development located at 70 and 80 Corporate Drive and 101 International Drive on Pease International Tradeport:

- Part 506.01(c) – Minimum cul-de-sac radius of 80 feet required where 45 feet is provided and maximum cul-de-sac street length of 500 feet required where approximately 800 feet is provided.

The abandonment of the 1,800 LF of Goosebay Drive along Lonza's existing frontage will result in a approximately 800 LF public right of way that will remain with a dead-end. The full portion of Goosebay Drive cannot be abandoned and merged with the proposed parcel because there is an existing driveway to an abutting property on the northeast portion of Goosebay Drive. The City of Portsmouth Department of Public Works (DPW) maintains the roads on Pease International Tradeport as per agreements with the PDA. A cul-de-sac will be constructed on the dead-end of this remaining public right to allow DPW maintenance vehilces to turn around at the end of the road.

The length of road needs to exceed the maximum length requirement due to the location of the abutter's driveway that necessitates this portion of road to remain a public right of way. The diameter of cul-de-sac has been designed with a reduced size to avoid wetland impacts. This cul-de-sac is similar in size to two (2) recent cul-de-sacs our office has designed for two (2) previously approved projects in the City of Portsmouth, the Borthwick Forest subdivision and Foundry Place parking garage. Thus, we anticipate the size is adequate to meet the needs for DPW maintenance activities.

We respectfully request a recommendation for approval to the PDA for the above requested waiver. If you have any questions or require any additional information, please do not hesitate to contact me at (603) 433-8818 or pmcrimmins@tighebond.com.

Sincerely,
TIGHE & BOND, INC.

Patrick M. Crimmins, P.E.
Senior Project Manager

Enclosures

L-0700-013
January 4, 2019

Mr. Eric D. Weinrieb
Altus Engineering, Inc.
133 Court Street
Portsmouth, New Hampshire 03801

Re: **Follow up Drainage Review**
Proposed Industrial Development, 70/80 Corporate Drive
Tax Map 305, Lots 1 and 2 – Portsmouth, NH
Altus Project 4940

Dear Eric:

On behalf of Lonza Biologics (applicant), we are pleased to submit the following supplemental information in support of a Pease Development Authority (PDA) Site Review Application for the above referenced project in response to the review meeting held at your office on December 20, 2018:

- One (1) copy of Technical Memo on Watershed Modeling for Hodson Brook by Streamworks, PLLC, last revised November 27, 2018
- One (1) copy of Technical Memo on Watershed Model Input and Calibration by Streamworks, PLLC, dated January 4, 2019
- One (1) copy of The Restoration of Hodgson Brook at the Iron Rail Parcel prepared by Streamworks, PLLC, last revised November 14, 2018;
- One (1) copy of the Long Term Operation and Maintenance Plan, last revised January 3, 2019

The enclosed sections and memorandums have been prepared or revised in response to requests for more information made at the December 20, 2018 meeting, and the following are the responses to each comment:

1. Altus requested that a memo be prepared detailing how the collected and calculated data by Streamworks and Tighe & Bond was used to generate the existing and proposed Hodsgon Brook watershed models. Specifically, how Streamworks and Tighe & Bond's proposed watershed models work together.

   The included Technical Memo on Watershed Model Input and Calibration by Streamworks, PLLC details how the collected and calculated data was used to generate the existing and proposed watershed models. Included in the memo is a section detailing how the data from the Streamworks model and the data from the Tighe & Bond model was used to obtain the final proposed conditions models for the overall watershed prepared by Streamworks and the on-site watershed prepared by Tighe & Bond.

2. Verify that the slope armoring at the triple culvert entrance at the outlet of the proposed stream channel is sufficient.

   The armoring at the triple culvert entrance at the outlet of the proposed stream channel was reviewed and determined to be sufficient as shown. The

armoring on the far end of the plunge pool extends up to elevation 38' which is the same elevation as the top of the three arch culverts. At this elevation the water will be ponded approximately 150' up the stream channel. This length of ponded water will dissipate the flow of the stream entering the pool prior to reaching the back wall of the plunge pool. Additionally, the top of the bank will be vegetated prior to flows being introduced to the stream channel providing additional erosion control.

3. Provide the revised Long Term Operation and Maintenance Plan that includes stream maintenance requirements.

   The latest version of the Long Term Operation and Maintenance Plan that includes stream maintenance requirements is included.

4. Provide the latest versions of all Streamworks reports and memorandums.

   All the latest versions of the report and memorandums prepared by Streamworks are included.

Sincerely,
TIGHE & BOND, INC.

Neil A. Hansen, P.E.
Project Engineer

Patrick M. Crimmins, P.E.
Senior Project Manager

J:\L\L0700 Lonza Biologics Expansion Was 1576F\013 Iron Parcel Redevelopment\Report_Evaluation\Applications\City Of Portsmouth\20190107_Supplemental PB Submission\20190104_Altus Response Letter.Docx

27 November 2018

Watershed Modeling for Hodgson Brook

Hodgson Brook is a highly urbanized stream system which passes through the Pease Tradeport, starting in Newington, and ending at North Mill Pond in Portsmouth. Traditional methods for predicting peak stream flows based on watershed characteristics alone (from nearby stream gages, using drainage-area weighting, from regional regression equations, SCS method, etc.) are very likely to produce results of low accuracy. Most traditional methods for predicting peak flows work best on less impacted, more natural systems or on smaller watershed sizes. Hodgson Brook at the Iron Rail Parcel has a watershed which has been extremely impacted by urbanization, and flows underground through almost one mile of storm sewer before daylighting downstream from the project site. In order to better predict expected peak flows and floodwater elevations at the site and its surroundings, a more appropriate method for analyzing urban watersheds was chosen; the EPA's Storm Water Management Model (SWMM). This program is freely available for use[1], and is meant to model urban hydrology and hydraulics in greater detail than traditional peak flow calculations. The program is able to use a wealth of information (infiltration rates, weather, real-time precipitation, stormwater infrastructure, ponding, etc.) to better calculate flow rates and water elevations.

Though SWMM is able to calculate flows and water elevations more precisely, it is most appropriate to check and calibrate the model against observations for the results to be considered as accurate. As with any model, precision can almost be guaranteed, but only with calibration data can the results be assumed accurate. Upon completion of a calibrated existing conditions model, proposed conditions may be modeled using site development plans. Results between the two models may then be compared, and results for the proposed model used for planning purposes.

Before creating the existing conditions model, it was known that there was almost no existing data to which a model could be calibrated. There are no stream gages along the stream, and little historic verbal observations were recounted[2]. It was also anticipated that the time of concentration for this site would be fairly small – most likely less than 30 minutes – meaning that both calculation time steps and precipitation distributions (long term, modeled, and monitored) would have to be less than that interval in order to accurately calibrate the model (one to 10 minutes, for example). Planning for these two key constraints for modeling, flows and elevations were monitored at three locations along the system, and the storms occurring during the monitoring period were obtained in 5-minute recorded intervals. These two correlating sources of information could thus be used to calibrate a SWMM model for the existing site conditions.

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[1] https://www.epa.gov/water-research/storm-water-management-model-swmm

[2] Verbal observations might include generalizations about locations within the watershed. Statements such as "I've never seen flows overtop that road," or "That field floods all the time," or "The water in our building was knee-deep during the flood of '86" are useful for analyzing historic modeling results. If the modeled results poorly reflect such observations, the model may be tweaked to better reflect reality, even if such accounts are quite general in their nature.

Among the purposes driving the creation of a watershed model for the site are planning for flows and water elevations at key locations along the system. Modeling the design scenario provides a confirmation that any pertinent proposed infrastructure performs as it is intended. The results from the proposed model may also be compared to past conditions, both to make observations on the relative performance of the system from past to future, and to ensure no adverse conditions are created resulting from the proposed project.

Among the initial efforts to develop a conceptual plan for modeling was to define points of interest, and the limits to which the model would extend. Members of the design team met with project reviewers (the city, the city's third-party reviewer, and the PDA – referred to as the Reviewers) during a 9/25/18 meeting in Portsmouth. During the meeting, it was a general consensus of the Reviewers that flood flows at the wetland behind Martin's Point, adjacent to the ball fields at Tony Rahn park, would be managed by the wetland system there and on downstream. This was considered, for modeling purposes, as the terminal point for the analysis. Therefore, any potential adverse impacts resulting from the project would be expected to occur somewhere between this location and immediately downstream from the project site. In that stretch, only two potential impact locations were identified; the swale at the outlet of the project site, adjacent to Goose Bay Drive (referred to as the GBSwale), and the wetland adjacent to Corporate Drive ending at the Pease Wastewater Treatment Facility (referred to as the PWTFDrive). Other key locations in which the Reviewers were interested included the upstream- and downstream-most ends of the project site. For reference, an image depicting some of these key locations may be seen in Figure 2, with the project subwatersheds delineated in Figure 1.

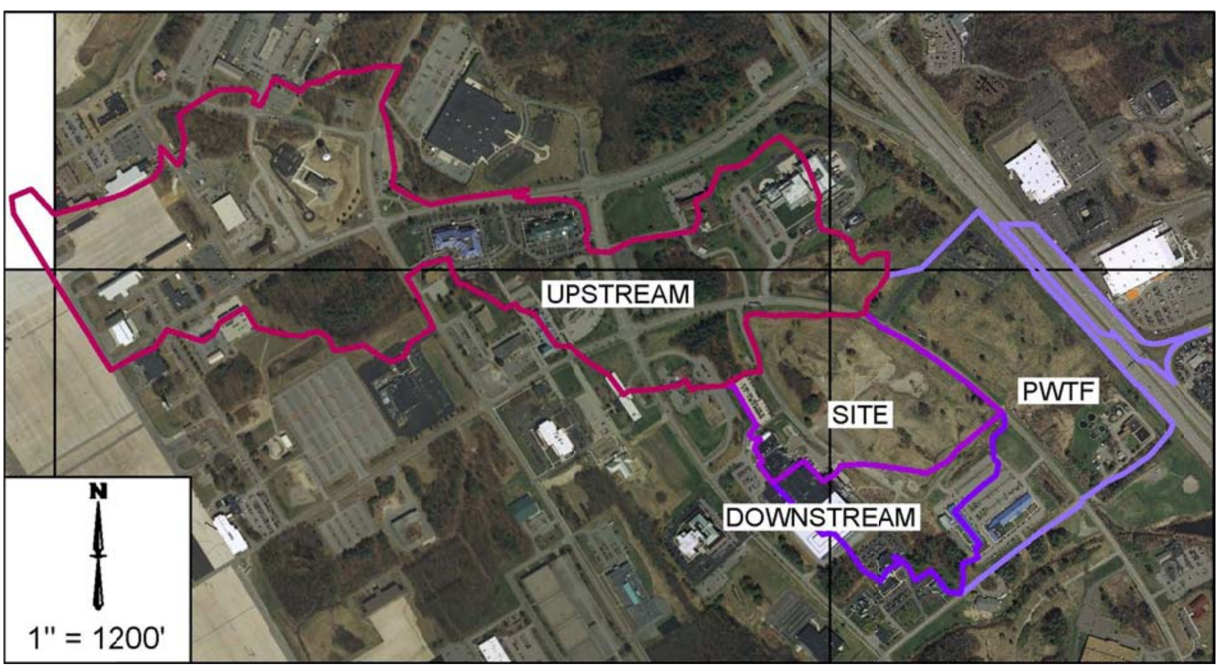


Figure 1 - Subwatersheds defined for the model

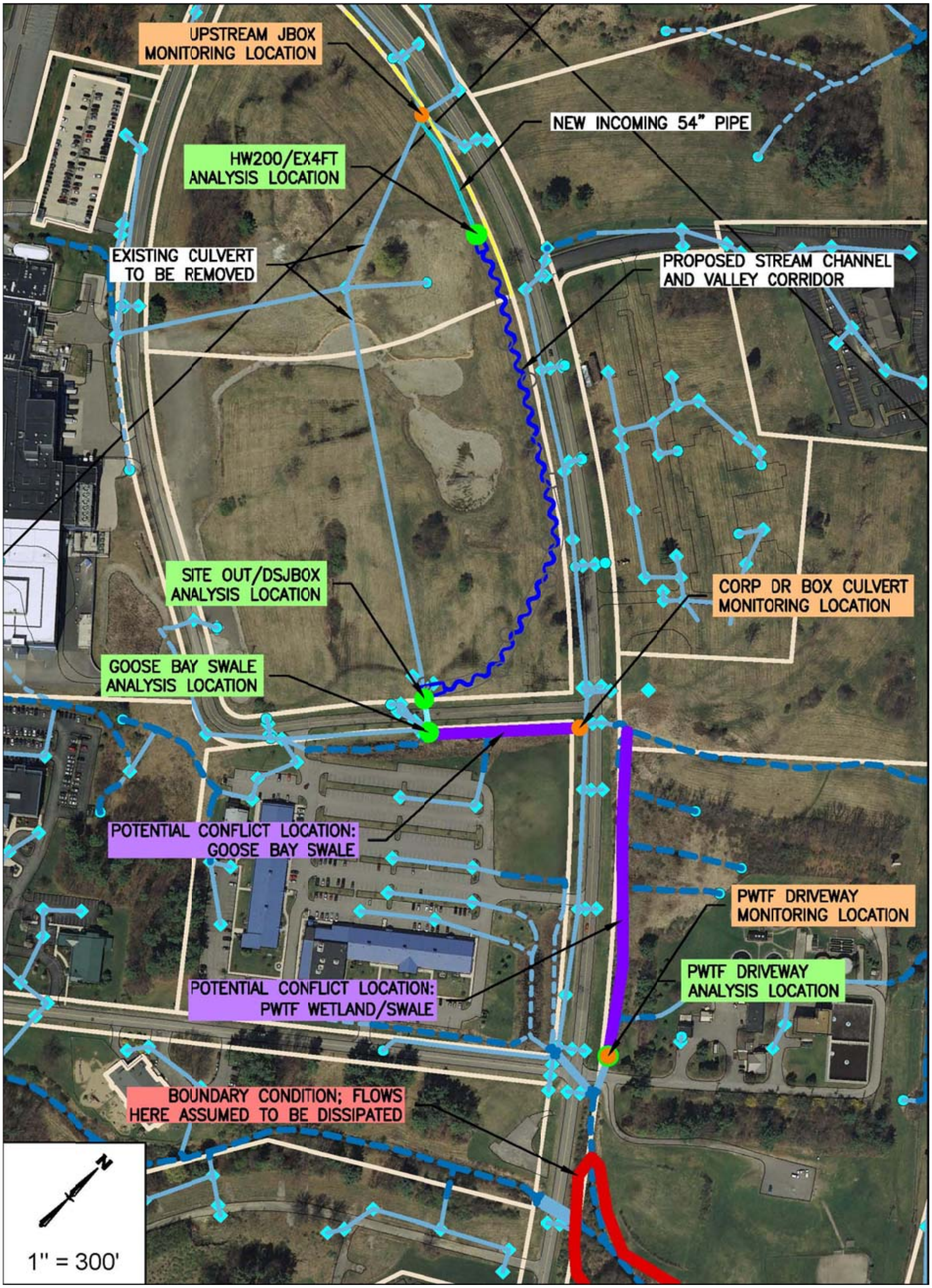


Figure 2 – Referenced Model Locations

The model of the Hodgson Brook watershed upstream from the PWTF Driveway was segmented into four subwatersheds, defined by key locations described previously. These four subwatersheds are identified (from upstream to downstream) as: Upstream, Site, Downstream, and PWTF, with the subwatershed outlets being located at the upstream junction box on the site, the downstream junction box at the site, the box culvert passing Hodgson Brook beneath Corporate Drive, and the PWTF Driveway, respectively (see Figure 1). Each subwatershed was chosen for specific reasons; the Upstream, Downstream, and PWTF subwatersheds may all be calibrated to monitoring data collected at each of their outlets, and the Site subwatershed contains the entire project site, where modeled conditions may be compared between the Existing and Proposed site conditions.

In order to calibrate the watershed model, monitoring was performed from 9/10 to 10/16 (37 days) at three locations: the upstream junction box, the inlet to the Corporate Drive box culvert, and at the PWTF driveway. At each of these locations, flows and water stages were recorded during low-flow and runoff conditions, for a multitude of flow depths. Flows were measured by stream gaging by selecting a cross section and utilizing a flow meter. Stream gaging methods follow the USGS procedures for the 0.6-depth method. The steam gaging was conducted during six storms over the span of the monitoring period. In addition to flow monitoring, pressure transducers were placed at the upstream junction box and the PWTF driveway, set to take readings every minute, which provided near-constant water elevations for 21 days. The stream gaging data was used to create a rating curve at each location; the measured flows and synoptic transducer water depths (converted to water surface elevations -WSELs) data was plotted and then best-fitting regression trendlines[3] were fitted to the data to obtain equations that then transformed the 1-minute transducer water elevations into observed hydrographs. Only two pressure transducers were available, therefor the hydrograph at the Corporate Drive box culvert was estimated by using concurrent readings between the three sites. In total, monitoring data was collected for nine storms during this time frame.

Recognizing that the watershed is highly responsive to rainfall, precipitation observations were necessary in as small a time step as possible. Larger time steps, especially those greater than the estimated 30-minute Upstream watershed time of concentration, result in poor model calibration. No nearby officially-managed rain gages were discovered to provide rainfall data in a time step less than one hour; three NOAA weather stations that are currently operational were discovered nearby – two in Durham and one on Pease – but all recorded data at hourly time steps. There is a long-term record at a weather station in Durham with 15-minute data, but only up until the year 2013, and another one which is currently operational and has (not very easily obtainable) minute weather observations – and was considered for use, but ultimately was abandoned in favor of another solution.

With the assumption that the time of concentration at the site was likely to be very short, and having only nine storms occurring during the monitoring phase, having an accurate rainfall distribution at a minimum time step was considered to be overly important for each storm. It was discovered that

[3] It is necessary in some instances to use more than one trendline; as water levels increase, the conditions which govern the amount of flow are not always the same. For example, at the Corporate Drive box culvert, monitored flows at water levels below the top of the culvert are well described by one trendline – when they reach the crown and higher, they are better described by another trendline, as flows begin to enter the field to the south east.

community-collected precipitation amounts in 5-minute intervals are publicly available; the data is collected by private enthusiasts and published by a weather company, Weather Underground (WU). Dozens of weather stations are located near to the site, of which six stations – forming a circle encompassing the site – were chosen to help determine storm precipitation hyetographs during the monitoring events. The location of the six WU stations may be seen in Figure 3, along with the other five mentioned weather stations, and a list of the all the mentioned rain gages relevant information about each may be found in Table 1.

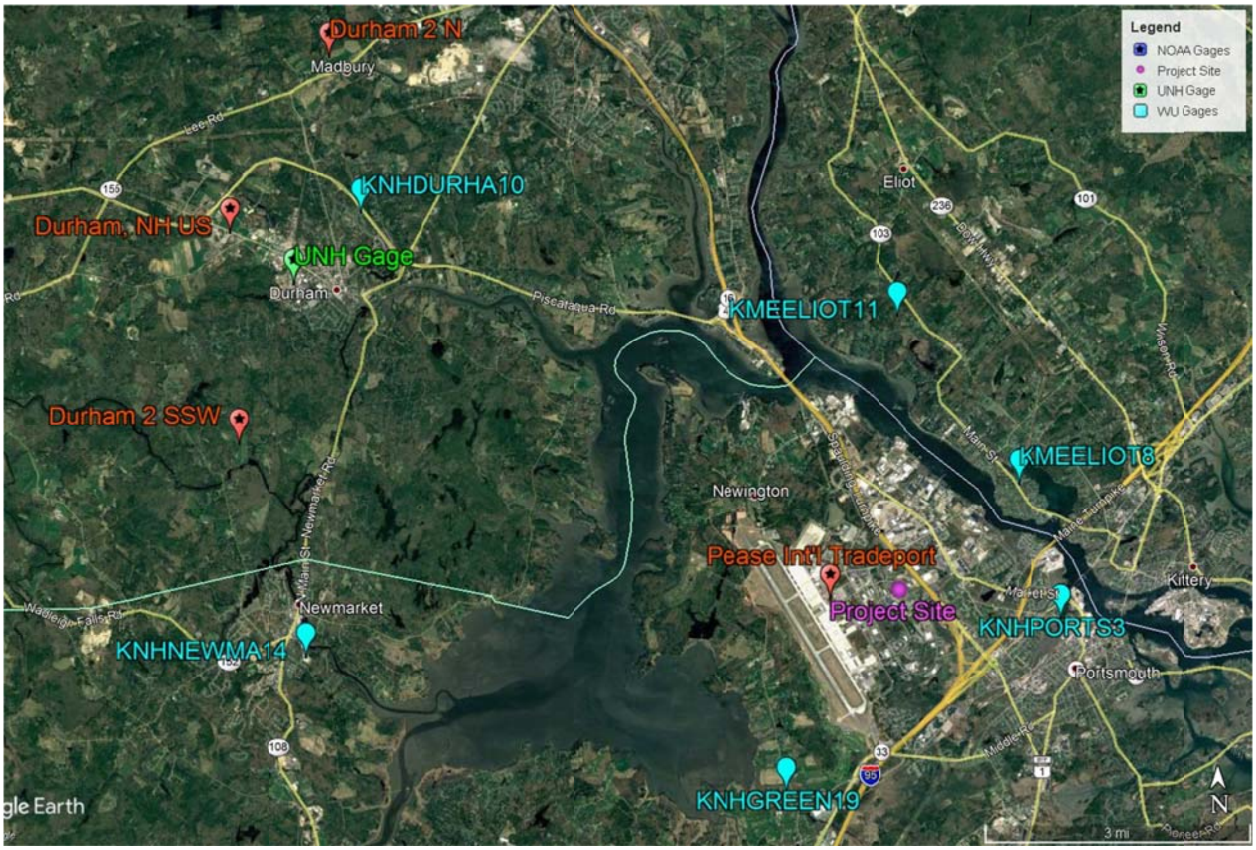


Figure 3 - Rain Gage Locations

The goal for using the amateur-collected rainfall observations was to obtain as accurate an account of the distribution of the rain occurring during each of the monitored storms. These weather stations record data every 5-minutes. For several purposes, more than one of these gages were used; no one gage was located within the model watershed, therefore many were used to more accurately represent site conditions. Also, as these are privately-owned stations, bias by any one station – if used alone – would pose issues with the accuracy of the calibrated model, and with overall credibility. In theory, a sample of individual data points (in this case, the gages) selected from a population (the true storm characteristics at the site) should represent the true average of the population, within a certain degree of probability. The larger the sample size, the more likely it is to accurately represent the population. For this reason, to make up for the lack of watershed rainfall data, the closest six WU gages surrounding the watershed were chosen. Though these may individually have slight inconsistencies from storm to storm, especially given that they are dispersed in their locations, when processed and accounted for as a group, the expectation is that they produce the most representative and relevant storm characteristics as possible.

Table 1 - Reference Rain Gages

Owner/ Publisher	Gage ID	Description	Municipality	State	Time Step (min)	Period of Record	Distance to Site (mi)	Direction from Site
WU	KNHDURHA10	Littlehale Rd	Durham	NH	5	9/10-10/16	7.4	NW
WU	KNHNEWMA14	Fire Department	Newmarket	NH	5	9/10-10/16	6.8	W
WU	KNHGREEN19	Airport	Greenland	NH	5	9/10-10/16	2.62	SSW
WU	KNHPORTS3	Maplewood Ave	Portsmouth	NH	5	9/10-10/16	1.85	E
WU	KMEELIOT8	Spinney Creek	Eliot	ME	15	9/10-10/16	1.78	NE
WU	KMEELIOT11	Sunset Hill	Eliot	ME	5	9/10-10/16	3.06	N
NOAA	99999954794	Durham 2 N	Madbury	NH	60	2001-Current	8.75	NW
NOAA	99999954795	Durham 2 SSW	Durham	NH	60	2001-Current	7.6	WNW
NOAA	72605504743	Pease Int'l Tradeport	Portsmouth	NH	60	2006-Current	0.8	W
NOAA	COOP:272174	Durham, NH US	Portsmouth	NH	15	1971-2013	8.53	WNW
UNH	CR1000	UNH Weather Station	Durham	NH	60	2000-Current	7.62	WNW

In order to confirm the reliability of the crowdsourced data, a number of checks were performed to determine, with a degree of confidence, the consistency of the WU gages against officially-published data. This was all determined by correlating the WU data to the hourly data collected at the Pease and Durham rain gages. The totals – both by hourly increments and storm totals – were analyzed for the departure between each increment and each storm. So long as the storm totals and hourly amounts were within reasonable similarity (approximately +/-15% for an overall performance, though the further away a WU gage was from a reference gage, the more lenient the range was considered to be), the gage records were considered acceptable for use. Ultimately, the six WU gages in Table 1 were considered to be reasonable surrogates for determining each of the watershed storm distributions to be used in SWMM calibration.

It is important to note that the WU gages were only used to develop each monitoring reference storm's *rainfall distribution*; ultimately the total storm rainfall amounts were defined using the NOAA gage at Pease. As this gage is very close to the site, and is an official source of QA/QC'd data, this was considered the most appropriate source for total rainfall. The community-supplied data was merely a method to interpret the hyetograph for each storm; both hyetograph time and interval rainfall depths were made dimensionless. The rainfall amounts at each gage in 5-minute intervals were divided by the total recorded rainfall at each gage to yield dimensionless rainfall depth each 5-minute period. The recording time was also converted to dimensionless time, with the storm peaks, beginnings, and ends made relative to all others. Since the relative location of each gage combined with the variable nature of the actual storm rainfall distribution results in differences between each gage's rainfall distribution, an optimization was run to determine suitable weighting factors for each of the six reference WU gages, and how much each should contribute to the final calculated unit hyetograph for the site. This was done by weighting each gage by a factor, resulting in a weighted average record for the site. This was optimized by comparing the produced storm distribution calculated from the WU gages to that of the hourly record for the Pease NOAA gage. The goal was to weight each gage in such a manner that the produced rainfall record for the site matched the hourly amount of rainfall at the Pease NOAA gage. The result was that no one calculated/weighted storm was off by more than 0.02" when compared hourly, and the total precipitation during the monitoring period for both the calculated data set and the NOAA set matched within a hundredth of an inch. For reference, the total rainfall amounts recorded by the NOAA Pease gage may be found for the calibration events appear in Table 2, and total 7.09 inches.

Table 2 - Storms Occurring During Monitoring Period with Storm Total Rainfall[4]

Storm Date in 2018	Total Rainfall (in)
10-Sep	1.36
18-Sep	2.76
25-Sep	0.61
26-Sep	0.65
27-Sep	0.07
28-Sep	0.02
1-Oct	0.15
2-Oct	0.42
3-Oct	0.17
11-Oct	0.73
16-Oct	0.15

The idea behind this method was that, while the WU data may not be subject to official QA/QC, any individual errors or inaccuracies should hopefully be countered by the sheer quantity of data. This method of using community-supplied data – while uncommon – is not without justification. Even federal agencies support the method; NOAA divisions, including the NCDC and NWS, support and reference the non-profit Community Collaborative Rain, Hail & Snow Network (CoCoRaHS). Furthermore, the WU data was only used to create a more appropriate rainfall account, at a smaller time step which was necessary in order to better calibrate the SWMM watershed model. Even then, this data was referenced against the hourly data collected on Pease, with storm totals being defined by the Pease NOAA gage. It was these storm totals which were used to transform the unit precipitation record back into 5-minute rainfall depths.

[4] Though 11 storms are shown in Table 2, two of them produced almost no runoff (those on 9/28 and 10/1), and therefore no monitored field observations were recorded during those storms. These storms were modeled, however, to ensure that little to no runoff was modeled as a result of those events.

In total, stream gaging and flow stages were collected during six storms (9/10, 9/12, 9/18 and Hurricane Florence remnants, 10/2, 10/11, and 10/16). The pressure transducers monitored conditions during an additional three storms (9/25, 9/26, and 9/27). Using the observed flows and stages, the continuous transducer data was calibrated, and a hydrograph spanning the 37 days of monitoring was created.

Concurrent with the monitoring, all necessary modeling input was collected. The city provided their GIS database, which included many important features such as impervious surfaces and infrastructure locations. While the database had a wealth of infrastructure information, most of the data was limited to X and Y coordinates, and infrastructure types (catch basins, pipes, manholes, stream, etc.). There was very little useable data regarding infrastructure dimensions or elevations. This data then needed to be collected in the field: manholes were opened, pipe materials were noted, sizes were recorded, and elevations were collected using a laser level and known elevations. LiDAR data obtained from NHGRANIT was also used to create topography of the watershed, accurate to 0.5 feet.

With all of the required information collected and processed, an existing condition watershed model was built in SWMM. Using the monitoring data at the three locations (as well as the generalized observations), the model was then calibrated against this data by adjusting selected parameters within acceptable their tolerances. The model was considered calibrated to an acceptable degree when the modeled peak flow rates, time to peaks, and total runoff volumes were all within 15% of the monitored conditions, which was almost entirely achieved (several of the storms had one of the calculated amounts outside the 15% limits – however, none of these amounts were off by greater than 25%).

With the calibrated existing conditions model, three modeled watershed scenarios were created using long-term gaged precipitation, design precipitation, and proposed conditions: the three modeled scenarios thereby named Long Term Existing, Design Storm Existing, and Proposed. The results for the three models were then compared, and used to analyze longer-term flows and water stages. The Long Term Existing conditions model was created using 15-minute gaged precipitation collected by the NOAA gage in Durham (Durham NH, US) and the existing conditions of the watershed. While not considered precise enough to use for the calibration storms, this weather station in Durham is suitable to use as a long-term historic record. While variations might be quite large over the short span of the monitoring period, the 41 years of long term existing rain data was considered to be more than representative as a surrogate for the Lonza site. The results from this Long Term Existing model are useful to estimate flows for the watershed as it exists today. With respect to instream flows, it is common to develop statistics based upon observed, historic peak or average daily flows. The Durham rain gage had 41 years of data, spanning 1971 to 2013, with a total of 3,078 days during which some rain was recorded. This long-term rainfall record was used as input to the SWMM model and the resulting runoff (flows) was calculated to yield a 41-year hydrograph. With this hydrograph, low flow and peak flow statistics were computed. A common practice in determining peak flows occurring at annual rates is to use a Log-Pearson Type 3 (LP3) analysis of the annual peak flows. This was done on the Long Term Existing modeled peak flows incoming to the site, the results of which may be found in Table 4.

The Design Storm Existing conditions model was created to analyze the results for the commonly used design storm precipitation. Design storm precipitation in New Hampshire is obtained from the Northeast

Regional Climate Center's (NRCC) Extreme Precipitation in New England and New York website (http://precip.eas.cornell.edu/). Precipitation totals determined by the NRCC reflect continually-adjusted climate rainfall amounts at specified return periods. Since the NRCC precipitation amounts are used for design purposes, a correlation to Long Term Existing model results may not be effective. For reference, the long-term existing record storm totals (as well as the modeled peak storm intensities), ranked using the Weibull method, may be found alongside the design precipitations (shown for the 24-hour total) given by the NRCC, in Table 3.

Table 3 – Peak Rainfall Rates and Total Amounts by Return Period for the NOAA Durham, NH US Gage and NRCC Design Storms

Return Period	Long Term (41 year) Record Peak Rate	Peak Rate by SCS Type 3 Distribution of the NRCC Totals	Long Term (41 year) Record Total Rainfall	NRCC Design Precipitation
Yrs	in/hr	in/hr	in	in
1	2.05	2.56	1.80	2.65
2	2.52	3.09	2.40	3.20
5	3.35	3.91	3.04	4.05
10	5.61	4.69	3.50	4.85
25	11.99	5.94	4.23	6.15
50	14.78	7.11	5.86	7.36
100	-	8.52	-	8.82

Of note, the NRCC total precipitation amounts needed to be transformed into a hyetograph representing the rainfall distribution over the 24-hour span for which the totals are shown. To do this, the standard SCS Type 3 rainfall distribution was used. This yields a design storm totaling the precipitation amounts, distributed throughout a 24-hour period – from which peak intensities for each of the storms could be determined, and compared to the long term record data. These may be found in Table 3. Caution should be exercised in comparing the rainfall amounts by return periods between the two sources, as the long-term precipitation values were generated using a Weibull ranking, while the NRCC uses more advanced statistical modeling and prediction methods. Since there were only 41 years of historic precipitation amounts, predictions beyond the 50-year were not made.

Finally, a Proposed conditions model was created, using the design for the site to update the Site watershed and infrastructure in the model[5], and the same NRCC design precipitation described above.

[5] Included in the Proposed conditions model are three Green Infrastructure stormwater basins which will manage all the stormwater on the site, also the removed 4' culvert which is to, in part, daylighted into a restored section of stream corridor.

Table 4 - Peak Flow Results at the Upstream Point of Analysis

Analysis Method / Return Period (years)	Long Term Existing Model	LP3 Predictions for Long Term Results	Design Storm Existing Conditions Model	Proposed Conditions Model
100-yr	-	175.87	205.59	174.68
50-yr	174.63	158.38	181.99	157.61
25-yr	159.96	140.81	162.64	144.23
10-yr	140.24	112.69	143.88	130.93
5-yr	88.74	87.40	136.66	124.73
2-yr	61.28	52.14	107.16	99.33
1-yr	43.27	34.04	73.08	73.13
1"	-	-	13.71	13.76

Ultimately, the results from the Proposed conditions model are used for all design purposes pertaining to site drainage infrastructure – stormwater basins, the stream design[6], culverts, etc. The results from the Design Storm Existing conditions model, while not used for any design purposes, are useful to demonstrate the reduced impacts of the Proposed conditions. By comparing the two models, conclusions may be made with respect to flows and water elevations: *do peak flows increase?*, *does flooding occur more frequently?*, *are floodwater elevations increased?*, etc. Results by storm events for select model conditions and/or analysis methods may be found in the following sections: each section being defined by the point-of-analysis location (reference Figure 2 for each location). Notes and remarks specific to each location and to each analysis method are detailed as well, to provide context and a brief summary.

It should also be noted that the model was calibrated to the previously-described storms. The nine storms provided excellent data with which to refine the model to a high degree. Although the range of these storm depths were very representative of common events, none were in the range of the design storm totals: the remnants of Hurricane Florence produced a storm in the amount of 2.76" with a peak intensity during the storm of about 2.4 in/hr, resulting in a peak flow at the upstream end of the site of roughly 55 cfs, which is on par with the estimated 2-year return period flow for peaks resulting from the Long Term Existing model, and below the 1-year Design Storm Existing model peak flow. The model performs extremely well for the smaller, more frequent storms. Although no design storms occurred during the monitoring period, it is assumed that the SWMM model yields an accurate representation of the resulting runoff characteristics for those storms.

[6] There is a caveat here: the stream restoration ultimately uses the results from the Long Term Existing model to help define the flows which will be expected at what return periods, which help geomorphically design the stream. However, for reference and site design purposes, the results from the Proposed model are shown and used in the AOT permit.

Results at the Upstream End of the Project Site

At the upstream end of the project site there exists a large concrete vault, into which three 3-foot diameter culverts used to pass Hodgson Brook and other areas under Corporate Drive to the vault. The vault outlet is a 4-foot diameter culvert. For the Long Term Existing and and Design Storm Existing models, this is the location where results are shown. Proposed conditions have the 4-foot diameter culvert removed almost in its entirety (only 11 feet of the culvert are to remain), where it will flow into a proposed junction box (PDMH203) along with the outlet from the proposed Subsurface Gravel Wetland 2 (GW2). A proposed 4.5-foot diameter culvert will then carry the flows parallel to Corporate Drive and daylight into the proposed restored stream corridor. Results shown in this section reflect the flows coming in to the site, at the existing junction box (Figure 4).

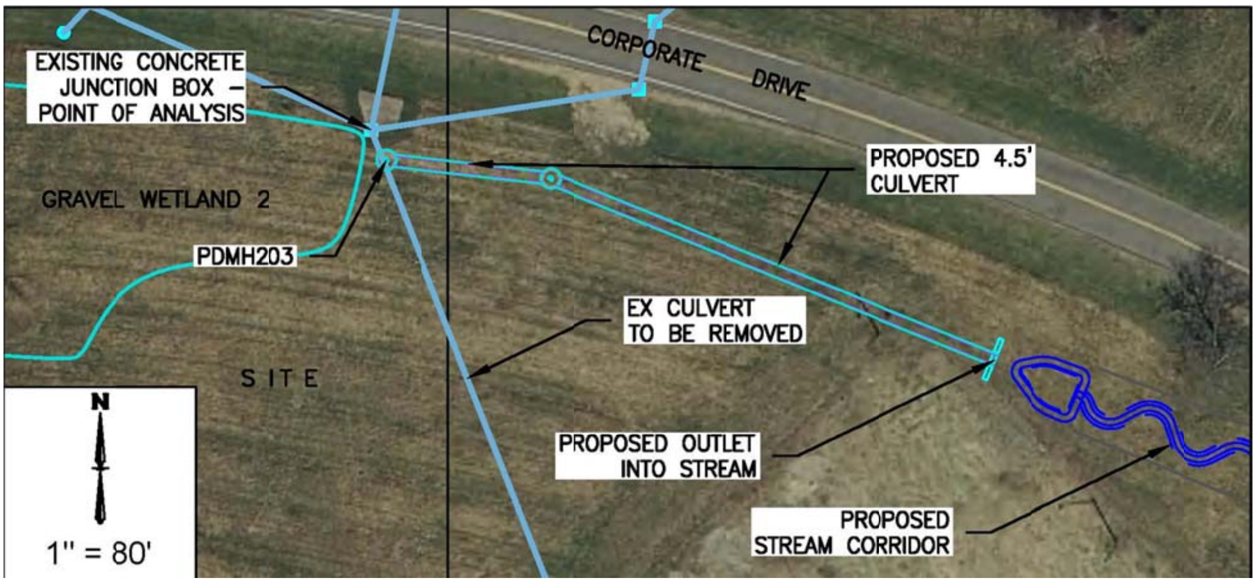


Figure 4 – Upstream Point of Analysis References

In Table 4, the results for storm peak flow events by various methods are presented however should not be compared without some context. The flows in the second column, for the Long Term Existing model, represent the results calculated in SWMM for the 41 years of long-term precipitation data, obtained from the NOAA Durham, NH US gage. The peak flows for each return period in this column reflect the flows calculated using the Weibull method, which determines a probability of exceedance based on the annual ranked peak flows, then determining a return period from those probabilities (the exact peak flows for the return periods shown were interpolated/extrapolated from the Weibull-ranked flows). The peak flows shown in the third column reflect a more robust statistical analysis of the results from the Long Term Existing model. Peak flows calculated by the Long Term Existing model were processed using the LP3 analysis method. These results are probably more accurate in saying, based on 'observed' long-term data, these are most likely the flows which may occur at these rates. The peak flows shown in the final two columns are the results which the model calculated using the NRCC design precipitation, for the Existing and Proposed models. The design precipitation was given for the return periods shown, and from these storms, these would be the expected flows.

Looking at the results, perhaps the most notable comparison is that of the peak flows calculated between the Design Storm Existing and Proposed models. Flows are calculated to be slightly higher during the less-frequent storms, should the current existing conditions remain. This is likely resulting from several factors, most of which are due to effects of the proposed infrastructure downstream from the existing junction box. Under existing conditions, there is almost no downstream storage – neither is there any upstream for quite a ways. Proposed conditions have the pipe quickly outletting into the proposed PDMH203, where the outlet is a larger culvert, which then outlets into the restored stream. Even though proposed conditions have an additional flow coming in from GW2, these flows were only calculated to be about 30 cfs during the 100-yr event, and are not enough to cause more strain on the upstream junction box performance compared to the existing conditions. The presence of the stream corridor also likely helps to lower the energy slope up through this location, as the wide valley will provide a much lower water elevation than the existing culvert, which has a maximum rise before it begins to act under pressure-flow conditions.

Results at the Downstream End of the Project Site

At the downstream end of the project site under existing conditions, the 4-foot diameter culvert passing Hodgson Brook through the site outlets into a large concrete box vault where it is then passed through three 42"x29" CMP culverts beneath Goose Bay Drive. Also existing are two catch basins in the field, which drain site flows into the concrete box. All this infrastructure is set to be removed as part of the project, with only the three CMP culverts remaining, just cut slightly shorter. Long-term observations[7] at the downstream end of the culverts, in the Goose Bay Swale, it was found that there is a nearly-constant pool of water at about an elevation of 36.1'.

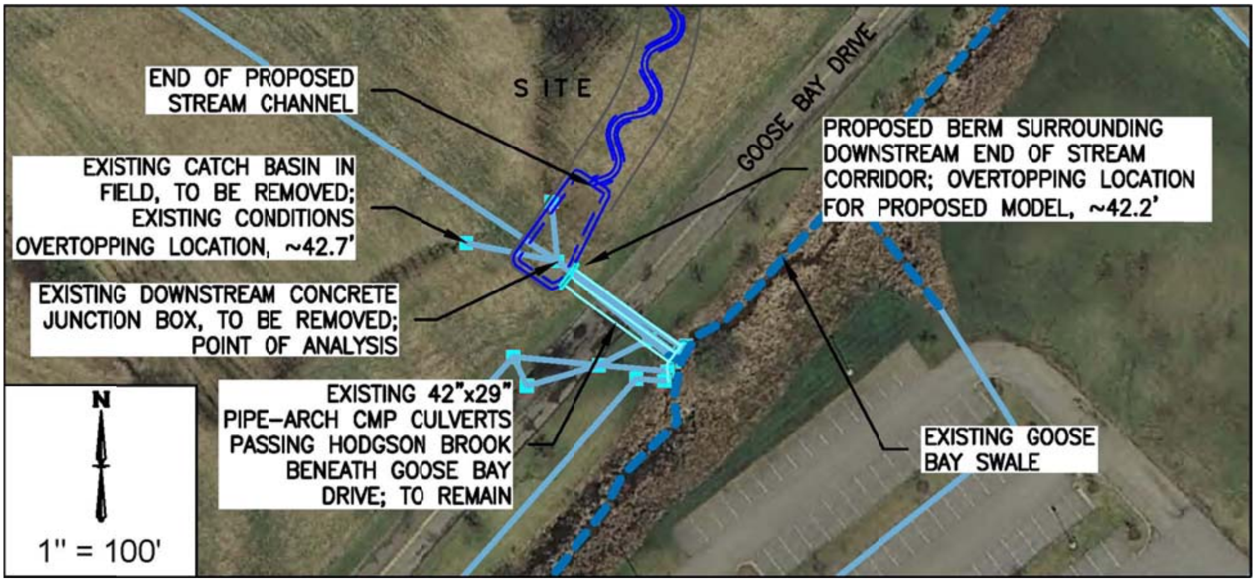


Figure 5 - Downstream Site Point of Analysis References

As detailed in the results section for the upstream end of the site, the peak flows shown in Table 5 reflect the modeled results with their respective return periods (an LP3 analysis was not performed on the Long Term Existing model flows here, as the flows were found to be nearly identical, the same may be said for the LP3 analysis). The relative difference in peak flows from Proposed to Long Term Precipitation Existing conditions may be seen in the final column. Again, the peak flows in the Design Storm Existing model do show that flows at this location are expected to be larger, should the existing conditions remain, when compared to the Proposed model results. These peak flows are the same values observed at the inlet for the Design Storm Existing model, which makes sense, as the system is almost entirely closed in its current manner. Interestingly, the peak flows from the Proposed model are calculated to be reduced slightly when compared to the flows incoming to the site – even though flows are added upstream from this location from the three stormwater systems. This is due to the increased storage provided by the restored stream and the stormwater systems, in conjunction with the timing of the peak flow rates relative to the upstream incoming flows and those leaving the stormwater basins.

[7] Over the span of the project, many observations have been taken which include the model calibration monitoring performed in the past 6 weeks, to surveying of the GBSwale done in the spring of 2016. It is from this long-term set of observations from which an overall estimation of the 'dry' condition WSEL has been approximated.

Table 5 - Peak Flow Results at the Downstream Point of Analysis

Analysis Method / Return Period (years)	Long Term Existing Model	Design Storm Existing Conditions Model	Proposed Conditions Model	Difference PRO-EX
100-yr	-	205.59	173.04	-33
50-yr	174.63	181.99	157.56	-24
25-yr	159.96	162.64	144.17	-18
10-yr	140.24	143.88	130.86	-13
5-yr	88.74	136.66	124.64	-12
2-yr	61.28	107.16	95.93	-11
1-yr	43.27	73.08	70.33	-2.8
1"	-	13.71	11.86	-1.8

Though a bit more difficult to compare directly, due to the amount of calibration data available and how the model handles infiltration, the total runoff volumes calculated for each model at the downstream point of analysis may be found in Table 6. These should be compared with caution – especially when referencing the Long Term Existing results. The results for that model, in the second column, do not represent storms observing the same rainfall distributions as the other two models. This is especially important with respect to how much rain infiltrates into the ground, however the results are shown anyways, for reference. Comparing the other two models, the most notable results are at the larger storm events. These storms are calculated to have a much larger amount of the total precipitation end up infiltrating into the ground. This amount tapers off towards the more frequent storms, with the 5-yr storm and more common results probably residing within the realm of statistical noise, regarding the comparative amounts.

Table 6 - Total Runoff Volumes at the Downstream Point of Analysis

Analysis Method / Storm Event	Long Term Existing Model	Design Storm Existing Conditions Model	Proposed Conditions Model	Difference PRO-EX
100-yr		3,705,086	3,158,663	-546,423
50-yr	2,398,022	2,949,938	2,710,728	-239,211
25-yr	1,432,794	2,341,158	2,291,853	-49,305
10-yr	1,198,874	1,705,911	1,690,479	-15,432
5-yr	1,039,307	1,322,663	1,312,978	-9,685
2-yr	606,374	931,910	927,902	-4,007
1-yr	402,897	696,871	691,077	-5,794
1"		105,559	105,757	199

Perhaps of greater interest at this location may be the peak flood stages which are calculated for each of the storms. The modeled results for these peak water surface elevations may be found in Table 7. Under existing conditions – which apply to the Long Term Existing and Design Storm Existing models – flooding occurs when flows surcharge up through the two catch basins in the field. The same is not true for the Proposed model; as the junction box and the catch basins are to be removed, flooding shall occur under the proposed scenario when water reaches the top of the proposed berm surrounding the restored stream. The results for the Design Storm Existing and Long Term Existing models may thus be compared directly to each other, but the results from the Proposed model is misleading, as flooding here occurs at a different elevation.

Table 7 - Peak Water Surface Elevations at the Inlet to the Triple Pipe-Arch Culverts Out of the Site

Analysis Method / Return Period (years)	Long Term Existing Model	Design Storm Existing Conditions Model	Proposed Conditions Model
100-yr	-	44.04	42.80
50-yr	43.26	43.61	42.71
25-yr	43.06	43.28	42.60
10-yr	42.84	42.97	42.35
5-yr	40.95	42.80	42.13
2-yr	39.83	41.45	40.05
1-yr	39.07	40.34	39.30
1"	-	37.70	37.28

As the flooding elevations vary from existing to proposed conditions, it may be most useful to compare the water stage relative to each scenario's flooding elevation. For the Long Term Existing and Design Storm Existing models, this occurs at about an elevation of 42.7 ft MSL. For the Proposed model, flooding occurs over the top of the proposed berm at an elevation of about 42.2 ft NAVD88. This is lower than existing because of the change in the existing and proposed conditions; currently at the site, overtopping occurs when the two catch basins in the field are exceeded (elevation 42.7'), under proposed conditions overtopping occurs when the proposed berm is exceeded (elevation 42.2'). The peak flood stages corresponding to the design storms may be found in Table 8.

Table 8 - Peak Water Surface Elevations Above Overtopping Elevation

Analysis Method / Return Period (years)	Long Term Existing Model	Design Storm Existing Conditions Model	Proposed Conditions Model	Difference PRO-EX
100-yr	-	1.34	0.60	-0.75
50-yr	0.56	0.91	0.51	-0.41
25-yr	0.36	0.58	0.40	-0.19
10-yr	0.14	0.27	0.15	-0.12
5-yr	-	0.10	-	-
2-yr	-	-	-	-
1-yr	-	-	-	-
1"	-	-	-	-

The relative difference in total depth of water above the flood stage from the Proposed and the Design Storm Existing model may be found in the final column. The proposed conditions show that flood depths are expected to be reduced compared to the Design Storm Existing model, and even a reduction in expected frequency of flooding, compared to the Long Term Existing model.

Results at the Goose Bay Swale, Downstream from the Site

Immediately downstream from the site, the three pipe-arch culverts pass Hodgson Brook under Goose Bay Drive into a swale which runs adjacent to the road before being passed under Corporate Drive by a box culvert. The swale here has flows incoming from the southwest in addition to those coming from the site. The field to the east of the outlets is relatively low compared to the road surfaces surrounding it. The box culvert is the primary outlet for the swale here however during larger flow events water ponds in the field, flowing over the driveway to the southeast before overtopping anywhere else – Goose Bay Drive, Corporate Drive, the parking lot to the south, etc. While being updated as part of the project, this culvert setting is set to remain almost the same from existing to proposed conditions. The primary concern at this point of analysis has been voiced as; does the project impact flows and water stages in a manner which may cause the swale to become full enough to cause flooding over Goose Bay Drive?

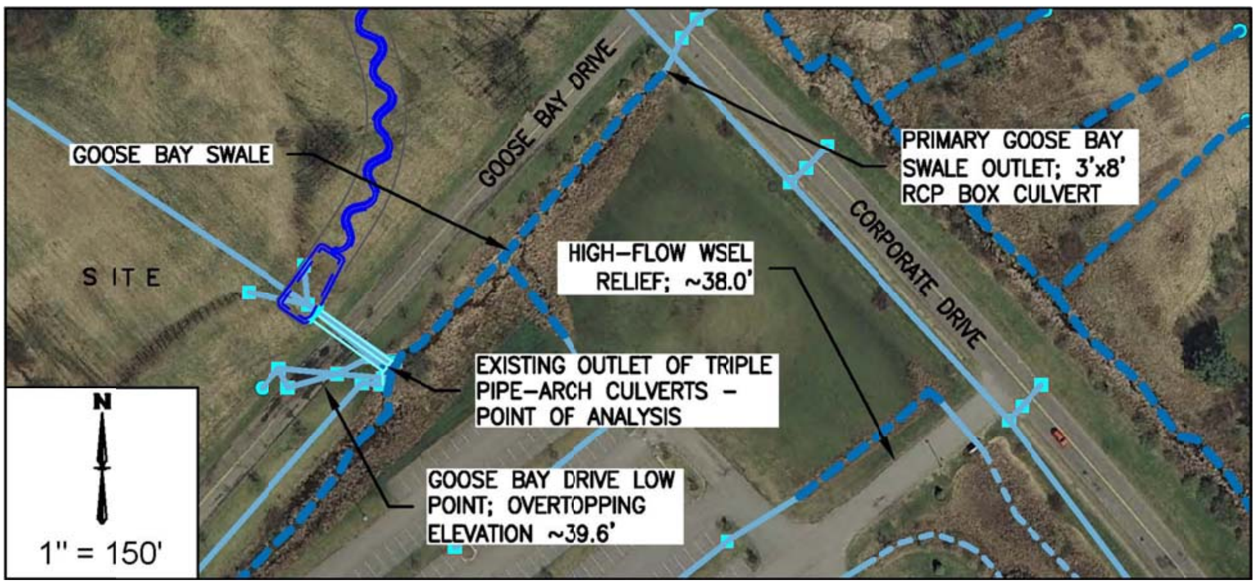


Figure 6 - Goose Bay Swale (Downstream from Site) Point of Analysis References

The lowest point in Goose Bay Drive, adjacent to the swale, is located almost above the three pipe-arches; this elevation is about 39.6 ft NAVD88. Flood stages would therefore have to overtop this elevation in order to flood the road. This is not expected to ever occur at this location because the driveway to the east has a low point of about 38.0 ft MSL. Flooding will occur for 1.5 feet over that driveway before ever overtopping Goose Bay Drive.

The most important result at this location is relative to flooding – how much and how often might it occur. The calculated peak flood elevations for each of the three models are shown in Table 9. As the lowest road elevation was assumed to remain constant, the values may be compared to one another. The final column represents the difference in the calculated peak flood elevations from the Proposed model to the Design Storm Existing.

As shown, the proposed conditions are expected to improve the flooding conditions relative to the Design Storm Existing model, and are about on par with the Long Term Existing model. It is interesting to see that for all three models, the driveway downstream is expected to overtop, on average, every year.

This was not ever observed as the correct estimation for an actual frequency – none was really ever given. With the lack of calibration data for this location, this type of possible modeling error is to be expected. However, though the rate of return of flooding at that driveway may be slightly off, the frequencies from one model to another may be compared with confidence. Proposed conditions are not calculated to flood the driveway, or Goose Bay Drive any more frequently than has been calculated historically. Furthermore, using the same design storms, the peak flooding depth above the driveway is projected to be reduced. This is due to the fact that while the peak flows are somewhat on the same magnitude between the Design Storm Existing and Proposed models, there is a greater volume of total runoff coming from upstream under existing conditions (reference Table 6). This, plus the attenuation of the flows provided by the proposed site, reduce the peak flow timing and the amount of required storm volume routing required by the field and swale.

Table 9 - Peak Water Surface Elevations in the Goose Bay Swale, Downstream from the Site

Analysis Method / Storm Event	Long Term Existing Model	Design Storm Existing Conditions Model	Proposed Conditions Model	Difference PRO-EX
100-yr	-	40.28	38.83	-1.46
50-yr	38.26	39.85	38.76	-1.09
25-yr	38.24	39.52	38.69	-0.83
10-yr	38.20	39.21	38.56	-0.65
5-yr	38.16	39.04	38.43	-0.61
2-yr	38.13	38.69	38.27	-0.42
1-yr	38.11	38.47	38.19	-0.28
1"	-	37.70	37.27	-0.44

Overall, by implementing the green infrastructure, daylighting the culvert, and creating a geomorphically designed stream; the proposed site conditions will result with reduced peak flows, reduced runoff volumes, and reduce water surface elevations compared to the existing conditions. Additionally, it may be said that upon the completion of the project, flooding is not expected to occur more frequently than it has in the past, anywhere along the modeled reach of the system. When analyzed for the design storms, the proposed conditions are expected to reduce the rate of flooding. These results are most affected by the proposed stormwater basins and restored stream corridor – both of which will supply infiltration and flow attenuation.

04 January 2019

Watershed Model Input and Calibration

To provide supporting calculations and to better design the water management at the Iron Rail Parcel development, a watershed model was built and calibrated in SWMM, as described in the technical memo, Watershed Modeling for Hodgson Brook (dated 27 November 2018). That memo describes, in detail, the collection and summary of the monitored and field-collected data used in developing the initial model: monitored storms, precipitation totals, hyetograph development, monitoring methods and locations, etc. The purpose of this memo is to further detail and summarize the initial model input, the calibration of select parameters, how the proposed model was built, and calculation methods.

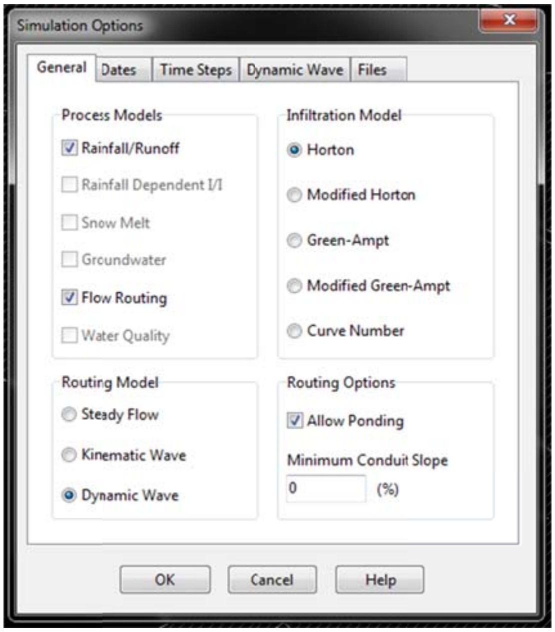
The Model and Methods

The program selected to model the hydrology and hydraulics in was the EPA's Storm Water Management Model (SWMM), version 5.1. The program is free to the public, is widely used, and has a wealth of support documentation. SWMM is able to perform many types of calculations which better estimate the hydrology and hydraulics of a watershed (especially urban ones) than many more common and simple methods or models. The most important facet of SWMM is that it can create long term hydrographs form long term, real-time precipitation data, rather than simple, event-based models. The program can account for many intricacies within an urban watershed which can have large effects on flows and water elevations, such as: time, surcharge, routing, retention, weather (sun, wind, temporal precipitation, seasonal variations, etc.), infiltration, baseflow, recharge, and snowmelt, among others. Calculations specifically performed as part of the models developed for this project were for storm sewer surcharge, routing, retention, precipitation (time-series hyetographs), and infiltration.

To account for infiltration, the Horton method was selected. This is a simple, common means to estimate infiltration, and is able to vary the rate as the soils saturate and dry. The method uses maximum and minimum infiltration rates defined for each watershed as constraints, and estimates the infiltration rate between dry and fully saturated conditions using a hysteretic infiltration curve; the limits of this curve being confined by the maximum and minimum infiltration rates, and its shape defined by a decay constant.

To perform hydrograph routing, the Dynamic Wave model was selected. This routing method solves the one-dimensional St. Venant flow equation, which incorporates continuity with momentum/energy relationships. Calculations are performed for pressurized flow, channel storage, backwater, entrance/exit losses, flow reversal, surcharge, overtopping, and flooding. Essentially, the model accounts for the way the water realistically moves and interacts with urban infrastructure over time from one location in the watershed to the next, and interactive/feedback effects. The method requires some important but relatively standard input and options to perform the Dynamic Wave method. Among these include defining the initial conditions, the means to calculate momentum, supercritical flow, friction and energy losses, surcharge, and tolerances to which calculations may be performed or optimized. Selected options and calculation methods used for the SWMM model may be seen in the two screen captures, Image 1 and Image 2.

The initial calibration model (the model created for the existing conditions, during the monitoring period) was run with a calculation and reporting time step of 1 minute to ensure a high degree of accuracy. Subsequent models (the existing conditions run with the long term [41 years] precipitation data record, and the existing and proposed conditions modeled with the AOT-required precipitation [115% NRCC values]) employed the 1-minute time step on days with rainfall and a 1-hour dry-weather time step (meaning during days when no rain fell, time steps were increased to 1 hour).



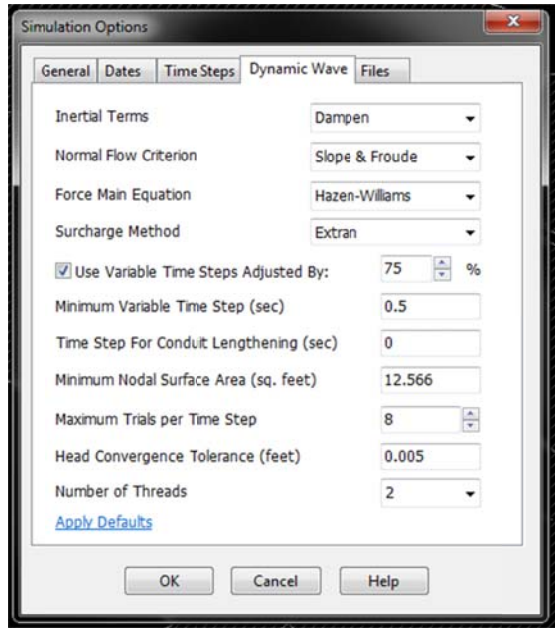


Image 1, to the left, shows the models and options selected for use. Image 2, to the right, shows the methods and options selected for use in the Dynamic Wave calculations.

INPUT DATA SOURCES AND TYPES

To build all four model scenarios, data input fell into three broad categories: observed (measured in the field), collected (from online or provided), and estimated (parameters input using typical or common) values.

Observed data includes all measured data collected directly in the field (water elevations and flows at the monitoring locations, surveyed elevations and cross sections, pipe properties and measurements, and various field-verified values obtained from other sources) or collected from another source which directly measured the data (precipitation amounts and timing, survey data within Lonza property). Much of this information was previously described in detail in the previously-mentioned Watershed Modeling for Hodgson Brook memo.

Collected data included a bulk of the remaining input, and mostly consists of indirectly observed or calculated data: topography developed from 0.5'-resolution LiDAR data, the infrastructure within the watershed (catch basins, pipes, junctions, manholes), impervious cover, land use cover and types, soil types, design precipitation, and design rainfall distributions.

Estimated data included data which were not directly observed, nor collected directly from another source; these are – for the most part – values which were used for input to the initial model with the intention that they would be calibrated appropriately. These data types include infiltration rates and limits, surface roughness values, friction and energy loss coefficients, and routing or attenuation factors.

Of course, not all the data listed above is directly input into the model; many of the actual inputs into the model had to be synthesized from a collection of the information. This is mostly true for the watershed characteristics, which often represented watershed-wide averages or totals. So a fourth class of 'synthesized' data may be more appropriate – data such as this would include subcatchment ponding amounts, flow lengths and slopes, infrastructure routing connections (essentially, what drains to what), drainage areas, overflow and surcharge depths and elevations, rating curves, and other various data.

SWMM Input Organization and Types

Aside from the manner in which data collected was classified (as listed in the previous section), the actual data input into SWMM may be classified as either atmospheric, surface, groundwater, or transport, with another set of methods and options classified as computational options. Furthermore, SWMM also lists data by the manner in which it is displayed, input, edited and/or accessed, defined as either visual or non-visual data. Visual data is displayed on the interface map, while non-visual data is applied or referenced via internal window boxes.

Visual objects include rain gages, subcatchments, junctions, outfalls, storage units, conduits (pipes and channels), orifices, weirs, and outlets. Examples of non-visual objects include unit hydrographs, cross sections, external inflows, curves, time series, computational options and time patterns[1]. Computational options were briefly listed earlier, and include selecting methods for modeling surface runoff, infiltration, flow routing, ponding, and pressurization as well as defining global model settings like computational step times, modeling constraint values, and units.

Building the Initial Model

The existing conditions calibration model was built for the entire watershed upstream from the two culverts passing Hodgson Brook below the Pease Wastewater Treatment Facility (PWTF) driveway. Three primary locations were monitored during the performance of this study, located at key locations for modeling: at the upstream junction box on the site (M-USJBOX), at the inlet to the box culvert passing Hodgson Brook beneath Corporate Drive (M-CORP), and at the terminus of the SWMM model, the inlet to the two culverts at the PWTF driveway (M-PWTF). Knowing these monitoring locations, and coupled with the site parcel which is planned for development, the model was segmented into four main subwatersheds: Upstream, Site, Downstream, and PWTF. For a visual reference, the monitoring locations, subwatersheds, and major infrastructure of interest may be found in Figure 1. The outlet to the Site subwatershed proved difficult to monitor for flows, due to the constant pool of water at the outlet of the pipe arch culverts, and the recessed culvert faces within the downstream junction box.

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[1] There are many additional data types which may be used in SWMM, but only those which are applicable to this project are listed and discussed.

Despite this, flows were expected to be very similar to those at the upstream junction box due to the fact that there is only one incoming connection between the two locations – a 15” culvert carrying primarily flows from roof runoff of the existing Lonza building.

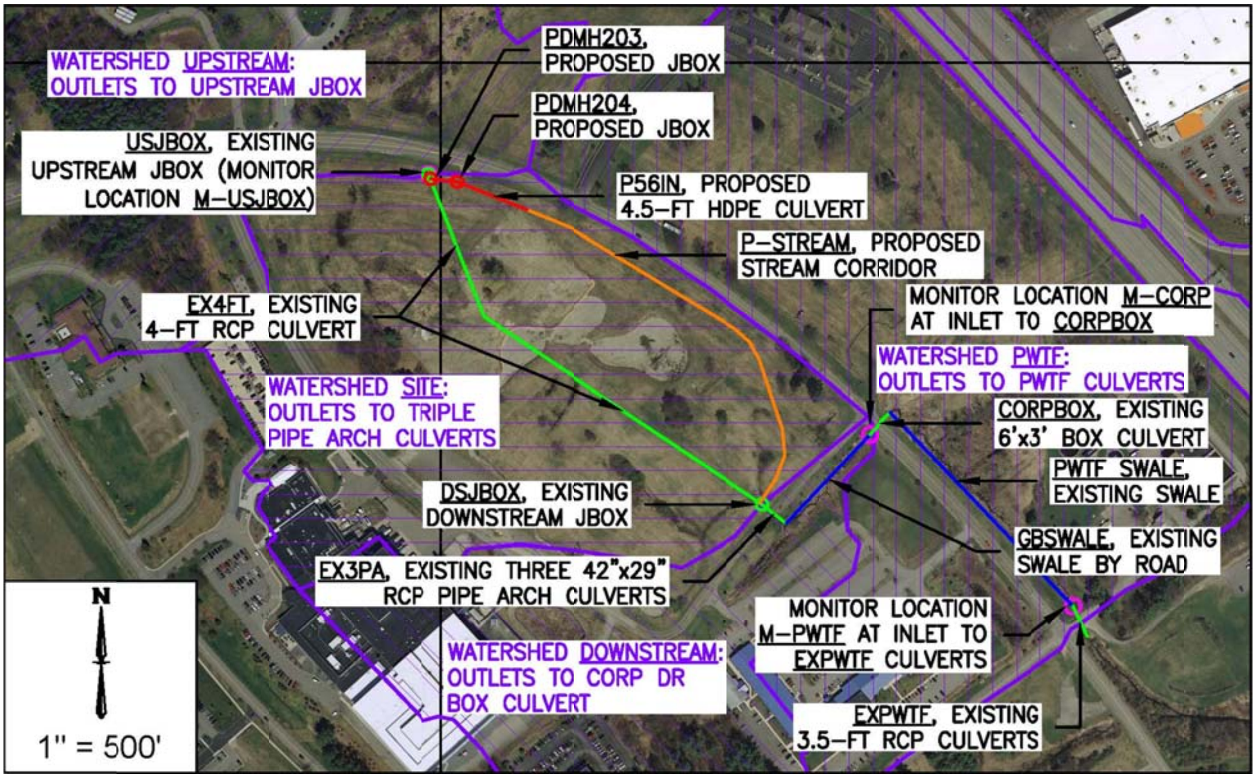

Figure 1 - Important model locations

Within each subwatershed, and for the model as a whole, drainage infrastructure was provided mostly from the City’s GIS database, and within Lonza property, via a survey performed by Doucet Survey, Inc. The survey provided by Doucet was accurate and fairly descriptive – only some of the infrastructure on the site was not recorded (some were inaccessible, not found, or otherwise unable to be surveyed). For the most part, the survey was accurate with regards to pipe dimensions, types, and materials. The City’s GIS layer was comprehensive and mostly complete with regards to infrastructure objects, connections, and locations, but understandably lacked most all of the conduit elevation, dimensions, and material information. The infrastructure provided by the city may be seen in Figure 2, with the watersheds visible for reference and relative locations.

Other key infrastructure and conduit data was obtained (and some of the other survey data verified) in the field, via a laser level survey (with other properties measured and noted during the survey). Elevations were recorded or checked for some culvert inverts, catch basin and manhole rims, and important overtopping locations. Modeled culverts were recorded for their physical properties, or were verified in the field. Cross sections were taken for open channels used in the model, with roughness values estimated using Chow’s method for open channels and floodplains.

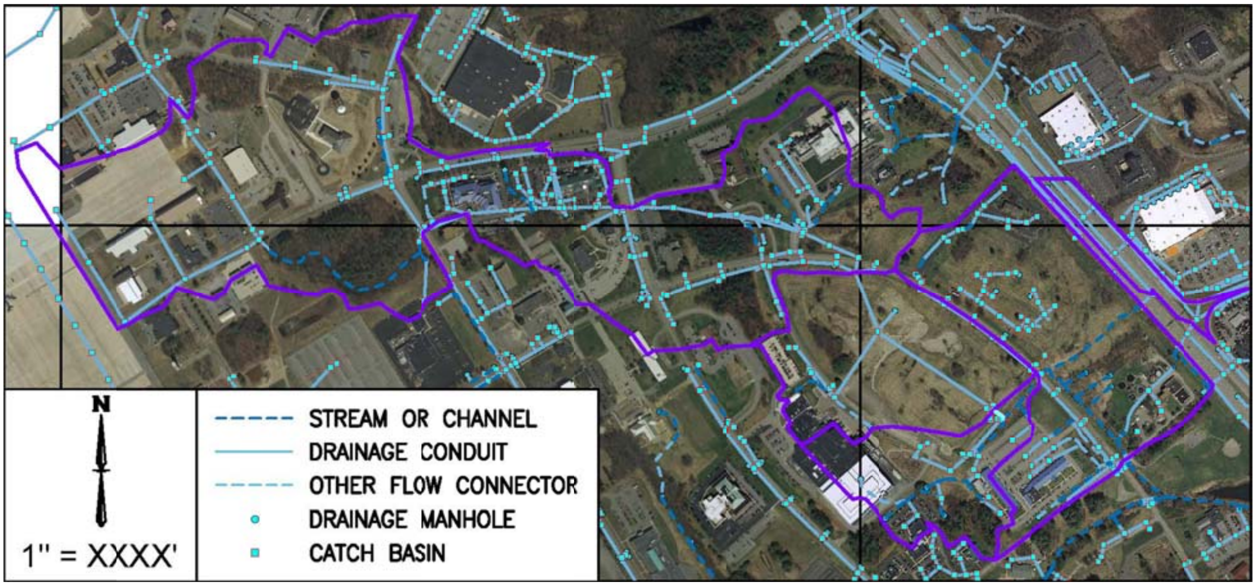

Figure 2 - Infrastructure provided by the City's GIS department

As there are hundreds of pieces of infrastructure within the model watershed, most of which had very little information provide, the model was simplified to contain all important infrastructure, but eliminated items which had no descriptive data other than location information.

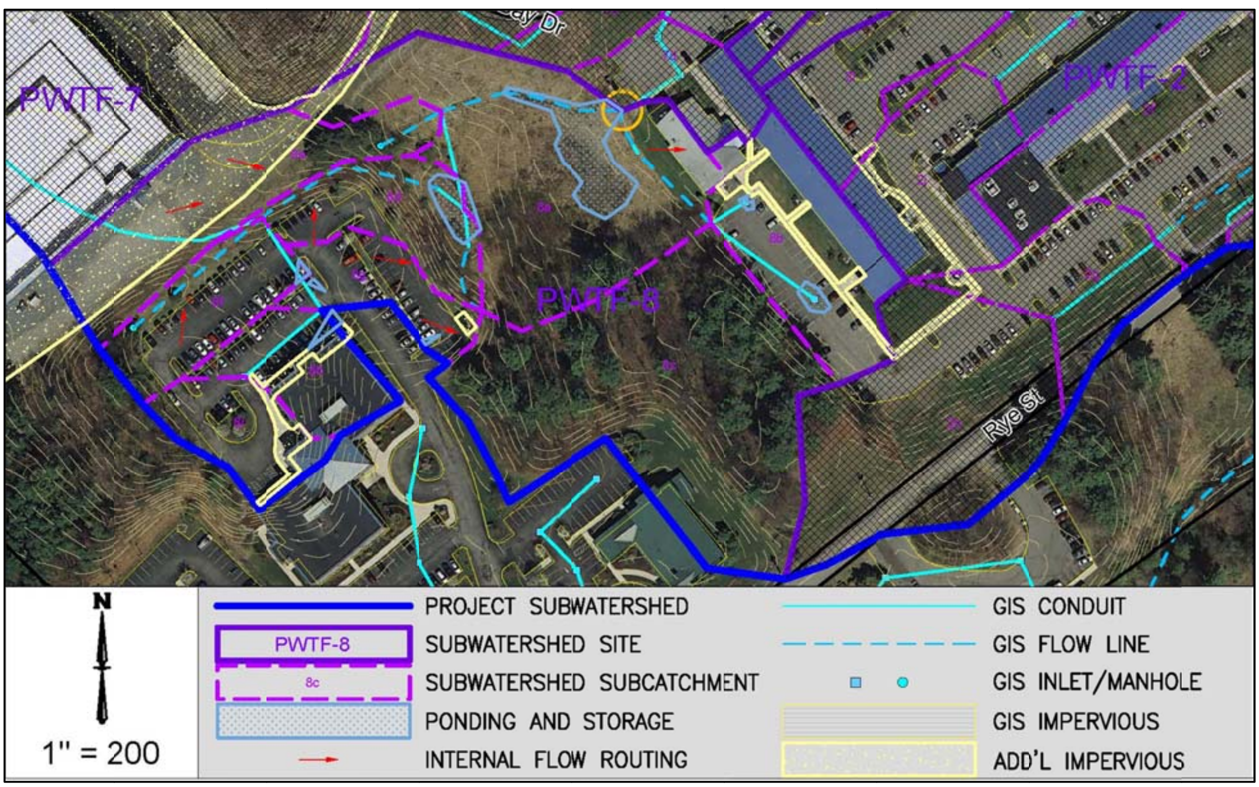

Figure 3 - Sample image showing one the subcatchments defined for one site within the PWTF project subwatershed. Each site was assigned a number, with each subcatchment being further identified by a lowercase letter. In this instance, the site is numbered 8 (PWTF-8), and has subcatchments labeled 8a through 8i. Segmenting these subcatchments made collecting important data to input into the model for each subcatchment, without requiring every single piece of infrastructure to be input into the model, as very little physical information was reported on the city's GIS drainage infrastructure layers.

Though the amount of infrastructure input to the model was reduced, the locations of the structures provided important means to extract more precise data with regards to the subwatershed properties. Most prominently, the locations of the catch basins were used along with the topography generated to define individual subcatchments, and determine important metrics within each. To keep drawings simple, and to create smaller, more manageable areas to analyze at one time, each subwatershed in the project was broken down into sites, with each site being defined as a drainage area to a well-defined outlet. Each site within each subwatershed could then be parsed into subcatchments, with each subcatchment defined by drainage infrastructure (or a similar, singular location, like the inlet to a culvert). A sample of one site within the PWTF subwatershed may be found in Figure 3.

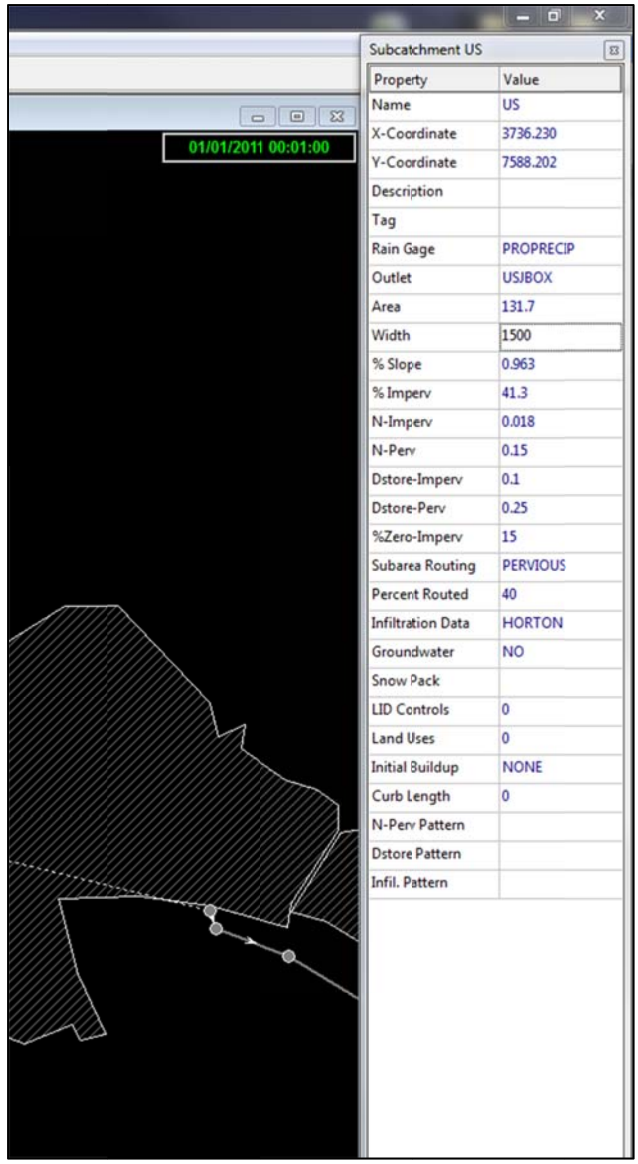

Image 3 - Subwatershed input table in SWMM

From these subcatchments, precise watershed metrics could be extracted at a manageable scale, then weighted to each subwatershed as a whole; for example, storage volumes could be calculated by determining the amount of ponding area possible and the ponding depth at each. The total amount of ponding volume within each subwatershed could then be used to represent the total amount of ponding area within each subwatershed at the average depth (total volume of ponding divided by the total amount of ponding area). These are used as input for the subwatersheds and allow the program to account for all the small, individual routing and storage effects to be accounted for without requiring all individual objects to be modeled.

Other ways in which the complete set of infrastructure was used to derive more precise information was to use the network to predict the longest flow paths, and to better refine watershed slopes and limits (thus, the watershed areas). With more accurate watershed areas, another input parameter used by SWMM was more precisely estimated: the representative subwatershed *width*. The watershed width is a parameter used by the program to calculate the reaction of runoff in each subwatershed to the precipitation. It is initially estimated as the drainage area divided by the longest flow path, though it is meant to be calibrated to better fit calculated results to observed ones.

Other parameters which SWMM uses as input for subwatersheds, for which values were able to be more precisely derived from the wealth of existing data include: percent impervious, pervious and impervious roughness, pervious and impervious ponding depths, percent of impervious with no ponding, internal subcatchment routing (whether water flows from impervious to pervious, or vice-versa), the percent of surface flows which are subject to the internal routing, infiltration data, and LID controls (if any). An example screen capture of the input box for a subcatchment within SWMM may be found in Image 3.

Initial values for each of these metrics were calculated in similar fashions – all of which used existing GIS data (topography, impervious cover, land use and types, infrastructure, etc.), analyzed in CAD to obtain highly accurate values:

- the average watershed slopes were determined directly within the CAD software, based off the surface created by the LiDAR data;
- impervious areas were determined from the City's land use layers, and supplemented or verified using aerial imagery;
- the total amount of ponding within each watershed was determined using the individual ponding estimations for each subcatchment, defined by catch basin locations;
- the roughness values were estimated for each different type of land use, then weighted for the watershed as a whole;
- the ponding depths were calculated from the amount of ponding volume calculated for each subwatershed as a whole;
- the amount of impervious cover with no ponding was determined from the previously-defined impervious cover areas and ponding areas, as was the percentage of area which was to be subject to internal routing; and
- infiltration rates were estimated by land use types for individual sections of each watershed, then weighted for the watershed as a whole[2].

CALIBRATING THE EXISTING MODEL

Upon completing the existing conditions model, the compiled monitoring rain record was used to run an initial calibration for the existing conditions, the results for which were then compared to the monitored flows and water elevations. Many of the previously-mentioned metrics were then adjusted with the goal of having the existing conditions model results for peak flow, time of peak, and runoff volume match the monitored results to within +/-15%. This was not universally achieved, especially for the timing of the peaks, but for the peak flow rates and total storm volumes, only several modeled results fell beyond 15% of the monitored amounts. The relative time between the modeled and monitored peak flows was considered to be the least important of the three comparisons, due to the fact that the watershed as a whole is very flashy – it reacts quickly to rainfall. The monitored storm hyetographs were compiled using a network of nearby rain gages, and as such any minor variation in the timing of the more intense rates during each storm can result in the model having different peak times than observed (especially during

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[2] A summary of the parameters initially determined for the model, as well as the final, calibrated values, and the values used in the proposed model may be found in tables at the end of this document.

storms with multiple peaks). An example of the monitored results compared to modeled results for the calibrated existing conditions model during the 9/18/2018 storm (Hurricane Florence remnants) at the USJBOX and PWTF culverts may be seen in Figures 4 and 5, and Tables 1 and 2.

It may be seen in this example storm, the peak times vary by about 15%, however the overall shapes of the hydrographs are quite similar. The peaks flows were predicted to be very similar, and the volumes were predicted within a reasonable amount. The smoother modeled hydrographs are the result of the many simplifications made to model the subwatersheds.

Table 1 - 9/18 Storm Model and Monitored Results at the Upstream Junction Box					
Property	Units	Monitored	Modeled	Difference	% Difference
Peak Flow	cfs	55.2	56.6	1.4	2.5
Runoff Volume	cf	635,112	698,193	63,080	9.9
Time to Peak	min	235	271	36	15.3

Table 2 - 9/18 Storm Model and Monitored Results at the Inlet to the PWTF Culverts					
Property	Units	Monitored	Modeled	Difference	% Difference
Peak Flow	cfs	110.3	110.8	0.5	0.4
Runoff Volume	cf	1,979,558	1,672,706	-306,853	15.5
Time to Peak	min	315	360	45	14.3

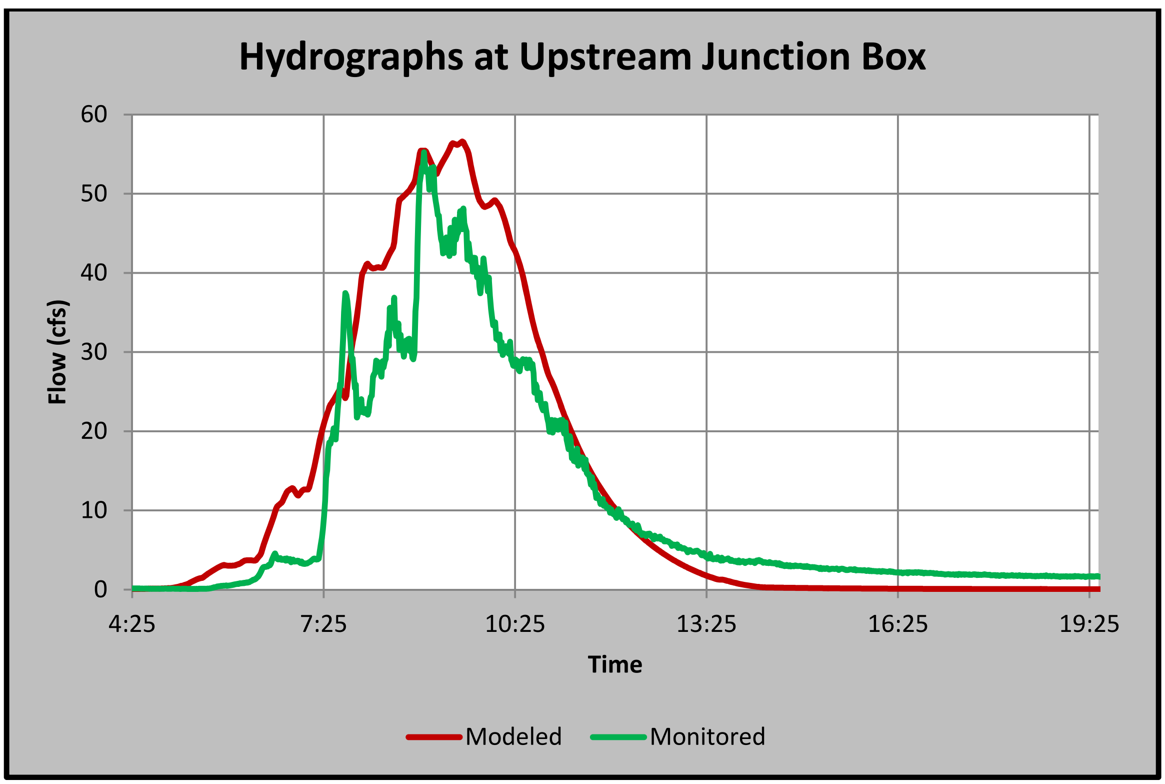

Figure 4 - Comparison of the modeled and monitored hydrographs at the upstream junction box during the 9/18/2018 storm. Notice that the overall shape of the hydrographs is similar, despite the slight variation in the peaks and troughs.

With the existing conditions model built and calibrated to the monitored storm events, the model was then run to simulate two separate precipitation records; one using a 41-year gaged record, and another run using the design events predicted by the Northeast Regional Climate Center (NRCC). The former rainfall record was used to more appropriately predict flows to design the stream to, while the latter was built in order to be able to directly compare the existing conditions to proposed conditions[3].

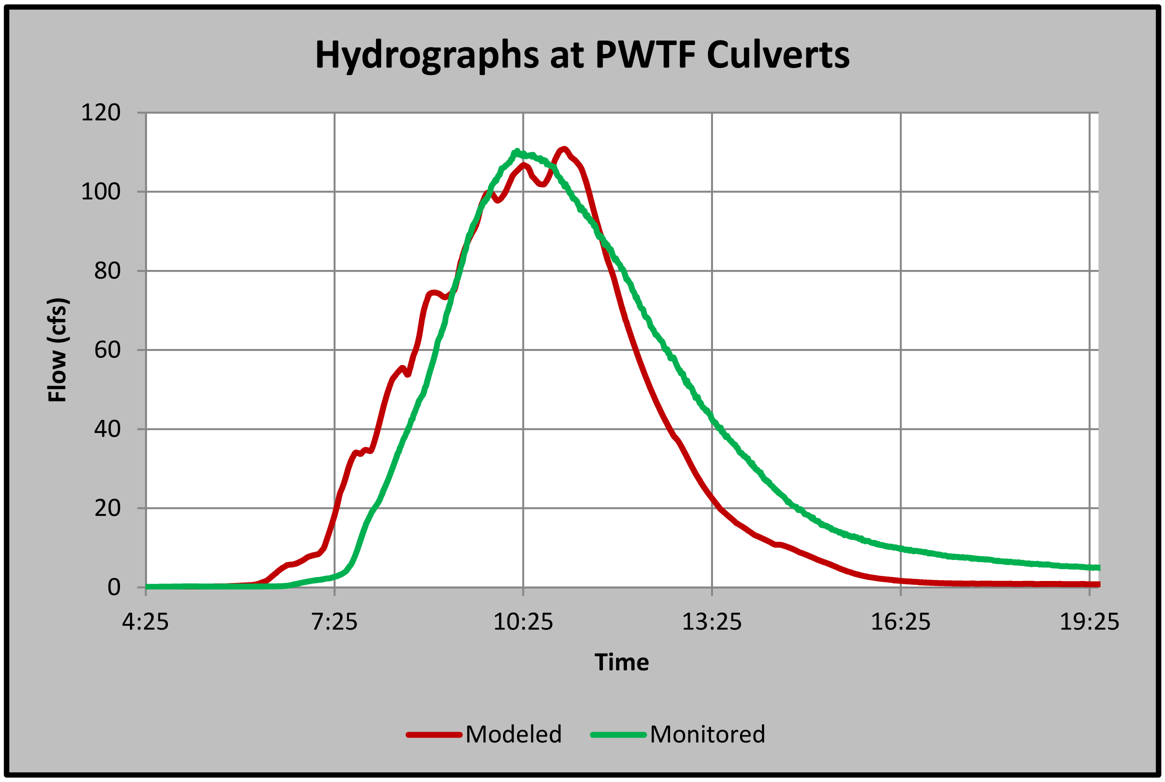

Figure 5 - Comparison of the modeled and monitored hydrographs at the inlet to the culverts at the PWTF Driveway

BUILDING THE PROPOSED MODEL

To build the proposed model, the Site watershed was removed[4], and infrastructure on the site was modified, removed or added according to the design. Stick diagrams showing the major structure for each model, as well as the major changes between the two models, may be found in Figures 6 and 7.

As the proposed stormwater basins were modeled by Tighe and Bond, their hydrographs were added as external flows into the proposed conditions model rather than building the systems into the model, for consistency. The modeled results for water elevations at the outlets to each system were then fed back to Tighe and Bond, at which point another analysis was performed for the hydraulic performance of the

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[3] As the proposed site development is subject to AOT regulations, all stormwater basins are required to be designed to manage the NRCC rainfall amounts, plus 15%. As such, the designed stormwater basins were built and modeled for these events, thus in order to compare the effect the project will have on the site and surrounding hydraulics, the existing conditions model must observe the same rain events.

[4] The Site watershed was removed from the model, but flows from the existing Lonza site were calculated and fed into the model as an external flow record, in the same manner which the proposed stormwater basins were input.

systems. The results from this were then updated in the proposed conditions model to obtain the final proposed conditions model results.

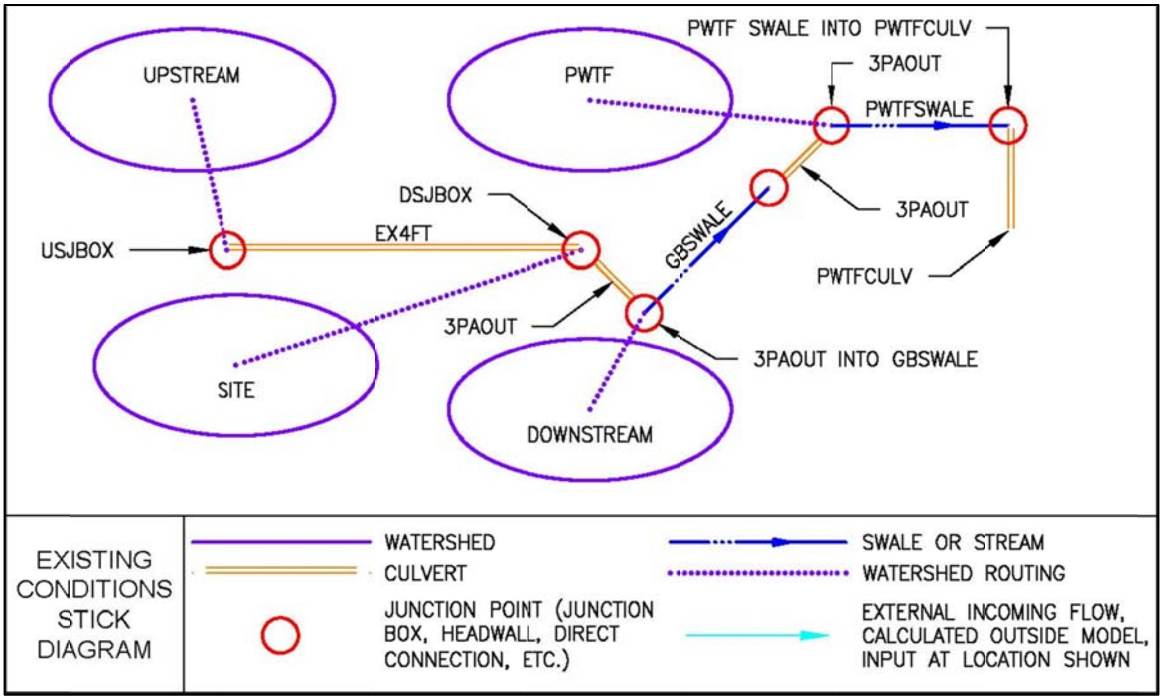


Figure 6 - Stick diagram depicting the basic structure of the existing conditions model

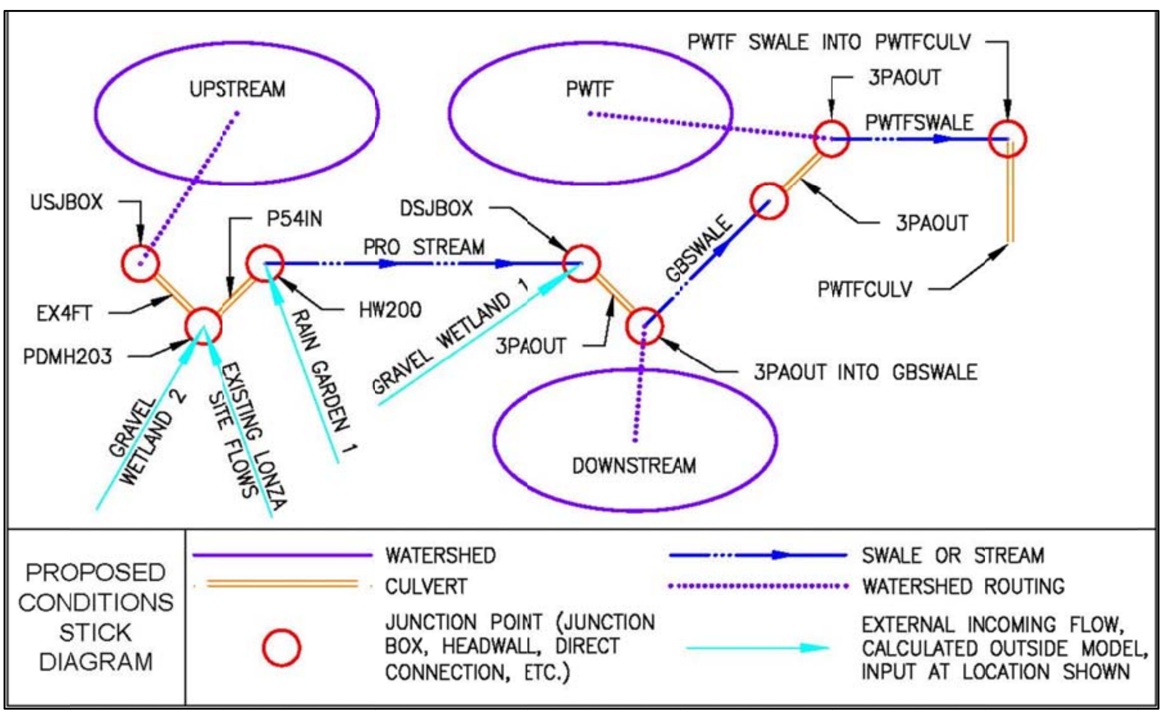


Figure 7 - Stick diagram depicting the basic structure of the proposed conditions model. Major differences are the removal of the Site watershed, replaced with correlating time series of the externally-calculated hydrographs, and the subtraction and addition of all appropriate infrastructure. In this scenario, though the proposed stream and gravel wetland 1 both outlet to a junction called "DSJBOX", there is not junction box modeled at that location within the proposed model, the notation simply wasn't changed in order to maintain a continuity in notation.

Summary of Input Metrics

The metrics used to build the models begin with initially-determined values which were then calibrated, then modified to reflect the conditions of the proposed site development. Metrics which changed during the calibration of the existing conditions model were those which affected the hydrology, and which represented a watershed-wide mean of the values. These metrics include [their ID in the following tables] (how they were initially estimated or calculated):

- The effective impervious cover [% Impervious] (initially estimated from the land use GIS layer, aerial imagery, impervious cover data – these were not actually calibrated values; initially the impervious amounts included all wetland and permanent water areas, however it was ultimately determined that those should not be included, as they are better accounted for in other ways. This is the reason these values changed from the initial model to the calibrated model, not because they were adjusted to help match the results.)
- The representative watershed widths [Width] (initially calculated, as suggested by SWMM documentation, as the watershed area divided by the longest flow path). Fundamentally, SWMM models subwatersheds as though they look like an open book with the drainage being the valley between the two halves. To more accurately reflect reality, the book dimensions are modified (here, the width).
- The average watershed slope [Watershed Slope] (initially calculated as the overall watershed slope, calculated via CAD software based on the LiDAR surface)
- The roughness of the impervious and pervious surfaces [Impervious n, Pervious n] (initially estimated using aerial imagery, the Land Use GIS layer, and travel paths defined for the subcatchments, all weighted accordingly for each subwatershed using typical values)
- The amount of storage depth for impervious and pervious surfaces [Impervious Storage, Pervious Storage] (initially estimated in the same manner as previous item)
- The amount of impervious area with no storage [% Zero Storage] (initially estimated from the subcatchments delineated, aerial imagery, and the impervious cover GIS layer)
- The amount of subwatershed internal routing – the area within each watershed where surface water was internally routed from impervious to pervious surfaces [Percent Routed] (initially estimated in the same manner as the above bullet)
- The infiltration rates: maximum rate, minimum rate, and decay coefficient [Max Infiltration, Min Infiltration, Infiltration Decay] (initially estimated from the soils data (Web Soil Survey), land use data, and typical values, all weighted accordingly per each subwatershed)
- The amount of ponding within each subwatershed [Ponded Area] (initially determined using the subcatchments and LiDAR topography to estimate ponding as a whole for each subwatershed)

As the subwatersheds mostly exhibit similarities throughout (all exist near to each other, and all have been subjected to similar histories) it would be expected that hydrologic parameters should be similar, if not the same. Therefore during the calibration process, many of the metrics which were changed (listed above), were adjusted globally throughout the model. Only when the calibrated model could not be built and run with similar results to monitored events were metrics changed individually for subwatersheds.

The principal differences between the existing and the proposed models were physical differences, resulting directly from the proposed design (as represented in Figures 6 and 7). No changes were made between existing and proposed models with respect to initially calibrated metrics.

A summary of some important metrics and physical infrastructure which were initially calculated or estimated, which were ultimately used or calibrated in the existing model, and which were used in the proposed model, may all be seen in the following tables. For visual similarity between the tables, all the infrastructure used throughout the three scenarios is shown for each table, despite some of the infrastructure not existing from one to the next. Instances where infrastructure is not used in one of the scenarios, the text will appear in a light gray, and its values containing "N/A". For quick and easy reference, values which changed from initial determination to calibrated conditions are highlighted in a light yellow. Items which changed from existing to proposed conditions are highlighted in light orange.

Table 3 - Summary of Initial Watershed Metrics					
Metric	Units	Upstream	Site	Downstream	PWTF
Drainage Area	ac	131.7	29.4	17.6	49.6
% Impervious	%	43.0	23.3	57.4	33.9
Width	ft	1,032	593	505	1,025
Watershed Slope	%	0.96	1.54	2.47	1.98
Impervious n	-	0.012	0.012	0.012	0.012
Pervious n	-	0.24	0.24	0.24	0.24
Impervious Storage	in	0.075	0.075	0.075	0.075
Pervious Storage	in	0.20	0.20	0.20	0.20
% Zero Storage	%	25	25	25	25
Percent Routed	%	25	10	15	50
Ponded Area	sf	171,990	7,461	182,878	262,366
Max Infiltration	in/hr	2.00	2.00	2.00	2.00
Min Infiltration	in/hr	0.43	0.43	0.43	0.43
Infiltration Decay	1/hr	4.50	4.50	4.50	4.50

Table 4 - Summary of Calibrated Watershed Metrics					
Metric	Units	Upstream	Site	Downstream	PWTF
Drainage Area	ac	131.7	29.4	17.6	49.6
% Impervious	%	41.3	22.2	53.4	31.2
Width	ft	1,500	900	900	1,000
Watershed Slope	%	0.96	2.25	2.50	2.50
Impervious n	-	0.018	0.018	0.018	0.018
Pervious n	-	0.15	0.24	0.24	0.24
Impervious Storage	in	0.1	0.1	0.1	0.1
Pervious Storage	in	0.25	0.25	0.50	0.50
% Zero Storage	%	15	5	5	5
Percent Routed	%	40	20	20	20
Ponded Area	sf	150,000	7461	206,000	262,366
Max Infiltration	in/hr	1.75	2.00	2.00	2.00
Min Infiltration	in/hr	0.15	0.15	0.15	0.15
Infiltration Decay	1/hr	4.00	4.00	4.00	4.00

Table 5 - Summary of Proposed Watershed Metrics					
Metric	Units	Upstream	Site	Downstream	PWTF
Drainage Area	ac	131.7	N/A	17.6	49.6
% Impervious	%	41.3	N/A	53.4	31.2
Width	ft	1,500	N/A	900	1,000
Watershed Slope	%	0.96	N/A	2.50	2.50
Impervious n	-	0.018	N/A	0.018	0.018
Pervious n	-	0.15	N/A	0.24	0.24
Impervious Storage	in	0.1	N/A	0.1	0.1
Pervious Storage	in	0.25	N/A	0.50	0.50
% Zero Storage	%	15	N/A	5	5
Percent Routed	%	40	N/A	20	20
Ponded Area	sf	150,000	N/A	206,000	262,366
Max Infiltration	in/hr	1.75	N/A	2.00	2.00
Min Infiltration	in/hr	0.15	N/A	0.15	0.15
Infiltration Decay	1/hr	4.00	N/A	4.00	4.00

Table 6 - Existing Conditions Conduit Properties							
ID	From Node	To Node	Length	Roughness	Kent	Kexit	Base Flow
-	-	-	ft	-	-	-	cfs
EX4FT	USJBOX	DSJBOX	1,266	0.013	0.2	1.0	0.075
P54IN	N/A	N/A	N/A	N/A	N/A	N/A	N/A
STREAM	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3PAOUT	DSJBOX	GBSWALE	68	0.022	0.5	1.0	0.075
GBSWALE	GBSWALE	CORPBOX	320	0.090	N/A	N/A	0.16
CORPBOX	CORPBOX	PWTFSWALE	80	0.020	0.5	1.0	0.16
PWTFSWALE	PWTFSWALE	PWTFDRIVE	770	0.095	N/A	N/A	0.25

Table 7 - Proposed Conditions Conduit Properties							
ID	From Node	To Node	Length	Roughness	Kent	Kexit	Base Flow
-	-	-	ft	-	-	-	cfs
EX4FT	USJBOX	PDMH203	11	0.013	0.2	1.0	0.075
P54IN	PDMH203	HW200	269	0.013	0.5	1.0	0
STREAM	HW200	DSJBOX	1,470	0.075	N/A	N/A	0
3PAOUT	DSJBOX	GBSWALE	60	0.022	0.8	1.0	0.075
GBSWALE	GBSWALE	CORPBOX	320	0.090	N/A	N/A	0.16
CORPBOX	CORPBOX	PWTFSWALE	80	0.020	0.5	1.0	0.16
PWTFSWALE	PWTFSWALE	PWTFDRIVE	770	0.095	N/A	N/A	0.25

The Restoration of Hodgson Brook at the Iron Rail Parcel at Pease Tradeport in Portsmouth, NH

The benefits of stream restoration

Collecting and processing reference data

Design metrics for the stream and floodplain using natural channel design

Construction sequencing

Planting plan for the floodplain and riparian corridor

Five year monitoring plan and methods

Streamworks, PLLC

Joel Ballestero

Thomas P. Ballestero

14 November 2018

Edits and Changes to the Report

The original submitted report, dated 04 September 2018 has been superseded by this version of the report, dated 14 November, 2018. A list of the changes made to the document may be found below.

1. Table 1 was updated to reflect flows calculated by the watershed model. The flows in the table represent an LP3 analysis of flows calculated from gaged historic rain events, which do not match the flows calculated for design precipitation storm events used in stormwater calculations, nor the Weibull-ranked historic flows shown in tables within the Watershed Modeling report. It is more common in stream restoration to use statistical analysis on flows, rather than designing to precipitation events, when possible. As this report details specifically the restoration of the brook, it refers to these flows in the document, and these were the flows used in calculations of the channel.

2. Updated the Design Metrics section of the report for language, and the values in Table 4 to show the range of metrics specified for each of the three design scenarios, which together represent the range of stream forms which shall be constructed in the field.

3. Updated the planting plan only slightly to include a biodegradable netting specified to be secured, starting at the toe of the stream bank underneath the coir log roll at the toe, up over the bank and onto the floodplain to the toe of the valley slope. This is to help ensure stability is maintained while vegetation is growing, for several years until the system is fully vegetated.

4. Updated the Post Construction Monitoring Plan to reflect the removal of the water quality sampling. Originally proposed to supplement sampling managed and performed by the Hodgson Brook LAC, this group has since dissolved, with no new sampling taking place. With no other concurrent data to correlate the water quality data to, and no foreseeable monitoring to occur, these items were removed (items removed were originally numbered 1, 2, 3, 4, and 10).

5. Included sections for Monitoring and Maintenance During Construction and an Adaptive Management Plan (ongoing during construction, and for the 5 years following the project completion).

6. Updated the Appendix to reflect all new changes to the design and any images depicting such changes.

The Benefits of Stream Restoration

The benefits to stream restoration are numerous to an ecosystem, especially so when land that had been developed into an urban area is reconstructed and allowed to grow more naturally again. This is the case throughout the history of Hodgson Brook, a stream whose watershed has been almost entirely developed. The watershed for the stream begins at the Pease Tradeport in Newington (though most of the watershed, including the site, is in Portsmouth), and ends in the tidal waters of North Mill Pond in Portsmouth. At the project site and upstream, other than flowing through open drainage ditches and some wetlands, the stream is buried through a network of pipes that carry water flowing directly off impervious surfaces. This system prevents precipitation from filtering into the ground and recharging the groundwater table, a process which otherwise would filter the water from the urban contaminants it collects along its path. With the reduction of water lost into the ground, the amount that ends up directly in the waterway is increased, and commonly, the time it spends in a healthier environment is reduced. The time the water does spend in open channels, is spent under a lack of natural cover where in the summer it therefore warms due to a lack of shade and a lack of cooler groundwater inflows that recharge the base flow, and moderate biogeochemical processes. The drainage ditch that is now Hodgson Brook is also poor habitat, lacking a diversity of flora and fauna that exist in a more natural setting.

This project proposes to daylight a section (~1,000 feet along the valley, ~1,200 feet of stream) of Hodgson Brook where it currently lies buried in a 4.5-foot diameter culvert before exiting the project site into a drainage ditch; this stream restoration will result in approximately 42,500 square feet (sf) of stream and riparian buffer being created.

Daylighting the stream will restore a more natural riffle-pool sequence to a system that when it is presently in the open, is unnaturally straight, having been relocated and straightened to make way for development. The new stream corridor will provide an opportunity for storm flows to enter into the channel and adjacent floodplain, providing a connection for water to reenter and filter into the ground, in addition to being filtered and used by vegetation. The stream and corridor are hydraulically rougher and longer than the existing pipe, and will create a slower travel time over the same valley distance, in addition to increased storage volume. The corridor will benefit from native, riparian vegetation that will be allowed to grow in a natural state, encouraging wildlife use, nutrient/pollutant removal, and shade to keep the water cool. The habitat will help filter out common pollutants such as nitrogen and phosphorous, all while reducing the amount of contaminated water that enters North Mill Pond. Obviously this is one piece of a greater system between the Tradeport and North Mill Pond, therefore while the benefits of this specific projects are very high, it should be recognized that there are other impairments along the watershed also in need of attention.

The restoration work will provide a reconnection for a portion of a watercourse that has been heavily altered in the past, and hopefully provide an example of how a stream corridor may be restored in an urban environment and serve as a reference for the future.

Collecting and Processing Existing Data

Hodgson Brook at the project site is extremely impaired. What was likely once a naturally-functioning stream – efficiently transporting water, sediment, and nutrients; providing habitat; and operating with relatively stable geomorphic metrics – has been almost entirely paved and piped through its course along the watershed. Relatively little sediment enters or exists the system; less surface water is able to enter into the ground; and almost no in-stream habitat is supported. To restore the system back to a functioning stream and valley corridor, a process of observing and mimicking nature will be employed in an attempt to maximize the effectiveness of the restoration.

Natural Channel Design involves obtaining fluvial geomorphic metrics that are measured on natural, healthy systems (reference stream) which are then employed to serve as a template for the design metrics to the impaired watercourse, as long as the watersheds and streams have similar properties. It is not uncommon for this reference stream section to exist in healthy sections of the same stream, or at sections of adjacent streams. In the case of Hodgson Brook, unfortunately there is no existing healthy/natural/undeveloped section of the brook that exists today, as most of the stream and its watershed exhibit significant urbanization and lack of stormwater management. There also exist few nearby streams that meet the criteria of being healthy, natural, and relatively unaltered that also share similar watershed characteristics; arguably, there exist few healthy, natural, and relatively unaltered streams in regions that exhibit highly impervious watersheds and little vegetation which also have low stream slopes and that are located near the New Hampshire coast. Simply put, there aren’t many healthy streams (to say nothing of natural) that exist in an urban environment. In this case, the stream should aim to mimic its historic, natural system as best as possible while accounting for the upstream watershed conditions.

Luckily, there exists a relative wealth of information that has already been collected about the history of the Hodgson Brook watershed, the development over the years, how it exists now, and goals for restoring it. A 2004 restoration plan for Hodgson Brook was prepared by D. B. Truslow Associates with cooperation from the Hodgson Brook Local Advisory Committee, with funding provided by NHDES. This publication (among others) is available online at the DES’ website for the watershed[1]. The publication contains much information about the history of the watershed, which provides a good place to start in order to find a relevant reference reach.

After reading the report, two sites were identified as having been restored at Pease – Grafton Ditch and Railroad Brook. Upon investigation of the two sites, and taking some brief measurements, neither site was suitable for use as a reference reach for Hodgson Brook. Both sites were rebuilt with very hard measures (a lot of rock bank and grade control), and both were far over-widened with little plan form geometry. However, stream form measurements were taken on Hodgson Brook immediately at the outlet from the Iron Rail Parcel – where the stream is in no way natural or healthy – but years of flowing through the drainage ditch there has allowed the confined brook to erode some of the banks, and establish some plan form geometry, and can provide metrics on what the channel is able to pass

[1] The website is located at: https://www.des.nh.gov/organization/divisions/water/wmb/was/hodgson/index.htm

currently. Classification of this section of stream, and the parameters used for evaluating the classification, may be seen in Table 2. The pipe system through the site was also surveyed, which provided the controlling upstream and downstream elevation, as well as the valley length.

Knowing the valley slope, the historic properties of the watershed, and approximate metrics from the regional geomorphic curves developed for New Hampshire, a dozen or so reference reaches around the seacoast area were walked and visually assessed. The most representative of all the reference reaches, Hutchins Creek in Kittery (43.106989°N, 70.705805°W), was then surveyed for plan form, cross sections, profile, and geomorphic properties. Overall, a 150-foot section of Hutchins Creek was surveyed (channel and floodplain). Planform geometry was collected for seven riffle-pool sequences over four meander wavelengths along the valley. Profiles of the thalweg, top of bank, bankfull, and water surface elevation were all collected. A total of 11 cross sections (7 riffles and 4 pools) were taken at locations where bankfull indicators were evident, and for each section all stream and floodplain widths, depths, and ratios were extracted and calculated. Of those, the sections were weighted according to which appeared to be the healthiest and most stable in the field.

The parameters for the Hodgson Brook and Hutchins Creek watersheds may be found in Table 1, and the geomorphic metrics for the profile, cross section, and planform of Hutchins Creek in Table 3 and Lower Hodgson Brook in Table 2b. Select values from the observed particle size distribution (done by pebble counts) for Lower Hodgson Brook may be found in Table 2a – with a plot of the data found in Figure 1. Additionally, planform and cross sectional definitions are shown on pages A1 and A2 of the Appendix, for reference.

It is important to note that at the time of this report, a brief investigation into the historic stream and valley slope of Hodgson Brook before development began revealed that the brook had approximate slopes of 0.25% and 0.30%, respectively. These slopes closely match those which were observed for Hutchins Creek, which are part of the many reasons it was chosen – along with the valley type, low development and highly natural watershed, watershed size, among others – to be the reference reach for this project.

The flow values in Table 1 for Hodgson Brook have been updated to show the results calculated by performing an LP3 analysis of calculated flows for a 41-yr record of historic precipitation data. Please refer to the Watershed Modeling document for more details on the hydrology modeled for the site.

Table 1 - Select Watershed and Hydrologic Properties				
Property	Code	Units	Lower Hodgson Brook - Iron Rail	Hutchins Creek
Drainage Area	DA	mi^2	0.21	0.40
2-yr Peak Flow	Q2	cfs	52.1	6.46
5-Yr Peak Flow	Q5	cfs	87.4	14.3
10-yr Peak Flow	Q10	cfs	113	18.4
25-yr Peak Flow	Q25	cfs	141	24.0
50-yr Peak Flow	Q50	cfs	158	28.5
100-yr Peak Flow	Q100	cfs	176	33.4
Pipe/Valley Slope	S	ft/ft	0.01057	0.00176

Table 2a - Particle Size Results for Pebble Counts at Riffles Along Lower Hodgson Brook		
Particle	Size (mm)	Size (in)
D10	0.19	0.007
D50	0.38	0.015
D80	1.5	0.059
D90	7	0.276
D95	14	0.551

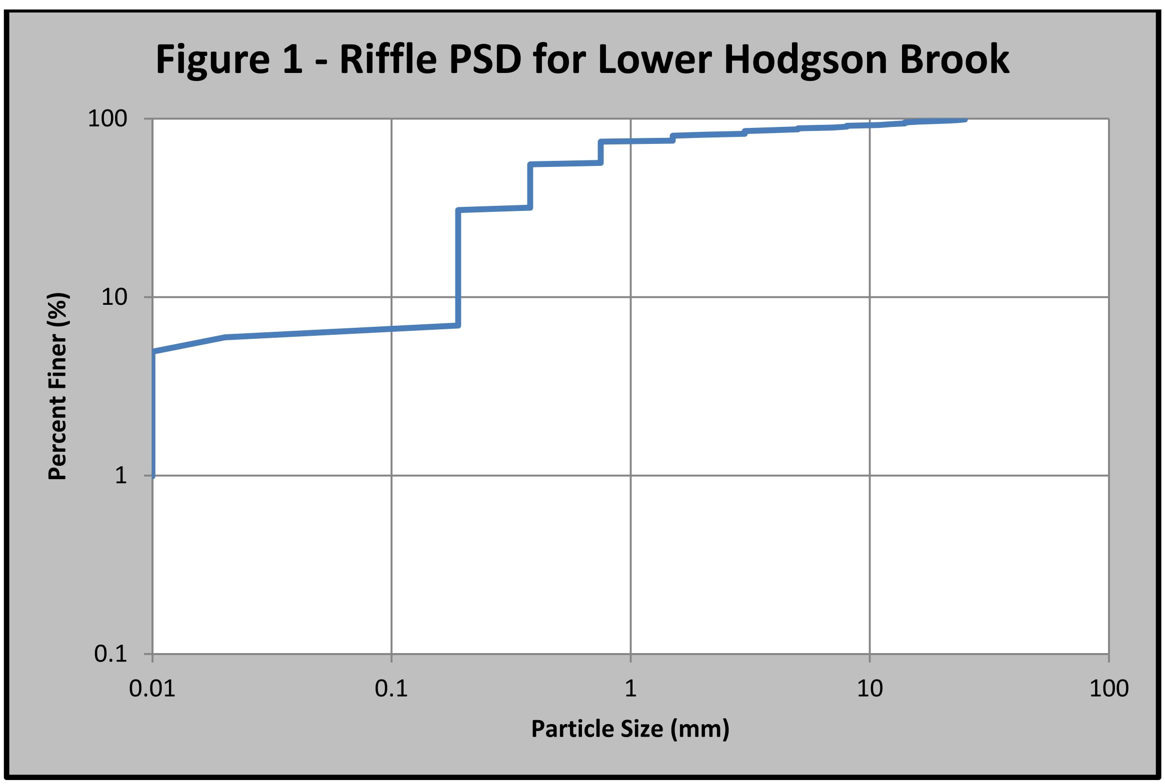


Table 2b - Lower Hodgson Brook at Iron Rail Parcel Reference Reach Data							
Characteristic		Code	Units	Lower Hodgson Brook Observations			
				1	2	3	4
Profile	Stream Slope	S	ft/ft	0.00316			
	Valley Slope	V_s	ft/ft	0.00565			
	Sinuosity	k		1.072			
	Pool Length	L_p	ft	9.2	5.3	20.6	10.6
	Pool to Pool Spacing	P-P	ft	18.7	11.1	22.6	37.6
Cross Section	Bankfull Width	W_{bkf}	ft	5.76	4.60	3.69	5.54
	Floodprone Width	W_{fp}	ft	7.03	9.35	6.26	9.67
	Maximum Bankfull Depth	D_{max}	ft	0.89	0.76	0.62	0.80
	Average Bankfull Depth	D_{avg}	ft	0.55	0.44	0.51	0.40
	Entrenchment Ratio	ER	ft/ft	1.22	2.03	1.70	1.75
	Width to Depth Ratio	W/D	ft/ft	10.50	10.49	7.22	13.81
Plan Form	Radius of Curvature	R_c	ft	40.7	15.8	22.4	8.9
	Arc Length		ft				
	Average Bankfull Width	W_{bkf}	ft	5.8	5.5	5.0	4.6
	Rc:Wbkf Ratio		ft/ft	7.01	2.87	4.48	1.94
	Meander Belt Width	MBW	ft	13.1	16.9	14.7	
	Average Bankfull Width	W_{bkf}	ft	4.6	5.0	5.8	
	MBW/Wbkf		ft/ft	2.85	3.38	2.53	
	Meander Length	ML	ft	56.04	56.53	46.32	
	Average Bankfull Width	W_{bkf}	ft	5.8	5	4.6	
	ML/Wbkf		ft/ft	9.66	11.31	10.07	
Classification	Entrenchment Ratio	ER	ft/ft	1.22	2.03	1.70	1.75
	Width to Depth Ratio	W/D	ft/ft	10.50	10.49	7.22	13.81
	Sinuosity	k		1.072	1.072	1.072	1.072
	Stream Slope	S	ft/ft	0.00316	0.00316	0.00316	0.00316
	Bed Material	-	-	Sand	Sand	Sand	Sand
	Classification	-	-	G5c	B5c	G5c	G5c

Table 3 - Hutchins Creek Reference Reach Data

	Characteristic	Code	Units	Hutchins Creek Observations										
				1	2	3	4	5	6	7	8	9	10	11
Profile	Stream Slope	S	ft/ft	0.00165										
	Valley Slope	Vs	ft/ft	0.00176										
	Sinuosity	k		1.20										
	Pool Length	Lp	ft	10.9	7.3	1.4	9.8	11.5	10.3	3.7				
	Pool to Pool Spacing	P-P	ft	24.4	13.5	14.6	15.1	15.1	21					
Cross Section	Bankfull Width	Wbkf	ft	7	6.5	6.5	5	5	7	5.5	5.5	6	5.5	5.0
	Floodprone Width	Wfp	ft	25	18	20	30	20	30	20	20	25	39.1	37.8
	Maximum Bankfull Depth	Dmax	ft	0.68	0.62	0.55	0.65	0.58	0.96	0.87	0.65	0.64	0.69	0.74
	Average Bankfull Depth	Davg	ft	0.476	0.434	0.385	0.455	0.406	0.672	0.609	0.455	0.448	0.38	0.48
	Entrenchment Ratio	ER	ft/ft	3.57	2.77	3.08	6.00	4.00	4.29	3.64	3.64	4.17	7.11	7.60
	Width to Depth Ratio	W/D	ft/ft	14.71	14.98	16.88	10.99	12.32	10.42	9.03	12.09	13.39	14.42	10.38
Plan Form	Radius of Curvature	Rc	ft	11.8	7.6	8.3	9.6	7.6	15.3	3.7	13.6			
	Arc Length		ft	16.3	7.0	10.1	11.6	8.1	13.6	7.4	12.0			
	Average Bankfull Width	Wbkf	ft	4.8	4.0	4.0	4.6	3.3	3.8	3.4	5.0			
	Rc:Wbkf Ratio		ft/ft	2.48	1.91	2.07	2.08	2.33	4.02	1.10	2.72			
	Meander Belt Width	MBW	ft	14.5	13.5	10.0	10.5	9.0	17.0					
	Average Bankfull Width	Wbkf	ft	5.0	4.5	4.5	4.0	4.0	5.0					
	MBW/Wbkf		ft/ft	2.90	3.00	2.22	2.63	2.25	3.40					
	Meander Length	ML	ft	40.1	23.8	27.2	30.4	30.3	36.0					
	Average Bankfull Width	Wbkf	ft	5.0	4.5	4.5	4.0	4.0	5.0					
	ML/Wbkf		ft/ft	8.02	5.28	6.04	7.59	7.57	7.20					
Classification	Entrenchment Ratio	ER	ft/ft	3.57	2.77	3.08	6.00	4.00	4.29	3.64	3.64	4.17	7.11	7.60
	Width to Depth Ratio	W/D	ft/ft	14.71	14.98	16.88	10.99	12.32	10.42	9.03	12.09	13.39	14.42	10.38
	Sinuosity	k		1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
	Stream Slope	S	ft/ft	0.00165	0.00165	0.00165	0.00165	0.00165	0.00165	0.00165	0.00165	0.00165	0.00165	0.00165
	Bed Material	-	-	Sand	Sand	Sand	Sand	Sand	Sand	Sand	Sand	Sand	Sand	Sand
	Classification	-	-	C5	C5	C5	C5	C5	C5	E5	C5	C5	C5	C5

Design Metrics for Stream and Floodplain Using Natural Channel Design

The natural channel design process uses the collected reference reach data to develop proposed metrics to create a stream design which can accommodate site constraints (usually things like incoming flows, upstream and downstream invert elevations, valley width, sediment supply, etc.) and provide a stable stream form. The site constraints control selected design metrics, which are then used to calculate – often quite iteratively – the remaining metrics within a range, determined by the reference reach data. The constraints at the project site include the stream inverts at the start and end (therefore the maximum stream slope), the valley width, the watershed properties, and the site hydrology. The most difficult of all the constraints to calculate for this project were the flows incoming to the site. Upstream of the site, the watershed is extremely developed, and in order to calculate flows using common methods (Rational Method, SCS Curve Number Method, regression equations, etc.), a full watershed model would have been necessary. Such a model is in development at the writing of this report; the output from which will provide return period flows, but may not well represent the most geomorphically-appropriate flows. The dominant channel-forming flow is referred to as the bankfull flow, and for undeveloped watersheds is commonly in the range of the 1.5- to 2-year peak flow. However, this is just an approximation, and is not globally true for all watersheds and streams. Recently, project team members were involved with a geomorphic assessment on a highly-impacted, urban stream in northeast Ohio. It was found that the bankfull flow for this stream was 60% of the Q1 – well below the expected return period for a typical, more natural stream. Ohio district employees further reaffirmed this finding, stating that nearby streams were found to have bankfull flows with return periods of 1 year and less. Across the United States, others have documented that the higher the degree of urbanization, the more frequent the bankfull flow (1-5 year return period or lower). So while flows with defined return periods are to be determined, the actual channel-forming flow may have a less common return period, and that is the flow to which the channel should be designed.

In order to appropriately estimate what this flow might be, a more site-specific method was used: estimating the bankfull flow from channel indicators. Immediately downstream of the site, Hodgson Brook has – for decades – existed in an overly deep drainage ditch with no access to its floodplain. Over those years, it has eroded the banks during larger flows, and created some observable bankfull indicators. Using the survey data taken at this location, with specific data taken at bankfull locations, values could be calculated to estimate the channel-forming and larger flows. The flows that formed the more natural sections of the unnatural drainage ditch may be assumed to be the same as what would flow in Hodgson Brook at the site. The return period of these flows were not estimated; rather, the flows which caused bankfull indicators were called the bankfull flows. In theory, the bankfull flow is the flow at which the majority of moves; or the discharge at which channel dimension maintenance is most effective. This happens in healthy streams, on average, around the 1.5- to 2-yr flow. For the stream and watershed at the site – the watershed being highly impervious, and lacking a consistent sediment supply – the return period of the bankfull flow is challenging to estimate. This is why the use of geomorphic indicators downstream of the site, coupled with the survey of those indicators and the stream, was determined the best way to estimate the bankfull flow for preliminary stream sizing. These calculated return period flows may be found in Table 1.

Knowing all the constraints at the site, the stream geomorphic metrics dictated by those constraints were calculated, and the remaining design metrics were iteratively determined to address the hydrology as best as possible, for a range of three design scenarios to which the stream is to be constructed, as laid out in more detail in the Adaptive Management Plan section of this report. The three design scenarios for which metrics are provided represent the range of stream forms which may be constructed, at the direction of the supervising stream restoration professional onsite during construction. The calculated stream geomorphic metrics and constraining variables may be found in Table 4. These proposed metrics are given and should be near to or within the range of values shown in the table. Due to the size of the stream channel, the exact metrics may be difficult to achieve with an extreme precision – however, so long as they are followed to within an acceptable degree, based on the judgement of the stream restoration engineers, no reconstruction shall be deemed necessary. The metrics are dependent on the controlling factors, such as inlet and outlet inverts, which allow adjusting the stream dimensions within the an acceptable tolerance on the order of +/-10-15% (or, if outside the ranges, the metrics may be adjusted based off the ratios shown: entrenchment ratio, width to depth ratio, pool-to-pool spacing, etc.).

In addition to the designed stream metrics, several other site-specific factors are important to consider, and have been accounted for in the design. Due to the highly developed nature of the watershed, the sediment supply to the site will be quite limited. Aside from the restored stream's bed and banks, there is not much of a source of sediment, other than construction activities and sanding during the winter. Thus, the sediment supply is sure to be of a much finer gradation and in much more limited supply than the natural stream used to have. Because of this, bankside vegetation will be very important to maintaining the stream dimensions/alignment, and the sediment gradation used for stream construction will need to be sized and mixed well to prevent against vertical erosion of the restored stream. In addition to the vegetation and sediment, in-stream structures (log vanes, log cross vanes, log sills) are recommended to help keep the stream in place both vertically and horizontally, and floodplain sills are recommended to help prevent against avulsions. To help the stream keep its plan form while vegetation grows, the banks may be constructed out of staked, biodegradable compost sock or coir logs. Additionally, as flows are meant to overtop the banks and enter the floodplain several times per year, coir netting (or similar biodegradable mesh) should be secured around the front of the coir log rolls, and extended up onto the floodplain to the toe of the valley slope. Both the coir log rolls and the coir netting usually have a lifespan of 3-5 years before they begin to degrade, which should allow sufficient growing seasons for faster-growing riparian vegetation and plants to take root and hold the stream form. Please refer to Figure 2 for a better idea of how these banks are to be used, and what one such project looks like four years after construction. These coir log banks should also provide stability, and help prevent against any avulsions, though the floodplain and channel should be able to handle them on their own.

Some of the design metrics are presented on pages A3 and A4 of the Appendix, for reference of each portion of the restored stream they apply, and their values. A more complete table of the proposed metrics may be found on pages A15 and A16 Conceptual details for constructing a log cross vane and a floodplain sill may also be found in the Appendix, on pages A5 and A6.

Figure 2 - Coir Log Rolls along Restored Pettee Brook, near Adams Towers on UNH Campus in Durham, four years after construction. Note how the coir logs are still intact, and have trapped sediment. Roots and grasses have grown into and through them.

The three scenarios for which metrics are provided in Table 4 represent the range of plan forms which may be constructed in the field. They are labeled according to the stream slope calculated for their design, as an easy reference point – minimum and maximum values for each metric will not necessarily correspond to the minimum and maximum slope labels. Rather than listing minimum and maximums for each design metric range, they are shown for the scenarios, which should make understanding the stream designs and ranges easier.

Table 4 - Proposed Metrics for Stream Form Design Range						
	Property	Units	Symbol	Smax	Styp	Smin
Cross Section	Maximum Bankfull Depth	ft	Dmax	0.65	0.65	0.60
	Average Bankfull Depth	ft	Davg	0.56	0.50	0.53
	Floodprone Depth	ft	Dfp	1.3	1.3	1.3
	Bankfull Width	ft	Wbkf	4.5	5.5	5.4
	Floodprone Width	ft	Wfp	30.0	30.0	30.0
	Width/Depth Ratio	-	W/D	8.09	11.08	10.13
	Entrenchment Ratio	-	ER	6.67	5.45	5.56
	Bankfull Area	sqft	Abkf	2.50	2.73	2.88
	Riffle Side Slopes	ftH:1ftV	SSr	1	2	1
	Pool Depth	ft	Dpool	1.50	1.25	0.90
	Pool Bankfull Width	ft	Wpool	5.75	6.00	5.60
	Pool Area	sf	Apool	5.53	5.16	3.42
	Pool Inner Side Slope	ftH:1ftV		2*	2	3
	Pool Outer Side Slope	ftH:1ftV		1	1	1
Plan Form	Riffle Length	ft	Lrif	13.74	8.37	7.73
	Riffle Slope	ft/ft	Srif	0.01320	0.01336	0.00918
	Sinuosity	-	k	1.196	1.226	1.538
	Meander Belt Width	ft	MBW	17.0	18.0	25.3
	Meander Length	ft	ML	40.0	40.0	40.0
	Radius of Curvature	ft	Rc	9.25	12.5	12
	Pool Length	ft	Lp	10.18	16.22	23
	Pool Slope	ft/ft	Spool	0.00393	0.00678	0.00652
	Pool to Pool Spacing	ft	P2P	23.92	24.59	30.725
	Stream Slope	**ft/ft**	**Slope**	**0.00925**	**0.00902**	**0.00719**
	Valley Slope	ft/ft	VS	0.01106	0.01106	0.01106
Particle Size Distributions	Riffle % Fines	%		5	5	5
	Riffle Coefficient of Uniformity	-	Cu	13.50	13.5	13.50
	Riffle D100/D50	-		4.00	4.00	4.00
	Riffle D10	in		0.08	0.075	0.08
	Riffle D30	in		0.42	0.39	0.34
	Riffle D50	in		0.83	0.72	0.63
	Riffle D60	in		1.09	1.01	0.95
	Riffle D90	in		1.84	1.71	1.60
	Riffle D100	in		3.34	2.89	2.52
	Pool % Fines	%		15	15	15
	Pool Coefficient of Uniformity	-	Cu	10.53	10.5	10.53
	Pool D100/D50	-		11.33	11.33	11.33
	Pool D10	in		0.01	0.01	0.01
	Pool D30	in		0.03	0.03	0.03
	Pool D50	in		0.14	0.12	0.10
	Pool D60	in		0.17	0.16	0.15
	Pool D90	in		0.64	0.59	0.55
	Pool D100	in		1.55	1.34	1.17

Construction Sequencing

In general, stream restoration begins at the upstream end of the project and works downstream. At the site, the proposed stream corridor does not follow the path of the existing pipe carrying Hodgson Brook, but parallels that pipe and will be reconnected to this infrastructure at the start and end of the project. This is beneficial, as the stream can be constructed in the dry and temporarily stabilized before being opened up to flows and fully vegetated. As this is a part of a larger development project, the construction sequence below details only activities pertaining to the stream corridor. It does not include activities that might usually be included in such a sequence, such as (but not limited to) clearing and grubbing, construction layout, traffic control, erosion control, staging areas and material disposal. The sequence is subject to change to integrate fluidly with the entire project, and may change to the desires of the contractor, as they see best fit. Any changes shall be discussed, cleared, and/or proposed by project engineers, and may be made in the field during construction. This construction sequence assumes that the existing drainage infrastructure is to remain in place until the stream is built, and that proposed drainage infrastructure that will direct flows into the stream will have already been installed. An overview of the sequence is listed below, followed by a detailed sequence which describes each step in greater detail.

Stream Corridor Construction Sequence Overview:

1. Excavate and grade the stream corridor from the top of the valley, down to the top of the floodplain, and on down towards the center of the corridor.
2. Perform fine grading of stream channel, banks, structures, and sills.
3. Seed the site with temporary stabilization grasses and allow to grow.
4. Open up the stream at each end to flows.
5. Seed and plant the site fully.
6. Establish monitoring locations and components.

Detailed Stream Corridor Construction Sequence:

1. Excavate and grade the stream corridor, from the top of the valley elevation, down to the top of the floodplain elevation and into the center of the corridor, leaving a construction access ramp at the start and end of the project. If required, the floodplain grade may be initially set lower to allow for backfilling of loam, should the existing earth be of poor material. Do not over-compact floodplain or valley slopes; compact only by track-walking or applying pressure with the bucket of the excavator. The floodplain and slopes should be left rough, to allow seed to grow more easily. Leave an access path along the top of the valley to one or both sides, to allow for the transport and temporary staging of in-stream materials and movement of heavy equipment. This may also be accomplished using the upstream access ramp to deliver materials behind the excavator, using the corridor as the path. This is not preferred, since over-compaction is likely to occur resulting from the excessive traffic of heavy equipment.
2. Construction will be performed in the dry, and will begin at the downstream end of the restored Hodgson Brook. Starting at the downstream end of the stream, begin by excavating the pool which will redirect water into the existing culverts below Goose Bay Drive from upstream of the

pool. Working from upstream of the section under construction, begin the fine grading of the stream channel. This may be done by over-excavating the channel and banks, then installing the compost/coir log roll stream banks (one base roll and one top roll – the base almost entirely embedded in the bed material, with the top roll forming the channel bank). Initially the bed slope of the stream is graded uniform, then riffles and pools may be graded near the finishing steps. The compost/coir log base should sit below the thalweg of the stream, and once set in place at the correct elevation, may have fill placed behind the rolls. The stream channel should then be backfilled at the riffles and pools with appropriately graded material, leaving the pools as deeper features in the stream channel. As construction continues upstream, merging the compost log rolls should be done such that the upstream-most end of the rolls is curled out from the bank, and the next upstream roll may be placed linearly into the bank, and flows will be directed as to not cause erosion or avulsion between the rolls (shiplapped construction). Extra heavy attachment (connections) of the rolls at these locations should be performed with biodegradable materials. While construction continues, backfilling of any floodplain loam – should it be deemed necessary – should be performed to the final floodplain grade. Construct in-stream structures (log cross vanes) as they are reached, as well as floodplain sills. Additional floodplain features may be constructed at this time, such as habitat logs and boulders, tree stands, and vernal pools (all optional, but recommended). Construction materials may be provided on-demand using the access path along the top of the valley. Materials (logs, rebar, geotextile, riffle material, compost rolls, etc.) may be set outside the stream corridor, and gathered by the excavator from inside the corridor, or less preferably, placed behind the excavator in the corridor. All fine grading and structures should be checked for elevations and geomorphic metrics before starting the next upstream section.

3. Seed and mulch the corridor and top of valley with the temporary stabilization seed mix (preferably a conservation mix with at least 10% wildflower seeds, though may be of a perennial ryegrass). Seed to the amounts as specified by the seed manufacturer – with greater application on the steeper valley slopes – and mulch with wood chips (90% ground coverage) or straw (to a depth of 1 inch). Water as specified by the seed manufacturer, if drought persists longer than the recommended watering frequency. Allow the grass to grow to a height of at least 3 inches before proceeding to the next step. If any bare patches exist, reseed and mulch to ensure stabilization. This step may be performed as a section of stream is completed, which may reduce the overall construction duration, though it may come at a cost of increased watering effort.
4. When all previous steps have been completed, the stream should be opened up to flows. First, the existing drainage culvert at the downstream end should be excavated and removed. Grade and temporarily stabilize the incoming flows to the downstream pool. Proceed to the upstream inlet to the stream and construct (if not already done in step 2) the inlet pool and grading. Flows may then be directed into the stream channel, in a manner that shall be determined in the field, based on the manner in which the incoming culvert and upstream infrastructure is being constructed. Allowing incoming flows to the stream may be performed concurrently with that of the outlet, provided the contractor has the labor and equipment available. However, caution should be exercised to ensure that flows are able to exit the corridor fully and appropriately, to prevent damage and/or flooding to the site. This step should be performed at low-flows.

5. With the stream now carrying flows, the relic culvert that carried the stream may be removed, and the entire site should be seeded and planted as specified in the planting plan. This may be done completely or partially as construction of the stream takes place. At this point the temporary stabilization grass should have taken hold enough to provide some cover for seeds, and keep in moisture during the day. This step should only be done during a growing season and not in mid-summer or winter, to help ensure planting success. This step may be done after step 6, if construction ends before a planting season is set to begin. This step should be performed when the appropriate equipment is available. This may help expedite the process, rather than performing it all completely by hand.
6. Finally, monitoring devices and components should be installed, measurements recorded, and instruments calibrated as necessary. Please refer to the monitoring plan section of this report for more details on the monitoring methods and schedules.

As noted in the detailed construction sequencing, some aspects of construction may overlap, or may be done concurrently, per the desires of the contractor. For example, backfilling of loam may be reserved for after the stream has been constructed, if it is desired to be performed from the top of the valley. Planting of livestakes and other riparian plants may be done as the stream is constructed. This may require watering to be performed regularly, especially lower on the floodplain, to ensure the vegetation has enough water to grow without any baseflow in the stream. It may also require longer stagnant time for the plants, which would have to be kept healthy during the duration of the construction. More detailed information and planting notes may be found in the following section. Habitat features (floodplain boulders, logs, vernal pools, etc.) may be constructed after the stream is finished, from the top of the valley. As stated before, any alterations to the construction sequence will first be cleared by the project engineers before implementing them during construction.

Planting Plan for the Floodplain and Riparian Corridor

The stream corridor has two distinct zones for planting: the floodplain (Zone 1) and the upland, or valley slopes (Zone 2). These two zones are defined, based on the available water, rate of inundation, and the drain rate. The two zones were broken down even further, with each zone having a Lower and an Upper part (1L, 1U; 2L, 2U). Furthermore, Zone 1L contains an additional sub-zone that refers to the stream banks, just up onto the top of the banks. Here, grasses and groundcover is often not successful, but shrubs may, and these are to be planted differently than the rest of Zone 1L, resulting in its own classification. This sub-zone contains two sections, one along the outer bank of each bend, and the other containing all the other banks (inner bend and riffles). The outer bank of each pool is referred to as Zone 1Lp, and the other banks are in Zone 1Lb. The difference in the two zones is only to differentiate between planting densities, and to help determine quantities.

Table 5 – Planting Plan Species			
Planting Species		Common Name	Zone
Grasses	Lolium Perenne	Perennial Ryegrass	1, 2
	Cornus canadensis	Bunchberry	1U
	Solidago spp.	Goldenrod	1
	Impatiens capensis	Jewelweed	1
	Mitchella repens	Partridgeberry	1U, 2
	Asclepias incarnata	Swamp Milkweed	1
	Thalictrum polyganum	Tall Meadow Rue	1
Shrubs	Prunus virginiana	Chokecherry	1U, 2
	Cornus racemosa	Gray Dogwood	1U, 2
	Viburnum alnifolium	Hobblebush	1
	Vaccinium angustifolium	Lowbush Blueberry	2
	Salix discolor	Pussy Willow	1
	Rubus idaeus	Raspberry	2
	Cornus stolonifera	Red Osier Dogwood	1
	Cornus amomum	Silky Dogwood	1
	Alnus rugosa	Speckled Alder	1
	Hammamelis virginiana	Witch Hazel	1
Trees	Salix nigra	Black Willow	2U
	Prunus serotine	Black Cherry	2U
	Acer rubrum	Red Maple	2U
	Quercus alba	White Oak	2U
	Fraxinus americana	White Ash	2U

The species selected for the project are listed in Table 5, and are sorted by the type of species – grasses and ground cover, bush-like trees and shrubs, and trees. Each species is listed by both their common name and Latin name, as well as the zone at which it is to be planted. The zone for each may be listed specifically (1L), or more broadly (2). These species were selected from the list of Native Shoreland/Riparian Buffer Plantings for New Hampshire; a table of species which are both native and non-invasive, which was published by the NH Department of Environmental Services. While this list provides many species, the final species used in construction of the site may not be limited to those listed. Any other species will be checked and approved by the engineer before being ordered, or placed in the field. This is especially true of any seed mix that may be used at the site; the selected mix (mixes) that the contractor shall use should be checked by the engineer before placement, or before ordering any such seed mix.

A list of densities and species to be planted in each zone may be found in Table 6, for quick reference.

Table 6 – Planting Plan Details

Planting Zone	Zone Description	Species	Density
1Lp	On the outer bend of a pool from the point of curvature to the point of tangency, beginning at the mid-bank elevation, up over the top of the bank, and offset from the top of the bank 1 foot.	Livestakes of Pussy Willow, Red Dogwood, Silky Dogwood, and Speckled Alder	1 livestake per 2 sf
1Lb	From the mid-bank elevation up over the top of the bank and back 1 foot, for all stream banks other than Zone 1Lp	Livestakes of Pussy Willow, Red Dogwood, Silky Dogwood, and Speckled Alder	1 livestake per 4 sf
1L	From one outer bend of the channel down one meander wavelength to the next outer bend of the channel, inwards along the top of the bank.	Perennial Rye (temporary stabilization); Native Wetland Seed Mix including but not limited to: Tall Meadow Rue, Goldenrod, Swamp Milkweed, Jewelweed, and Ryegrass; Hobblebush, Pussy Willow, Red Dogwood, Silky Dogwood, Speckled Alder, and Witch Hazel	Rye: per seed mix Wetland Mix: per seed mix Shrubs: 1 plant per 75 sf
1U	On the floodplain bench, outside the meander belt width corridor, up to the top of the floodplain bench	Perennial Rye (temporary stabilization); Native Wetland Seed Mix (as described previously); Bunchberry, Partridgeberry, Swamp Milkweed, Chokecherry, Gray Dogwood, Hobblebush, Pussy Willow, Witch Hazel	Rye: per seed mix Wetland Mix: per seed mix Shrubs: 1 plant per 50 sf
2L	From the top of the floodplain bench, up 1/4 of the way up the riparian corridor slope	Perennial Rye (temporary stabilization); Native Conservation Seed Mix; Partridgeberry, Chokecherry, Gray Dogwood, Lowbush Blueberry, Raspberry, Black Willow	Rye: per seed mix Shrubs: 1 plant per 20 lf
2U	From the top of Zone 2L, up over the top of the riparian corridor and back 1 foot.	Perennial Rye (temporary stabilization); Native Conservation Seed Mix; Lowbush Blueberry, Raspberry; Black Willow, Black Cherry, Red Maple, White Oak, White Ash	Rye: per seed mix Shrubs: 1 plant per 25 lf Trees: 1 tree per 40 lf

For further details on the planting plan, including diagrams of the planting locations on a plan view and a complete description of the benefits of each species, please refer to the Appendix.

Vegetating the project site will be done using several types of planting methods. Closest to the stream, livestakes should be placed, rather than planting full shrubs. Livestakes are relatively straight clippings two to four feet in length and no greater than an inch in diameter at the base, cut from live and healthy species, and should be cleared from leaves and smaller branches. Leaves left on the livestake cause it to dry out more easily. From places where branches and buds are removed, roots and new branches will sprout from the clipping. Livestakes should be soaked in water for at least two days prior to installation, if at all possible, long enough for roots to sprout. To plant a livestake, first create a hole using a sledge hammer and a hammer rod (a piece of 1” diameter rebar works as well), to a depth of one third the length of the livestake. Gently place the livestake in the hole without damaging the base, and tamp-down the ground around the hole with a hand or foot. Livestakes should be kept wet for the first two weeks, until they have had the opportunity to sprout roots.

Seed will also be placed and mulched as described following, all along the floodplain and upland slopes. Seeding will first be done with a rye grass to stabilize any bare earth expected to exist longer than 5 days. The floodplain may then be seeded with a wetland, riparian, or conservation seed mix that contains no invasive or non-native species. Seeding with such a mix should follow the manufacturer’s guidelines. A general specification for the final seeding is a conservation mix with at least 10% wildflower seeds.

Finally, planting of trees and shrubs (and flowering plants, should no wetland/riparian seed mix be used) will be performed throughout the floodplain and upland areas. It is preferable to have mature plants over planting seeds, and more mature plants are preferred to saplings. Younger plants are more vulnerable to being transplanted, and do not recover well – if at all – from grazing. Again, trees and shrubs should be placed in their appropriate zones, and should be planted in a non-linear fashion.

To begin the planting, first the grounds should be checked for any invasive plant species or any debris/trash, and cleared of these. Seeding should occur over the entire construction area, and should begin with temporary stabilization. Stabilization should be of a Rye seed mix, which should be mulched with straw, preferably (to a depth of 1”). The mulch should be clean and free of invasives and any other contaminants. The grounds should be watered as necessary, or as specified by the seed manufacturer. At the same time, livestakes (if they were not already set during construction) may be placed in the stream banks and at the top of the banks.

After the grass has been allowed to grow, and any bare spots have been reseeded, planting and seeding of the remaining site may be performed, beginning at the lowest part of the floodplain, on up to the top of the valley slopes. Protective tubing may be desirable to help prevent any young plants from grazing before they reach a more adult size. Support stakes and twine may also be used, to help stabilize the plants until they develop larger root systems. Planting instructions for each plant should be followed, as some require more specific needs than others, and may even have different planting seasons when they should be installed. The instructions for each may be very important, as a survival rate of 75% within the first 3 years is commonly determined to be the goal of a restoration project in New Hampshire.

One addition to the planting plan shall be to install a biodegradable netting, covering the stream banks and the floodplain to the toe of the valley. This should be done by securing the netting first below the lowest coir log roll forming the stream bank, wrapping the stream bank with the netting, up to the valley toe. Upstream netting should overlap downstream netting, and the netting should be installed to the manufacturer's specifications. The netting may be held in place by livestakes for the most part, but should have notched wood stakes (0.5"x2"x1' minimum sizing) at a minimum of every 2 feet around the perimeter of each section of netting, with the wood stakes hammered flush to the ground surface. This netting will provide stability of the floodplain and banks until vegetation takes root, and around the banks will support trapping sediments and forming a more precise bank slope.

When performing the final planting, it is important to note that the densities shown are for an average over the corridor, and to help determine quantities. Plantings should be performed in a non-linear (irregular) fashion, and should avoid being homogenous. Some areas should be more or less dense, with greater or fewer different species than other areas. Trees in the upland should be planted at the top of the valley, and partway down the slope; bushes may be clumped together near or far from the channel; livestakes should be planted mid-bank and to the top of the bank. The zones and densities are shown for reference, but are not firm constraints. Natural systems are usually very diverse and random, and projects should attempt to embrace and mimic that variability. In addition to Tables 5 and 6, a list of the wildlife which benefit from the planting species, as well as the food value each species provide, may be found in Table A1, on pages A7 and A8 in the Appendix.

Monitoring and Maintenance Plans

Monitoring and Maintenance plans detailed in this section are to occur during and after construction of the project, to ensure the project is constructed to the design, and to observe the performance of the system in the long term. They also detail how alterations may be made, or maintenance may be performed to repair or improve the stream conditions should it be at risk of failing to provide natural forms and functions.

Five Year Post-Construction Monitoring Plan and Methods

Hodgson Brook is the main source of fresh water to North Mill Pond in Portsmouth, and as such, the health of the stream is important to several local organizations (Advocates for the North Mill Pond [ANMP], Hodgson Brook Local Advisory Committee [HB LAC], Pease Development Authority [PDA]), and governments (City of Portsmouth, NH DES). There have been several studies completed on the watershed that are publicly available, and quite a few documents published that cover the history, water quality, and goals for restoring the watershed. Some of the publicly available documents include[2]: an Environmental Quality Characterization for Hodgson Brook in Portsmouth, New Hampshire (2003), a Watershed Restoration Plan for Hodgson Brook (2004), a Hodgson Brook Watershed Monitoring Plan – A guide for Monitoring Environmental Quality (2004), and an Implementation Plan for Hodgson Brook Watershed Restoration (2005). These documents provide detailed accounts of the history of the watershed, the current use and quality, and sets goals for restoring the watershed and methods to achieve those goals. The information provided in those documents was used to help develop the monitoring plan for the site. Monitoring of the site will be performed for five years after the construction of the project.

The NH DES lists water quality standards that provide a framework for assessing surface waters in the state, based on seven designated uses. The standards are divided into three parts: designated uses, water quality criteria, and antidegradation. The seven designated uses represent the ways in which the surface water is intended to be used: aquatic life, fish consumption, shellfish consumption, drinking water supply, primary contact recreation, secondary contact recreation, and wildlife. The water quality criteria are defined for each designated use by markers and limits, aimed at protecting each surface water use. Finally, the antidegradation provision is set to protect existing uses and to prevent any degradation to any surface water in terms of the existing water quality or designated uses.

Hodgson Brook (as detailed in the Watershed Monitoring Plan [WMP]), has been assigned three designated uses for which monitoring should be performed: Primary and Secondary Contact Recreation, and Aquatic Life. Indicators for each, and the recommended monitoring methods, were defined in the WMP, and are listed below. The methods and indicators below were cropped to eliminate indicators and methods that the report either did not recommend, or were considered not applicable. Also not

[2] All four documents may be found at the DES website for Hodgson Brook: https://www.des.nh.gov/organization/divisions/water/wmb/was/hodgson/reports.htm

included are some of the recommended monitoring methods that may not be applicable or may be included within other methods. Some of the monitoring frequencies have been adjusted in order to provide better data for a restoration project, and not existing conditions. In addition to the recommended monitoring methods given in the WMP, methods for monitoring the vegetation and stability of the constructed stream were developed. The full list of monitoring methods, schedules, and frequencies may be found in Table 7.

Originally, there were ten indicators to be monitored as part of the post-construction plan. However, the sampling methods detailed in the Hodgson Brook reference documents – managed and performed by the HB LAC – have since been discontinued, without any plans to be resumed. As such, the original indicators for water quality – items numbered 1, 2, 3, 4, and 10 – have been removed from this monitoring plan. With no concurrent data to compare to, nor a database to contribute to, these indicators are rendered irrelevant to the performance of the stream (though improvements to the indicators should be provided by the stream, they are not necessarily representative of the performance of the stream geomorphically).

An annual monitoring report shall be produced and sent to all interested parties (ANMP, NH DES, etc.) and all data provided to NH DES for inclusion in the state databases at the same time. Please refer to state protocols for data reporting; different data may require different protocols. The monitoring reports may be used by DES to determine the degree of the success of the project, however each monitoring report will include the judgements and conclusions of the qualified stream restoration engineers, to provide insight into their decision.

Table 7 - Iron Rail Parcel Restoration Monitoring Methods and Scheduling

Indicator Number	Indicator	Monitoring Method	Events per Year	Number of Locations	Total Events
5	Habitat Assessment	Complete using DES Habitat Assessment Field Data Sheets annually during late fall	1	1	5
6	Flow	Monitor flow conditions to determine baseflow and stormwater discharge for a range of flows may be done concurrently with sampling events, or as required to obtain enough flows to develop a comprehensive rating curve	4	2	40
7	Stream Stability	Full site survey of all topographic features performed once as an as built, then again in years 3 and 5	1	1	3
8	Planting Success	Visual site assessment for any high-mortality areas, assessment of 4 vegetation plots three times; once after the first full growing season, then every other year (may be done during full survey)	1	4	12
9	Visual Health Assessment	Pictures taken at set photo points twice per year, during the spring and the fall	2	1	10

In addition to the monitoring methods shown, per the request of DES and the local conservation commission, trash shall be removed from the stream and site as part of the scheduled maintenance for the landscaping at the site. If trash is observed during regular maintenance, it shall be removed and disposed of properly.

Monitoring locations for each of the methods listed in Table 7 should be determined either as construction is ongoing, or after completion. A map of suggested monitoring locations may be found on page A14 of the Appendix. Not all locations shown on the map are definite; many will be determined and set in the field, after construction is completed. For example, benchmarks and photo points will need to be located in locations with good viewing angles, and away from trafficked or maintained areas; staff gages (or monitoring probes) should be set in easily accessible locations, but in permanent water; vegetation plots should be set at areas of high interest, or in locations that represent a diverse range of variables (species, zones, sunlight, infrastructure, etc.), among other things. Detailed descriptions of the monitoring methods, recommended locations, and data are as follows:

Observations and Visual Assessments

Data that will be taken at the site should assess the stream system health, both observationally and via opinions from the stream restoration engineers, and should include vegetation plots, photo points, habitat assessments, and flows. Photo points should be set after the construction has been completed, and should be marked at locations that can be repeated in subsequent years by both location and direction, so that pictures may be compared through the years. The photo points should capture the entire site, as well as any notable features, such as the vegetation plots, or any culvert inverts (to show scour, perhaps). Photo points should be taken twice per year, in the spring and fall, and should be included in the annual reports.

The habitat assessments will be performed using the Habitat Assessment Field Data Sheets for Low Gradient Streams. The assessment rates habitat parameters for health on a scale of 0 to 20, using descriptions to guide the assessor as to what to look for. The data should be compiled in the field, using any pictures as evidence and a field book for notes, and should be performed once each year in the fall, during a period of low flow. These sheets were obtained from the DES' VRAP website, and may be found reproduced here in the Appendix, on pages A9-A11.

Vegetation plots should be set after construction and the complete planting and seeding of the site has been completed, and should not be assessed until after one full growing season has passed. It is recommended that four vegetation plots be set, representing a thorough sample of variables; sunlight, planting zones, species density, etc. Two vegetation plots should span the width of the stream corridor, and two should be located in 10'x10' squares on the floodplain. These plots should be assessed for mortality of planted plants, coverage, invasives, and species diversity. In addition to the four plots, a site-wide visual assessment for the mortality of any of the planted plants should be conducted, tallied, and reported. A goal of 75% survival is usually recommended for projects of this type. The reason for the mortality of any plants should also be recorded to the most accurate extent possible – water content, sunlight, trampling, foraging, animal burrowing, etc.

Finally, flows should be observed, recorded, or downloaded from pressure transducers for a range of flows, including at least 8 low flows (flows observed during each of the four seasons, during a time when there has been no precipitation for the preceding three days) and 8 storm flows (collected via gaging or via pressure transducer). More data is recommended to help create an accurate rating curve for each location. It is recommended to have two flow locations at the upstream and downstream ends of the project. To begin, theoretical hydraulic rating curves (water depth versus discharge) for each site should be developed. Over time, and with base flows and storm flows measurements, the curves may be more accurately empirically developed. Flow calibration should be performed at both sites for a range of flows, with a concentration of measurements at the low-flows. Calibration may be performed using a flow meter in the stream, or in a pipe, surveying a pipe and calculating the flow based on the flow depth, or by calibrated weirs or flumes that will give accurate flows, provided the water upstream has filled the reservoir created by the device. For each site, a minimum of 8 calibration flows are recommended for the empirical rating curve, and more points are encouraged. Early and frequent, accurate rating curve calibration will make the collection of this data go much more quickly in subsequent years.

Site Survey

The final monitoring method will be to perform a full site topographic survey, making sure to include all relevant and important features, such as: benchmarks, sampling locations, staff gages, infrastructure, in-stream structures, stream and corridor features, floodplain features, photo points, and all topographic features. From this survey, maps should be produced that display all monitoring locations, comparisons of the stream features from year-to-year, and any other relevant information. Stream comparisons may include stream profiles, cross sections, as well as any notable failures. A full site survey should be conducted first as an as-built survey of the site, then again in years 3 and 5, following the completion of the project. The products built from the site surveys should be included in the annual reports, during the years they are performed.

Maintenance

During the post-construction monitoring, and included within each annual report, shall be an assessment of the overall stream health as opined by the stream restoration professionals, as well as a determination of any specific failures within the stream corridor which will be recommended for maintenance. Ultimately, the stream will be judge for its ability to maintain its form naturally, and the degree to which it appears to be providing its function. Should any failure – in the eyes of the stream restoration professionals, and as requested by NH DES – be discovered or determined, a plan shall be developed and approved to repair the failing sections. This is especially true with respect to the bedload and the stream's ability to naturally create a low-flow channel. Such a channel is not proposed for construction, rather the stream will be 'seeded' with finer sediments and gravels with the hopes that the stream will create the channel naturally, and more successfully. This success is to be monitored closely for the six months following the project completion. Within a month, low flows should travel on the surface of the stream bed and not underground. Within two months, the stream should form its own low-flow channel. During construction, sediments are to be backfilled slightly higher than the proposed grade in anticipation of transport, which occurs naturally until the stream is fully imbricated. Should additional sediment be required to help the stream form a healthy channel bottom, material shall be deposited at the upstream pool until the stream has reached an equilibrium. Sediments are to be added only at the direction of the stream restoration engineers, only using the material specified in the sediment size distribution (basically the same distribution as the riffle PSD, only with no particles larger than 1”), and in quantities defined by the engineers. The timing of any sediment additions shall be coordinated with moderate rain events expected (1” and less), which should provide enough power to transport and compact the sediments, without excessive erosion which would cause the added sediments to contribute to sedimentation and turbidity downstream from the project site. Should any excessive erosion result in the transport of a large quantity of sediments being deposited in the pool at the downstream end of the restored stream, these sediments may be dredged and reused upstream, to reduce the overall sediment load transported out of the project reach as a direct result of this action.

Monitoring and Adaptive Management During Construction

Stream restoration is partly an art in conjunction with the engineering and science of it. As such, designs drawn up in a proposed phase may not always maximize the potential benefits a stream could provide, and the design may not account for any unforeseen constraints which may affect the ultimate best solution. With this in mind, NH DES recommended the inclusion of an Adaptive Management Plan, which would provide the ability to construct the stream in the field, departing from the typical stream design shown in approved wetland permit sheets, at the direction of a qualified stream restoration professional during construction to reduce homogeneity and maximize potential benefits. The stream shall be constructed within a range of forms, as detailed in the construction sheets, governed by the range of design metrics laid out in this report. The wetland permit shall approve a conceptual stream design for the entire site, as well as the range of design forms, and shall allow for the stream to be created with variability – mimicking a more natural appearance – than otherwise might be efficiently and accurately done in a design phase. Compliance with the wetland permit’s approval of the Adaptive Management Plan shall be that the stream is only to be constructed within the range of proposed stream forms as defined in this report (allowing for an acceptable tolerance of +/-10-15% of as-built dimensions), and only at the specific direction of the qualified stream restoration professional overseeing the construction each day. If a supervising professional is unavailable for any amount of days, temporary construction drawings shall be submitted for review by NH DES in the week prior to the range of days which the stream restoration professional is unavailable, and shall provide construction designs to which the stream is to be constructed in their absence.

Included within this plan, monitoring of the immediately-constructed system shall be performed concurrent with activity, or at the end of each day. The constructed section of stream shall have its dimensions recorded (widths, depths, slopes, etc.), which will be compiled and summarized on a weekly basis.

During each week which construction of the stream occurs, a monitoring report shall be compiled by the stream restoration engineers which shall summarize the dimensions of the stream as it has been constructed since the last report, as well as a summary of construction activities, structures installed, and an overall status of the project. Thoughts and comments regarding the stream form shall be noted, as well as recommendations on how the construction is commencing as a whole. As the stream shall be constructed per the judgment of the supervising stream restoration engineer, it may be that alterations to the metrics going forward will be suggested. These suggestions, as well as the reasons behind the alterations to the design, shall be detailed in the weekly report to NH DES, who then may determine whether such actions are within reason and fall within the approval of the included Adaptive Management Plan condition of the permit.

In addition to the weekly monitoring report, a construction summary report shall be provided to NH DES upon completion of the project. An as-built survey shall be performed immediately following the project completion, and from the survey, the stream metrics shall be determined, provided via a range from the typical minimum to the typical maximum, and the median design metrics which were constructed. Plan sheets depicting the survey and dimensions shall be included in the report. The report shall also summarize the stream construction activities, including the types of structures installed, the range of metrics observed, surveyed locations of set monitoring locations, and any thoughts or conclusions drawn from the project.

For the six-month period following the project completion, the site shall be observationally monitored at least once each month, and after every storm event with 1" of rain or more. The stream shall be monitored for its overall performance with regards to stability, imbrication, and the formation of a low-flow channel. The observations taken during this time period shall be included with the first annual post-construction monitoring report, but not beforehand. However, should the stream show any failures in its form, or if it has failed to imbricate and create a low-flow channel, a solution shall be developed and submitted to NH DES to notify them of any maintenance or repairs which are suggested for the site. Upon completion of any repairs or maintenance, monitoring shall recommence for an additional six month period, until such a period has passed without requiring any such activity.

Adaptive management measures which may be performed at the direction of the supervising stream restoration professional may include, but are not limited to:

- Variations in the plan, profile, and section dimensions of the stream. This will principally be done by varying the stream slope, and appropriately sizing the stream metrics based on the proposed slope. Other variability may be performed to plan forms: creating multiple bends in one direction before an alternate bend, increasing or decreasing bend, riffle, and pool lengths, making bends sharper or more rounded, etc.

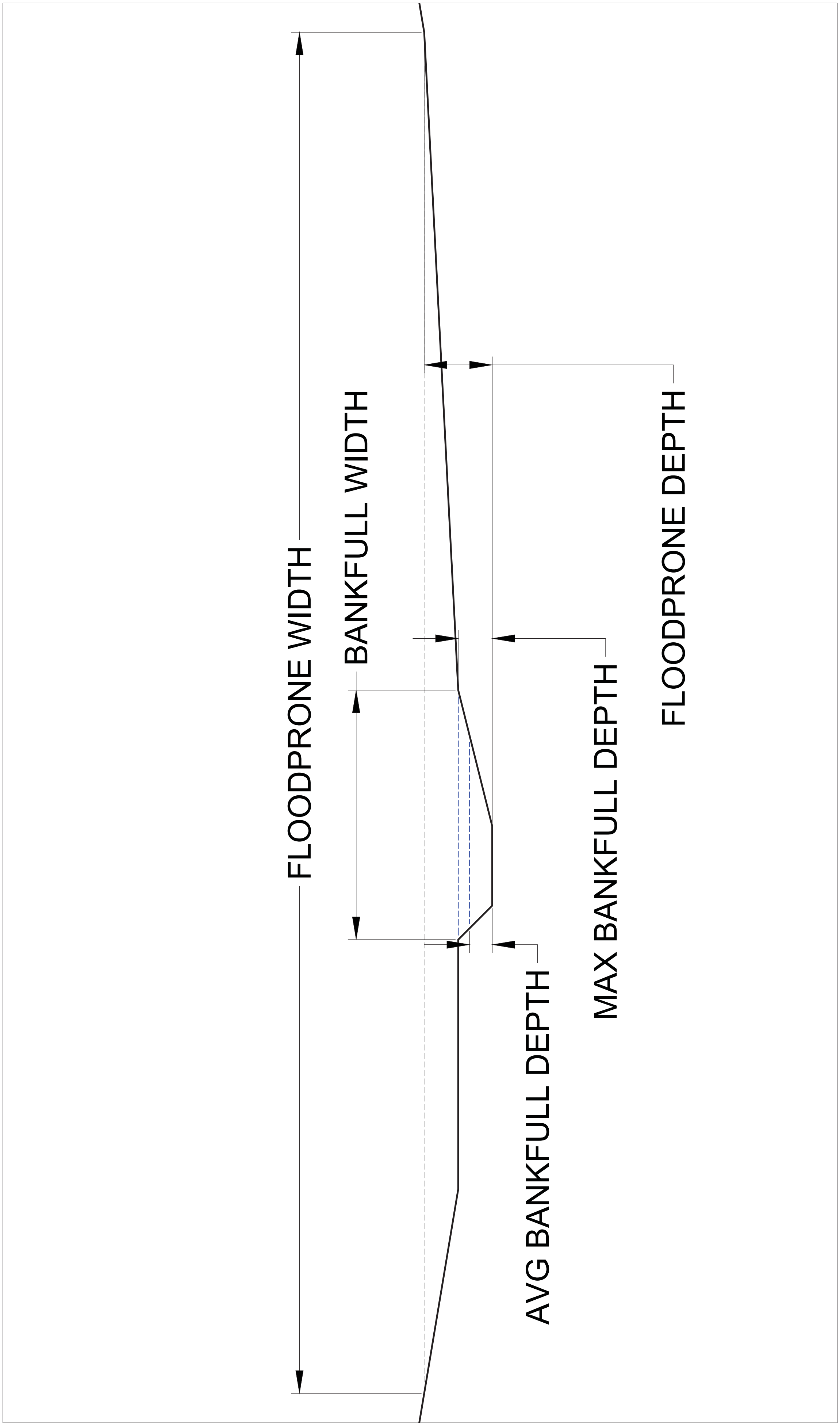
- The location, frequency, and type of instream structures to be constructed. These should occur in general at least every four meander wavelengths, though may be located as determined in the field, based on the presumed risk of a constructed section; especially those which occur under steeper stream slope conditions. Structures which may be constructed include log cross vanes, log vanes, log step vanes, and log sills.

- The location, frequency, and type of floodplain structures and features to be constructed. Floodplain structures may include floodplain sills, vane arm sills, log debris, log stands, habitat boulders, and biodegradable netting. Floodplain features may include constructed pools (depressions which may contain permanent water, or may ultimately be vernal), sloughs and hummocks, and grading of the floodplain within the inner bend of the stream. Although many of these floodplain items are not required, opportunities may be encountered which could initiate the construction of these items (for example, logs damaged during delivery may be suitable for floodplain debris, logs which are far too small may be inserted upright into the ground to form a tree stand or stump, large boulders encountered during excavation may be recycled as habitat boulders, etc.).

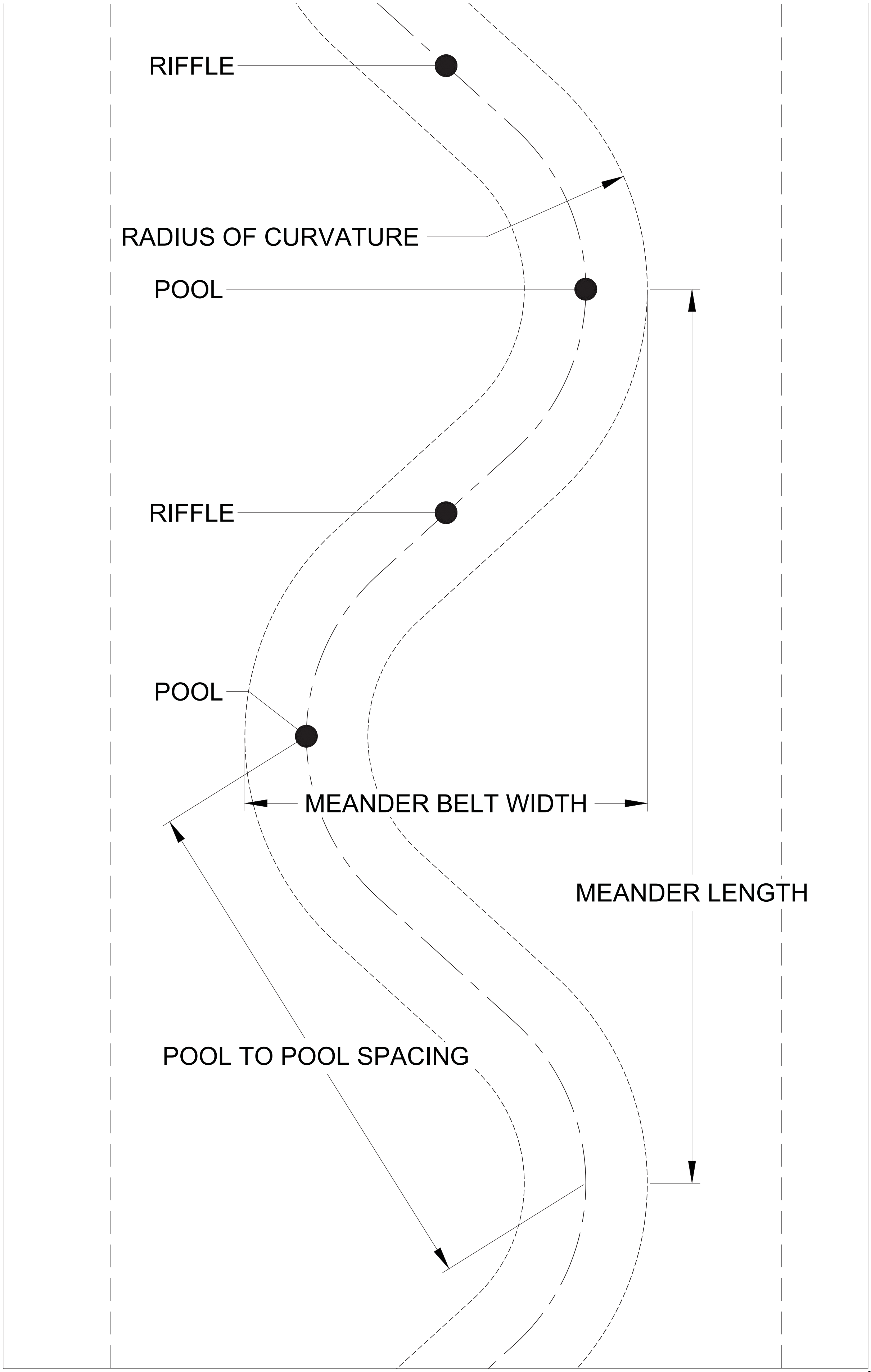
- The location, species, and densities of plantings and seed may be directed to where they are most necessary, or at locations which may experience increased forces. Mostly this will take the form of increased or decreased planting densities, seed locations and rates, and adjustments to the locations of the planting zones, based on the stream form and surrounding floodplain characteristics.
- The location, depths, and sediment distributions located at riffles and in pools along the stream channel. In general, steeper sections and longer riffles will be sized with larger distributions (larger D50) and placed to greater depths than typical. This will most notably take the form of the sediment which is to be placed in the upstream reach (the upstream third of the project), which shall be provided as a sediment source for the stream to use in order to imbricate and form a low flow channel.
- Though not required, the stream may be flooded prior to opening the channel up to flows. This may be done using water trucked to the site, or via a hose connected to a fire hydrant. Flows may be directed into the pool at the upstream end of the project, and should flow down the stream at a smaller depth (less than ½ bankfull) to help imbricate the stream before it is opened up to larger flows incoming to the site, at which point an unarmored stream bed would be more susceptible to erosion. Flows may be allowed reach just upstream from the active construction site before cutting off the source and allowing water to infiltrate into the ground. This may be done frequently to provide a well armored and imbricated stream bed prior to full use.

Appendix

Metric Definitions - Section

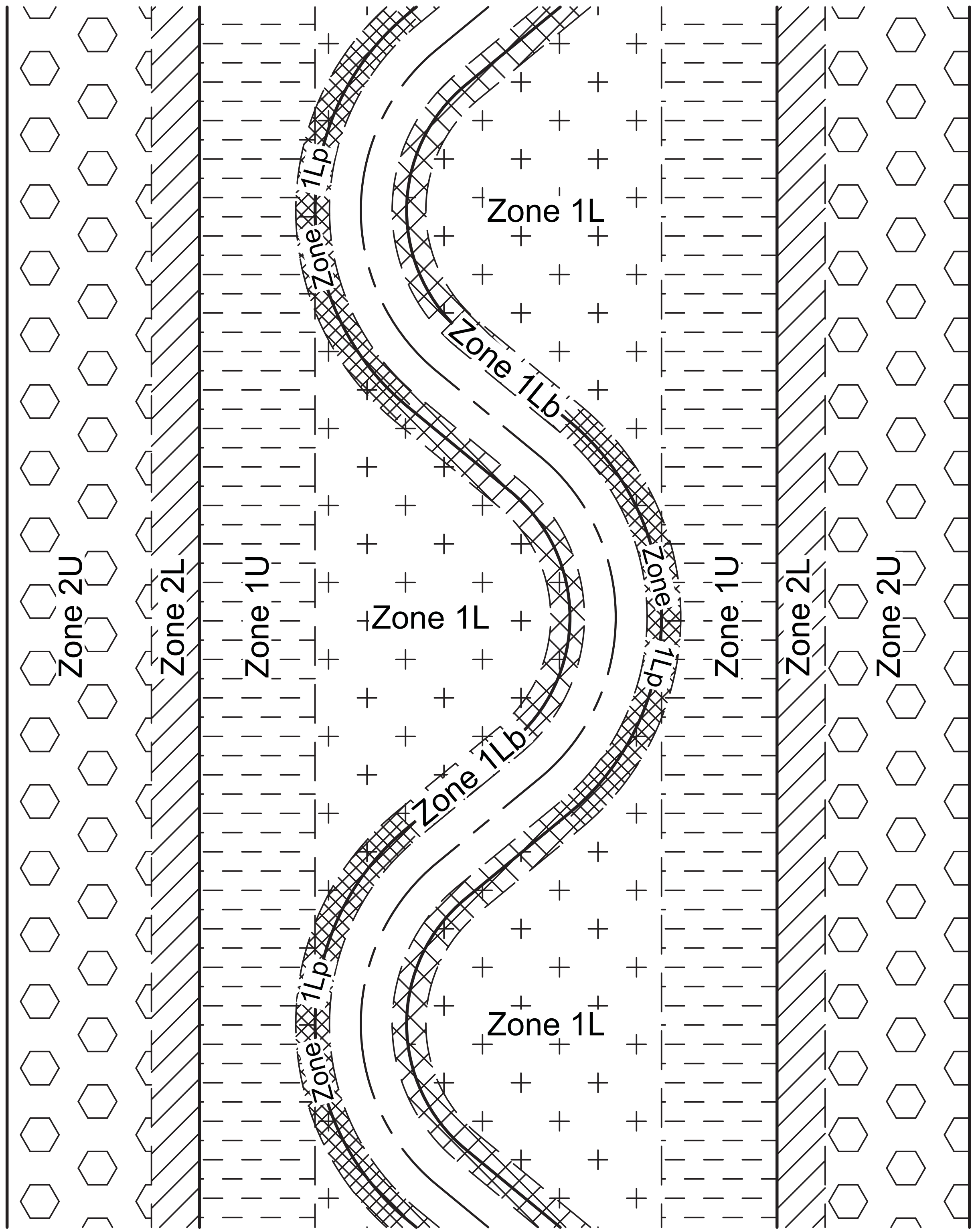


Metric Definitions - Plan

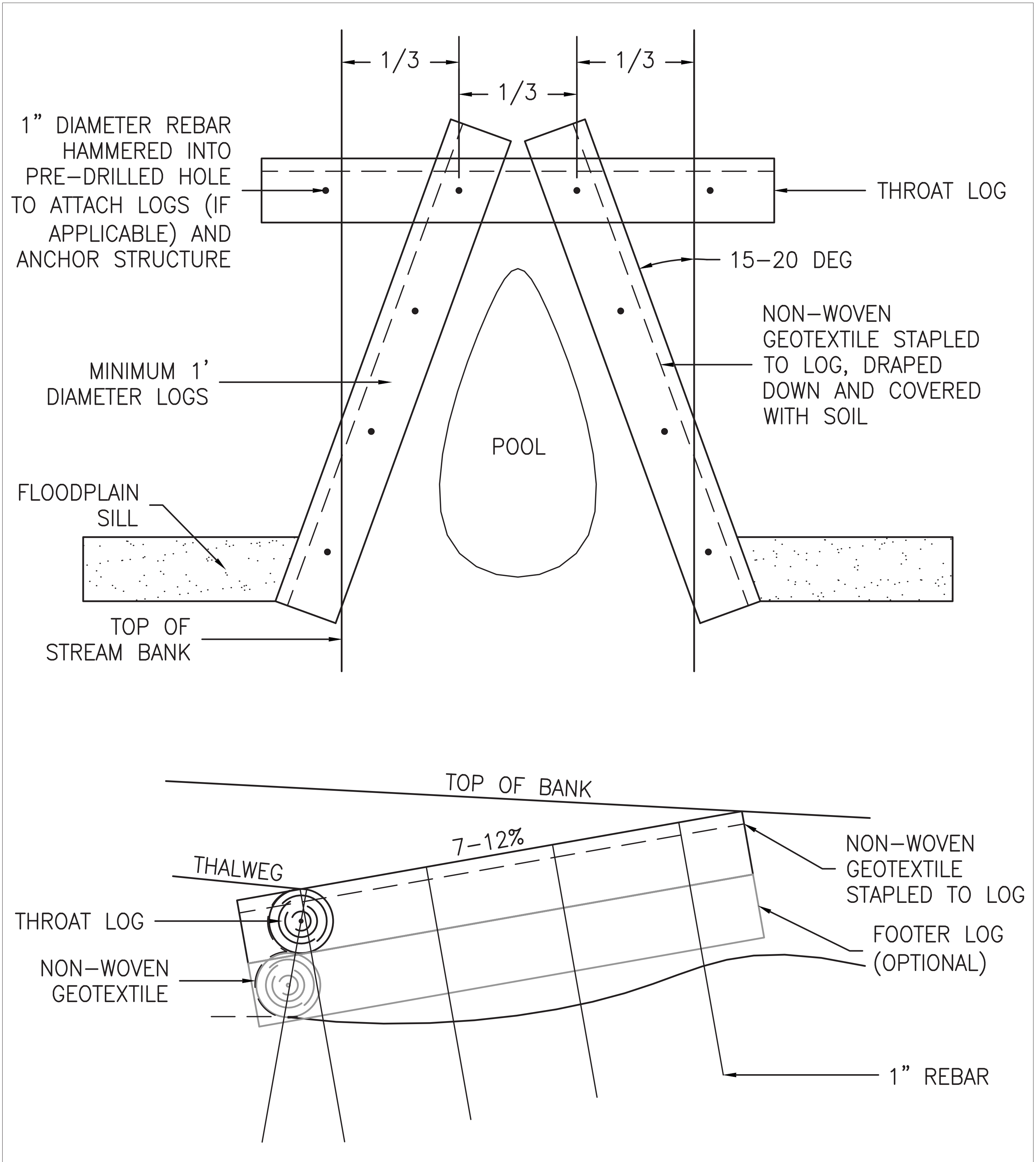


A2

Planting Zones



GENERIC LOG CROSS VANE DETAILS



GENERIC FLOODPLAIN SILL DETAILS

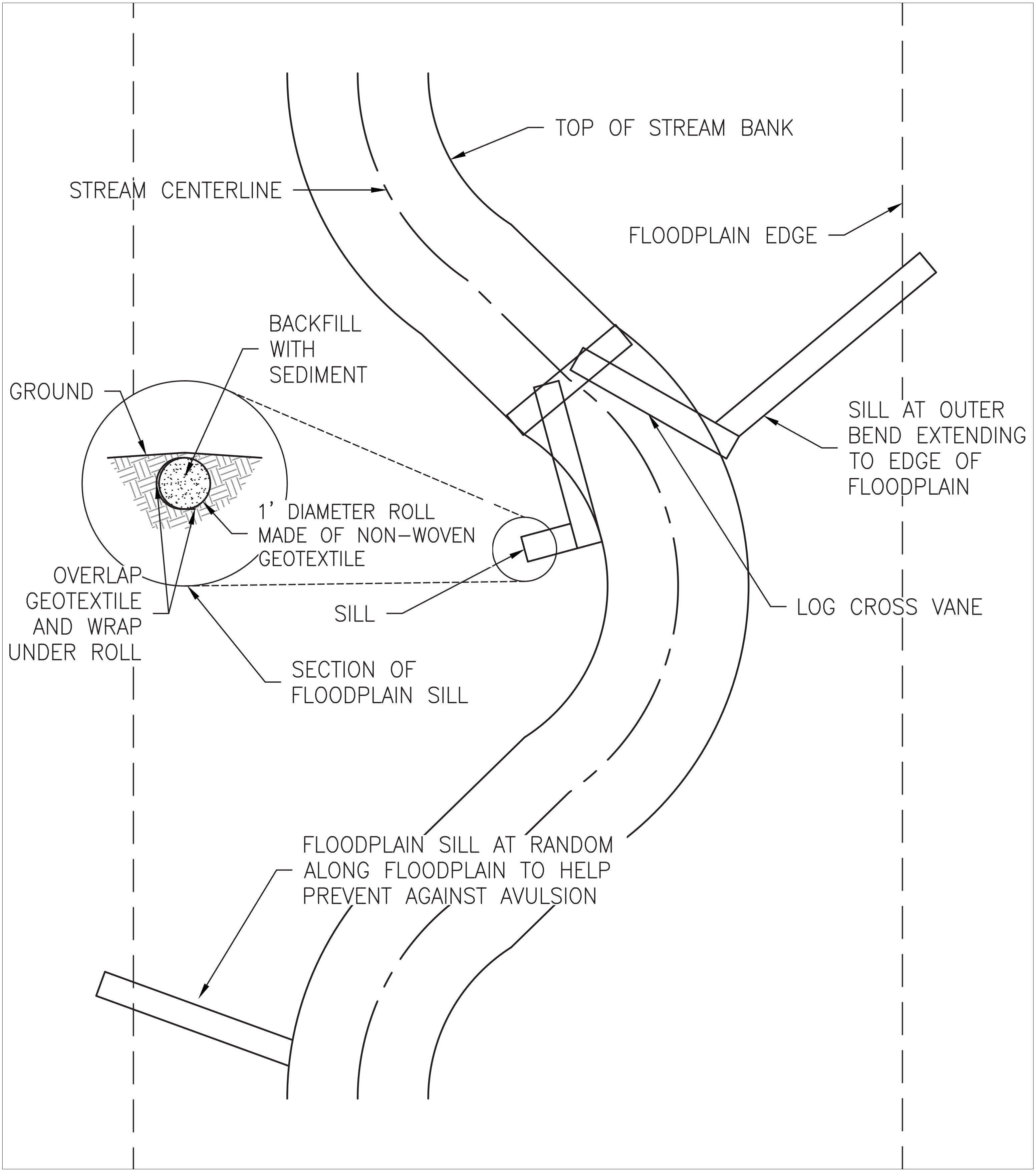


Table A1 – Associated Birds & Mammals, and Food Value	
Species	Wildlife and Food Value
Ryegrass	Temporary stabilization
Bunchberry	Wildlife: sharp-tailed grouse, spruce-grouse, moose Food: fruit, buds
Goldenrod	Wildlife: goldfinch, junco, ruffed grouse, swamp sparrow, butterflies and other insects, cottontail, meadow mice Food: seeds, nectar
Jewelweed	Wildlife: ring-necked pheasant, stuffed grouse, ruby-throated hummingbird, veery, butterflies and insects, white-footed mouse Food: nectar, seeds
Partridgeberry	Wildlife: grouse, mammals Food: berries
Swamp Milkweed	Wildlife: black duck, mallards, red-winged blackbird, ruby-throated hummingbird, monarch butterfly, other butterflies and insects, muskrat Food: nectar, seeds
Tall Meadow Rue	Wildlife: bees, butterflies Food: nectar
Chokecherry	Wildlife: bluebird, brown thrasher, catbird, crow, eastern kingbird, evening grosbeak, orioles, pileated woodpecker, ring-necked pheasant, robin, rose grosbeak, ruffed grouse, thrushes, yellow-bellied sapsucker, rabbit, squirrel Food: berries, buds, foliage
Gray Dogwood	Wildlife: blue jay, cardinal, catbird, cedar warwing, eastern kingbird, finch, flycatcher, grosbeak, hairy woodpecker, northern flicker, phoebe, pileated woodpecker, pine grosbeak, pine warbler, red-bellied woodpecker, ring-necked pheasant, robin, ruffed grouse, starling, swamp sparrow, tufted titmouse, veery, vireo, wild turkey, wood duck, wood thrush, woodcock, yellow-bellied sapsucker, chipmunk, deer, red fox, rabbit, squirrel Food: berries, twigs
Hobblebush	Wildlife: brown thrasher, cardinal, cedar warwing, evening grosbeak, robin Food: fruit
Lowbush Blueberry	Wildlife: blue jay, grouse, kingbird, oriole, robin, tangers, woodpeckers, squirrel Food: berries, foliage, twigs
Pussy Willow	Wildlife: American goldfinch, ruffed grouse, beaver, hare, rabbits, squirrel Food: buds, catkins, twigs, bark

Table A1 – Associated Birds & Mammals, and Food Value (cont.)	
Raspberry	Wildlife: songbirds and mammals Food: fruits
Red Osier Dogwood	Wildlife: bluebird, brown thrasher, cardinal, catbird, cedar waxwing, downy woodpecker, eastern kingbird, finches, northern flicker, pine warbler, purple finch, ringed-neck pheasant, ruffed grouse, vireo, wild turkey, woodpeckers, wood duck, chipmunk, deer, rabbit, squirrel Food: berries, twigs
Silky Dogwood	Wildlife: baltimore oriole, black-capped chickadee, blue jay, brown thrasher, cardinal, catbird, cedar waxwing, downy woodpecker, eastern kingbird, flycatcher, mockingbird, northern flicker, pine warbler, purple finch, red-bellied woodpecker, ringed-neck pheasant, robin, rose-breasted grosbeak, ruffed grouse, song sparrow, starlings, tufted-titmouse, wild turkey, wood duck, wood thrush, veery, chipmunk, deer, rabbit, raccoon, skunk, squirrel, white-footed mouse Food: buds, twigs, bark, leaves
Speckled Alder	Wildlife: alder flycatcher, catbird, goldfinch, mallards, pheasant, pine siskin, red-winged blackbird, ruffed grouse, swamp sparrow, yellow-bellied flycatcher, woodcock, bear, beaver, deer, cottontail, moose, muskrat, snowshoe hare Food: buds, twigs, bark, leaves
Witch Hazel	Wildlife: cardinal, ring-necked pheasant, ruffed grouse, wild turkey, deer, squirrels Food: seeds, buds, twigs, bark
Black Willow	Wildlife: songbirds and mammals Food: buds, catkins
Black Cherry	Wildlife: bluebird, blue jay, brown thrasher, cardinal, catbird, cedar waxwing, common crow, eastern kingbird, evening grosbeak, mockingbird, northern flicker, northern oriole, robin, ruffed grouse, sparrows, thrushes, veery, vireo, yellow-bellied sapsucker, bear, chipmunk, deer, fox, raccoon, squirrel Food: berries, buds, sap
Red Maple	Wildlife: cardinal, chickadee, evening and pine grosbeaks, finches, robin, yellow-bellied sapsucker, beaver, chipmunk, deer, opossum, squirrel, snowshoe hare Food: seeds, buds, bark, twigs, sap
White Oak	Wildlife: blue jay, brown thrasher, nuthatch, quail, ruffed grouse, towhee, wild turkey, wood duck, woodpecker, chipmunk, bear, deer, gopher, opossum, raccoon, squirrel Food: acorns
White Ash	Wildlife: finches, grosbeaks, red-winged blackbird, wood duck, deer, squirrel Food: seeds, foliage

Habitat Assessment Field Data Sheet
Low Gradient Streams

Stream Name	
Station #________ Rivermile _________	
Lat ____________ Long ____________	
Storet #	
Form Completed By	Date ______ Time _____ AM PM

Habit Parameter				
1. Epifaunal Substrate/ Available Cover	Greater than 50% of substrate favorable for epifaunal colonization and fish cover, mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient).	30 - 50% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	10 - 30% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 10% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	
2. Pool Substrate Characterization	Mixture of substrate materials, with gravel and firm sand prevalent; root mats and submerged vegetation common.	Mixture of soft sand, mud, or clay; mud may be dominant; some root mats and submerged vegetation present.	All mud or clay or sand bottom; little or no root mat; no submerged vegetation.	Hard-pan clay or bedrock; no root mat or vegetation.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	
3. Pool Variability	Even mix of large-shallow, large-deep, small-shallow, small-deep pools present.	Majority of pools large-deep; very few shallow.	Shallow pools much more prevalent than deep pools.	Majority of pools small-shallow or pools absent.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	

4. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% (<20% for low-gradient streams) of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5-30% (20-50% for low-gradient) of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30-50% (50%-80% for low-gradient) of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% (80% for low-gradient) of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
6. Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
7.Channel Sinuosity	The bends in the stream increase the stream length 3 to 4 times longer than if it was in a straight line. (Note-channel braiding is considered normal in coastal plains and other low-lying areas. This parameter is not easily rated in these areas.	The bends in the stream length 2 to 3 times longer than if it was in a straight line.	The bends in the stream increase the stream length 2 to 1 times longer than if it was in a straight line.	Channel straight; waterway has been channelized for a long distance.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Bank Stability (score each bank)	Banks stable: evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; “raw” areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
SCORE ____ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ____ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

9. Vegetative Protection (score each bank) Note: determine left or right side by facing downstream.	More than 90% of the streambank surfaces and immediate riparian zone covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.
SCORE ____ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ____ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
10. Riparian Vegetative Zone Width (score each bank riparian zone)	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clearcuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters; little or no riparian vegetation due to human activities.
SCORE ____ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ____ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

Example Monitoring Locations

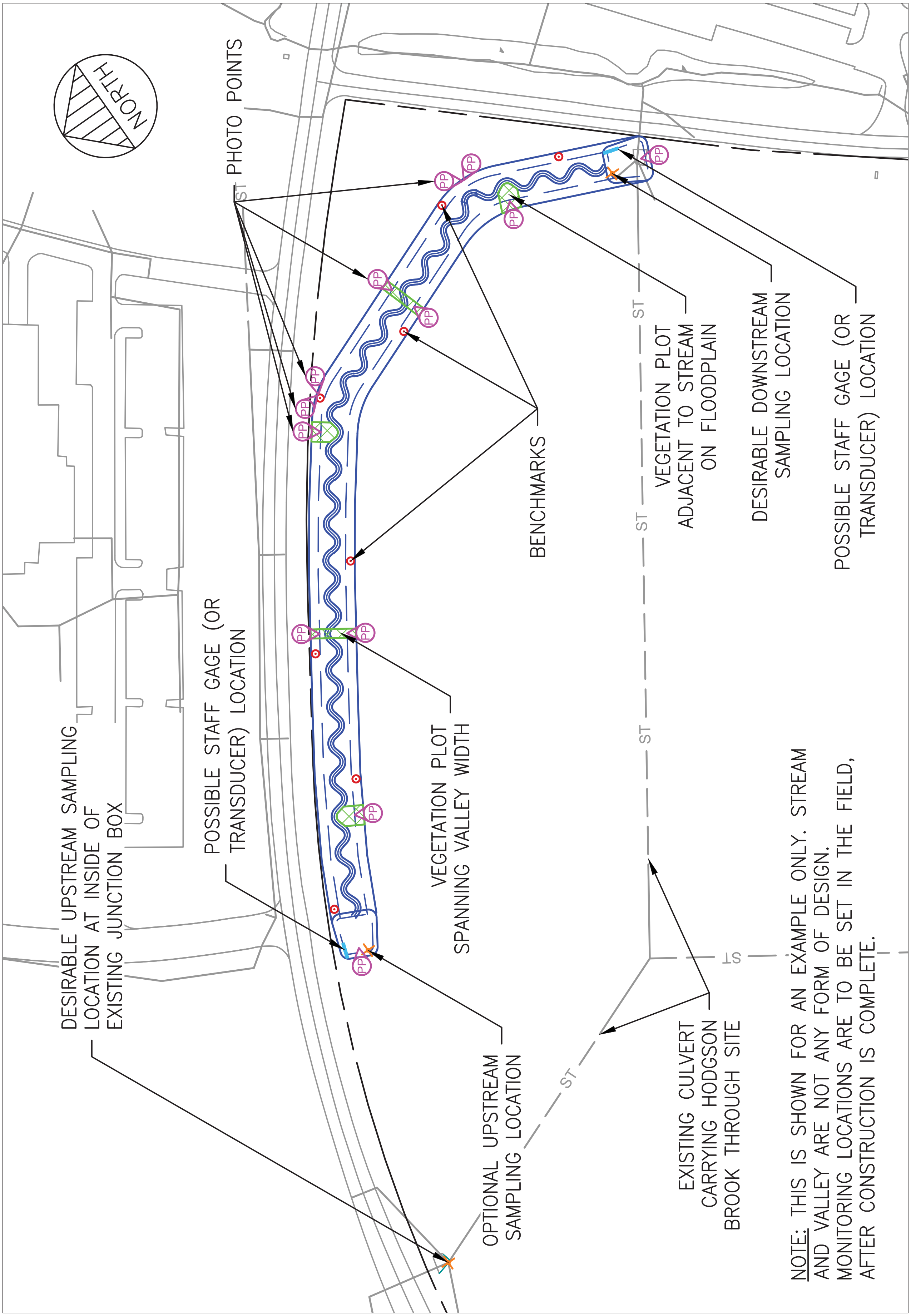
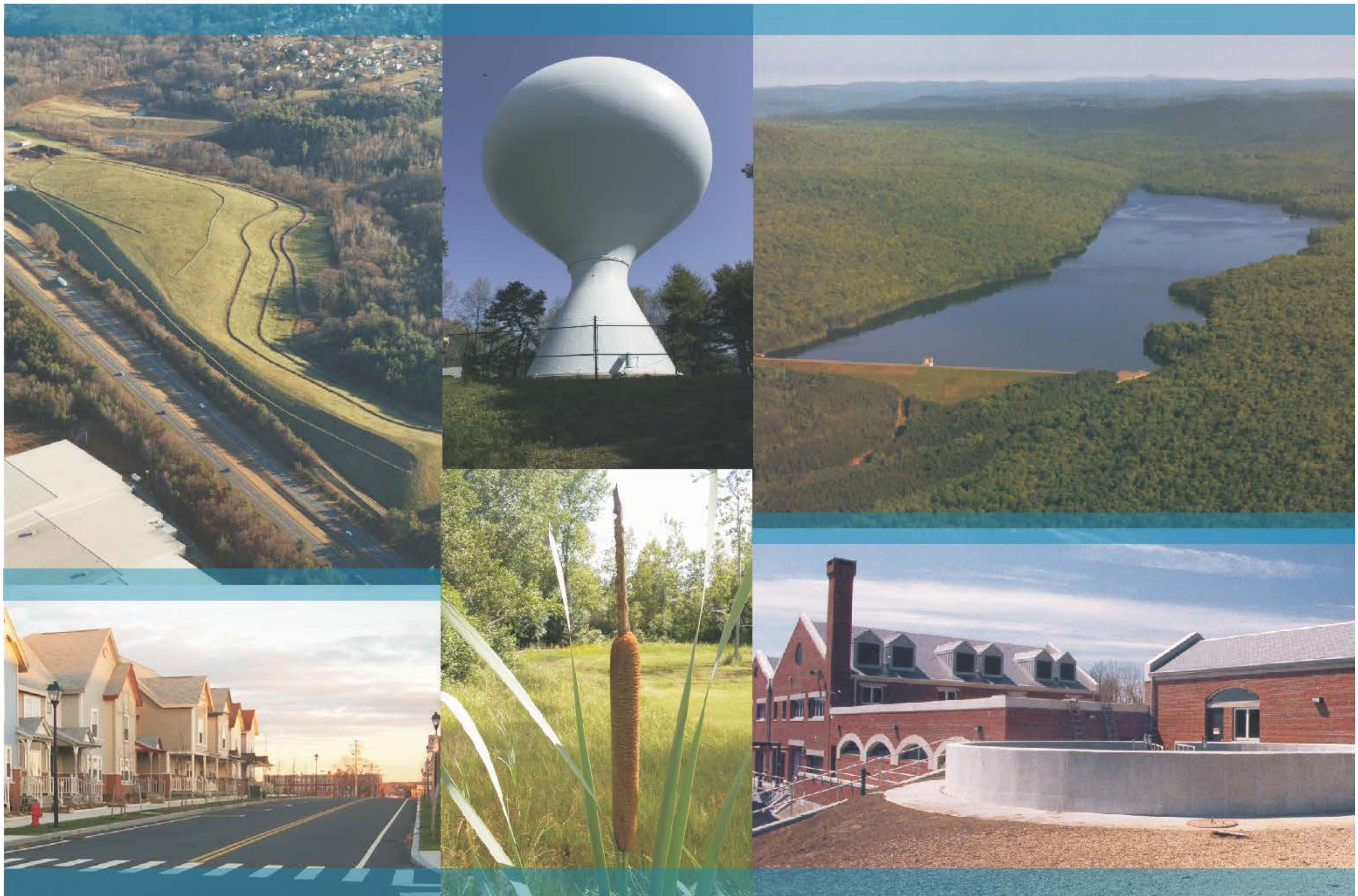


Table A2 - Proposed Metrics for Stream Form Design Range						
	Property	Units	Symbol/Equation	Smax	Styp	Smin
Cross Section	Maximum Bankfull Depth	ft	Dmax	0.65	0.65	0.60
	Average Bankfull Depth	ft	Davg	0.56	0.50	0.53
	Floodprone Depth	ft	Dfp	1.3	1.3	1.3
	Bankfull Width	ft	Wbkf	4.5	5.5	5.4
	Floodprone Width	ft	Wfp	30.0	30.0	30.0
	Width/Depth Ratio	-	W/D	8.09	11.08	10.13
	Entrenchment Ratio	-	ER	6.67	5.45	5.56
	Bankfull Area	sqft	Abkf	2.50	2.73	2.88
	Riffle Side Slopes	ftH:1ftV	SSr	1	2	1
	Pool Depth	ft	Dpool	1.50	1.25	0.90
	Pool Bankfull Width	ft	Wpool	5.75	6.00	5.60
	Pool Area	sf	Apool	5.53	5.16	3.42
	Pool Inner Side Slope	ftH:1ftV		2*	2	3
	Pool Outer Side Slope	ftH:1ftV		1	1	1
Plan Form	Riffle Length	ft	Lrif	13.74	8.37	7.73
	Riffle Slope	ft/ft	Srif	0.01320	0.01336	0.00918
	Sinuosity	-	k	1.196	1.226	1.538
	Meander Belt Width	ft	MBW	17.0	18.0	25.3
	Meander Length	ft	ML	40.0	40.0	40.0
	Radius of Curvature	ft	Rc	9.25	12.5	12
	Pool Length	ft	Lp	10.18	16.22	23
	Pool Slope	ft/ft	Spool	0.00393	0.00678	0.00652
	Pool to Pool Spacing	ft	P2P	23.92	24.59	30.725
	Stream Slope	**ft/ft**	**Slope**	**0.00925**	**0.00902**	**0.00719**
	Valley Slope	ft/ft	VS	0.01106	0.01106	0.01106
Particle Size Distributions	Riffle % Fines	%		5	5	5
	Riffle Coefficient of Uniformity	-	Cu	13.50	13.5	13.50
	Riffle D100/D50	-		4.00	4.00	4.00
	Riffle D10	in		0.08	0.075	0.08
	Riffle D30	in		0.42	0.39	0.34
	Riffle D50	in		0.83	0.72	0.63
	Riffle D60	in		1.09	1.01	0.95
	Riffle D90	in		1.84	1.71	1.60
	Riffle D100	in		3.34	2.89	2.52
	Pool % Fines	%		15	15	15
	Pool Coefficient of Uniformity	-	Cu	10.53	10.5	10.53
	Pool D100/D50	-		11.33	11.33	11.33
	Pool D10	in		0.01	0.01	0.01
	Pool D30	in		0.03	0.03	0.03
	Pool D50	in		0.14	0.12	0.10
	Pool D60	in		0.17	0.16	0.15
	Pool D90	in		0.64	0.59	0.55
	Pool D100	in		1.55	1.34	1.17



Iron Parcel Redevelopment
70 & 80 Corporate Drive
Portsmouth, New Hampshire

Long Term Operation & Maintenance Plan

Prepared For:

Lonza Biologics
101 International Drive
Portsmouth, New Hampshire

January 3, 2019

Section 11
Long Term Operation & Maintenance Plan

It is the intent of this Operation and Maintenance Plan to identify the areas of this site that need special attention and consideration, as well as implementing a plan to assure routine maintenance. By identifying the areas of concern as well as implementing a frequent and routine maintenance schedule the site will maintain a high quality stormwater runoff.

11.1 Contact/Responsible Party

Lonza Biologics
101 International Drive
Portsmouth, NH 03801

(Note: The contact information for the Contact/Responsible Party shall be kept current. If ownership changes, the Operation and Maintenance Plan must be transferred to the new party.)

11.2 Maintenance Items

Maintenance of the following items shall be recorded:

- Litter/Debris Removal
- Landscaping
- Catchbasin Cleaning
- Pavement Sweeping
- Gravel Wetland Maintenance
- Rain Garden Maintenance
- Stream Maintenance

The following maintenance items and schedule represent the minimum action required. Periodic site inspections shall be conducted, and all measures must be maintained in effective operating condition. The following items shall be observed during site inspection and maintenance:

- Inspect vegetated areas, particularly slopes and embankments for areas of erosion. Replant and restore as necessary
- Inspect catch basins for sediment buildup
- Inspect site for trash and debris

11.3 Chloride Management Plan

Winter Operational Guidelines

The following Chloride Management Plan is for the Lonza Biologics – Iron Parcel Redevelopment in Portsmouth, New Hampshire. The Plan includes operational guidelines including: winter operator certification requirements, weather monitoring, equipment calibration requirements, mechanical removal, and salt usage evaluation and monitoring. Due to the evolving nature of chloride management efforts, the Chlorides Management Plan will be reviewed annually, in advance of the winter season, to reflect the current management standards.

11.3.1 Background Information

The Lonza Biologics – Iron Parcel Redevelopment located within the Upper Hodgson Brook Watershed in Newington and Portsmouth, New Hampshire. The Upper Hodgson Brook is identified as a chloride-impaired waterbody.

11.3.2 Operational Guidelines – Chloride Management

All Lonza Biologics private contractors engaged at the Lonza Biologics premises for the purposes of winter operational snow removal and surface maintenance, are responsible for assisting in meeting compliance for the following protocols. Lonza Biologics private contractors are expected to minimize the effects of the use of de-icing, anti-icing and pretreatment materials by adhering to the strict guidelines outlined below.

The Lonza Biologics winter operational de-icing, anti-icing and pretreatment materials will adhere to the following protocols:

11.3.2.1 Winter Operator Certification Requirements

All private contractors engaged at the Lonza Biologics premises for the purpose of winter operational snow removal and surface maintenance must be current UNHT2 Green SnowPro Certified operators or equivalent and will use only pre-approved methods for spreading abrasives on private roadways and parking lots. All private contractors engaged at the Lonza Biologics premises for the purpose of winter operational snow removal and surface maintenance shall provide to Lonza Biologics management two copies of the annual UNHT2 Green SnowPro certificate or equivalent for each operator utilized on the Lonza Biologics premises. The annual UNHT2 Green SnowPro certificate or equivalent for each operator will be available on file in the Lonza Biologics Facilities Management office and be present in the vehicle/carrier at all times.

11.3.2.2 Improved Weather Monitoring

Lonza Biologics will coordinate weather information for use by winter maintenance contractors. This information in conjunction with site specific air/ground surface temperature monitoring will ensure that private contractors engaged at the Lonza Biologics premises for the purpose of winter operational snow removal and surface maintenance will make more informed decisions as to when and to what extent de-icing, anti-icing and pretreatment materials are applied to private roadways, sidewalks, and parking lots.

11.3.2.3 Equipment Calibration Requirements

All equipment utilized on the Lonza Biologics premises for the purpose of winter operational snow removal and surface maintenance will conform to the following calibration requirements.

11.3.2.3.1 Annual Calibration Requirements

All private contractors engaged at the Lonza Biologics premises for the purpose of winter operational snow removal and surface maintenance shall provide two copies of the annual calibration report for each piece of equipment utilized on the Lonza Biologics premises. Each calibration report shall include the vehicle/carrier VIN number and the serial numbers for each component including, but not limited to, spreader control units, salt aggregate spreader equipment, brining/pre-wetting equipment, ground speed orientation unit, and air/ground surface temperature monitor. Annual calibration reports will be available on file in the Lonza Biologics Facilities Management office and be present in the vehicle/carrier at all times.

Prior to each use, each vehicle/carrier operator will perform a systems check to verify that unit settings remain within the guidelines established by the Lonza Biologics Management Team in order to accurately dispense material. All private contractors engaged at the Lonza Biologics premises for the purpose of winter operational snow removal and surface maintenance will be subject to spot inspections by members of the Lonza Biologics Management Team to ensure that each vehicle/carrier is operating in a manner consistent with the guidelines set herein or State and Municipal regulations. All units will be recalibrated, and the updated calibration reports will be provided each time repairs or maintenance procedures affect the hydraulic system of the vehicle/carrier.

11.3.2.4 Increased Mechanical Removal Capabilities

All private contractors engaged at the Lonza Biologics premises will endeavor to use mechanical removal means on a more frequent basis for roadways, parking lots and sidewalks. Dedicating more manpower and equipment to increase snow removal frequencies prevents the buildup of snow and the corresponding need for de-icing, anti-icing and pretreatment materials. Shortened maintenance routes, with shorter service intervals, will be used to stay ahead of snowfall. Minimized snow and ice packing will reduce the need for abrasives, salt aggregates, and/or brining solution to restore surfaces back to bare surface states after winter precipitation events.

After storm events the Lonza Biologics management team will be responsible for having the streets swept to recapture un-melted de-icing materials, when practical.

11.3.3 Salt Usage Evaluation and Monitoring

All private contractors engaged at the Lonza Biologics premises for the purpose of winter operational snow removal and surface maintenance shall provide two copies of a storm report, which includes detailed information regarding treatment areas and the use of de-icing, anti- icing and pretreatment materials applied for the removal of snow and surface maintenance on the Lonza Biologics premises. Lonza Biologics will maintain copies of Summary Documents, including copies of the Storm Reports, operator certifications, equipment used for roadway and sidewalk winter maintenance, calibration reports and amount of de-icing materials used.

11.3.4 Summary

The above-described methodologies are incorporated into the Lonza Biologics Operational Manual and are to be used to qualify and retain all private contractors engaged at the Lonza Biologics premises for the purpose of winter operational snow removal and surface maintenance. This section of the Manual, is intended to be an adaptive management document that is modified as required based on experience gained from past practices and technological advancements that reflect chloride BMP standards. All Lonza Biologics employees directly involved with winter operational activities are required to review this document and the current standard Best Management Practices published by the UNH Technology Transfer (T2) program annually. All Lonza Biologics employees directly involved with winter operational activities, and all private contractors engaged at the Lonza Biologics premises for the purposes of winter operational snow removal and surface maintenance, must be current UNHT2 Green SnowPro Certified operators or equivalent and undergo the necessary requirements to maintain this certification annually.

11.4 Overall Site Operation & Maintenance Schedule

Overall Site Operation and Maintenance Schedule		
Maintenance Item	**Frequency of Maintenance**	**Operation**
Litter/Debris Removal - Trash and debris to be removed including long the full length of the stream.	Weekly	Management Company
Pavement Sweeping - Sweep impervious areas to remove sand and litter.	Annually	Parking Lot Sweeper
Sediment Forebay - Trash and debris to be removed including at check dam. - Embankment to be mowed. - Any required maintenance shall be addressed. - Inspect sediment accumulation and clean as needed.	Periodically (At least two (2) times annually)	Management Company
Gravel wetland - Trash and debris to be removed including at outlet structure. - Embankment to be mowed. - Any required maintenance shall be addressed.	Periodically (At least two (2) times annually)	Management Company
Rain Gardens/Infiltration Basin - Trash and debris to be removed. - Any required maintenance shall be addressed.	Two (2) times annually and after any rainfall event exceeding 2.5” in a 24-hr period	Management Company
Rip Rap Aprons - Trash and debris to be removed. - Any required maintenance shall be addressed.	Annually	Management Company
Catch Basin (CB) Cleaning - CB to be cleaned of solids and oils.	Annually	Vacuum Truck

Landscaping - Landscaped islands to be maintained and mulched.	Maintained as required and mulched each Spring	Management Company

Sediment Forebay Inspection / Maintenance Requirements		
Inspection / Maintenance	**Frequency**	**Action**
Monitor Sediment Accumulation	Annually	- Install and maintain a staff gage or other measuring devise, to indicate depth of sediment accumulation and level at which clean-out is required
Visual inspection	Annually	- Remove trash and debris as needed - Remove any woody vegetation - Inspect and repair embankments - Inspect check dam
Mowing	Periodically (At least two (2) times annually)	- Embankments shall be mowed

Gravel Wetland Inspection / Maintenance Requirements		
Inspection / Maintenance	**Frequency**	**Action**
Inspect inlets and outlets to ensure good condition and no evidence of deterioration. Check to see if high-flow bypass is functioning.	Annually, more frequently in the first year of operation	Repair or replace any damaged structural parts, inlets and outlets. Clear or remove debris or restrictions.
Check for internal erosion, evidence of short circuiting, and animal burrows.	Annually, more frequently in the first year of operation	Soil erosion from short-circuiting or animal boroughs should be repaired when they occur.
Monitor to ensure that Gravel Wetland functions effectively after storms	Four (4) times annually (quarterly) and after any rainfall event exceeding 2.5” in a 24-hr period	- Trash and debris to be removed - Any required maintenance shall be addressed

Inspect Vegetation	Annually	- Inspect the condition of all gravel wetland vegetation -Vegetation should cover >75% of the system and should be reseeded and cared for as needed. - Prune back overgrowth - Replace dead vegetation - Remove any invasive species -Coordinate with UNH Stormwater Center for further vegetation management guidelines
Cut and remove vegetation from the Gravel Wetland System and forebay in order to maintain nitrogen removal performance.	Once every 3 years	- The vegetation should be cut and removed from the system to prevent nitrogen from cycling back into the system.
Inspect Drawdown Time - The system shall drawdown between 24 and 48-hours following a rainfall event.	Annually, more frequently in the first year of operation	- Hire qualified professional to assess the condition of the facility to determine measures required to restore the filtration function, including but not limited to removal of accumulated sediments or reconstruction of the filter.

Additional Gravel Wetland Operation and Maintenance Requirements:

- ***1st Year Post-Construction:*** Inspection frequency shall be after every storm in the first year following construction.
- Inspect to be certain system drains within 24 - 48 hours (within the design period, but also not so quickly as to minimize stormwater treatment).
- Watering plants as necessary during the first growing season.
- Re-vegetating poorly established areas as necessary.
- Treating diseased vegetation as necessary.
- Inspect soil and repair eroded areas, especially on slopes, at a minimum quarterly.
- Check inlets, outlets, and overflow spillway for blockage, structural integrity and evidence of erosion.

Cleaning Criteria for Gravel Wetland Treatment Cells: Sediment shall be removed from the gravel wetland surface when it accumulates to a depth of several inches (>10 cm) across the wetland surface. Materials shall be removed with rakes rather than heavy construction equipment to avoid compaction of the gravel wetland surface. Heavy equipment may be used if the equipment is located outside the gravel wetland, while a backhoe shovel reaches inside the gravel wetland to remove sediment. Removed sediments shall be dewatered (if necessary) and disposed of in accordance with all local, state and federal requirements. Removal of vegetation within the gravel wetland shall occur every three (3) growing seasons, or the end of the summer of the third year. This is to prevent decay and release of nutrients from accumulated biomass.

Rain Garden Inspection/Maintenance Requirements		
Inspection/ Maintenance	**Frequency**	**Action**
Monitor to ensure that Rain Gardens function effectively after storms	Two (2) times annually and after any rainfall event exceeding 2.5" in a 24-hr period	- Trash and debris to be removed - Any required maintenance shall be addressed
Inspect Vegetation	Annually	- Inspect the condition of all Rain Garden vegetation - Prune back overgrowth - Replace dead vegetation - Remove any invasive species
Inspect Drawdown Time - The system shall drawdown within 48-hours following a rainfall event.	Annually	- Assess the condition of the facility to determine measures required to restore the filtration function, including but not limited to removal of accumulated sediments or reconstruction of the filter.

Rip Rap Inspection/Maintenance Requirements		
Inspection/ Maintenance	**Frequency**	**Action**
Visual Inspection	Annually	- Visually inspect for damage and deterioration - Repair damages immediately

Stream Inspection / Maintenance Requirements		
Inspection / Maintenance	**Frequency**	**Action**
Visual Inspection	Annually	- Visually inspect for damage and deterioration - Repair damages immediately
Litter/Debris Removal - Trash and debris to be removed including long the full length of the stream.	Weekly	Management Company

<u>Stream Restoration Operation and Maintenance Requirements:</u>

Stream restoration operation and maintenance requirements are detailed in the Stream Restoration report prepared by Streamworks PLLC, and in the NHDES Hodgson Brook Watershed Management Plan.

11.4.1 Disposal Requirements

Disposal of debris, trash, sediment and other waste material should be done at suitable disposal/recycling sites and in compliance with all applicable local, state and federal waste regulations.

11.4.2 Snow & Ice Management for Standard Asphalt and Walkways

Snow storage areas shall be located such that no direct untreated discharges are possible to receiving waters from the storage site (snow storage areas have been shown on the Site Plan). Salt storage areas shall be covered or located such that no direct untreated discharges are possible to receiving waters from the storage site. Salt and sand shall be used to the minimum extent practical (refer to the attached for de-icing application rate guideline from the New Hampshire Stormwater Management Manual, Volume 2,).

Deicing Application Rate Guidelines

24' of pavement (typcial two-lane road)

These rates are not fixed values, but rather the middle of a range to be selected and adjusted by an agency according to its local conditions and experience.

			Pounds per two-lane mile			
Pavement Temp. (°F) and Trend (↑↓)	Weather Condition	Maintenance Actions	Salt Prewetted / Pretreated with Salt Brine	Salt Prewetted / Pretreated with Other Blends	Dry Salt*	Winter Sand (abrasives)
> 30° ↑	Snow	Plow, treat intersections only	80	70	100*	Not recommended
	Freezing Rain	Apply Chemical	80 - 160	70 - 140	100 - 200*	Not recommended
30° ↓	Snow	Plow and apply chemical	80 - 160	70 - 140	100 - 200*	Not recommended
	Freezing Rain	Apply Chemical	150 - 200	130 - 180	180 - 240*	Not recommended
25° - 30° ↑	Snow	Plow and apply chemical	120 - 160	100 - 140	150 - 200*	Not recommended
	Freezing Rain	Apply Chemical	150 - 200	130 - 180	180 - 240*	Not recommended
25° - 30° ↓	Snow	Plow and apply chemical	120 - 160	100 - 140	150 - 200*	Not recommended
	Freezing Rain	Apply Chemical	160 - 240	140 - 210	200 - 300*	400
20° - 25° ↑	Snow or Freezing Rain	Plow and apply chemical	160 - 240	140 - 210	200 - 300*	400
20° - 25° ↓	Snow	Plow and apply chemical	200 - 280	175 - 250	250 - 350*	Not recommended
	Freezing Rain	Apply Chemical	240 - 320	210 - 280	300 - 400*	400
15° - 20° ↑	Snow	Plow and apply chemical	200 - 280	175 - 250	250 - 350*	Not recommended
	Freezing Rain	Apply Chemical	240 - 320	210 - 280	300 - 400*	400
15° - 20° ↓	Snow or Freezing Rain	Plow and apply chemical	240 - 320	210 - 280	300 - 400*	500 for freezing rain
0° - 15° ↑↓	Snow	Plow, treat with blends, sand hazardous areas	Not recommended	300 - 400	Not recommended	500 - 750 spot treatment as needed
< 0°	Snow	Plow, treat with blends, sand hazardous areas	Not recommended	400 - 600**	Not recommended	500 - 750 spot treatment as needed

* Dry salt is not recommended. It is likely to blow off the road before it melts ice.

** A blend of 6 - 8 gal/ton $MgCl_2$ or $CaCl_2$ added to NaCl can melt ice as low as -10°.

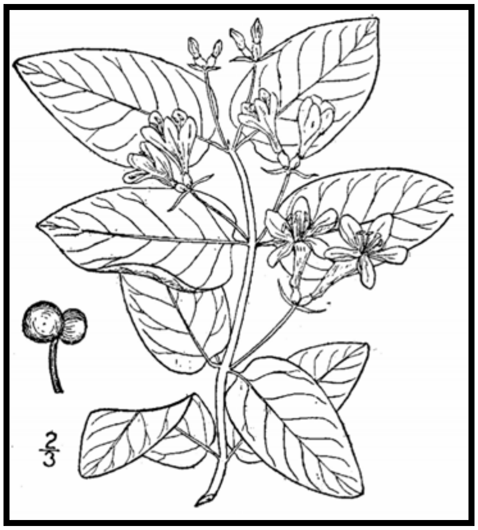
Anti-icing Route Data Form				
Truck Station:				
Date:				
Air Temperature	Pavement Temperature	Relative Humidity	Dew Point	Sky
Reason for applying:				
Route:				
Chemical:				
Application Time:				
Application Amount:				
Observation (first day):				
Observation (after event):				
Observation (before next application):				
Name:				

11.4.3 Invasive Species

With respect to a particular ecosystem, any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem is classified as an invasive species. Refer to the following fact sheet prepared by the University of New Hampshire Cooperative Extension entitled Methods for Disposing Non-Native Invasive Plants for recommended methods to dispose of invasive plant species.

Methods for Disposing Non-Native Invasive Plants

Prepared by the Invasives Species Outreach Group, volunteers interested in helping people control invasive plants. Assistance provided by the Piscataquog Land Conservancy and the NH Invasives Species Committee. Edited by Karen Bennett, Extension Forestry Professor and Specialist.



Tatarian honeysuckle
Lonicera tatarica
USDA-NRCS PLANTS Database / Britton, N.L., and A. Brown. 1913. *An illustrated flora of the northern United States, Canada and the British Possessions.* Vol. 3: 282.

Non-native invasive plants crowd out natives in natural and managed landscapes. They cost taxpayers billions of dollars each year from lost agricultural and forest crops, decreased biodiversity, impacts to natural resources and the environment, and the cost to control and eradicate them.

Invasive plants grow well even in less than desirable conditions such as sandy soils along roadsides, shaded wooded areas, and in wetlands. In ideal conditions, they grow and spread even faster. There are many ways to remove these non-native invasives, but once removed, care is needed to dispose the removed plant material so the plants don't grow where disposed.

Knowing how a particular plant reproduces indicates its method of spread and helps determine the appropriate disposal method. Most are spread by seed and are dispersed by wind, water, animals, or people. Some reproduce by vegetative means from pieces of stems or roots forming new plants. Others spread through both seed and vegetative means.

Because movement and disposal of viable plant parts is restricted (see NH Regulations), viable invasive parts can't be brought to most transfer stations in the state. Check with your transfer station to see if there is an approved, designated area for invasives disposal. This fact sheet gives recommendations for rendering plant parts non-viable.

Control of invasives is beyond the scope of this fact sheet. For information about control visit www.nhinvasives.org or contact your UNH Cooperative Extension office.

New Hampshire Regulations

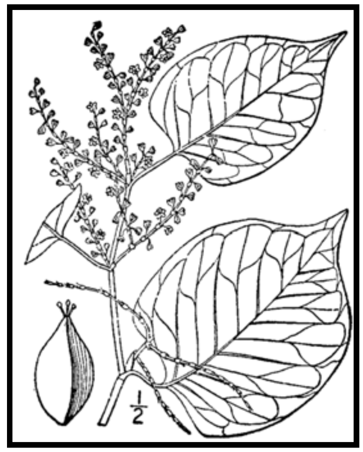
Prohibited invasive species shall only be disposed of in a manner that renders them nonliving and nonviable. (Agr. 3802.04)

No person shall collect, transport, import, export, move, buy, sell, distribute, propagate or transplant any living and viable portion of any plant species, which includes all of their cultivars and varieties, listed in Table 3800.1 of the New Hampshire prohibited invasive species list. (Agr 3802.01)

How and When to Dispose of Invasives?

To prevent seed from spreading remove invasive plants before seeds are set (produced). Some plants continue to grow, flower and set seed even after pulling or cutting. Seeds can remain viable in the ground for many years. If the plant has flowers or seeds, place the flowers and seeds in a heavy plastic bag "head first" at the weeding site and transport to the disposal site. The following are general descriptions of disposal methods. See the chart for recommendations by species.

Burning: Large woody branches and trunks can be used as firewood or burned in piles. For outside burning, a written fire permit from the local forest fire warden is required unless the ground is covered in snow. Brush larger than 5 inches in diameter can't be burned. Invasive plants with easily airborne seeds like black swallow-wort with mature seed pods (indicated by their brown color) shouldn't be burned as the seeds may disperse by the hot air created by the fire.



Japanese knotweed
Polygonum cuspidatum
USDA-NRCS PLANTS Database / Britton, N.L., and A. Brown. 1913. *An illustrated flora of the northern United States, Canada and the British Possessions.* Vol. 1: 676.

Bagging (solarization): Use this technique with softer-tissue plants. Use heavy black or clear plastic bags (contractor grade), making sure that no parts of the plants poke through. Allow the bags to sit in the sun for several weeks and on dark pavement for the best effect.

Tarping and Drying: Pile material on a sheet of plastic and cover with a tarp, fastening the tarp to the ground and monitoring it for escapes. Let the material dry for several weeks, or until it is clearly nonviable.

Chipping: Use this method for woody plants that don't reproduce vegetatively.

Burying: This is risky, but can be done with watchful diligence. Lay thick plastic in a deep pit before placing the cut up plant material in the hole. Place the material away from the edge of the plastic before covering it with more heavy plastic. Eliminate as much air as possible and toss in soil to weight down the material in the pit. Note that the top of the buried material should be at least three feet underground. Japanese knotweed should be at least 5 feet underground!

Drowning: Fill a large barrel with water and place soft-tissue plants in the water. Check after a few weeks and look for rotted plant material (roots, stems, leaves, flowers). Well-rotted plant material may be composted. A word of caution- seeds may still be viable after using this method. Do this before seeds are set. This method isn't used often. Be prepared for an awful stink!

Composting: Invasive plants can take root in compost. Don't compost any invasives unless you know there is no viable (living) plant material left. Use one of the above techniques (bagging, tarping, drying, chipping, or drowning) to render the plants nonviable before composting. Closely examine the plant before composting and avoid composting seeds.

Be diligent looking for seedlings for *years* in areas where removal and disposal took place.

Suggested Disposal Methods for Non-Native Invasive Plants

This table provides information concerning the disposal of removed invasive plant material. If the infestation is treated with herbicide and left in place, these guidelines don't apply. Don't bring invasives to a local transfer station, unless there is a designated area for their disposal, or they have been rendered non-viable. This listing includes wetland and upland plants from the New Hampshire Prohibited Invasive Species List. The disposal of aquatic plants isn't addressed.

Woody Plants	Method of Reproducing	Methods of Disposal
Norway maple *(Acer platanoides)* European barberry *(Berberis vulgaris)* Japanese barberry *(Berberis thunbergii)* autumn olive *(Elaeagnus umbellata)* burning bush *(Euonymus alatus)* Morrow's honeysuckle *(Lonicera morrowii)* Tatarian honeysuckle *(Lonicera tatarica)* showy bush honeysuckle *(Lonicera x bella)* common buckthorn *(Rhamnus cathartica)* glossy buckthorn *(Frangula alnus)*	**Fruit and Seeds**	**Prior to fruit/seed ripening** Seedlings and small plants ▪ Pull or cut and leave on site with roots exposed. No special care needed. Larger plants ▪ Use as firewood. ▪ Make a brush pile. ▪ Chip. ▪ Burn.
		After fruit/seed is ripe Don't remove from site. ▪ Burn. ▪ Make a covered brush pile. ▪ Chip once all fruit has dropped from branches. ▪ Leave resulting chips on site and monitor.
oriental bittersweet *(Celastrus orbiculatus)* multiflora rose *(Rosa multiflora)*	**Fruits, Seeds, Plant Fragments**	**Prior to fruit/seed ripening** Seedlings and small plants ▪ Pull or cut and leave on site with roots exposed. No special care needed. Larger plants ▪ Make a brush pile. ▪ Burn.
		After fruit/seed is ripe Don't remove from site. ▪ Burn. ▪ Make a covered brush pile. ▪ Chip – only after material has fully dried (1 year) and all fruit has dropped from branches. Leave resulting chips on site and monitor.

<table>
<tr><th>Non-Woody Plants</th><th>Method of Reproducing</th><th>Methods of Disposal</th></tr>
<tr><td rowspan="2">garlic mustard
(Alliaria petiolata)
spotted knapweed
(Centaurea maculosa)
▪ Sap of related knapweed can cause skin irritation and tumors. Wear gloves when handling.
black swallow-wort
(Cynanchum nigrum)
▪ May cause skin rash. Wear gloves and long sleeves when handling.
pale swallow-wort
(Cynanchum rossicum)
giant hogweed
(Heracleum mantegazzianum)
▪ Can cause major skin rash. Wear gloves and long sleeves when handling.
dame's rocket
(Hesperis matronalis)
perennial pepperweed
(Lepidium latifolium)
purple loosestrife
(Lythrum salicaria)
Japanese stilt grass
(Microstegium vimineum)
mile-a-minute weed
(Polygonum perfoliatum)</td><td rowspan="2">**Fruits and Seeds**</td><td>**Prior to flowering**
Depends on scale of infestation
Small infestation
▪ Pull or cut plant and leave on site with roots exposed.

Large infestation
▪ Pull or cut plant and pile. (You can pile onto or cover with plastic sheeting).
▪ Monitor. Remove any re-sprouting material.</td></tr>
<tr><td>**During and following flowering**
Do nothing until the following year or remove flowering heads and bag and let rot.

Small infestation
▪ Pull or cut plant and leave on site with roots exposed.

Large infestation
▪ Pull or cut plant and pile remaining material. (You can pile onto plastic or cover with plastic sheeting).
▪ Monitor. Remove any re-sprouting material.</td></tr>
<tr><td>common reed
(*Phragmites australis*)
Japanese knotweed
(Polygonum cuspidatum)
Bohemian knotweed
(Polygonum x bohemicum)</td><td>**Fruits, Seeds, Plant Fragments**
Primary means of spread in these species is by plant parts. Although all care should be given to preventing the dispersal of seed during control activities, the presence of seed doesn't materially influence disposal activities.</td><td>**Small infestation**
▪ Bag all plant material and let rot.
▪ Never pile and use resulting material as compost.
▪ Burn.

Large infestation
▪ Remove material to unsuitable habitat (dry, hot and sunny or dry and shaded location) and scatter or pile.
▪ Monitor and remove any sprouting material.
▪ Pile, let dry, and burn.</td></tr>
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Managing Invasive Plants

Methods of Control

by Christopher Mattrick

They're out there. The problem of invasive plants is as close as your own backyard.

Maybe a favorite dogwood tree is struggling in the clutches of an Oriental bittersweet vine. Clawlike canes of multiflora rose are scratching at the side of your house. That handsome burning bush you planted few years ago has become a whole clump in practically no time … but what happened to the azalea that used to grow right next to it?

If you think controlling or managing invasive plants on your property is a daunting task, you're not alone. Though this topic is getting lots of attention from federal, state, and local government agencies, as well as the media, the basic question for most homeowners is simply, "How do I get rid of the invasive plants in my own landscape?" Fortunately, the best place to begin to tackle this complex issue is in our own backyards and on local conservation lands. We hope the information provided here will help you take back your yard. We won't kid you—there's some work involved, but the payoff in beauty, wildlife habitat, and peace of mind makes it all worthwhile.

PLAN OF ATTACK

Three broad categories cover most invasive plant control: mechanical, chemical, and biological. Mechanical control means physically removing plants from the environment through cutting or pulling. Chemical control uses herbicides to kill plants and inhibit regrowth. Techniques and chemicals used will vary depending on the species. Biological controls use plant diseases or insect predators, typically from the targeted species' home range. Several techniques may be effective in controlling a single species, but there is usually one preferred method—the one that is most resource efficient with minimal impact on non-target species and the environment.

Spraying chemicals to control invasive plants.

MECHANICAL CONTROL METHODS

Mechanical treatments are usually the first ones to look at when evaluating an invasive plant removal project. These procedures do not require special licensing or introduce chemicals into the environment. They do require permits in some situations, such as wetland zones. [See sidebar on page 23.] Mechanical removal is highly labor intensive and creates a significant amount of site disturbance, which can lead to rapid reinvasion if not handled properly.

Pulling and digging

Many herbaceous plants and some woody species (up to about one inch in diameter), if present in limited quantities, can be pulled out or dug up. It's important to remove as much of the root system as possible; even a small portion can restart the infestation. Pull plants by hand or use a digging fork, as shovels can shear off portions of the root system, allowing for regrowth. To remove larger woody stems (up to about three inches in diameter), use a Weed Wrench,™ Root Jack, or Root Talon. These tools, available from several manufacturers, are designed to remove the aboveground portion of the plant as well as the entire root system. It's easiest to undertake this type of control in the spring or early summer when soils are moist and plants come out more easily.

Using tools to remove woody stems.

Volunteers hand pulling invasive plants.

Suffocation

Try suffocating small seedlings and herbaceous plants. Place double or triple layers of thick UV-stabilized plastic sheeting, either clear or black (personally I like clear), over the infestation and secure the plastic with stakes or weights. Make sure the plastic extends at least five feet past the edge of infestation on all sides. Leave the plastic in place for at least two years. This technique will kill everything beneath the plastic—invasive and non-invasive plants alike. Once the plastic is removed, sow a cover crop such as annual rye to prevent new invasions.

Cutting or mowing

This technique is best suited for locations you can visit and treat often. To be effective, you will need to mow or cut infested areas three or four times a year for up to five years. The goal is to interrupt the plant's ability to photosynthesize by removing as much leafy material as possible. Cut the plants at ground level and remove all resulting debris from the site. With this treatment, the infestation may actually appear to get worse at first, so you will need to be as persistent as the invasive plants themselves. Each time you cut the plants back, the root system gets slightly larger, but must also rely on its energy reserves to push up new growth. Eventually, you will exhaust these reserves and the plants will die. This may take many years, so you have to remain committed to this process once you start; otherwise the treatment can backfire, making the problem worse.

CHEMICAL CONTROL METHODS

Herbicides are among the most effective and resource-efficient tools to treat invasive species. Most of the commonly known invasive plants can be treated using only two herbicides—glyphosate (the active ingredient in Roundup™ and Rodeo™) and triclopyr (the active ingredient in Brush-B-Gone™ and Garlon™). Glyphosate is non-selective, meaning it kills everything it contacts. Triclopyr is selective and does not injure monocots (grasses, orchids, lilies, etc.). Please read labels and follow directions precisely for both environmental and personal safety. These are relatively benign herbicides, but improperly used they can still cause both short- and long-term health and environmental problems. Special aquatic formulations are required when working in wetland zones. You are required to have a state-issued pesticide applicator license when applying these chemicals on land you do not own. To learn more about the pesticide regulations in your state, visit or call your state's pesticide control division, usually part of the state's Department of Agriculture. In wetland areas, additional permits are usually required by the Wetlands Protection Act. [See sidebar on page 23.]

Foliar applications

When problems are on a small scale, this type of treatment is usually applied with a backpack sprayer or even a small handheld spray bottle. It is an excellent way to treat large monocultures of herbaceous plants, or to spot-treat individual plants that are difficult to remove mechanically, such as goutweed, swallowwort, or purple loosestrife. It is also an effective treatment for some woody species, such as Japanese barberry, multiflora rose, Japanese honeysuckle, and Oriental bittersweet that grow in dense masses or large numbers over many acres. The herbicide mixture should contain no more than five percent of the active ingredient, but it is important to follow the instructions on the product label. This treatment is most effective when the plants are actively growing, ideally when they are flowering or beginning to form fruit. It has been shown that plants are often more susceptible to this type of treatment if the existing stems are cut off and the regrowth is treated. This is especially true for Japanese knotweed. The target plants should be thoroughly wetted with the herbicide on a day when there is no rain in the forecast for the next 24 to 48 hours.

Cut stem treatments

There are several different types of cut stem treatments, but here we will review only the one most commonly used. All treatments of this type require a higher concentration of the active ingredient than is used in foliar applications. A 25 to 35 percent solution of the active ingredient should be used for cut stem treatments, but read and follow all label instructions. In most cases, the appropriate herbicide is glyphosate, except for Oriental bittersweet, on which triclopyr should be used. This treatment can be used on all woody stems, as well as phragmites and Japanese knotweed.

For woody stems, treatments are most effective when applied in the late summer and autumn—between late August and November. Stems should be cut close to the ground, but not so close that you will lose track of them. Apply herbicide directly to the cut surface as soon as possible after cutting. Delaying the application will reduce the effectiveness of the treatment. The herbicide can be applied with a sponge, paintbrush, or spray bottle.

Cut stem treatment tools.

For phragmites and Japanese knotweed, treatment is the same, but the timing and equipment are different. Plants should be treated anytime from mid-July through September, but the hottest, most humid days of the summer are best for this method. Cut the stems halfway between two leaf nodes at a comfortable height. Inject (or squirt) herbicide into the exposed hollow stem. All stems in an infestation should be treated. A wash bottle is the most effective application tool, but you can also use an eyedropper, spray bottle, or one of the recently developed high-tech injection systems.

It is helpful to mix a dye in with the herbicide solution. The dye will stain the treated surface and mark the areas that have been treated, preventing unnecessary reapplication. You can buy a specially formulated herbicide dye, or use food coloring or laundry dye.

There is not enough space in this article to describe all the possible ways to control invasive plants. You can find other treatments, along with more details on the above-described methods, and species-specific recommendations on The Nature Conservancy Web site (tncweeds.ucdavis.edu). An upcoming posting on the Invasive Plant Atlas of New England (www.ipane.org) and the New England Wild Flower Society (www.newfs.org) Web sites will also provide further details.

Hollow stem injection tools.

Biological controls—still on the horizon

Biological controls are moving into the forefront of control methodology, but currently the only widely available and applied biocontrol relates to purple loosestrife. More information on purple loosestrife and other biological control projects can be found at www.invasiveplants.net.

DISPOSAL OF INVASIVE PLANTS

Proper disposal of removed invasive plant material is critical to the control process. Leftover plant material can cause new infestations or reinfest the existing project area. There are many appropriate ways to dispose of invasive plant debris. I've listed them here in order of preference.

1. **Burn it**—Make a brush pile and burn the material following local safety regulations and restrictions, or haul it to your town's landfill and place it in their burn pile.

2. **Pile it**—Make a pile of the woody debris. This technique will provide shelter for wildlife as well.

3. **Compost it**—Place all your herbaceous invasive plant debris in a pile and process as compost. Watch the pile closely for resprouts and remove as necessary. Do not use the resulting compost in your garden. The pile is for invasive plants only.

Injecting herbicide into the hollow stem of phragmites.

4. **Dry it/cook it**—Place woody debris out on your driveway or any asphalt surface and let it dry out for a month. Place herbaceous material in a doubled-up black trash bag and let it cook in the sun for one month. At the end of the month, the material should be non-viable and you can dump it or dispose of it with the trash. The method assumes there is no viable seed mixed in with the removed material.

Care should be taken in the disposal of all invasive plants, but several species need extra attention. These are the ones that have the ability to sprout vigorously from plant fragments and should ideally be burned or dried prior to disposal: Oriental bittersweet, multiflora rose, Japanese honeysuckle, phragmites, and Japanese knotweed.

Christopher Mattrick is the former Senior Conservation Programs Manager for New England Wild Flower Society, where he managed conservation volunteer and invasive and rare plant management programs. Today, Chris and his family work and play in the White Mountains of New Hampshire, where he is the Forest Botanist and Invasive Species Coordinator for the White Mountain National Forest.

Controlling Invasive Plants in Wetlands

Special concerns; special precautions

Control of invasive plants in or around wetlands or bodies of water requires a unique set of considerations. Removal projects in wetland zones can be legal and effective if handled appropriately. In many cases, herbicides may be the least disruptive tools with which to remove invasive plants. You will need a state-issued pesticide license to apply herbicide on someone else's property, but all projects in wetland or aquatic systems fall under the jurisdiction of the Wetlands Protection Act and therefore require a permit. ***Yes, even hand-pulling that colony of glossy buckthorn plants from your own swampland requires a permit.*** Getting a permit for legal removal is fairly painless if you plan your project carefully.

1. Investigate and understand the required permits and learn how to obtain them. The entity charged with the enforcement of the Wetlands Protection Act varies from state to state. For more information in your state, contact:

ME: Department of Environmental Protection
www.state.me.us/dep/blwq/docstand/nrpapage.htm

NH: Department of Environmental Services
www.des.state.nh.us/wetlands/

VT: Department of Environmental Conservation
www.anr.state.vt.us/dec/waterq/permits/htm/pm_cud.htm

MA: Consult your local town conservation commission

RI: Department of Environmental Management
www.dem.ri.gov/programs/benviron/water/permits/fresh/index.htm

CT: Consult your local town Inland Wetland and Conservation Commission

2. Consult an individual or organization with experience in this area. Firsthand experience in conducting projects in wetland zones and navigating the permitting process is priceless. Most states have wetland scientist societies whose members are experienced in working in wetlands and navigating the regulations affecting them. A simple Web search will reveal the contact point for these societies. Additionally, most environmental consulting firms and some nonprofit organizations have skills in this area.

3. Develop a well-written and thorough project plan. You are more likely to be successful in obtaining a permit for your project if you submit a project plan along with your permit application. The plan should include the reasons for the project, your objectives in completing the project, how you plan to reach those objectives, and how you will monitor the outcome.

4. Ensure that the herbicides you plan to use are approved for aquatic use. Experts consider most herbicides harmful to water quality or aquatic organisms, but rate some formulations as safe for aquatic use. Do the research and select an approved herbicide, and then closely follow the instructions on the label.

5. If you are unsure—research, study, and most of all, ask for help. Follow the rules. The damage caused to aquatic systems by the use of an inappropriate herbicide or the misapplication of an appropriate herbicide not only damages the environment, but also may reduce public support for safe, well-planned projects.

11.4.4 Annual Updates and Log Requirements

The Owner and/or Contact/Responsible Party shall review this Operation and Maintenance Plan once per year for its effectiveness and adjust the plan and deed as necessary.

A log of all preventative and corrective measures for the stormwater system shall be kept on-site and be made available upon request by any public entity with administrative, health environmental or safety authority over the site including NHDES.

Stormwater Management Report						
Project Name		**Lonza – Iron Parcel**				
BMP Description	**Date of Inspection**	**Inspector**	**BMP Installed and Operating Properly?**	**Cleaning / Corrective Action Needed**	**Date of Cleaning / Repair**	**Performed By**
			❑Yes ❑No			
			❑Yes ❑No			
			❑Yes ❑No			
			❑Yes ❑No			
			❑Yes ❑No			
			❑Yes ❑No			
			❑Yes ❑No			
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			❑Yes ❑No			
			❑Yes ❑No			
			❑Yes ❑No			
			❑Yes ❑No			

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