GREAT RIVER HYDRO, LLC

ILP Study 2 and Study 3
Riverbank Transect and Riverbank Erosion Study

Supplement to Final Study Report

In support of Federal Energy Regulatory Commission Relicensing of:

Wilder Hydroelectric Project (FERC Project No. 1892-026)
Bellows Falls Hydroelectric Project (FERC Project No. 1855-045)
Vernon Hydroelectric Project (FERC Project No. 1904-073)

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EXECUTIVE SUMMARY

A supplementary study was conducted at the 21 erosion monitoring sites that were part of the Riverbank Transect Study (ILP Study 2) and Riverbank Erosion Study (ILP Study 3) to address requests made by FERC regarding the potential for sediment entrainment during project operations. While FERC suggested the analysis could be conducted using either hydraulic modeling or sediment sampling, the analysis was completed using both data sources to enable a robust comparison at all 21 monitoring sites between modeled velocities and shear stresses occurring at the sites with the critical shear stresses and velocities, based on sediment size, needed to initiate sediment entrainment. Two-dimensional hydraulic modeling was used to estimate the shear stresses and velocities occurring at the sites during low, medium, and maximum operational flows. The critical shear stress values used in the analysis were based on published literature and are known to significantly underestimate the forces required to entrain sediment. Measuring shear stress is very difficult, so estimates of the critical shear stress are originally based, and continue to significantly rely, on well controlled laboratory experiments that do not adequately account for sediment characteristics, such as cohesion, that greatly inhibit sediment transport. Consequently, shear stress occurring at the sites must greatly exceed the critical shear stress values used before any sediment is likely to be entrained.

Even when analyzing the data without accounting for the underestimated values, sediment entrainment is highly unlikely at over 75 percent of the sites. While the entrainment of bank sediment is considered possible at 5 of the 21 sites based on the analysis, actual entrainment is considered unlikely because: 1) the banks at 2 of the 5 sites are stable, 2) published studies indicate that the critical shear stress and velocity values used in the analysis are significantly underestimated while the modeled results are only slightly above the necessary thresholds for entrainment, 3) the modeled shear stresses and velocities used in the analysis were taken 20 ft further into the channel, and thus, higher than at the sampling site, and 4) the presence of vegetation on the banks, wood at the base of the bank, and irregularities in bank shape, not accounted for in the analysis, can increase the critical shear stresses and velocities or result in lower shear stress and velocity values estimated by the hydraulic modeling. As a result, flows occurring under project operations, while perhaps capable of sediment entrainment in isolated incidents, cannot be responsible for widespread bank sediment entrainment or bank erosion. Therefore, the analysis of sediment entrainment at the monitoring sites further supports the conclusions of ILP Study 3 that flood discharges exceeding operational flows are needed to remove sediment accumulating at the base of the river banks and sustain the erosion cycle that drives bank erosion within project affected areas.

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List of Abbreviations

CFS	Cubic feet per second
FERC	Federal Energy Regulatory Commission
ILP	Integrated Licensing Process
WSE	Water surface elevation

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1.0 INTRODUCTION

This document provides supplemental results from additional assessment and analysis conducted during 2017 as part of the Riverbank Transect and Riverbank Erosion Studies (ILP Studies 2 and 3). The studies were originally conducted from 2013 to 2015 (Field Geology and Normandeau, 2016; 2017) in support of FERC relicensing for the Wilder Hydroelectric Project (FERC Project No. 1892), Bellows Falls Hydroelectric Project (FERC No. 1855), and the Vernon Hydroelectric Project (FERC No. 1904).

1.1 Scope of Additional Assessment

The additional assessment and analysis was completed to address requests made in the July 21, 2017 Study Plan Determination issued by FERC on the Final (revised) Study Report that was filed February 4, 2017. The Study Plan Determination stated:

> *"Because critical shear stress and near-bank velocities can play a significant role in the erosion process, staff recommends that Great River Hydro file an addendum to the revised study report by November 15, 2017, that includes an analysis of estimated critical shear stress, near-bank velocity, and the potential correlation of these factors with project operation at the 21 monitoring sites. This discussion should include a table for each monitoring site that lists critical shear stresses and near-bank velocities with respect to water surface elevations corresponding to project operation (e.g., minimum flow, average project operating ranges, maximum hydraulic capacity). For each monitoring site, Great River Hydro should describe the river channel features corresponding to each water surface elevation, including stratigraphy, the presence or absence of vegetation, the presence of any visual erosion indicators (e.g., slumps, falls, notching, undercutting), and other notable bank features (e.g., groundwater seeps).*
>
> *Due to the complicating factors associated with determining critical shear stress, Great River Hydro should provide a best estimate of critical shear stress in the November 15, 2017 addendum to the revised study report. Where appropriate, critical shear stress could be estimated based on grain size/shape (e.g., Shield's diagram)*[1] *or interpreted using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) model (e.g., comparison to overbank shear stress).*[2] *Any estimates or assumptions made should be discussed in the November 15, 2017 addendum to the revised study report."*

[1] Shields, A., 1936, Application of Similarity Principles and Turbulence Research to Bed-Load Movement, translated by W.P. Ott and J.C. Uchelen (Mitt. Preuss. Verschsanst., Berlin, Wasserbau Schiffbau; California Institute of Technology, Pasadena, California, 1936), Report No. 167.

[2] If complex river morphology at some sites prohibits a meaningful estimation of critical shear stress or near-bank velocities, Great River Hydro should reconsider the use of the two-dimensional model, as proposed in the revised study plan.

2.0 METHODOLOGY

A methodology was developed to address the requests made in the Study Plan Determination. Additional information was collected at the 21 monitoring sites to further characterize the conditions at the site, focusing on those factors that could influence: 1) near-bank shear stress and velocity experienced during project operations, and 2) the critical shear stress and velocity that must be exceeded before sediment entrainment can occur at the 21 monitoring sites. Estimates of near-bank shear stress and velocity were derived from 2D hydraulic modeling conducted for each monitoring site, while the critical shear stress and velocity used in the analysis was based on the average particle size of sediment samples collected at each site. A comparison of the modeled shear stresses and velocities with the critical shear stresses and velocities was the basis for determining whether sediment entrainment at the 21 monitoring sites is possible during project operations. Further details are provided below regarding the approach and methods used in: 1) gathering additional information on site characteristics and sediment samples, 2) hydraulic modeling, and 3) comparing modeled shear stresses and velocities with critical shear stresses and velocities. Results, discussion and analysis for each site are provided in Appendix A., Various components are discussed here in the Methodology section to clarify how the information and results in the tables were derived (Appendix A).

2.1 Characteristics of sites and sediment samples

Site characteristics are based on previously collected site information presented in Field Geology and Normandeau (2016 and 2017), additional observations made during a visit to the monitoring sites August 26-28, 2017, and during sediment sampling August 29-September 7, 2017. Particular focus was paid to the presence of seeps, vegetation, and erosion near the base of the bank. Wood at the base of the bank along the edge of the river was also noted as were other features, such as irregularities in the bank shape, that could potentially influence either the shear stresses and velocities experienced at the monitoring sites or the critical shear stress and velocity required to entrain sediment. Freshly exposed bank sediments were to be used to supplement stratigraphic descriptions of the monitoring sites previously presented in Field Geology and Normandeau (2016 and 2017), but no new exposures were present. Colluvial material derived from erosion higher on the bank still covered the stratigraphy at the base of the banks at many of the monitoring sites as was the case during the two years of monitoring from 2013 to 2015.

At each site, sediment samples were taken at water surface elevations (WSE) corresponding to the 3 project operational conditions suggested in FERC's Study Plan Determination: minimum flow, average project operating ranges (which we have interpreted to mean a mid-range flow), and maximum hydraulic capacity of the station (also referred to as minimum, medium and maximum flows; Figure 2.1-1). Establishing the sampling elevation was complicated by the fact that WSE at the monitoring sites can be a function of: 1) the WSE at the downstream dam, 2) inflows from above the monitoring sites, and 3) discharge at the upstream dam for riverine sites. Each of these factors can apply, but may not all apply at any given monitoring site. For instance, WSE at the downstream dam has no material effect on some of the riverine sites upstream of that dam. Similarly, sites just above a dam are mainly affected by the WSE at the dam and less by inflow from upstream. WSE at sites in the middle to upper impoundments are affected more significantly by inflow than WSE at the dam.

In order to establish the soil sampling elevations, the HEC-RAS model was used to provide guidance by providing a matrix of the range of WSE at the downstream dam and the three specified flow conditions. The mid-range operating elevation at the dam was primarily used to determine soil samples collection locations based upon the three flows, however, to the extent that a change in sediment type was apparent within the full range of WSE at the dams, a sample was included to ensure the full range of project operations was considered in the analysis. This was the case at 6 sites where WSE based on the mid-range WSE at the dam did not reach the base of the riverbank even at maximum hydraulic capacity. In these instances, a higher WSE at the dam was evaluated if operational flows at that higher elevation directly impinged on the riverbank (although at WR01 and VR01 flows did not reach the riverbank even at the highest WSE at the dam and maximum operational flows). For the other 4 sites, considering the upper WSE at the dam ensured that at least one sediment sample was collected for analysis to determine if flows within the operating range of the projects were capable of entraining bank sediment.

After using hydraulic modeling to establish WSEs corresponding to the 3 project operational conditions at each site (see Section 2.2), a Sokkia Set 5 electronic total station relocated the elevation along the monitoring transect using benchmarks from the earlier monitoring that were still available. Once the locations were identified, the morphological feature (e.g., gravel bar, riverbank) present at the WSEs corresponding to the 3 project operational conditions were recorded and a field assessment made of the sediment texture. Where the WSE for 2 or more operational conditions were on the same morphological feature at a single site and a field textural analysis indicated similar sediment, then only one sediment sample was taken to represent the sediment texture for multiple operational scenarios. Similarly, at some sites, especially impoundment sites just upstream of a dam (e.g., W12), the WSE for the 3 operational conditions were essentially at the same elevation since the nearby dam WSE remained unchanged for all operational flows considered. In these instances, a single sediment sample was taken. These reasons explain why 1 sediment sample sometimes represents multiple operational conditions at a monitoring site, whereas multiple sediment samples were taken at other sites to ensure bank sediments were sampled where project operations impinge on the bank (Appendix A).

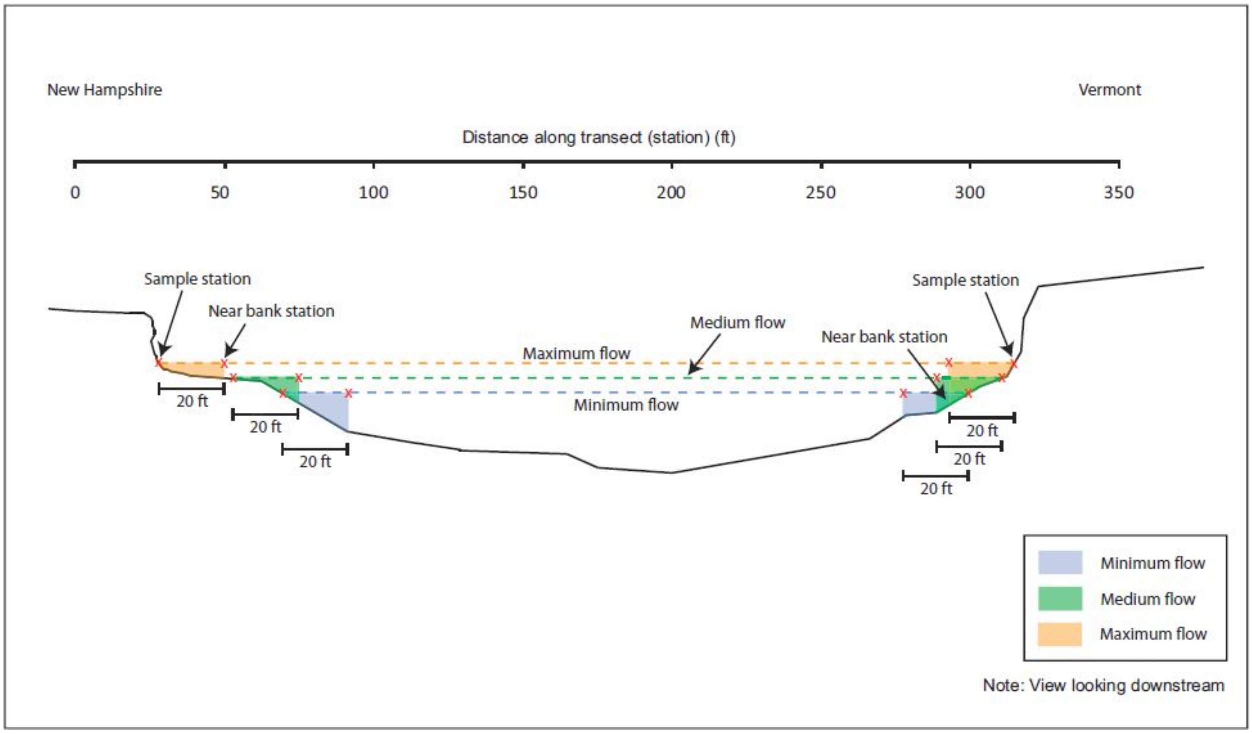

Figure 2.1-1. River cross section showing features used in sediment entrainment summary.

Enough sediment was collected at each sampling location to fill a quart-sized resealable plastic bag. Sediment samples were collected with a trowel by scraping the top three inches of the surface. Submerged samples were collected in a similar manner; minor loss in the silt and clay fraction due to suspension in the water column was not considered significant enough to appreciably alter the analysis. All samples were delivered to GEI Consultants, Inc's, sediment laboratory in Woburn, MA for sieve analysis to determine grain size distribution and D_{50} particle size (Appendix B). A hydrometer analysis was also conducted on samples that had a combined silt and clay fraction of more than 5 percent to determine the percentage of each component (i.e., clay and silt) in the given sample.

2.2 Hydraulic modeling

Hydraulic modeling was used in two ways for the supplementary analysis presented here. The HEC-RAS model completed as part of ILP Study 4 (GEI, 2016) was used to establish the WSE corresponding to the 3 project operational conditions at each site. For the model, cross sections were established at each monitoring site to ensure that the elevations derived from the model were as precise as possible for sediment sampling. The data used to construct the cross sections are based on LiDAR derived topography and bathymetry collected by Normandeau (2015). The cross sections were drawn from a selected point on the floodplain (or terrace) on the eastern (New Hampshire) side of the river valley to a point west of the river (in Vermont). Stationing (i.e., marked distances along the transect) does not begin at the top of the riverbank, but rather at the starting point of the cross section on the eastern or

New Hampshire side of the river valley. Consequently, the station location numbering for sites in New Hampshire are less for those locations closer to the riverbank (and at a higher elevation on the bank) while for sites in Vermont the station distance is greater for sites closer to the riverbank (Figure 2.1-1 and Appendix A).

Hydraulic modeling was also used to estimate the near bank shear stresses and velocities associated with the 3 operational flow conditions (i.e., minimum flow, average project operating ranges, maximum hydraulic capacity). A 2D hydraulic model was developed for this purpose as detailed in Appendix C. This was the most appropriate method to estimate near bank shear stresses and velocities given the range of operational conditions of interest to the FERC and the limited timeframe available for completing the supplemental study report. Based on the 10-foot grid size of the model and recognizing that shear stress and velocity would be close to zero at the water's edge and increasingly greater toward the center of the channel, near bank shear stresses and velocities extracted from the model were taken 20 ft further into the channel (referred to as the "near bank station") from the point of interest (referred to as the "sample station") to ensure the results did not include zero values near the bank due to natural edge effects. As a result, the model produced and the analysis considered more conservative (higher) values of shear stress and velocity than experienced at the sample station. Three shear stress and velocity values were estimated for each near bank station representing conditions for the minimum, medium, and maximum flows. Soil sampling locations associated with the medium and maximum flows are generally above the WSE for the minimum flow condition, so the shear stress and velocity are recorded as "dry" in Appendix A to indicate they are not inundated for the given operational scenario. The soil sampling location at the water's edge associated with the minimum flow will generally be under a certain depth of water and a certain distance from the water's edge during the higher flow conditions. Although the distance of the sampling station might be more than 20 ft from the water's edge at higher flows, the 20-foot setback from a sample station was maintained for the near bank station regardless of how far the associated sample station was from the water's edge at higher flow conditions (see Figure 2.1-1).

2.3 Threshold analysis

Shear stress is commonly used as a measure of a stream's ability to entrain and transport bed and bank materials. Entrainment occurs only when the shear stress acting upon a particle crosses a threshold that exceeds the resistance of that particle to movement. This threshold value is commonly referred to as the critical shear stress (VANR, 2004). To determine if sediment can be entrained at the 21 monitoring sites under the 3 operational flow conditions, the estimated near bank shear stress and velocity values extracted from the 2D hydraulic model were compared with published critical shear stress and velocity values necessary to initiate sediment transport. The critical shear stress and velocity values used in the analysis were based on the D_{50} particle size determined from the sediment sample grain size analyses (Appendix B). Where the estimated values during a specified operational condition are less than the critical values, sediment entrainment is considered unlikely, whereas, values higher than the critical values suggest sediment entrainment may be possible.

Flume experiments by Shields in the 1930s established the critical shear stress needed to entrain non-cohesive sediments of a given size (Knighton, 1998). Later refinements of Shields' early studies, originally conducted in a laboratory on sediment of uniform size, established methods for determining the critical shear stress for sediments of varying size and character (Fischenich, 2001). These studies formed the basis for assigning a critical shear stress value to the sediment samples collected at the 21 monitoring sites. Analyses of sediment based on Shields' work have been found to considerably underestimate critical shear stress (Clark and Wynn, 2007), so the results presented in Appendix A should be considered conservative. Recognizing this, VANR (2004) indicates that shear stress values must substantially exceed published critical shear stress values before channel erosion results.

For this analysis, a refinement of Shields' original equation was used to calculate critical shear stress for the samples that ranged in size from silt to medium sand (non-cohesive; i.e., D_{50} values of less than 1.0 mm) (VANR, 2004). Since the Shields equation is largely based on the size of individual particles, the critical shear stress for cohesive particles such as clay and colloidal silt with higher shear strength, is likely significantly underestimated (Clark and Wynn, 2007). Given these limitations, the critical shear stress value for the single sample classified as a clay (from W10) was taken from Figure 8-17 in NRCS (2007), used to determine the allowable shear stress for designing channels in cohesive clays. (The sample, taken from an indurated varved deposit, was considered compact in order to use Figure 8-17 without a measurement of the void ratio.) The effect of cohesion on the critical shear stress of cohesive silts (with higher shear strength) was not satisfactorily addressed in the literature reviewed, so the critical shear stresses for the 6 samples considered cohesive silts were determined using the revised Shields equation for non-cohesive sediments (VANR, 2004). These critical shear stress values, therefore, must be considered conservative and underestimated. The 6 samples were collected at 4 monitoring sites: W03, WR09, B09, and VR02. While 17 samples in total were classified as silt, these 6 samples are considered cohesive because they are compact and of glacial origin (4 samples) or are alluvial with an admixture of clay but without any sand (2 samples). Critical shear stress for coarse sand and gravel (i.e., D_{50} > 1.0 mm) was determined by using Figure 8-16 in NRCS (2007) with an assumption of clear water conditions.

The critical velocity needed to entrain sediment at the 21 monitoring sites was also selected by reviewing published literature. Velocity thresholds are often used to determine the highest permissible velocity that can pass through a design channel or canal without causing erosion. When used for design purposes, a factor of safety is included, so the results can be considered conservative estimates with higher velocities most likely needed to entrain sediment (NRCS, 2007). Figure 8-3 in NRCS's (2007) channel design document was used to assign critical velocities for the non-cohesive sediments collected at the monitoring sites based on the D_{50} particle size and an assumption of a 5 foot water depth. Critical velocities for cohesive clay and silt were based on Table 8-3 in NRCS (2007). While no single equation or chart for determining critical shear stress and velocity will be perfectly suited for all conditions encountered, the use of multiple approaches in the analysis recognizes that variations in critical shear stress and velocity values arise from differences in grain sizes and associated properties (e.g., cohesiveness).

3.0 RESULTS AND DISCUSSION

At the 21 monitoring sites, sediment entrainment is considered possible when the modeled shear stress or velocity is greater than the critical shear stress or velocity needed to entrain the sediment sampled at the sites (Appendix A). In several instances, sediment entrainment for the same sample is predicted based on the critical shear stress but not predicted based on velocity. The opposite scenario was not encountered: where sediment entrainment was predicted based on the critical velocity but not shear stress. Shear stress values based on the Shields equation and later refinements do not account for cohesion, compaction, or other forces resisting entrainment that may be present in certain sediment samples, while the critical velocity values, based on empirical field studies, does account for these resisting forces to some extent. This suggests critical shear stress is more significantly underestimated than critical velocity values and is likely related to differences in how the critical values are determined. Since FERC requested an analysis of shear stress and velocity, the results of both are presented here. Despite the sometimes contradictory findings between shear stress and velocity, both the critical shear stress and velocity values must be considered underestimates and sediment entrainment unlikely unless the modeled shear stress and velocity values far exceed the critical values.

Even based on these conservative underestimated values for critical shear stress and velocity, only 8 out of 21 sites show any potential for sediment entrainment. These are riverine (n=5) or upper reservoir sites (n=3) largely affected by inflow or upstream dam discharge rather than downstream project operations: W02, WR01, WR08, WR09, B01, B03, BR05, and VR02 (Appendix A). Most of the predicted sediment entrainment occurs on beaches or bars at an elevation lower than the toe of bank. Sediment entrainment at such sites is not unexpected since these sites, on beaches and bars, are part of depositional features formed from sediment transported from upstream under conducive flow conditions. However, sediment entrainment on these depositional features does not in any way reflect the potential for bank erosion.

Predicted sediment entrainment of bank material is possible at only 5 sites (WR08, WR09, B01, BR05, and VR02) but nearly always at the maximum hydraulic capacity of the projects with little entrainment predicted at lower flows (Appendix A). Of the 189 possible scenarios analyzed (i.e., 3 operational conditions at 3 elevations at each of 21 sites), entrainment of bank sediment is predicted only 8 times, 6 of which occur during the maximum hydraulic capacity of the associated project and the other 2 during medium flow conditions (Appendix A).

While the results of the analysis suggest sediment entrainment is possible at the maximum operational flow for a small fraction of the numerous scenarios considered, project operations should not, as a result, be considered capable of causing significant bank erosion. At 2 of the 5 monitoring sites where sediment entrainment of bank material is predicted (WR08 and VR02), the banks were classified as stable during the 2014 erosion mapping (Field Geology and Normandeau, 2016), indicating that sediment entrainment of bank material, if occurring at all, does not necessarily result in erosion. At 2 of the 3 remaining sites (WR09 and BR05), only the critical shear stress threshold is passed but not the velocity threshold. This discrepancy leaves some ambiguity as to whether sediment entrainment of bank material at the site is actually possible under operational conditions, especially given that the modeled velocity does not greatly exceed the critical value required to initiate sediment entrainment. Critical shear stress can be underestimated by four orders of magnitude in some instances (Clark and Wynn, 2007). The critical velocity values used in the analysis are also considered underestimates (see Section 2.3), so modeled values that are only slightly above the critical velocity values for entrainment cannot be considered a definitive indication that sediment entrainment occurs.

Only the grain size of sediment is considered in the sediment entrainment analysis, although other characteristics of the sites can influence the potential for sediment mobilization. Bank vegetation greatly increases the critical shear stress and velocity needed to mobilize sediment and is growing at the base of the bank at many monitoring sites (Appendix A). At the 5 sites where sediment entrainment of bank sediments was determined to be possible, 4 have some vegetation or tree roots, sometimes dense growth, present where the sediment samples were collected. (The fifth site [BR05] has two sample elevations located on the bank, the lower of which did have vegetation growth.) Given the ambiguity in entrainment potential due to modeled values being close to the underestimated critical values or only the critical shear stress but not velocity threshold being crossed, even a small amount of vegetation would likely be sufficient to prevent sediment entrainment. In addition to the effects of vegetation on the critical shear stresses and velocities needed to entrain sediment, wood along the base of the bank and irregularities in the bank shape can reduce near bank velocities and shear stresses. Such factors are not accounted for in the modeled velocities and shear stresses, so could inhibit sediment entrainment even if the analysis based on grain size alone suggests entrainment is possible. While vegetation is not growing at the location of sampled bank sediments at BR05, large wood found at the base of the bank could be preventing sediment entrainment by reducing near bank velocities and shear stresses.

Seeps emanating from bank sediments could potentially increase the potential for sediment entrainment by increasing the forces acting on the bank or by reducing the resistance of the bank sediment to erosion. Only 3 of the 21 monitoring sites showed any evidence of seeps (Appendix A). At two of the sites (WR09 and VR01), the seeps were dry at the time of the site visit in August 2017 but the small shallow rills on the bank surface carved by seeps indicate they originated high on the bank slope well above water levels associated with project operations. The third seep, at BR05, was active, but weak, in August 2017 but not necessarily associated with project operations given that the adjacent landscape is a floodplain forest indicative of a wetland or an elevated water table. Given the other factors described above that could inhibit sediment entrainment at WR05, the minor discharge from the seeps, regardless of their cause, is not considered to be greatly enhancing the potential for sediment entrainment.

4.0 CONCLUSIONS

Two dimensional hydraulic modeling together with an analysis of sediment samples at 21 erosion monitoring sites were completed to determine if near bank shear stresses and velocities generated by various operational flows at Wilder, Bellows Falls, and Vernon dams on the Connecticut River are sufficient to entrain sediment and, therefore, contribute to bank erosion. Sediment entrainment was considered possible for flows where near bank shear stresses and velocities, as determined by the hydraulic modeling, exceed the critical shear stress or velocity necessary to entrain the D_{50} particle size for the sediment samples collected at the monitoring sites. The results show entrainment of bank sediment during operational flows is highly unlikely at over 75 percent of the sites (n=16). At the remaining 5 sites, the analysis suggests entrainment of bank sediment is possible during maximum operational flows; however, such entrainment is considered unlikely because: 1) the banks at 2 of the 5 sites are stable, 2) published studies indicate that the critical shear stress and velocity values used in the analysis are significantly underestimated while the modeled results are only slightly above the necessary thresholds for entrainment, 3) the modeled shear stresses and velocities used in the analysis were taken 20 ft further into the channel, and thus, higher than at the sampling site, and 3) the presence of vegetation on the banks, wood at the base of the bank, and irregularities in bank shape, not accounted for in the analysis, can increase the critical shear stresses and velocities or result in lower shear stress and velocity values estimated by the hydraulic modeling. As a result, project operations, while perhaps causing sediment entrainment in isolated incidents, cannot be responsible for widespread bank sediment entrainment or bank erosion. Therefore, the analysis of sediment entrainment at the monitoring sites further supports the conclusions of Field Geology and Normandeau (2016 and 207) that flood discharges exceeding operational flows are needed to remove sediment accumulating at the base of the river banks and sustain the erosion cycle that drives bank erosion within project affected areas.

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APPENDIX A

Sediment Entrainment Summary

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W02 – Bedell Bridge Site

The Bedell Bridge Site (W02) is located in Haverhill, NH near the upstream end of Wilder impoundment. A wide bar fronts the bank where the water surface rests at the minimum and average operating flows when WSE at Wilder dam is 382.6 ft. At maximum operating capacity, the water surface falls on a layer of alluvial fine sandy silt at the bank's base. A comparison between modeled and critical shear stresses and velocities suggests entrainment of the bar sediments is not possible under operational conditions and only minimally possible at the "maximum" flow of 12,000 cfs. At maximum flow, modeled near-bank velocity is basically equal to the threshold velocity and modeled shear stress are higher but only minimally. To place this in context, modeled channel velocity at this site ranges from 0.3 ft/sec at 1000 cfs to above 3 ft/sec at a flow of 25,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 1000 cfs and 0.11 lb/sq^2 at a flow of 25,000 cfs. These levels are excessively higher and likely to exert much greater entrainment potential particularly during sustained flood flow periods.

W02 - Bedell Bridge (New Hampshire)

Sample characteristics									
Sample elevation (NAVD88 ft)	382.6 (minimum)			384.4 (medium)			388.6 (maximum)		
Sample ID	W02-1			W02-1			W02-2		
Morphological feature	Bar			Bar			Bank		
Sediment composition	Silty fine sand			Silty fine sand			Sandy silt		
D50 grain size (mm)	0.1022			0.1022			0.0641		
Stratigraphy	Not applicable - below bank			Not applicable - below bank			Alluvial fine sandy silt		
Erosion features	None			None			Notching		
Presence/character vegetation	None			None			Moderate tree/shrub cover		
Presence of seeps	None			None			None		
Other characteristics	Wood parallel to bank			Wood parallel to bank			Wood parallel to bank, tree roots		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	382.6			382.6			382.6		
Model flow (cfs)	700	5000	12000	700	5000	12000	700	5000	12000
Sample station (ft)	87	87	87	81	81	81	70	70	70
Near bank station (ft)	108	108	108	101	101	101	90	90	90
Velocity (ft/sec)	0.145	0.943	1.823	Dry	0.829	1.669	Dry	Dry	1.279
Shear stress (lb/ft^2)	0.0004	0.014	0.046	Dry	0.011	0.040	Dry	Dry	0.027
Threshold analysis									
Threshold velocity (ft/sec)	1.8	1.8	1.8	1.8	1.8	1.8	2.0	2.0	2.0
Velocity threshold passed	No	No	Yes	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.026	0.026	0.026	0.026	0.026	0.026	0.038	0.038	0.038
Shear stress threshold passed	No	No	Yes	No	No	Yes	No	No	No

Notes:

Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.

Sample station refers to distance along the cross section.

Near bank station refers to a point 20 feet out from sample station.

See further explanation in text.

Site photo

W03 – Bellavance Site

The Bellavance Site (W03) is located in Bradford, VT in the upper third of Wilder impoundment. A wide bench of resistant material protrudes almost 10 ft from the base of the bank and is where the water surface at the minimum and average operating flows rests when Wilder dam is at an elevation of 382.6 ft. The water surface at maximum capacity falls on colluvium accumulating at the bank's base. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is not possible on either the bench or bank under operational conditions. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures. To further place this in context, modeled channel velocity at this site ranges from 0.12 ft./sec at 1000 cfs to above 2.25 ft/sec at a flow of 25,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 1000 cfs and 0.06 lb/sq^2 at a flow of 25,000 cfs. These levels are significantly higher and likely to exert greater entrainment potential particularly during sustained flood flow periods.

W03 - Bellavance (Vermont)

Sample characteristics									
Sample elevation (NAVD88 ft)	382.6 (minimum)			383.8 (medium)			387.3 (maximum)		
Sample ID	W03-1			W03-1			W03-2		
Morphological feature	Bench			Bench			Bank		
Sediment composition	Silt			Silt			Silty sand		
D50 grain size (mm)	0.0382			0.0382			0.0821		
Stratigraphy	Compact glacial silt and clay			Compact glacial silt and clay			Colluvium		
Erosion features	Forms resistant shelf at bank toe			Forms resistant shelf at bank toe			Planar slip/topple block		
Presence/character vegetation	None			None			Thick herbaceous growth		
Presence of seeps	None			None			None		
Other characteristics	Large submerged slip block			Large submerged slip block			Large submerged slip block		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	382.6			382.6			382.6		
Model flow (cfs)	700	5000	12000	700	5000	12000	700	5000	12000
Sample station (ft)	2391	2391	2391	2394	2394	2394	2407	2407	2407
Near bank station (ft)	2371	2371	2371	2374	2374	2374	2387	2387	2387
Velocity (ft/sec)	0.085	0.606	1.327	Dry	0.552	1.250	Dry	Dry	0.941
Shear stress (lb/ft^2)	0.0001	0.006	0.026	Dry	0.006	0.024	Dry	Dry	0.016
Threshold analysis									
Threshold velocity (ft/sec)	3.75	3.75	3.75	3.75	3.75	3.75	1.8	1.8	1.8
Velocity threshold passed	No	No	No	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.034	0.034	0.034	0.034	0.034	0.034	0.021	0.021	0.021
Shear stress threshold passed	No	No	No	No	No	No	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

W07 – Tullando Site

The Tullando Site (W07) is located in Orford, NH in Wilder impoundment. A wide beach fronts the bank where the water surface at the minimum and average operating flows rests when Wilder dam is at an elevation of 382.6 ft. The water surface at maximum capacity falls on colluvium accumulating at the bank's base. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is not possible on either the beach or bank under operational conditions. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures. To further place this in context, modeled channel velocity at this site ranges from 0.13 ft/sec at 1000 cfs to above 2 ft/sec at a flow of 25,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 1000 cfs and 0.05 lb/sq^2 at a flow of 25,000 cfs. These levels are at or below threshold levels.

W07 - Tullando (New Hampshire)

Sample characteristics									
Sample elevation (NAVD88 ft)	382.6 (minimum)			382.9 (medium)			384.4 (maximum)		
Sample ID	W07-1			W07-1			W07-2		
Morphological feature	Beach			Beach			Bank		
Sediment composition	Silty fine sand			Silty fine sand			Fine sand		
D50 grain size (mm)	0.2438			0.2438			0.3399		
Stratigraphy	Not applicable - below bank			Not applicable - below bank			Colluvium		
Erosion features	None			None			Notching		
Presence/character vegetation	None			None			Moss		
Presence of seeps	None			None			None		
Other characteristics	Leaning tree at base of bank			Leaning tree at base of bank			Leaning tree at base of bank		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	382.6			382.6			382.6		
Model flow (cfs)	700	5000	12000	700	5000	12000	700	5000	12000
Sample station (ft)	1255	1255	1255	1253	1253	1253	1250	1250	1250
Near bank station (ft)	1276	1276	1276	1273	1273	1273	1271	1271	1271
Velocity (ft/sec)	0.067	0.473	1.074	Dry	0.433	0.993	Dry	Dry	0.946
Shear stress (lb/ft^2)	0.0001	0.003	0.017	Dry	0.003	0.015	Dry	Dry	0.014
Threshold analysis									
Threshold velocity (ft/sec)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Velocity threshold passed	No	No	No	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.062	0.062	0.062	0.062	0.062	0.062	0.058	0.058	0.058
Shear stress threshold passed	No	No	No	No	No	No	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

W09 – Mudge Site

The Mudge Site (W09) is located in Lyme, NH in Wilder impoundment. A wide beach fronts the bank where the water surface at the minimum and average operating flows rests when Wilder dam is at an elevation of 382.6 ft. The water surface at maximum capacity with a higher dam elevation of 384.6 ft falls on colluvium near the bank's base. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is not possible on either the beach or bank under operational conditions. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures. To further place this in context, modeled channel velocity at this site ranges from 0.13 ft/sec at 1000 cfs to 2.75 ft/sec at a flow of 25,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 1000 cfs and 0.09 lb/sq^2 at a flow of 25,000 cfs. These levels are significantly higher and likely to exert greater entrainment potential particularly during sustained flood flow periods.

W09 - Mudge (New Hampshire)

Sample characteristics									
Sample elevation (NAVD88 ft)	382.6 (minimum)			382.8 (medium)			384.6 (maximum)		
Sample ID	W09-1			W09-1			W09-2		
Morphological feature	Beach			Beach			Bank		
Sediment composition	Silty sand			Silty sand			Silty sand		
D50 grain size (mm)	0.1113			0.1113			0.0804		
Stratigraphy	Not applicable - below bank			Not applicable - below bank			Colluvium		
Erosion features	None			None			Notching		
Presence/character vegetation	None			None			Moderate herbaceous cover		
Presence of seeps	None			None			None		
Other characteristics	Wood along bank			Wood along bank			Wood along bank		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	382.6			382.6			384.6		
Model flow (cfs)	700	5000	12000	700	5000	12000	700	5000	12000
Sample station (ft)	165	165	165	163	163	163	159	159	159
Near bank station (ft)	185	185	185	184	184	184	179	179	179
Velocity (ft/sec)	0.056	0.402	0.960	Dry	0.385	0.923	0.046	0.329	0.794
Shear stress (lb/ft^2)	0.000	0.003	0.014	Dry	0.002	0.013	0.000	0.002	0.010
Threshold analysis									
Threshold velocity (ft/sec)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Velocity threshold passed	No	No	No	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.028	0.028	0.028	0.028	0.028	0.028	0.021	0.021	0.021
Shear stress threshold passed	No	No	No	No	No	No	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

W10 – Vaughn Site

The Vaughn Site (W10) is located in Thetford, VT in Wilder impoundment. A wide beach fronts the bank where the water surface at the minimum and average operating flows rests when Wilder dam is at an elevation of 382.6 ft. The water surface at maximum capacity falls on glaciolacustrine varves at the bank's base and is 1 foot below a sandy unit. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is not possible on either the beach or bank under operational conditions. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures. To further place this in context, modeled channel velocity at this site ranges from 0.11 ft/sec at 1000 cfs to 2.33 ft/sec at a flow of 25,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 1000 cfs and 0.06 lb/sq^2 at a flow of 25,000 cfs. These levels are slightly above, at or below threshold levels.

W10 - Vaughn (Vermont)

Sample characteristics									
Sample elevation (NAVD88 ft)	382.6 (minimum)			382.8 (medium)			383.4 (maximum)		
Sample ID	W10-1			W10-1			W10-2		
Morphological feature	Beach			Beach			Bank		
Sediment composition	Fine sand with silt			Fine sand with silt			Silty clay		
D50 grain size (mm)	0.2459			0.2459			0.0029		
Stratigraphy	Not applicable - below bank			Not applicable - below bank			Glaciolacustrine varves*		
Erosion features	None			None			Notching		
Presence/character vegetation	Moderate aquatic vegetation			Moderate aquatic vegetation			None		
Presence of seeps	None			None			None		
Other characteristics	Shrubs along base of bank			Shrubs along base of bank			Shrubs along base of bank		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	382.6			382.6			382.6		
Model flow (cfs)	700	5000	12000	700	5000	12000	700	5000	12000
Sample station (ft)	569	569	569	569	569	569	571	571	571
Near bank station (ft)	548	548	548	548	548	548	550	550	550
Velocity (ft/sec)	0.039	0.280	0.670	0.039	0.280	0.670	Dry	Dry	0.638
Shear stress (lb/ft^2)	0.000	0.001	0.007	0.000	0.001	0.007	Dry	Dry	0.006
Threshold analysis									
Threshold velocity (ft/sec)	2.0	2.0	2.0	2.0	2.0	2.0	3.75	3.75	3.75
Velocity threshold passed	No	No	No	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.063	0.063	0.063	0.063	0.063	0.063	0.3	0.3	0.3
Shear stress threshold passed	No	No	No	No	No	No	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
*Sample taken 1 foot below contact with coarse and medium sand unit above.
See further explanation in text.

Site photo

W12 – Pine Park Site

The Pine Park Site (W12) is located in Hanover, NH near the downstream end of Wilder impoundment. A wide beach fronts the bank where the water surface at the minimum and average operating flows rests when Wilder dam is at an elevation of 382.6 ft. The water surface at maximum capacity with a higher dam elevation of 384.6 ft falls on a stratigraphic unit of interbedded sands near the bank's base. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is not possible on either the beach or bank under operational conditions. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures. To further place this in context, modeled channel velocity at this site ranges from 0.1 ft/sec at 1000 cfs to 2.41 ft/sec at a flow of 25,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 1000 cfs and 0.07 lb/sq^2 at a flow of 25,000 cfs. The upper range of velocity levels are slightly above, similarly the upper range of shear stress estimates are significantly higher and suggest entrainment potential particularly during sustained flood flow periods.

W12 - Pine Park (New Hampshire)

Sample characteristics									
Sample elevation (NAVD88 ft)	382.6 (minimum and medium)			382.8 (maximum)			384.7 (maximum)		
Sample ID	W12-1			W12-1			W12-2		
Morphological feature	Beach			Beach			Bank		
Sediment composition	Silty fine sand			Silty fine sand			Silty fine sand		
D50 grain size (mm)	0.0876			0.0876			0.1064		
Stratigraphy	Not applicable - below bank			Not applicable - below bank			Interbedded sand		
Erosion features	None			None			None		
Presence/character vegetation	None			None			Moss		
Presence of seeps	None			None			None		
Other characteristics	Upstream of large tree and armor			Upstream of large tree and armor			Upstream of large tree and armor		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	382.6			382.6			384.6		
Model flow (cfs)	700	5000	12000	700	5000	12000	700	5000	12000
Sample station (ft)	71	71	71	71	71	71	68	68	68
Near bank station (ft)	92	92	92	92	92	92	89	89	89
Velocity (ft/sec)	0.039	0.276	0.663	0.039	0.276	0.663	0.035	0.251	0.603
Shear stress (lb/ft^2)	0.000	0.001	0.007	0.000	0.001	0.007	0.000	0.001	0.006
Threshold analysis									
Threshold velocity (ft/sec)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Velocity threshold passed	No	No	No	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.022	0.022	0.022	0.022	0.022	0.022	0.027	0.027	0.027
Shear stress threshold passed	No	No	No	No	No	No	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

WR01 – Hartford Site

The Hartford Site (W02) is located in Hartford, VT just downstream of Wilder dam. A wide beach fronts the bank where the water surface rests at all operational flows. Only flood flows reach the base of the bank above the beach. A comparison between modeled and critical shear stresses and velocities suggests entrainment of the beach sediments is not possible under low and mid flow operations and only possible at the "maximum" flow of 12,000 cfs where sand/silt are predominant in the soil; not high enough to entrain larger gravel/sand/silt soil material. At mid and maximum flows, modeled near-bank velocity and shear stress estimates are reasonably equal to the threshold velocity and shear stresses. A consistently graded beach appears stable up to elevation 337 ft msl where previous monitoring identified the first indication of notching into the beach face. Elevation 337 at the site corresponds with a flow of approximately 27,000 cfs.

To further provide context, modeled channel velocity at this site ranges from 0.31 ft/sec at 700 cfs to about 2.8 ft/sec at a flow of 25,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 1000 cfs and 0.08 lb/sq^2 at a flow of 25,000 cfs. These levels are higher and may exert greater entrainment potential particularly during sustained flood flow periods. Field evidence suggests that bank recession occurs at higher elevations corresponding to mainstem flows of 40,000 cfs or more. During periods of high flows, discharge from the White River is also high and can cause a backwater effect in the main channel above the confluence further complicating the analysis and identification of entrainment-flow relationships.

WR01 - Hartford (Vermont)

Sample characteristics									
Sample elevation (NAVD88 ft)	324.9 (minimum)			328.8 (medium)			332.0 (maximum)		
Sample ID	WR01-1			WR01-2			WR01-3		
Morphological feature	Beach			Beach			Beach		
Sediment composition	Medium sand with silt			Silty fine sand			Gravel with sand and silt		
D50 grain size (mm)	0.5373			0.1535			2.5331		
Stratigraphy	Not applicable - below bank			Not applicable - below bank			Not applicable - below bank		
Erosion features	None			None			Notching on beach		
Presence/character vegetation	None			None			None		
Presence of seeps	None			None			None		
Other characteristics	Trees downed and growing			Trees downed and growing			Trees downed and growing		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	290.2			290.2			290.2		
Model flow (cfs)	700	5000	12000	700	5000	12000	700	5000	12000
Sample station (ft)	594	594	594	604	604	604	607	607	607
Near bank station (ft)	574	574	574	584	584	584	587	587	587
Velocity (ft/sec)	0.287	1.683	2.541	Dry	1.543	2.414	Dry	Dry	2.346
Shear stress (lb/ft^2)	0.001	0.036	0.072	Dry	0.030	0.064	Dry	Dry	0.060
Threshold analysis									
Threshold velocity (ft/sec)	2.2	2.2	2.2	1.9	1.9	1.9	2.8	2.8	2.8
Velocity threshold passed	No	No	Yes	No	No	Yes	No	No	No
Critical shear stress (lb/ft^2)	0.055	0.055	0.055	0.039	0.039	0.039	0.06	0.06	0.06
Shear stress threshold passed	No	No	Yes	No	No	Yes	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

WR05 – Edgewater Farm Site

The Edgewater Farm Site (WR05) is located in Plainfield, NH in the riverine section downstream of Wilder dam. A wide bar fronts the bank where the water surface at the minimum and average operating flows rests when Bellows Falls dam is at an elevation of 290.2 ft. The water surface at maximum capacity falls on interbedded sand and silts at the bank's base. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is not possible on either the beach or bar under operational conditions. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures. To further place this in context, modeled channel velocity at this site ranges from 0.17 ft/sec at 700 cfs to 2.47 ft/sec at a flow of 25,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 1000 cfs and 0.05 lb/sq^2 at a flow of 25,000 cfs. The upper flow velocity and shear stress levels are slightly above thresholds and suggest entrainment potential particularly during sustained flood flow periods.

WR05 - Edgewater Farm (New Hampshire)

Sample characteristics									
Sample elevation (NAVD88 ft)	313.1 ft (minimum)			317.2 ft (medium)			320.4 ft (maximum)		
Sample ID	WR05-1			WR05-1			WR05-2		
Morphological feature	Bar			Bar			Bank		
Sediment composition	Gravel with sand and silt			Gravel with sand and silt			Sandy silt		
D50 grain size (mm)	14.0877			14.0877			0.0735		
Stratigraphy	Not applicable - below bank			Not applicable - below bank			Sandy silt interbedded with sand		
Erosion features	None			None			Notching		
Presence/character vegetation	None			Sparse herbaceous cover			Sparse herbaceous cover		
Presence of seeps	None			None			None		
Other characteristics	Large wood parallel to bank			Large wood parallel to bank			Large wood parallel to bank		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	290.2			290.2			290.2		
Model flow (cfs)	700	5000	12000	700	5000	12000	700	5000	12000
Sample station (ft)	222	222	222	210	210	210	204	204	204
Near bank station (ft)	242	242	242	230	230	230	224	224	224
Velocity (ft/sec)	0.390	1.369	2.088	Dry	1.076	1.784	Dry	Dry	1.622
Shear stress (lb/ft^2)	0.002	0.020	0.042	Dry	0.014	0.034	Dry	Dry	0.029
Threshold analysis									
Threshold velocity (ft/sec)	5.0	5.0	5.0	5.0	5.0	5.0	2.0	2.0	2.0
Velocity threshold passed	No	No	No	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.2	0.2	0.2	0.2	0.2	0.2	0.043	0.043	0.043
Shear stress threshold passed	No	No	No	No	No	No	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

WR08 – Great River Farm Site

The Great River Farm Site (WR08) is located in Windsor, VT at the downstream end of Wilder riverine. A wide beach fronts the bank where the water surface at the minimum and average operating flows rests when Bellows Falls dam is at an elevation of 290.2 ft. The water surface at maximum capacity falls on alluvial sandy silt at the bank's base. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is not possible on the beach given the coarse sediment present. Bank sediment is potentially entrained but only at maximum capacity. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures at low to mid flows and only slightly higher at "maximum" 12,000 cfs flows. Based on these estimates and observations during field monitoring of sand deposition and no other changes, it would support the belief that this site is experiencing a general state of equilibrium or aggradation under higher flows rather than degradation. To further place the estimates in context, modeled channel velocity at this site ranges from 0.68 ft/sec at 700 cfs to 3.97 ft/sec at a flow of 25,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 1000 cfs and 0.14 lb/sq^2 at a flow of 25,000 cfs. The upper flow velocity and shear stress levels are slightly above thresholds and suggest entrainment potential particularly during sustained flood flow periods.

WR08 - Great River Farm (Vermont)

Sample characteristics									
Sample elevation (NAVD88 ft)	293.6 (minimum)			296.9 (medium)			300.1 (maximum)		
Sample ID	WR08-1			WR08-2			WR08-3		
Morphological feature	Beach			Beach			Bank		
Sediment composition	Coarse gravel with sand			Coarse gravel with sand and silt			Sandy silt		
D50 grain size (mm)	21.5350			22.4172			0.0561		
Stratigraphy	Not applicable - below bank			Not applicable - below bank			Alluvial sandy silt		
Erosion features	None			None			None		
Presence/character vegetation	None			Thick herbaceous cover			Thick herbaceous cover		
Presence of seeps	None			None			None		
Other characteristics	None			None			None		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	290.2			290.2			290.2		
Model flow (cfs)	700	5000	12000	700	5000	12000	700	5000	12000
Sample station (ft)	1134	1134	1134	1145	1145	1145	1154	1154	1154
Near bank station (ft)	1114	1114	1114	1125	1125	1125	1134	1134	1134
Velocity (ft/sec)	0.559	1.993	3.069	Dry	1.738	2.790	Dry	Dry	2.344
Shear stress (lb/ft^2)	0.004	0.043	0.090	Dry	0.034	0.077	Dry	Dry	0.058
Threshold analysis									
Threshold velocity (ft/sec)	5.4	5.4	5.4	5.4	5.4	5.4	2.0	2.0	2.0
Velocity threshold passed	No	No	No	No	No	No	No	No	Yes
Critical shear stress (lb/ft^2)	0.3	0.3	0.3	0.3	0.3	0.3	0.033	0.033	0.033
Shear stress threshold passed	No	No	No	No	No	No	No	No	Yes

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

WR09 – Hartwell Site

The Hartwell Site (WR09) is located in Cornish, NH at the downstream end of Wilder riverine. A narrow beach fronts the bank where the water surface at the minimum flow rests when Bellows Falls dam is at an elevation of 290.2 ft. The water surface at average flow and maximum capacity falls on colluvium at the bank's base. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is possible on the beach. Bank sediment is potentially entrained but only at maximum capacity. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures at low flows and only slightly-moderately higher at "medium" 5,000 cfs flows. At "maximum" flow of 12,000 cfs, near-bank velocities and shear stress increase beyond their respective thresholds for the sandy silt beach material sampled at the lowest operating limit. This is likely reflecting the channel flow funneling down the eastern side of Chase Island and continuing to be driven by the bar extending downstream from the island. However, the sandy material sampled is colluvium from upslope erosion and is unlikely to be the native clay bank material that extends to this depth. Medium and maximum flow near-bank velocities are less than velocity thresholds associated with the soils sampled farther upslope. Medium and maximum flow near-bank shear stress estimates slightly-moderately exceed the shear stress thresholds associated with the soil samples, but again it appears as though the material tested was colluvium originating from the upper banks- well above the operating or flood level range of WSE. Evidence of seeps during monitoring of this site suggested that much of the observed tumbled blocks of clay was likely a function of seepage rather than project operations as the seeps and block erosion occur much further upslope.

Based on these estimates and observations during field monitoring, it would support the conclusion found in the Final Report that that this site is experiencing a general state of equilibrium or potentially aggradation (beach sandy silt) rather than degradation. To further place the estimates in context, modeled channel velocity at this site ranges from 0.77 ft/sec at 700 cfs to 3.64 ft/sec at a flow of 25,000 cfs (frequently experienced); and channel shear stresses range between 0.01 lb/sq^2 at 1000 cfs and 0.12 lb/sq^2 at a flow of 25,000 cfs. The upper flow velocity and shear stress levels associated with these flows are slightly above thresholds and suggest entrainment potential particularly during sustained flood flow periods, but again, the soils tested at this location are unlikely to be the bank material found at the WSE.

WR09 - Hartwell (New Hampshire)

Sample characteristics									
Sample elevation (NAVD88 ft)	290.5 (minimum)			293.7 (medium)			297.0 (maximum)		
Sample ID	WR09-1			WR09-2			WR09-3		
Morphological feature	Beach			Bank			Bank		
Sediment composition	Sandy silt			Silt with clay			Silt		
D50 grain size (mm)	0.0547			0.0130			0.0221		
Stratigraphy	Not applicable - below bank			Colluvium			Colluvium		
Erosion features	None			Topple block			Topple block		
Presence/character vegetation	None			Moderate herbaceous cover			Thick herbaceous cover		
Presence of seeps	Dry, upslope seepage			Dry, upslope seepage			Dry, upslope seepage		
Other characteristics	Abundant tree roots			Abundant roots			Abundant roots		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	290.2			290.2			290.2		
Model flow (cfs)	700	5000	12000	700	5000	12000	700	5000	12000
Sample station (ft)	186	186	186	181	181	181	172	172	172
Near bank station (ft)	207	207	207	202	202	202	192	192	192
Velocity (ft/sec)	0.123	1.471	3.023	Dry	1.414	2.952	Dry	Dry	2.605
Shear stress (lb/ft^2)	0.0002	0.025	0.092	Dry	0.024	0.088	Dry	Dry	0.069
Threshold analysis									
Threshold velocity (ft/sec)	2.0	2.0	2.0	3.75	3.75	3.75	3.75	3.75	3.75
Velocity threshold passed	No	No	Yes	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.032	0.032	0.032	0.012	0.012	0.012	0.020	0.020	0.020
Shear stress threshold passed	No	No	Yes	No	Yes	Yes	No	No	Yes

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

B01 – Lipfert Site

The Lipfert Site (B01) is located in Cornish, NH at the upstream end of Bellows Falls impoundment. A beach fronts the bank where the water surface at the minimum and average operating flows rests when Bellows Falls dam is at an elevation of 290.2 ft. The water surface at maximum capacity falls on colluvium at the bank's base. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is not possible on the gravelly lower beach but is possible at average flows and maximum capacity on the sandy upper beach. Bank sediment is potentially entrained but only at maximum capacity. Modeled near-bank velocity and shear stress estimates are lower than the threshold velocity and shear stress threshold figures at low flows and near or slightly higher with medium flow thresholds associated with the beach material. "Maximum" 12,000 cfs flow showed less-to-moderately higher numbers than threshold values for the various soils. To further place the estimates in context, modeled channel velocity at this site ranges from 1.34 ft/sec at 2000 cfs to 3.37 ft/sec at a flow of 30,000 cfs (frequently experienced); and channel shear stresses range between 0.03 lb/sq^2 at 2000 cfs and 0.11 lb/sq^2 at a flow of 30,000 cfs. Worth noting is the higher near-bank velocity versus the overall channel velocity, largely presumed to be a function of the overall river channel morphology in which the channel flow is directed at the monitoring site largely due to the extensive sand bar on the right and middle portions of the river.

Based on these estimates and observations during field monitoring it would support the belief that this site is experiencing bank erosion largely due to river morphology and independent of project operation.

B01 - Lipfert (New Hampshire)

Sample characteristics									
Sample elevation (NAVD88 ft)	290.6 (minimum)			292.0 (medium)			295.0 (maximum)		
Sample ID	B01-1			B01-2			B01-3		
Morphological feature	Beach			Beach			Bank		
Sediment composition	Fine gravel			Coarse sand			Silty fine sand		
D50 grain size (mm)	7.7773			1.8460			0.0798		
Stratigraphy	Not applicable - below bank			Not applicable - below bank			Colluvium		
Erosion features	None			None			Planar slip/topple block		
Presence/character vegetation	None			None			Moderate herbaceous cover		
Presence of seeps	None			None			None		
Other characteristics	None			None			Abundant roots		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	290.2			290.2			290.2		
Model flow (cfs)	2000	5000	12000	2000	5000	12000	2000	5000	12000
Sample station (ft)	118	118	118	113	113	113	105	105	105
Near bank station (ft)	138	138	138	133	133	133	126	126	126
Velocity (ft/sec)	1.662	2.670	3.248	Dry	2.495	3.102	Dry	Dry	2.720
Shear stress (lb/ft^2)	0.032	0.078	0.102	Dry	0.068	0.095	Dry	Dry	0.077
Threshold analysis									
Threshold velocity (ft/sec)	4.0	4.0	4.0	2.7	2.7	2.7	1.8	1.8	1.8
Velocity threshold passed	No	No	No	No	No	Yes	No	No	Yes
Critical shear stress (lb/ft^2)	0.12	0.12	0.12	0.05	0.05	0.05	0.020	0.020	0.020
Shear stress threshold passed	No	No	No	No	Yes	Yes	No	No	Yes

Notes:

Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.

Sample station refers to distance along the cross section.

Near bank station refers to a point 20 feet out from sample station.

See further explanation in text.

Site photo

B03 – Jarvis Island Site

The Jarvis Island Site (B03) is located in Weathersfield, VT near the upstream end of Bellows Falls impoundment. A beach fronts the bank where the water surface at the minimum and average operating flows rests when Bellows Falls dam is at an elevation of 290.2 ft. The water surface at maximum capacity falls on colluvium at the bank's base. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is possible on the beach. Entrainment of bank sediment is not possible under operational conditions. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures at low to mid flows and both slightly lower and higher at "maximum" 12,000 cfs flows. To further place the estimates in context, modeled channel velocity at this site ranges from 0.49 ft/sec at 2000 cfs to 3.6 ft/sec at a flow of 30,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 2000 cfs and 0.12 lb/sq^2 at a flow of 30,000 cfs. Both velocity and shear stress estimates exceed thresholds at the high end of this range, which are well above the project operating range and suggest entrainment potential particularly during sustained flood flow periods.

B03 - Jarvis Island (Vermont)

Sample characteristics									
Sample elevation (NAVD88 ft)	290.3 (minimum)			290.6 (medium)			292.0 (maximum)		
Sample ID	B03-1			B03-1			B03-2		
Morphological feature	Beach			Beach			Bank		
Sediment composition	Silty fine sand			Silty fine sand			Sandy silt		
D50 grain size (mm)	0.0761			0.0761			0.0558		
Stratigraphy	Not applicable - below bank			Not applicable - below bank			Colluvium		
Erosion features	None			None			Planar slip/topple block		
Presence/character vegetation	None			None			Moderate herbaceous cover		
Presence of seeps	None			None			None		
Other characteristics	None			None			Abundant roots		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	290.2			290.2			290.2		
Model flow (cfs)	2000	5000	12000	2000	5000	12000	2000	5000	12000
Sample station (ft)	1290	1290	1290	1293	1293	1293	1298	1298	1298
Near bank station (ft)	1270	1270	1270	1273	1273	1273	1278	1278	1278
Velocity (ft/sec)	0.323	0.799	1.729	Dry	0.740	1.637	Dry	Dry	1.486
Shear stress (lb/ft^2)	0.001	0.009	0.036	Dry	0.007	0.033	Dry	Dry	0.028
Threshold analysis									
Threshold velocity (ft/sec)	1.8	1.8	1.8	1.8	1.8	1.8	2.0	2.0	2.0
Velocity threshold passed	No	No	No	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.019	0.019	0.019	0.019	0.019	0.019	0.033	0.033	0.033
Shear stress threshold passed	No	No	Yes	No	No	Yes	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

B07 – Charlestown Site

The Charlestown Site (B07) is located in Charlestown, NH in the Bellows Falls impoundment. A beach fronts the bank where the water surface at the minimum and average operating flows rests at the same elevation when Bellows Falls dam is at an elevation of 290.2 ft. The water surface at maximum capacity falls on colluvium accumulating at the bank's base. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is not possible on either the beach or bank under operational conditions. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures. To further place this in context, modeled channel velocity at this site ranges from 0.15 ft/sec at 2000 cfs to 2.21 ft/sec at a flow of 35,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 2000 cfs and 0.05 lb/sq^2 at a flow of 35,000 cfs. These upper flow velocity and shear stress levels are slightly above thresholds and suggest entrainment potential particularly during sustained flood flow periods.

B07 - Charlestown (New Hampshire)

Sample characteristics						
Sample elevation (NAVD88 ft)	290.2 (minimum and medium)			290.4 (maximum)		
Sample ID	B07-1			B07-2		
Morphological feature	Beach			Bank		
Sediment composition	Sandy silt			Sandy silt		
D50 grain size (mm)	0.0624			0.0619		
Stratigraphy	Not applicable - below bank			Colluvium		
Erosion features	None			Planar slip/topple block		
Presence/character vegetation	None			Thick herb and shrub cover		
Presence of seeps	None			None		
Other characteristics	Large slip block along bank			Large slip block along bank		
Model parameters and outputs						
Dam elevation (NAVD88 ft)	290.2			290.2		
Model flow (cfs)	2000	5000	12000	2000	5000	12000
Sample station (ft)	114	114	114	112	112	112
Near bank station (ft)	135	135	135	133	133	133
Velocity (ft/sec)	0.123	0.307	0.730	Dry	Dry	0.692
Shear stress (lb/ft^2)	0.0002	0.001	0.005	Dry	Dry	0.005
Threshold analysis						
Threshold velocity (ft/sec)	2.0	2.0	2.0	2.0	2.0	2.0
Velocity threshold passed	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.037	0.037	0.037	0.036	0.036	0.036
Shear stress threshold passed	No	No	No	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

B09 – North Walpole Site

The North Walpole Site (B09) is located in Walpole, NH near the downstream end of the Bellows Falls impoundment. A wide beach fronts the bank where the water surface at the minimum flow, average flow, and maximum capacity rests at the same elevation when Bellows Falls dam is at an elevation of 290.2 ft. The water surface at maximum capacity falls on colluvium accumulating at the bank's base when the dam elevation is 291.2 ft. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is not possible on either the beach or bank under operational conditions. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures. To further place this in context, modeled channel velocity at this site ranges from 0.11 ft/sec at 2000 cfs to 1.93 ft/sec at a flow of 35,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 2000 cfs and 0.03 lb/sq^2 at a flow of 35,000 cfs. Estimated modeled channel velocity and shear stress at 70,000 cfs are 3.73 ft/sec. Flows in this range can occur during spring freshet and these high flow velocity and shear stress levels suggest entrainment potential occurs mainly during sustained high flow flood flow periods.

B09 - North Walpole (New Hampshire)

Sample characteristics						
Sample elevation (NAVD88 ft)	290.2 (min, med, max)			291.2 (maximum)		
Sample ID	B09-1			B09-2		
Morphological feature	Beach			Bank		
Sediment composition	Medium sand with gravel			Silt		
D50 grain size (mm)	0.5276			0.0233		
Stratigraphy	Not applicable - below bank			Colluvium		
Erosion features	None			Notching		
Presence/character vegetation	None			Thick herb. and shrub cover		
Presence of seeps	None			None		
Other characteristics	Shrubs along base of bank			Shrubs along base of bank		
Model parameters and outputs						
Dam elevation (NAVD88 ft)	290.2			291.2		
Model flow (cfs)	2000	5000	12000	2000	5000	12000
Sample station (ft)	75	75	75	71	71	71
Near bank station (ft)	95	95	95	91	91	91
Velocity (ft/sec)	0.040	0.099	0.237	0.034	0.084	0.201
Shear stress (lb/ft^2)	0.000	0.0001	0.001	0.000	0.0001	0.0004
Threshold analysis						
Threshold velocity (ft/sec)	2.2	2..2	2.2	3.75	3.75	3.75
Velocity threshold passed	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.054	0.054	0.054	0.021	0.021	0.021
Shear stress threshold passed	No	No	No	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

BR01 – Walpole Beach Site

The Walpole Beach Site (BR01) is located in Walpole, NH just downstream of Bellows Falls dam. A wide beach fronts the bank where the water surface at the minimum flow rests when Vernon dam is at an elevation of 217.6 ft. The water surface at average flow and maximum capacity falls on a unit of silt loam stratigraphically above a layer of clay loam. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is not possible on either the beach or bank under operational conditions. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures. To further place this in context, modeled channel velocity at this site ranges from 0.27 ft/sec at 2000 cfs to 2.01 ft/sec at a flow of 35,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 2000 cfs and 0.04 lb/sq^2 at a flow of 35,000 cfs. Sustained periods of flow at or above 35,000 cfs occur annually, at a minimum, during each spring freshet and these high flow velocity and shear stress levels suggest entrainment potential occurs mainly during such high flood flow periods.

BR01 - Walpole Beach (New Hampshire)

Sample characteristics									
Sample elevation (NAVD88 ft)	224.4 (minimum)			226.3 (medium)			229.6 (maximum)		
Sample ID	BR01-1			BR01-2			BR01-3		
Morphological feature	Beach			Bank			Bank		
Sediment composition	Sandy silt			Sandy silt			Sandy silt		
D50 grain size (mm)	0.0720			0.0557			0.0519		
Stratigraphy	Not applicable - below bank			Silt loam*			Silt loam		
Erosion features	None			Overhang			None		
Presence/character vegetation	None			None			Thick shrub cover		
Presence of seeps	None			None			None		
Other characteristics	None			Abundant roots			None		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	217.6			217.6			217.6		
Model flow (cfs)	2000	5000	12000	2000	5000	12000	2000	5000	12000
Sample station (ft)	137	137	137	132	132	132	123	123	123
Near bank station (ft)	158	158	158	153	153	153	143	143	143
Velocity (ft/sec)	0.106	0.286	0.672	Dry	0.267	0.646	Dry	Dry	0.568
Shear stress (lb/ft^2)	0.0002	0.001	0.006	Dry	0.001	0.005	Dry	Dry	0.004
Threshold analysis									
Threshold velocity (ft/sec)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Velocity threshold passed	No	No	No	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.042	0.042	0.042	0.033	0.033	0.033	0.03	0.03	0.03
Shear stress threshold passed	No	No	No	No	No	No	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
*Sample taken 0.4 ft above contact with clay loam.
See further explanation in text.

Site photo

BR05 – Malnati Site

The Malnati Site (BR05) is located in Walpole, NH in the riverine section downstream of Bellows Falls dam. A beach fronts the bank where the water surface at the minimum flow rests when Vernon dam is at an elevation of 217.6 ft. The water surface at average flow and maximum capacity falls on colluvium at the bank's base and near the level of weak seeps emanating from the bank. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is possible on both the beach and bank but only at maximum capacity. Modeled near-bank velocity and shear stress estimates are in the general proximity of the threshold velocity and shear stress threshold figures. To further place these estimates in context, modeled channel velocity at this site ranges from 0.84 ft/sec at 2000 cfs to 4.19 ft/sec at a flow of 35,000 cfs (frequently experienced); and channel shear stresses range between 0.01 lb/sq^2 at 2000 cfs and 0.19 lb/sq^2 at a flow of 35,000 cfs. Sustained periods of flow at or above 35,000 cfs occur annually, at a minimum, during each spring freshet and these high flow velocity and shear stress levels suggest entrainment potential occurs mainly during such high flood flow periods.

BR05 - Malnati (New Hampshire)

Sample characteristics									
Sample elevation (NAVD88 ft)	218.8 (minimum)			220.8 (medium)			224.0 (maximum)		
Sample ID	BR05-1			BR05-2			BR05-3		
Morphological feature	Beach			Bank			Bank		
Sediment composition	Silty fine sand			Silty fine sand			Silty fine sand		
D50 grain size (mm)	0.1278			0.0801			0.0786		
Stratigraphy	Not applicable - below bank			Colluvium			Colluvium		
Erosion features	None			Planar slip/topple block			Planar slip/topple block		
Presence/character vegetation	None			None			Thick herbaceous cover		
Presence of seeps	Yes, from lower bank			Yes, from lower bank			Yes, from lower bank		
Other characteristics	Large wood, abundant roots			Large wood, abundant roots			Large wood, abundant roots		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	217.6			217.6			217.6		
Model flow (cfs)	2000	5000	12000	2000	5000	12000	2000	5000	12000
Sample station (ft)	163	163	163	156	156	156	145	145	145
Near bank station (ft)	184	184	184	176	176	176	166	166	166
Velocity (ft/sec)	0.711	1.331	2.273	Dry	1.111	2.014	Dry	Dry	1.583
Shear stress (lb/ft^2)	0.008	0.025	0.065	Dry	0.018	0.052	Dry	Dry	0.036
Threshold analysis									
Threshold velocity (ft/sec)	1.9	1.9	1.9	1.8	1.8	1.8	1.8	1.8	1.8
Velocity threshold passed	No	No	Yes	No	No	Yes	No	No	No
Critical shear stress (lb/ft^2)	0.033	0.033	0.033	0.020	0.020	0.020	0.020	0.020	0.020
Shear stress threshold passed	No	No	Yes	No	No	Yes	No	No	Yes

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

V02 – River View Farm Site (Upstream)

The River View Farm Site (Upstream) (V02) is located in Putney, VT near the upstream end of Vernon impoundment. A wide beach fronts the bank where the water surface at the minimum flow and average operating flows rests when Vernon dam is at an elevation of 217.6 ft. The water surface at maximum capacity falls on colluvium accumulating at the bank's base. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is not possible on either the beach or bank under operational conditions. Modeled near-bank velocity and shear stress estimates are significantly lower than the velocity and shear stress threshold figures for minimum to medium project flows; in the general proximity of the threshold velocity and shear stress threshold figures for maximum flows. To further place this in context, modeled channel velocity at this site ranges from 0.32 ft/sec at 2000 cfs to 3.12 ft/sec at a flow of 35,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 2000 cfs and 0.11 lb/sq^2 at a flow of 35,000 cfs. Sustained periods of flow at or above 35,000 cfs occur annually, at a minimum, during each spring freshet and these high flow velocity and shear stress levels suggest entrainment potential occurs mainly during such high flood flow periods.

V02 - River View Farm US (Vermont)

Sample characteristics									
Sample elevation (NAVD88 ft)	217.6 (minimum)			218.0 (medium)			219.7 (maximum)		
Sample ID	V02-1			V02-1			V02-2		
Morphological feature	Beach			Beach			Bank		
Sediment composition	Silty fine sand			Silty fine sand			Silty fine sand		
D50 grain size (mm)	0.0903			0.0903			0.0956		
Stratigraphy	Not applicable - below bank			Not applicable - below bank			Colluvium		
Erosion features	None			None			Planar slip/topple block		
Presence/character vegetation	Thick aquatic vegetation			Thick aquatic vegetation			Thick herbaceous cover		
Presence of seeps	None			None			None		
Other characteristics	None			None			None		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	217.6			217.6			217.6		
Model flow (cfs)	2000	6000	15000	2000	6000	15000	2000	6000	15000
Sample station (ft)	755	755	755	757	757	757	760	760	760
Near bank station (ft)	735	735	735	737	737	737	739	739	739
Velocity (ft/sec)	0.183	0.543	1.260	Dry	0.514	1.207	Dry	Dry	1.151
Shear stress (lb/ft^2)	0.001	0.004	0.022	Dry	0.004	0.020	Dry	Dry	0.019
Threshold analysis									
Threshold velocity (ft/sec)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Velocity threshold passed	No	No	No	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.023	0.023	0.023	0.023	0.023	0.023	0.024	0.024	0.024
Shear stress threshold passed	No	No	No	No	No	No	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

V03 – River View Farm Site (Downstream)

The River View Farm Site (Downstream) (V03) is located in Putney, VT near the upstream end of Vernon impoundment. A wide beach fronts the bank where the water surface at the minimum flow and average operating flows rests when Vernon dam is at an elevation of 217.6 ft. The water surface at maximum capacity falls on colluvium accumulating at the bank's base. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is not possible on either the beach or bank under operational conditions. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures. To further place this in context, modeled channel velocity at this site ranges from 0.23 ft/sec at 2000 cfs to 2.86 ft/sec at a flow of 35,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 2000 cfs and 0.08 lb/sq^2 at a flow of 35,000 cfs. Sustained periods of flow at or above 35,000 cfs occur annually, at a minimum, during each spring freshet and these high flow velocity and shear stress levels suggest entrainment potential occurs mainly during such high flood flow periods.

V03 - River View Farm DS (Vermont)

Sample characteristics									
Sample elevation (NAVD88 ft)	217.6 (minimum)			218.0 (medium)			219.4 (maximum)		
Sample ID	V03-1			V03-1			V03-2		
Morphological feature	Beach			Beach			Bank		
Sediment composition	Silty fine sand			Silty fine sand			Sandy silt		
D50 grain size (mm)	0.1011			0.1011			0.0705		
Stratigraphy	Not applicable - below bank			Not applicable - below bank			Colluvium		
Erosion features	None			None			Planar slip/topple block		
Presence/character vegetation	Thick aquatic vegetation			Thick aquatic vegetation			Thick herbaceous vegetation		
Presence of seeps	None			None			None		
Other characteristics	None			None			None		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	217.6			217.6			217.6		
Model flow (cfs)	2000	6000	15000	2000	6000	15000	2000	6000	15000
Sample station (ft)	597	597	597	597	597	597	602	602	602
Near bank station (ft)	577	577	577	577	577	577	581	581	581
Velocity (ft/sec)	0.142	0.415	1.024	0.142	0.415	1.024	Dry	Dry	0.936
Shear stress (lb/ft^2)	0.0003	0.002	0.014	0.000	0.002	0.014	Dry	Dry	0.012
Threshold analysis									
Threshold velocity (ft/sec)	1.8	1.8	1.8	1.8	1.8	1.8	2.0	2.0	2.0
Velocity threshold passed	No	No	No	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.026	0.026	0.026	0.026	0.026	0.026	0.041	0.041	0.041
Shear stress threshold passed	No	No	No	No	No	No	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

V06 – LaCroix Site

The LaCroix Site (V06) is located in Chesterfield, NH in the Bellows Falls impoundment. A wide beach fronts the bank where the water surface at the minimum flow and average operating flows rests when Vernon dam is at an elevation of 217.6 ft. The water surface at maximum capacity falls on stratified sand and gravel at the bank's base when the dam elevation is 219.6 ft. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is not possible on either the beach or bank under operational conditions. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures. To further place this in context, modeled channel velocity at this site ranges from 0.2 ft./sec at 2000 cfs to 3.23 ft/sec at a flow of 35,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 2000 cfs and 0.08 lb/sq^2 at a flow of 35,000 cfs. Sustained periods of flow at or above 35,000 cfs occur annually, at a minimum, during each spring freshet and these high flow velocity and shear stress levels suggest entrainment potential occurs mainly during such high flood flow periods.

V06 - LaCroix (New Hampshire)

Sample characteristics									
Sample elevation (NAVD88 ft)	217.6 (minimum)			217.7 (medium)			219.6 (maximum)		
Sample ID	V06-1			V06-1			V06-2		
Morphological feature	Beach			Beach			Bank		
Sediment composition	Coarse sand with gravel			Coarse sand with gravel			Medium sand		
D50 grain size (mm)	3.0297			3.0297			0.6387		
Stratigraphy	Not applicable - below bank			Not applicable - below bank			Stratified sand and gravel		
Erosion features	None			None			Notching		
Presence/character vegetation	None			None			Moderate herb and shrub cover		
Presence of seeps	None			None			None		
Other characteristics	None			None			None		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	217.6			217.6			219.6		
Model flow (cfs)	2000	6000	15000	2000	6000	15000	2000	6000	15000
Sample station (ft)	33	33	33	33	33	33	30	30	30
Near bank station (ft)	53	53	53	53	53	53	50	50	50
Velocity (ft/sec)	0.093	0.279	0.696	0.093	0.2792	0.696	0.084	0.251	0.629
Shear stress (lb/ft^2)	0.0001	0.001	0.005	0.0001	0.001	0.005	0.0001	0.001	0.004
Threshold analysis									
Threshold velocity (ft/sec)	3.0	3.0	3.0	3.0	3.0	3.0	2.2	2.2	2.2
Velocity threshold passed	No	No	No	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.08	0.08	0.08	0.08	0.08	0.08	0.066	0.066	0.066
Shear stress threshold passed	No	No	No	No	No	No	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

VR01 –Vernon Bank Site

The Vernon Bank Site (VR01) is located in Hinsdale, NH just downstream of Vernon dam. A wide beach fronts the bank where the water surface rests at all operational flows. Only flood flows reach the base of the bank above the beach. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment of the coarse beach sediments is not possible under operational conditions. Entrainment of bank sediment is also not possible under operational conditions as only flood flows reach the base of the bank. Modeled near-bank velocity and shear stress estimates are significantly lower than the threshold velocity and shear stress threshold figures. To further place this in context, modeled channel velocity at this site ranges from 0.1 ft./sec at 2000 cfs to 0.95 ft/sec at a flow of 35,000 cfs (frequently experienced); and channel shear stresses range between <0.01 lb/sq^2 at 2000 cfs and 0.01 lb/sq^2 at a flow of 35,000 cfs. Sustained periods of flow at or above 35,000 cfs occur annually, at minimum during each spring freshet and these high flow velocity and shear stress levels suggest entrainment potential occurs mainly during such high flood flow periods.

VR01 - Vernon Bank (New Hampshire)

Sample characteristics									
Sample elevation (NAVD88 ft)	181.1 (minimum)			182.7 (medium)			185.8 (maximum)		
Sample ID	VR01-1			VR01-2			VR01-2		
Morphological feature	Beach			Beach			Beach		
Sediment composition	Silty coarse gravel			Medium sand with gravel			Medium sand with gravel		
D50 grain size (mm)	5.0579			1.1681			1.1681		
Stratigraphy	Shallowly buried glacial varves			Not applicable - below bank			Not applicable - below bank		
Erosion features	None			None			None		
Presence/character vegetation	None			None			None		
Presence of seeps	Evidence of upslope seepage			Evidence of upslope seepage			Evidence of upslope seepage		
Other characteristics	Large wood parallel to beach			Large wood parallel to beach			Large wood parallel to beach		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	180.6			180.6			180.6		
Model flow (cfs)	2000	6000	15000	2000	6000	15000	2000	6000	15000
Sample station (ft)	116	116	116	95	95	95	82	82	82
Near bank station (ft)	137	137	137	115	115	115	102	102	102
Velocity (ft/sec)	0.004	0.020	0.065	Dry	0.010	0.047	Dry	Dry	0.038
Shear stress (lb/ft^2)	0.000	0.000	0.0001	Dry	0.000	0.000	Dry	Dry	0.000
Threshold analysis									
Threshold velocity (ft/sec)	5.4	5.4	5.4	2.5	2.5	2.5	2.5	2.5	2.5
Velocity threshold passed	No	No	No	No	No	No	No	No	No
Critical shear stress (lb/ft^2)	0.3	0.3	0.3	0.05	0.05	0.05	0.05	0.05	0.05
Shear stress threshold passed	No	No	No	No	No	No	No	No	No

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
See further explanation in text.

Site photo

VR02 – Stebbins Island Site

The Stebbins Island Site (VR02) is located in Hinsdale, NH in the Turners Falls impoundment downstream of Vernon Dam. A wide beach fronts the bank where the water surface at the minimum flow and average operating flows rests when Turners Falls dam is at an elevation of 180.6 ft. The water surface at maximum capacity falls on sandy silt near the bank's base. A comparison between modeled and critical shear stresses and velocities suggests sediment entrainment is possible on the lower beach at all flows but only at average flows and maximum capacity on the upper beach. Bank sediment is potentially entrained at maximum capacity. Modeled near-bank velocity estimates are generally at or slightly above the threshold velocity levels, while shear stress estimates are slight to moderately higher than the shear stress threshold figures. To place this in context, modeled channel velocity at this site ranges from 0.71 ft./sec at 2000 cfs to 2.61 ft/sec at a flow of 35,000 cfs (frequently experienced); and channel shear stresses range between 0.01 lb/sq^2 at 2000 cfs and 0.09 lb/sq^2 at a flow of 35,000 cfs.

There are other significant factors that affect velocity, shear stress estimates at this monitoring location. The range between operational minimum and maximum flow from Vernon can affect a 4.1-foot elevation range at this site based upon a specific WSE of 180.6 ft (NAVD88) at Turner Falls Dam as noted below. However, operation Turners Falls/Northfield Mountain project operations also affects WSE at the site and thereby affecting channel velocity and shear stress. At a TF WSE of 182.6 channel velocities and shear stress are slightly reduced and at WSE 178.6 channel velocities and shear stress are slightly increased. Additionally, based on previous observations, survey data and hydraulic modeling, as indicated in the February 2017 final report, at flows above 50,000 cfs, which occur at least on an annual basis during spring freshet, the entire monitoring site is submerged and retains an elevated pool of water above the top of bank.

VR02 - Stebbins Island (New Hampshire)

Sample characteristics									
Sample elevation (NAVD88 ft)	180.9 (minimum)			182.0 (medium)			184.8 (maximum)		
Sample ID	VR02-1			VR02-1			VR02-2		
Morphological feature	Beach			Beach			Bank		
Sediment composition	Sandy silt			Sandy silt			Sandy silt		
D50 grain size (mm)	0.0473			0.0473			0.0439		
Stratigraphy	Not applicable - below bank			Not applicable - below bank			Sandy silt*		
Erosion features	None			None			Notching		
Presence/character vegetation	None			None			Moss/sparse herbaceous cover		
Presence of seeps	None			None			None		
Other characteristics	None			None			Abundant roots		
Model parameters and outputs									
Dam elevation (NAVD88 ft)	180.6			180.6			180.6		
Model flow (cfs)	2000	6000	15000	2000	6000	15000	2000	6000	15000
Sample station (ft)	50	50	50	47	47	47	43	43	43
Near bank station (ft)	71	71	71	67	67	67	64	64	64
Velocity (ft/sec)	1.256	2.166	2.333	Dry	2.043	2.249	Dry	Dry	2.149
Shear stress (lb/ft^2)	0.029	0.080	0.082	Dry	0.072	0.077	Dry	Dry	0.072
Threshold analysis									
Threshold velocity (ft/sec)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Velocity threshold passed	No	Yes	Yes	No	Yes	Yes	No	No	Yes
Critical shear stress (lb/ft^2)	0.028	0.028	0.028	0.028	0.028	0.028	0.026	0.026	0.026
Shear stress threshold passed	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes

Notes:
Minimum refers to minimum flow, medium refers to medium dam operation, maximum refers to maximum project hydraulic capacity.
Sample station refers to distance along the cross section.
Near bank station refers to a point 20 feet out from sample station.
*Sample taken 1.1 ft below contact with sand loam.
See further explanation in text.

Site photo

APPENDIX B

Grain Size Analysis Results

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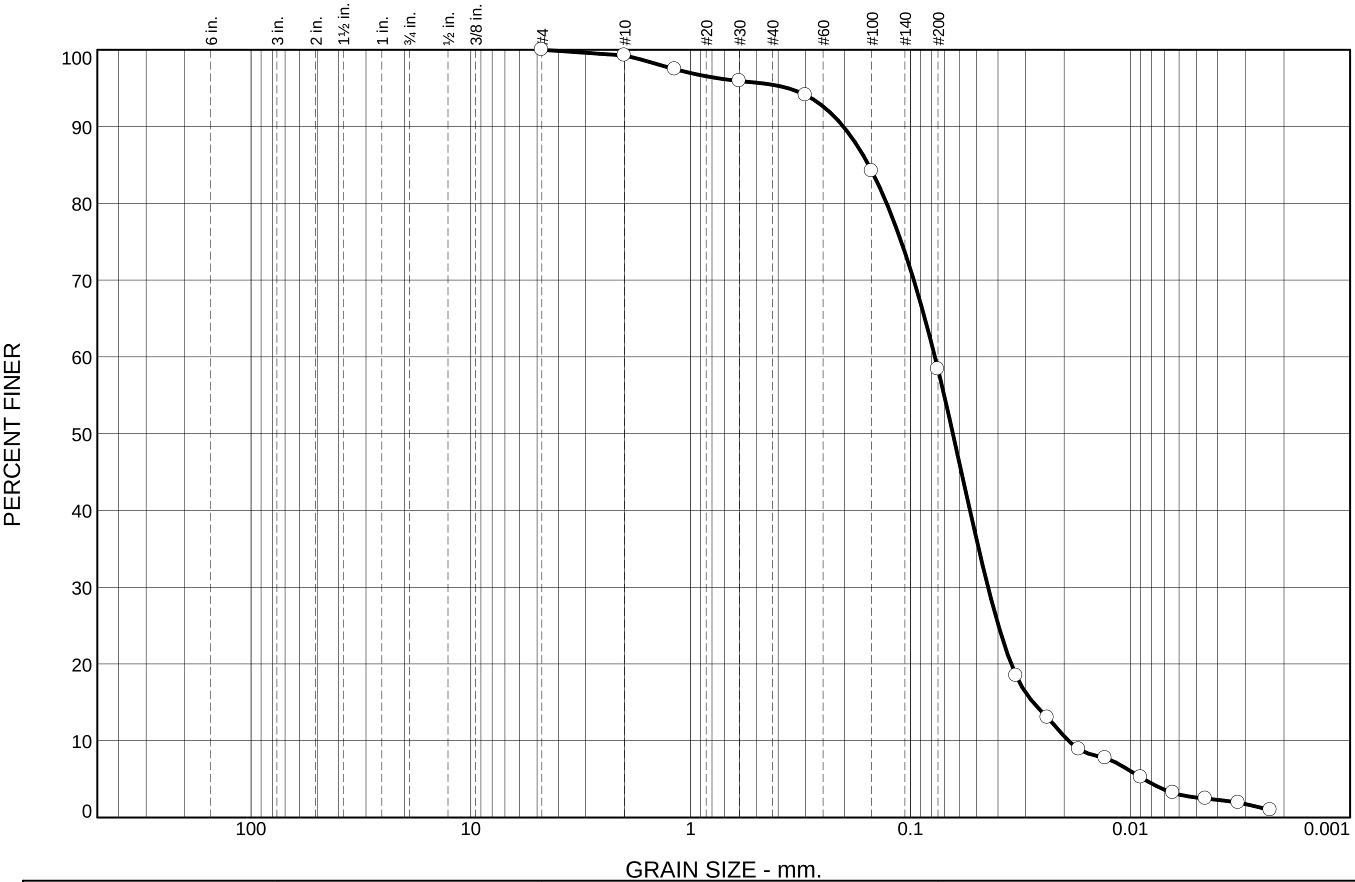
Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.7	3.8	37.1	55.8	2.6

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1551	0.0774	0.0641	0.0444	0.0277	0.0191	1.33	4.06

Material Description	USCS	AASHTO
○ Silty SAND	ML	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** W02 **Depth:** El. 388.5 ft **Sample Number:** Bank

Remarks:

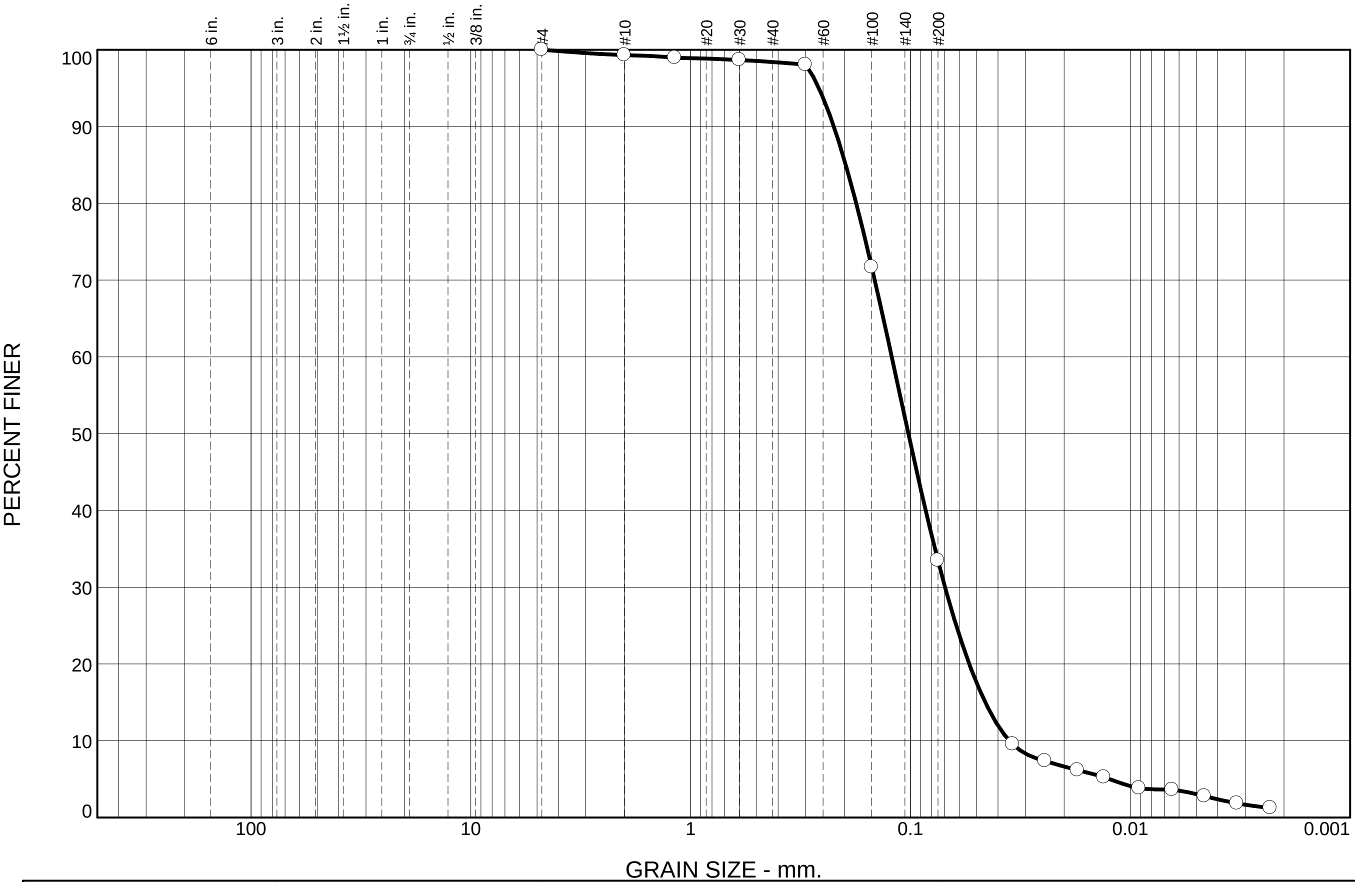
○Bedell Bridge

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: JG **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.7	0.9	64.9	30.5	3.0

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1970	0.1217	0.1022	0.0696	0.0457	0.0355	1.12	3.43

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** W02 **Depth:** El. 384.2 ft **Sample Number:** Beach

Remarks:

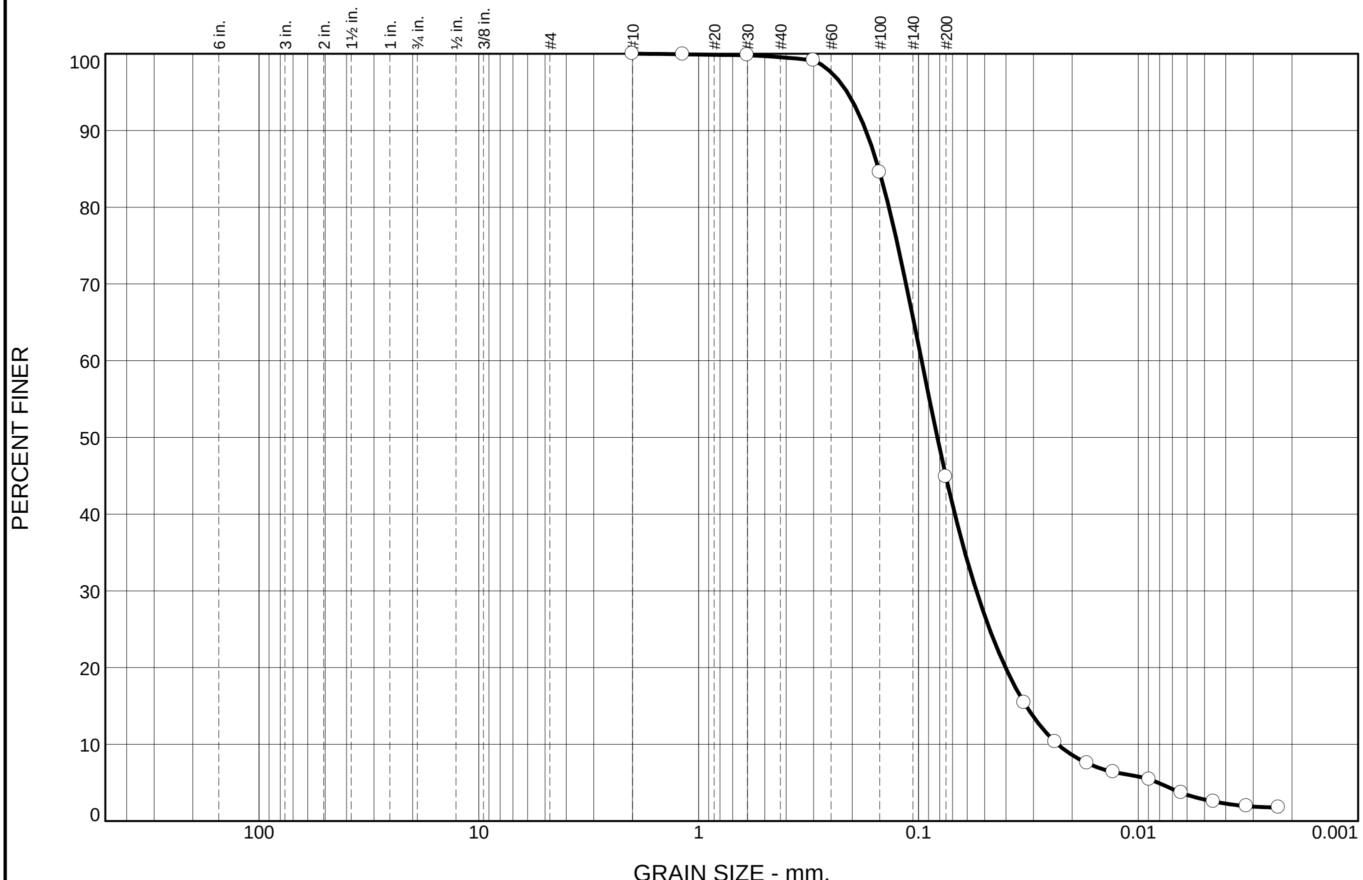
○Bedell Bridge

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.0	0.4	54.7	42.1	2.8

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1517	0.0967	0.0821	0.0545	0.0324	0.0232	1.32	4.16

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** W3 **Depth:** El. 387.1 ft

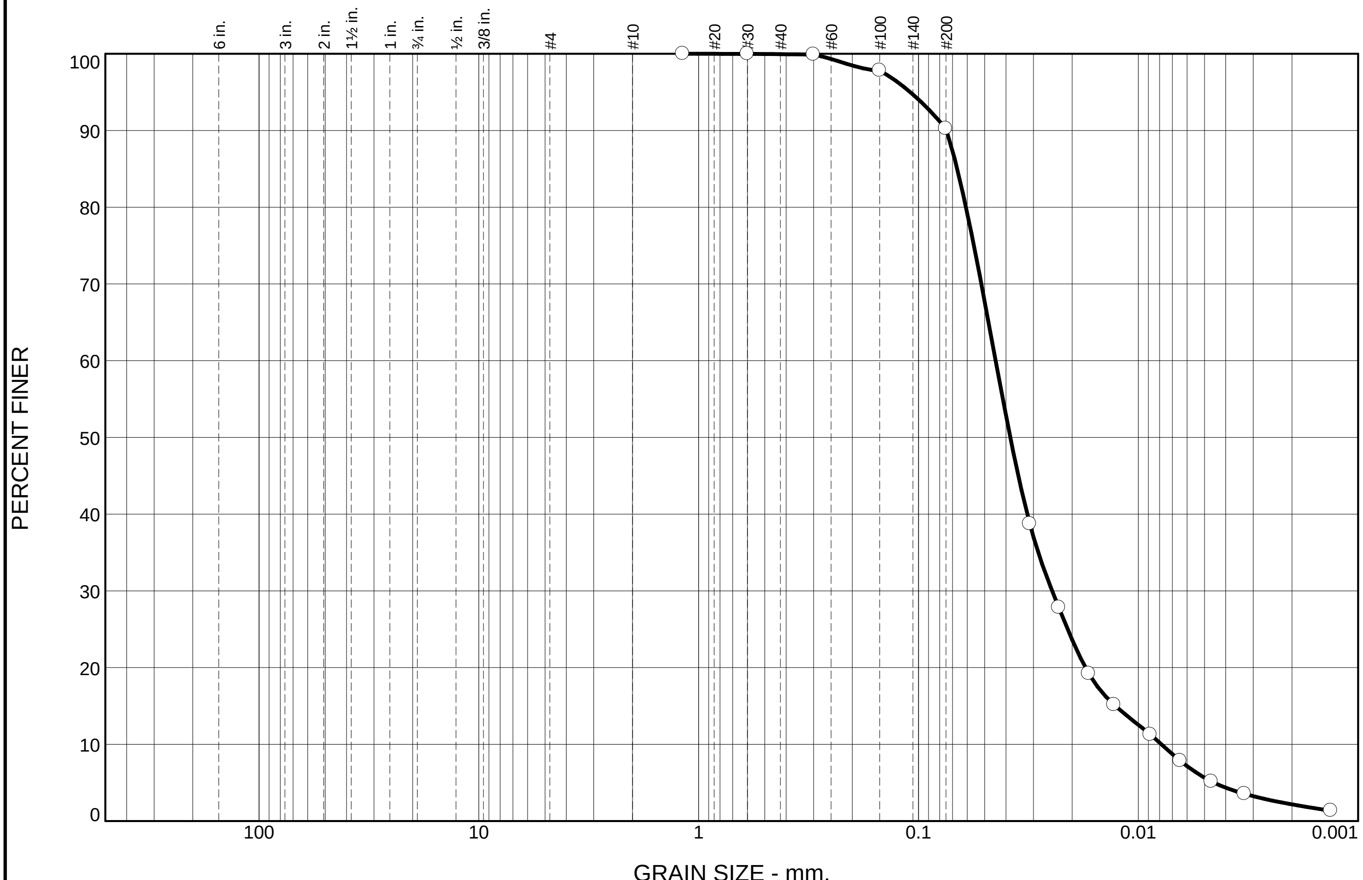
Remarks:
○Bellavance

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: JG/EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.0	0.1	9.7	84.5	5.7

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.0666	0.0446	0.0382	0.0247	0.0127	0.0078	1.74	5.68

Material Description	USCS	AASHTO
○ SILT	ML	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** W3 **Depth:** El. 383.5 ft

Remarks:

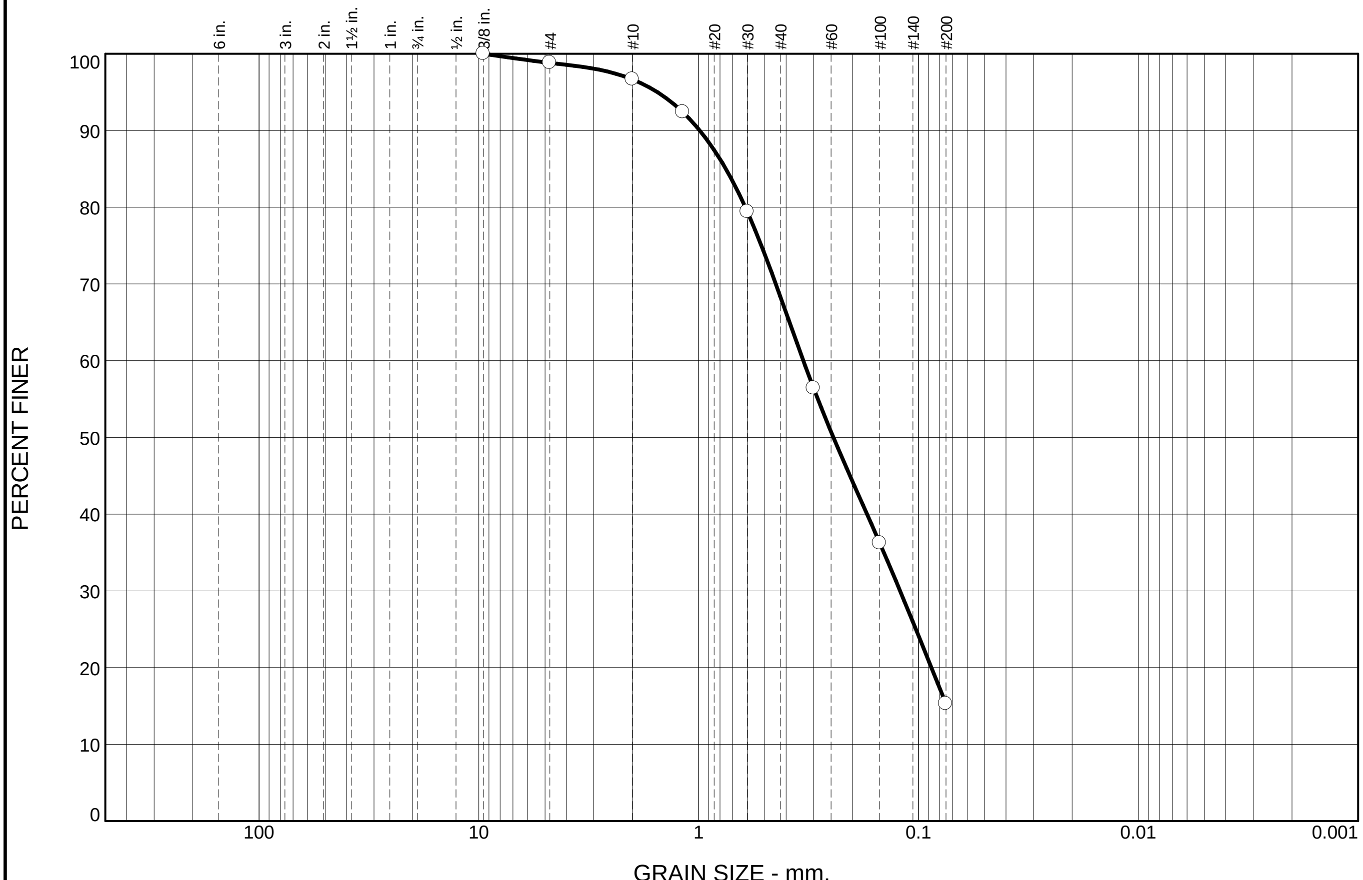
○Bellavance

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	1.2	2.1	28.3	53.1	15.3	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.7522	0.3340	0.2438	0.1213				

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro
Project: Erosion Study

○ **Source of Sample:** W7 **Depth:** El. 382.12 ft **Sample Number:** 1

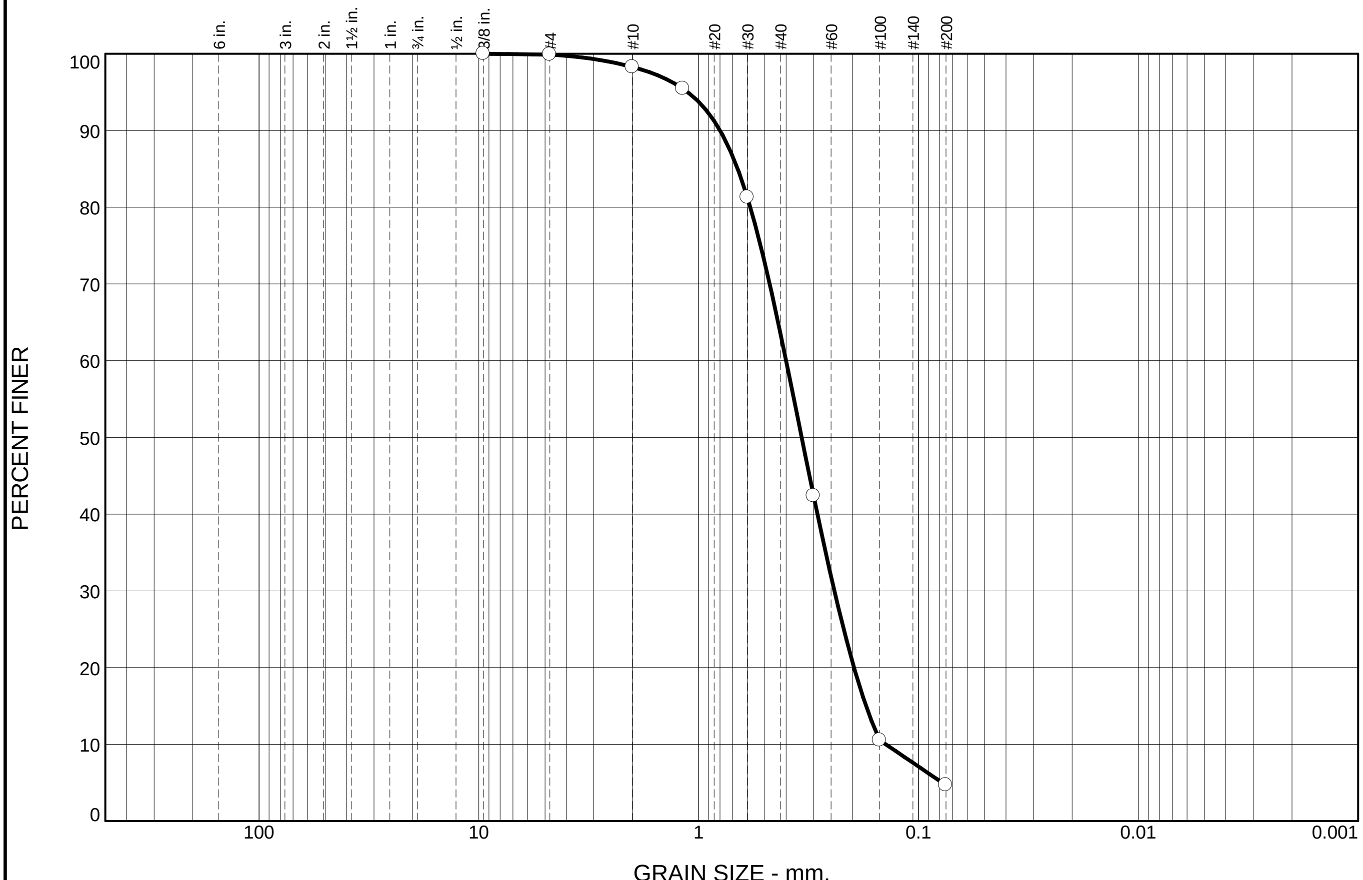
Remarks:
○Tullando Farm

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.1	1.6	34.7	58.9	4.7	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	NV	NP	0.6643	0.4001	0.3399	0.2413	0.1732	0.1408	1.03	2.84

Material Description	USCS	AASHTO
○ Narrowly Graded SAND	SP	A-3

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** W7 **Depth:** El. 384.55 ft **Sample Number:** 2

Remarks:
○Tullando Farm

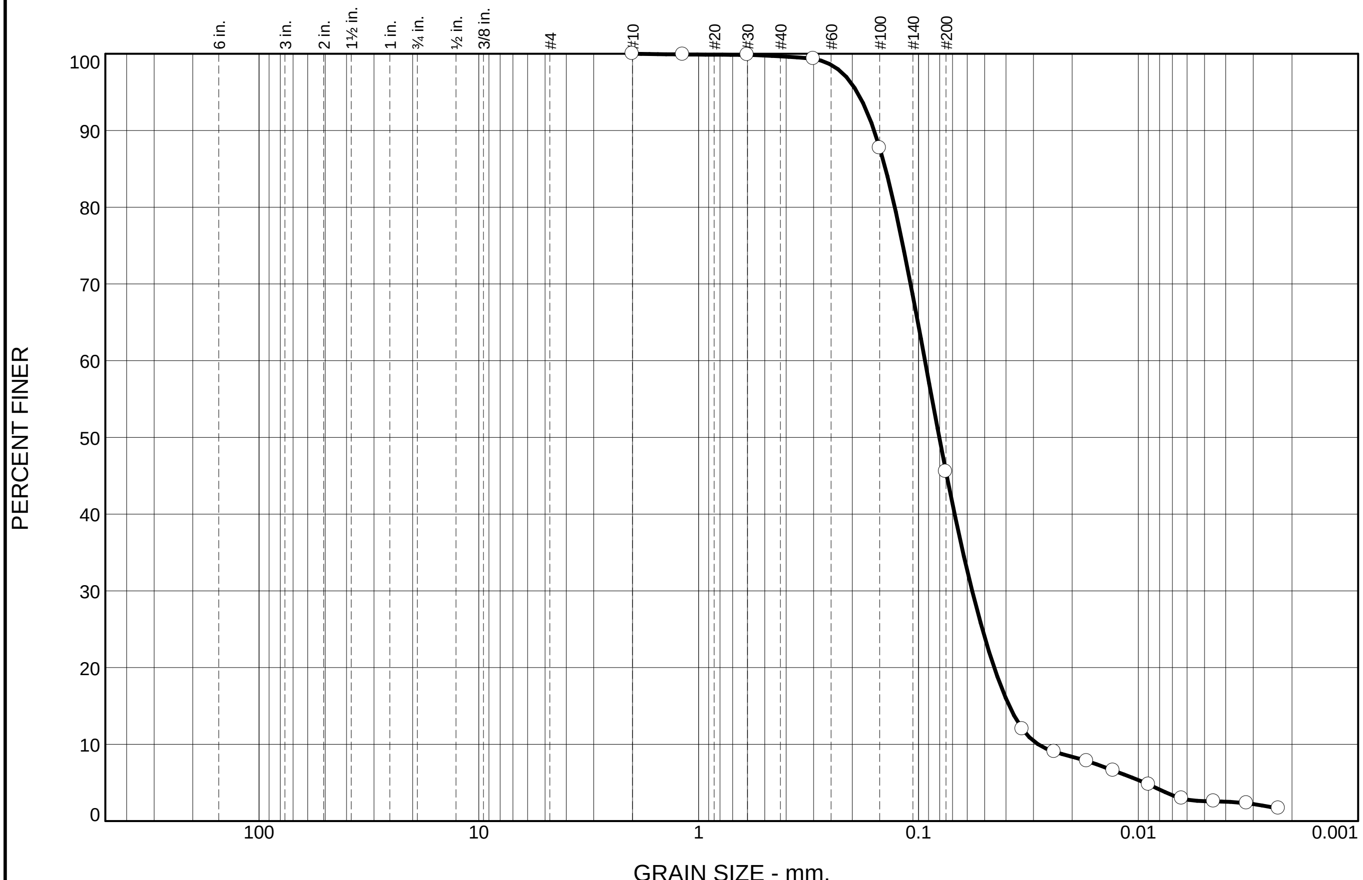
GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

GEI Consultants

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.0	0.3	54.2	42.9	2.6

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1412	0.0934	0.0804	0.0570	0.0386	0.0286	1.22	3.27

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** W09 **Depth:** El. 384.5 ft

Remarks:

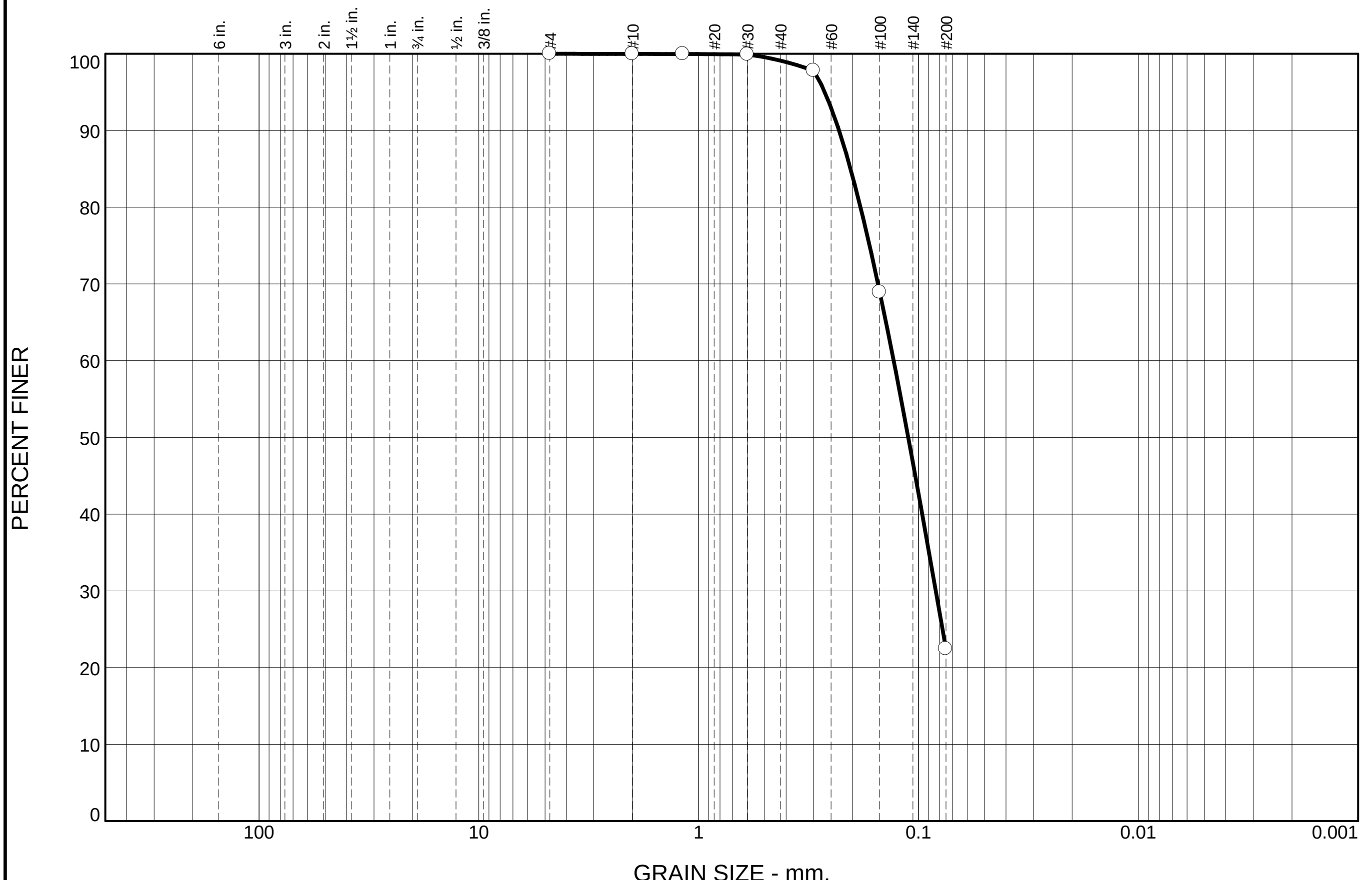
○Mudge

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF/JG **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.0	0.9	76.7	22.4	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.2038	0.1297	0.1113	0.0834				

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** W09 **Depth:** El. 382.38 ft **Sample Number:** S1

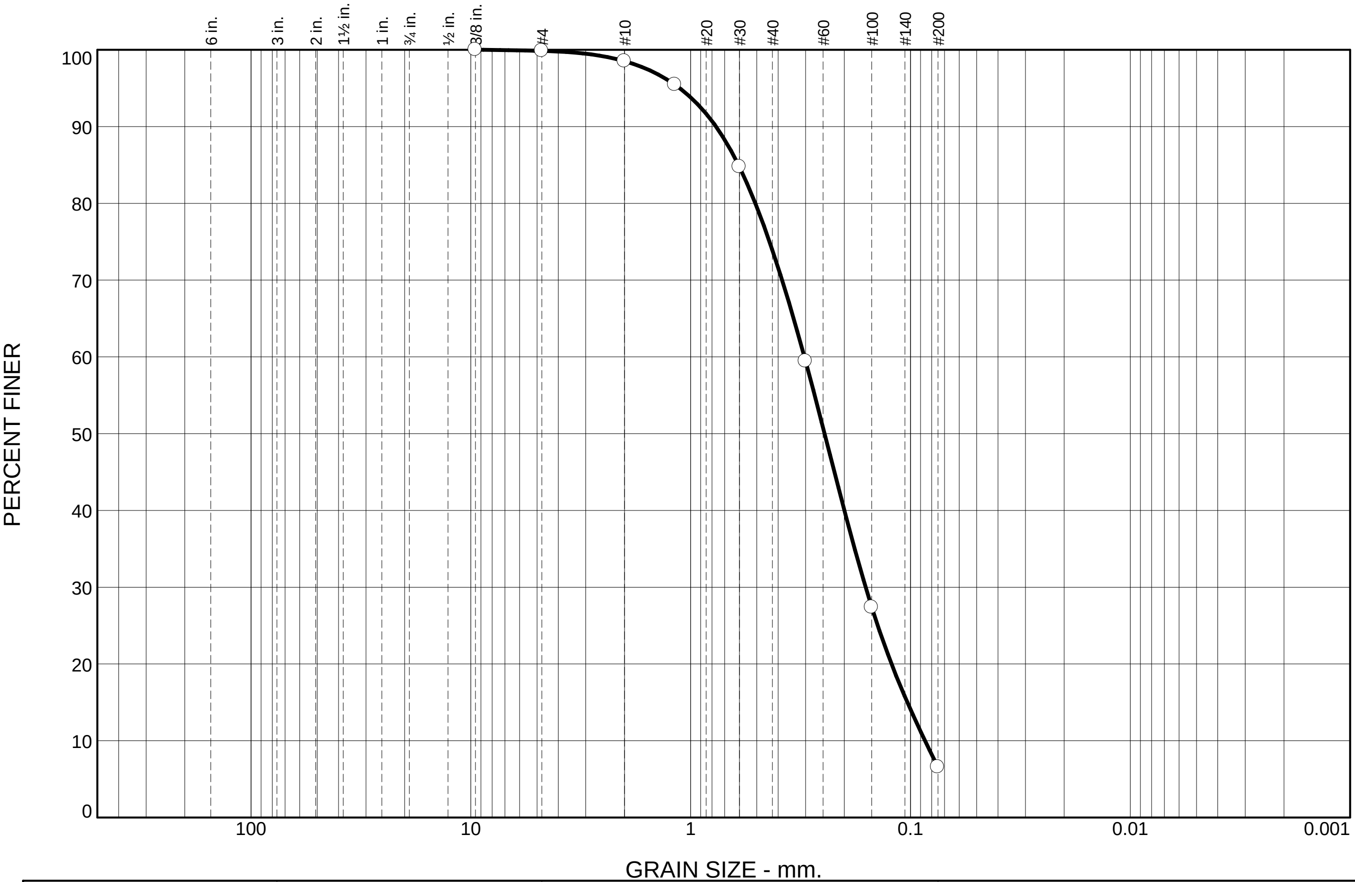
Remarks:
○Mudge

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.1	1.4	24.6	67.3	6.6	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.6058	0.3037	0.2459	0.1600	0.1033	0.0858	0.98	3.54

Material Description	USCS	AASHTO
○ Narrowly Graded SAND with Silt	SP-SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** W10 **Depth:** El. 382.05 ft **Sample Number:** S1

Remarks:

○Vaughn

GEI Consultants, Inc.
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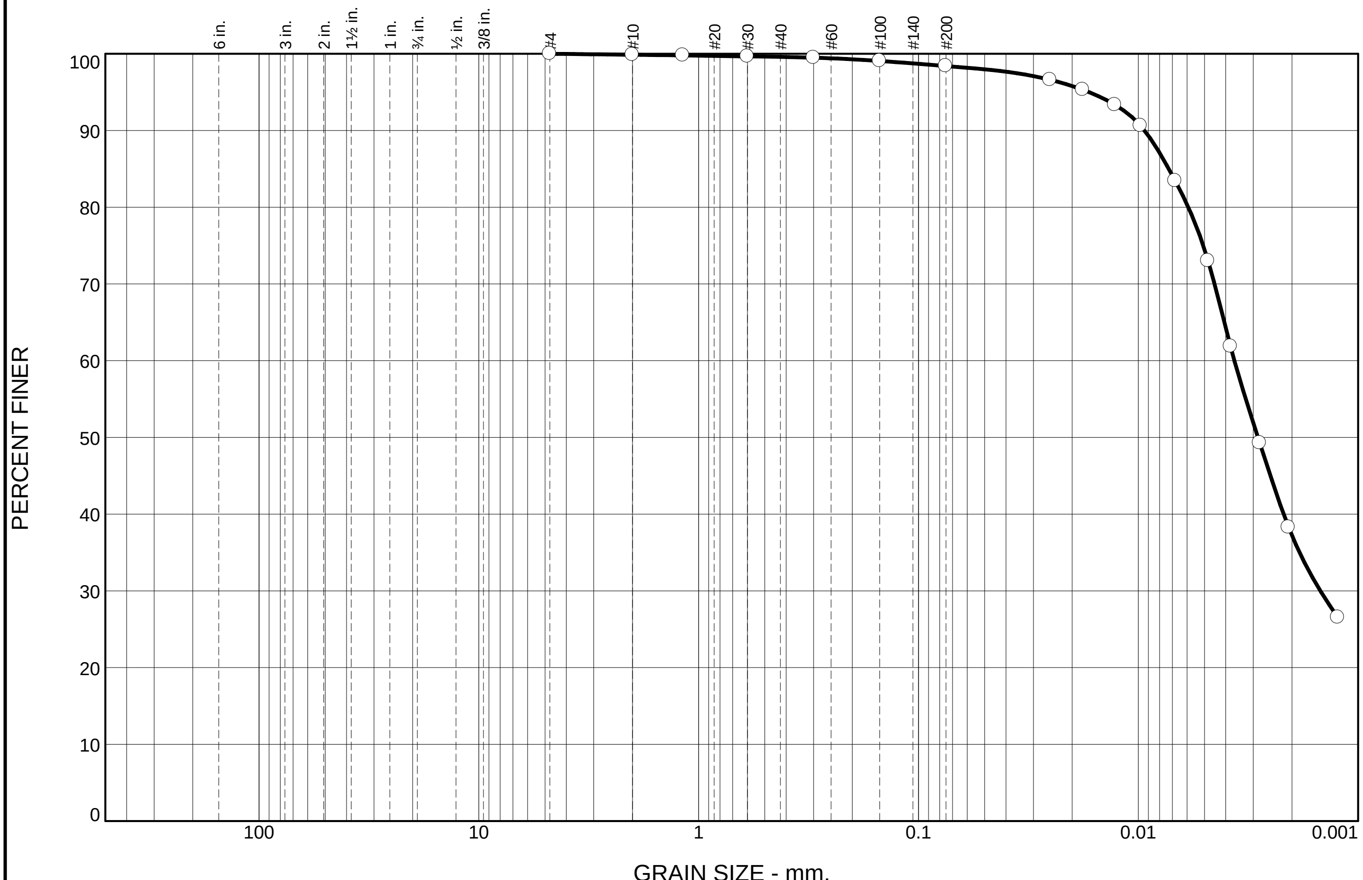
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.1	0.3	1.2	23.9	74.5

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.0073	0.0037	0.0029	0.0015				

Material Description	USCS	AASHTO
○ LEAN CLAY	CL	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** W10 **Depth:** El. 384.01 ft **Sample Number:** Varves

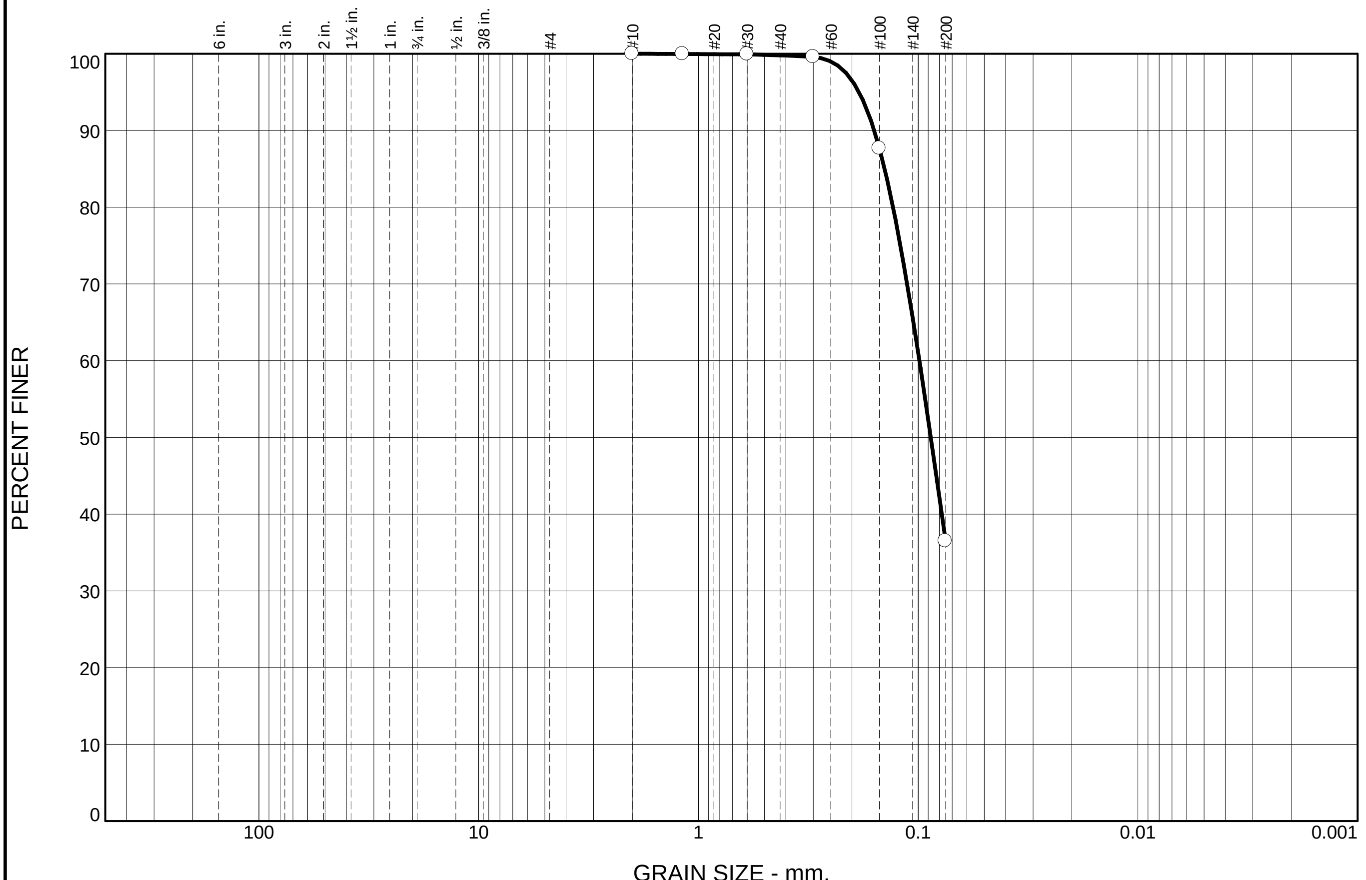
Remarks:
○Vaughn

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF/JG **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.0	0.2	63.3	36.5	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1420	0.0987	0.0876					

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** W12 **Depth:** El. 382.1 ft **Sample Number:** 1

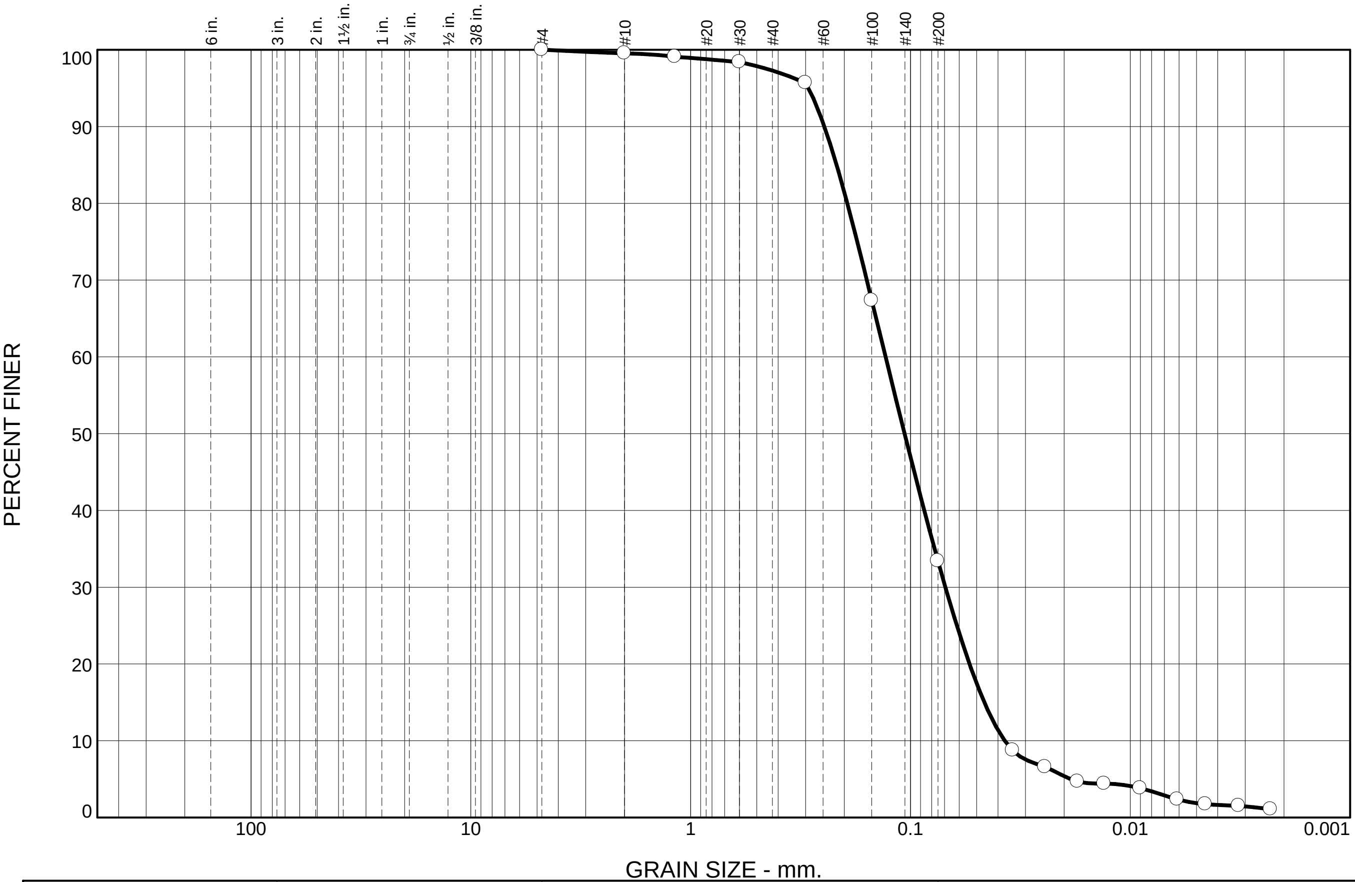
Remarks:
○Pine Park

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.5	2.2	63.9	31.5	1.9

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.2168	0.1298	0.1064	0.0694	0.0461	0.0373	1.00	3.48

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** W12 **Depth:** El. 384.64 ft **Sample Number:** 2

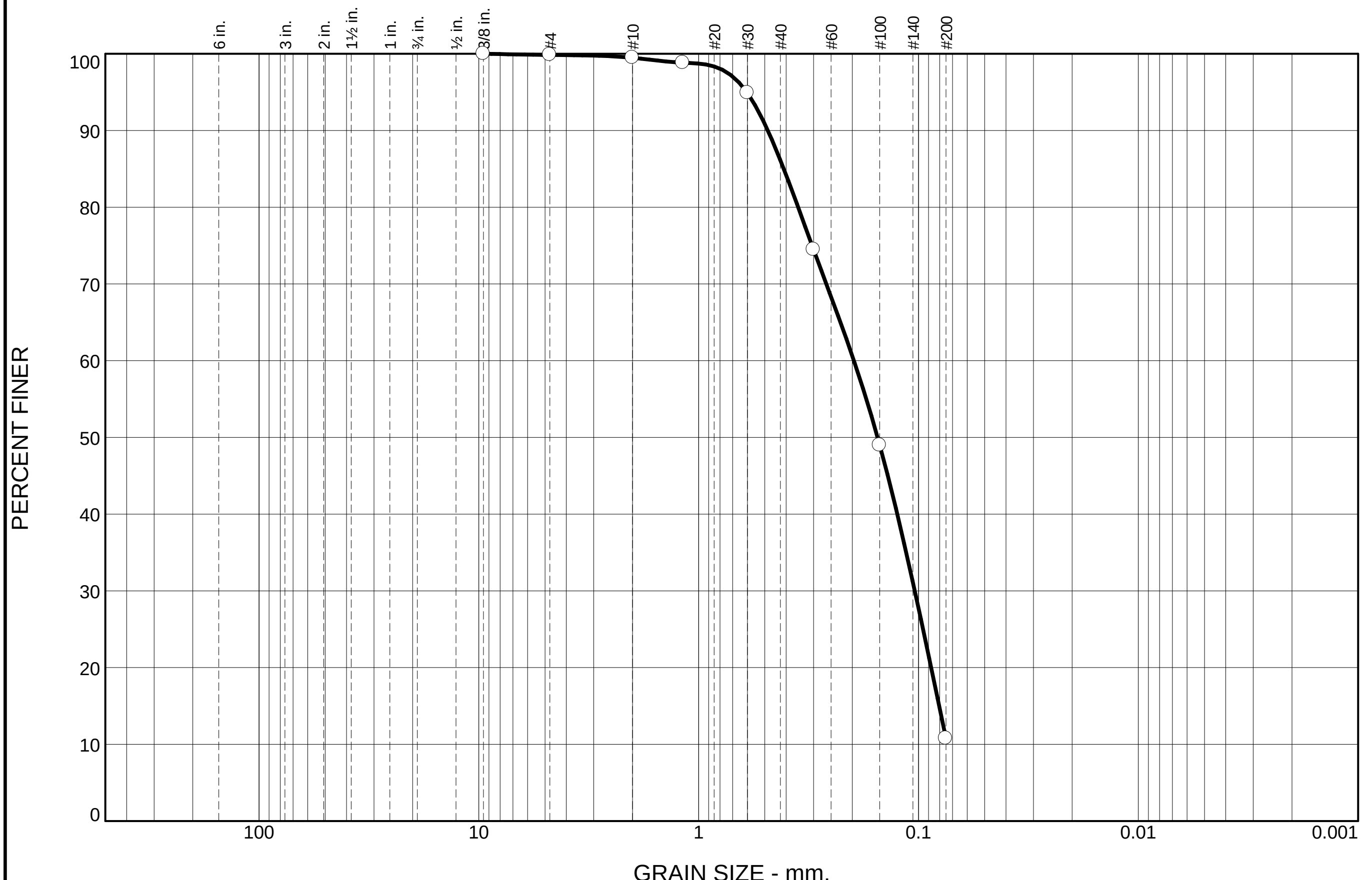
Remarks:
○Pine Park

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.1	0.4	13.4	75.3	10.8	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.4101	0.1967	0.1535	0.1040	0.0805			

Material Description	USCS	AASHTO
○ Narrowly Graded SAND with Silt	SP-SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** WR1 **Depth:** El. 328.77 ft **Sample Number:** S2

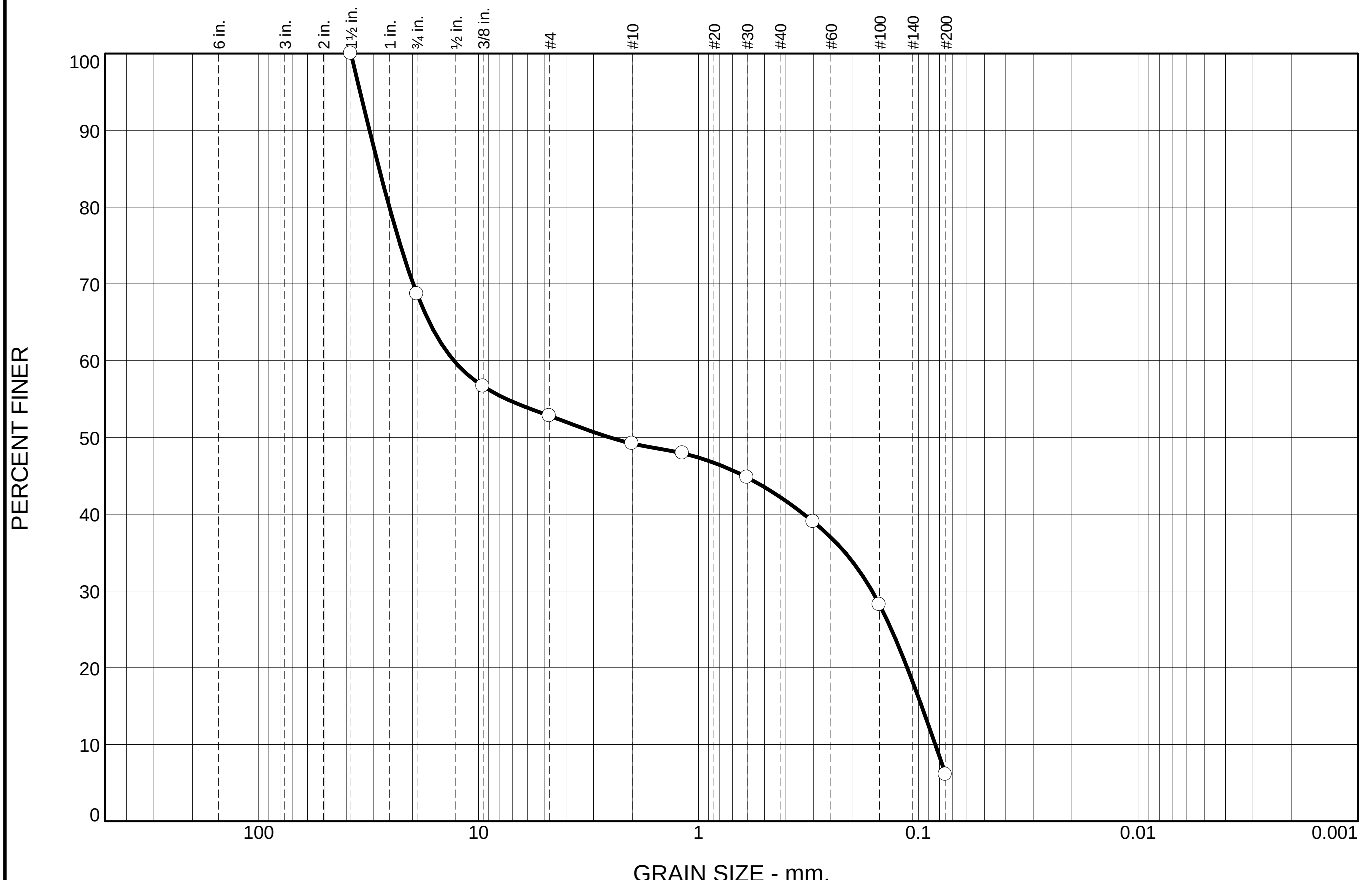
Remarks:
○Hartford

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** NM

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	31.3	15.9	3.6	7.0	36.1	6.1	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	28.3358	12.9652	2.5331	0.1622	0.0965	0.0837	0.02	154.98

Material Description	USCS	AASHTO
○ Narrowly graded GRAVEL with silt and sand	GP-GM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** WR1 **Depth:** El. 332.14 ft **Sample Number:** S3

Remarks:
○Hartford

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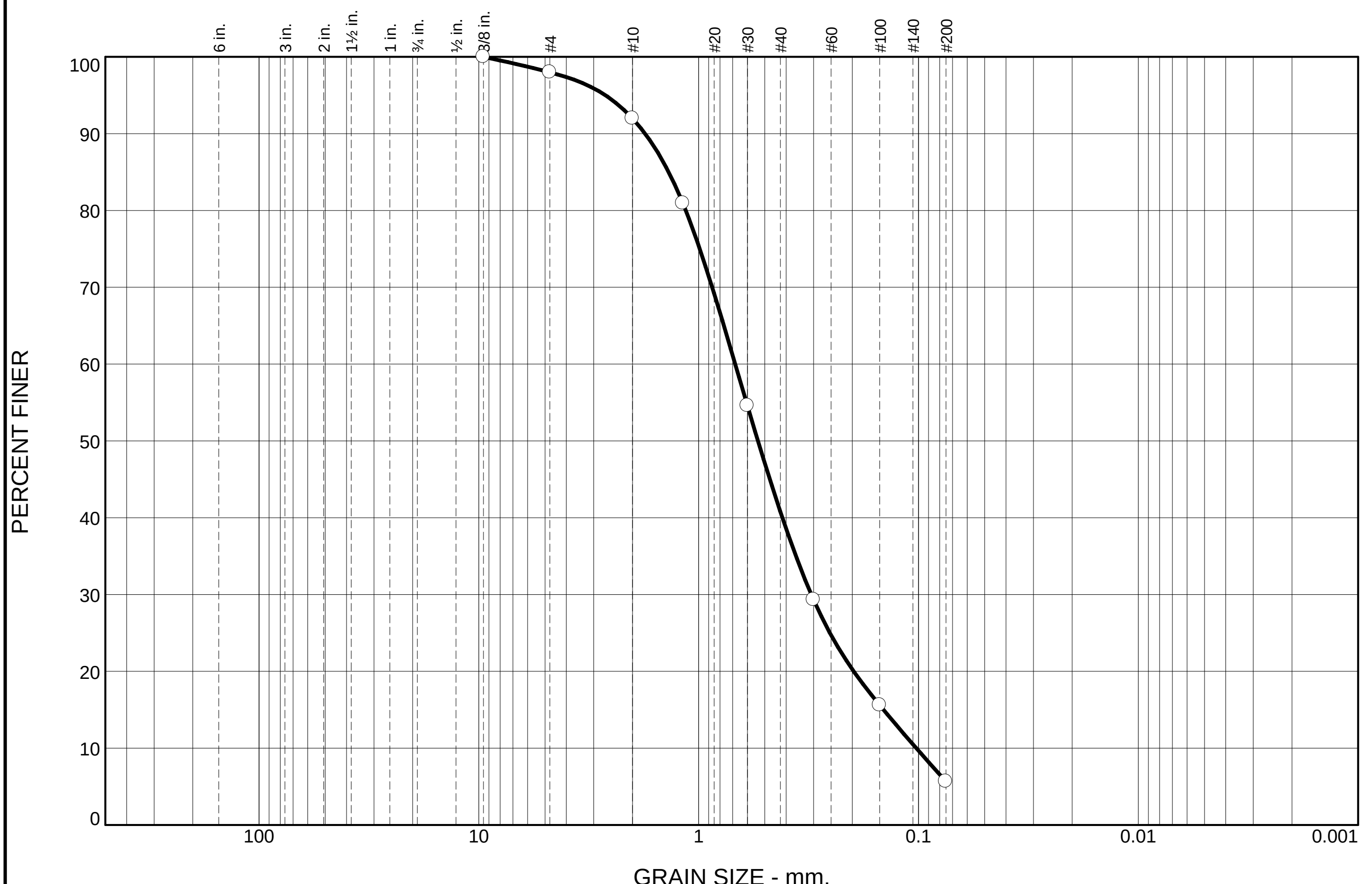
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: DJA **Checked By:** NM

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	2.0	6.0	51.2	35.1	5.7	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	1.3695	0.6819	0.5373	0.3073	0.1443	0.1023	1.35	6.67

Material Description	USCS	AASHTO
○ Widely Graded SAND with Silt	SW-SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** WR1 **Depth:** El. 324.9 ft **Sample Number:** Sand

Remarks:

○Hartford

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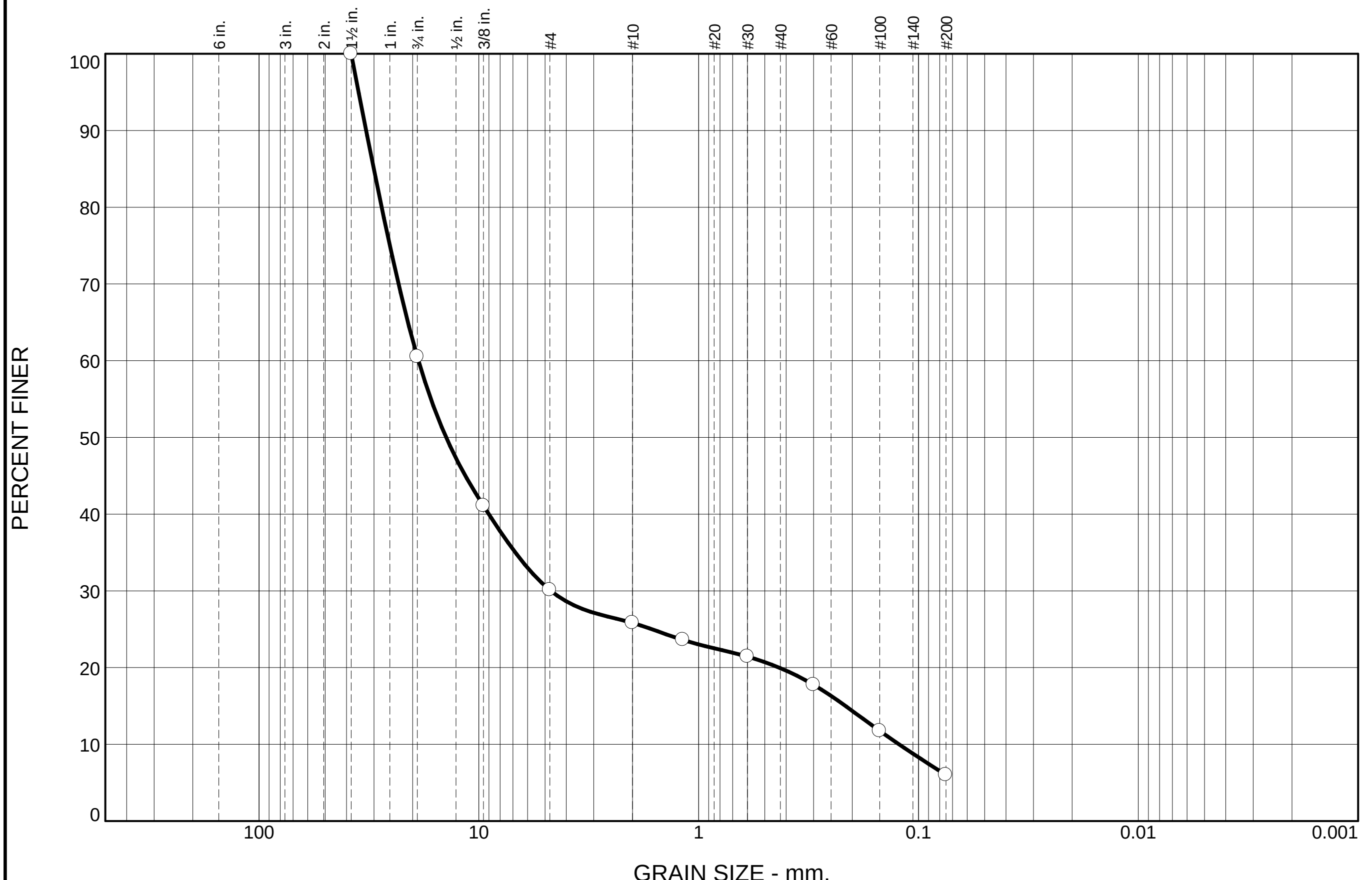
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	39.5	30.4	4.3	5.9	13.9	6.0	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	30.0515	18.8231	14.0877	4.7026	0.2148	0.1225	9.59	153.60

Material Description	USCS	AASHTO
○ Narrowly graded GRAVEL with Sand and Silt	GP-GM	-

Project No. 1402390 **Client:** Great River Hydro
Project: Erosion Study

○ **Source of Sample:** WR5 **Depth:** El. 317.3

Remarks:
○Edgewater Farm

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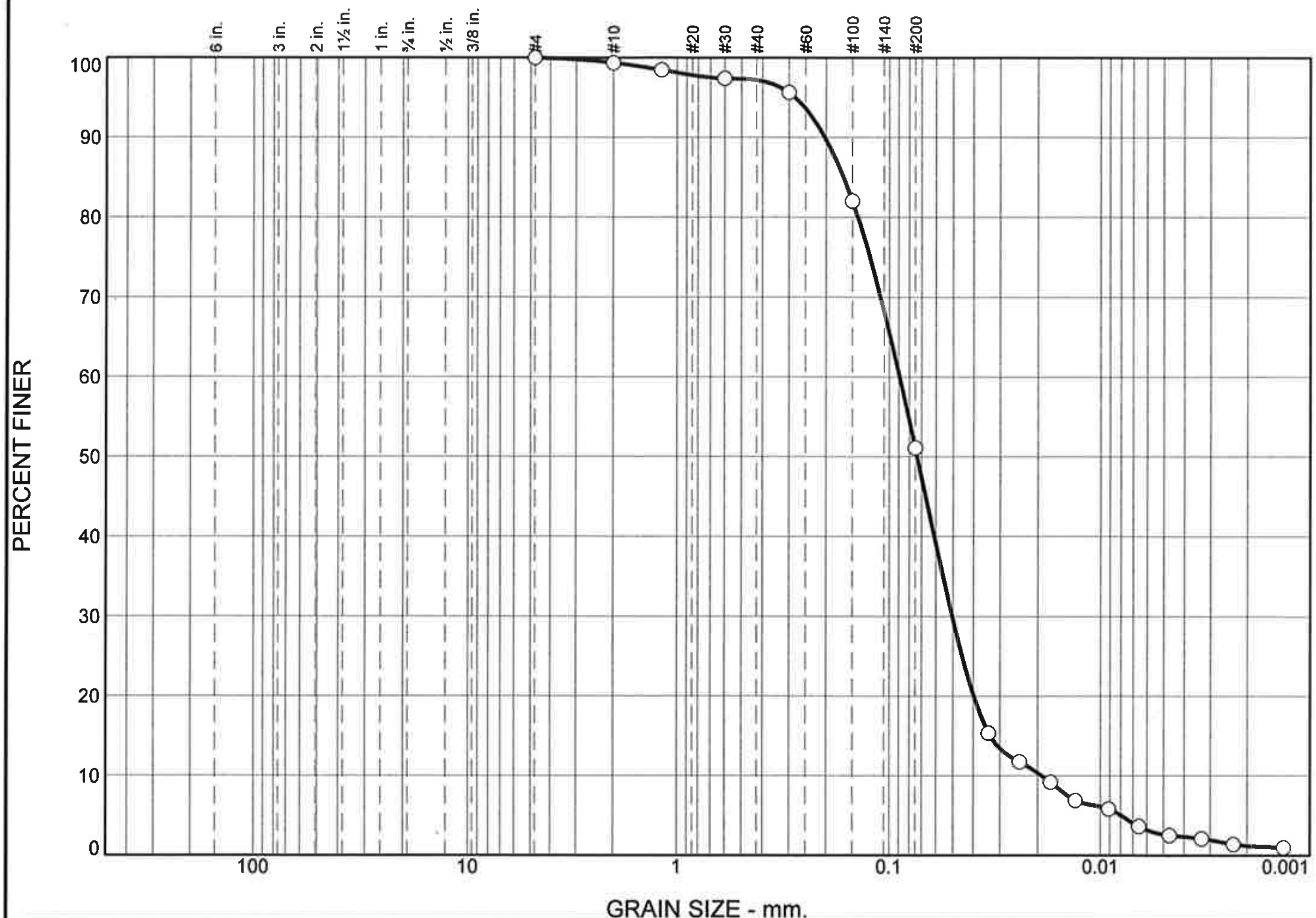
Woburn, MA 01801

GEI Consultants

Figure

Tested By: JG **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.6	2.2	46.1	48.5	2.6

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1654	0.0891	0.0735	0.0504	0.0333	0.0192	1.49	4.65

Material Description	USCS	AASHTO
○ Sandy SILT	ML	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** WR5 **Depth:** El. 320.5 ft

Remarks:

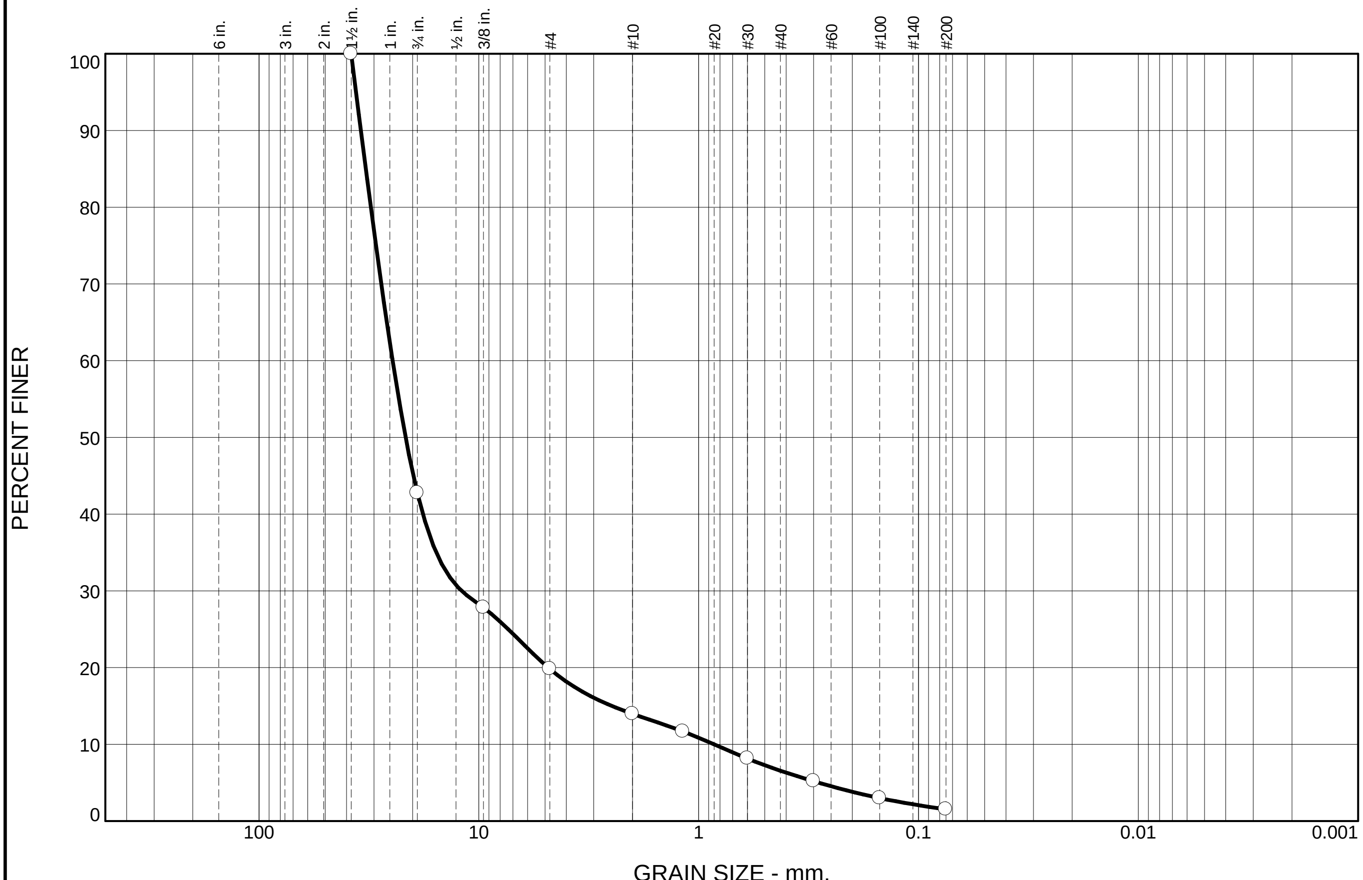
○ Edgewater Farm

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	57.2	23.0	5.8	7.4	5.1	1.5	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	32.6668	24.6788	21.5350	11.9760	2.4811	0.8512	6.83	28.99

Material Description	USCS	AASHTO
○ Narrowly Graded GRAVEL with Sand	GP	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** WR8 **Depth:** El. 293.5 ft

Remarks:

○Great River Farm

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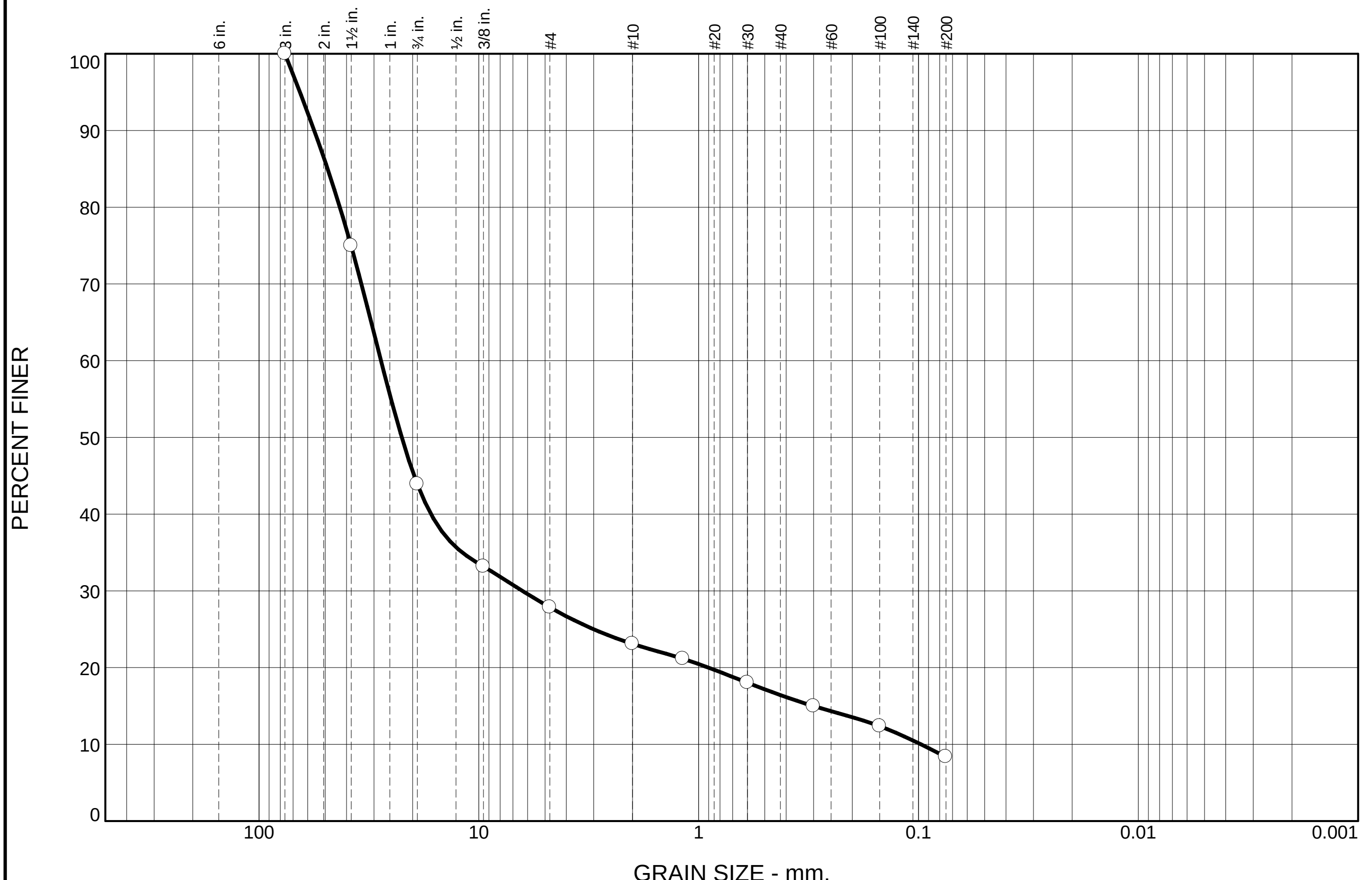
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: JG **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○		56.1	16.0	4.8	6.7	8.0	8.4	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	48.7570	27.8746	22.4172	6.3326	0.3011	0.0975	14.76	286.03

Material Description	USCS	AASHTO
○ Narrowly Graded GRAVEL with Silt and Sand	GP-GM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** WR8 **Depth:** El. 297 ft

Remarks:

○Great River Farm

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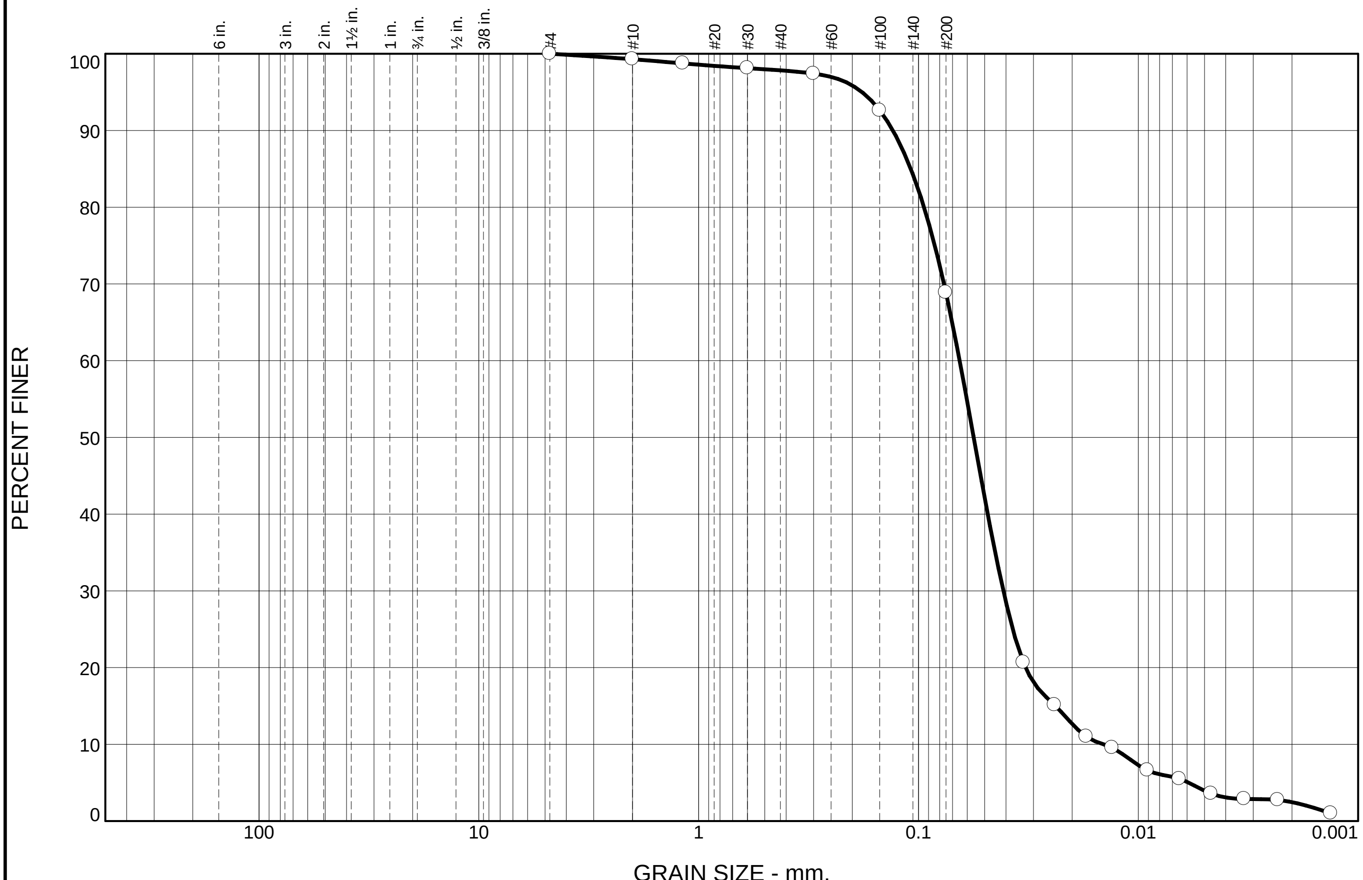
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: JG **Checked By:** EF

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.7	1.5	28.9	64.9	4.0

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1084	0.0650	0.0561	0.0411	0.0238	0.0144	1.81	4.52

Material Description	USCS	AASHTO
○ Sandy SILT	ML	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** WR8 **Depth:** El. 300.3 ft

Remarks:

○Great River Farm

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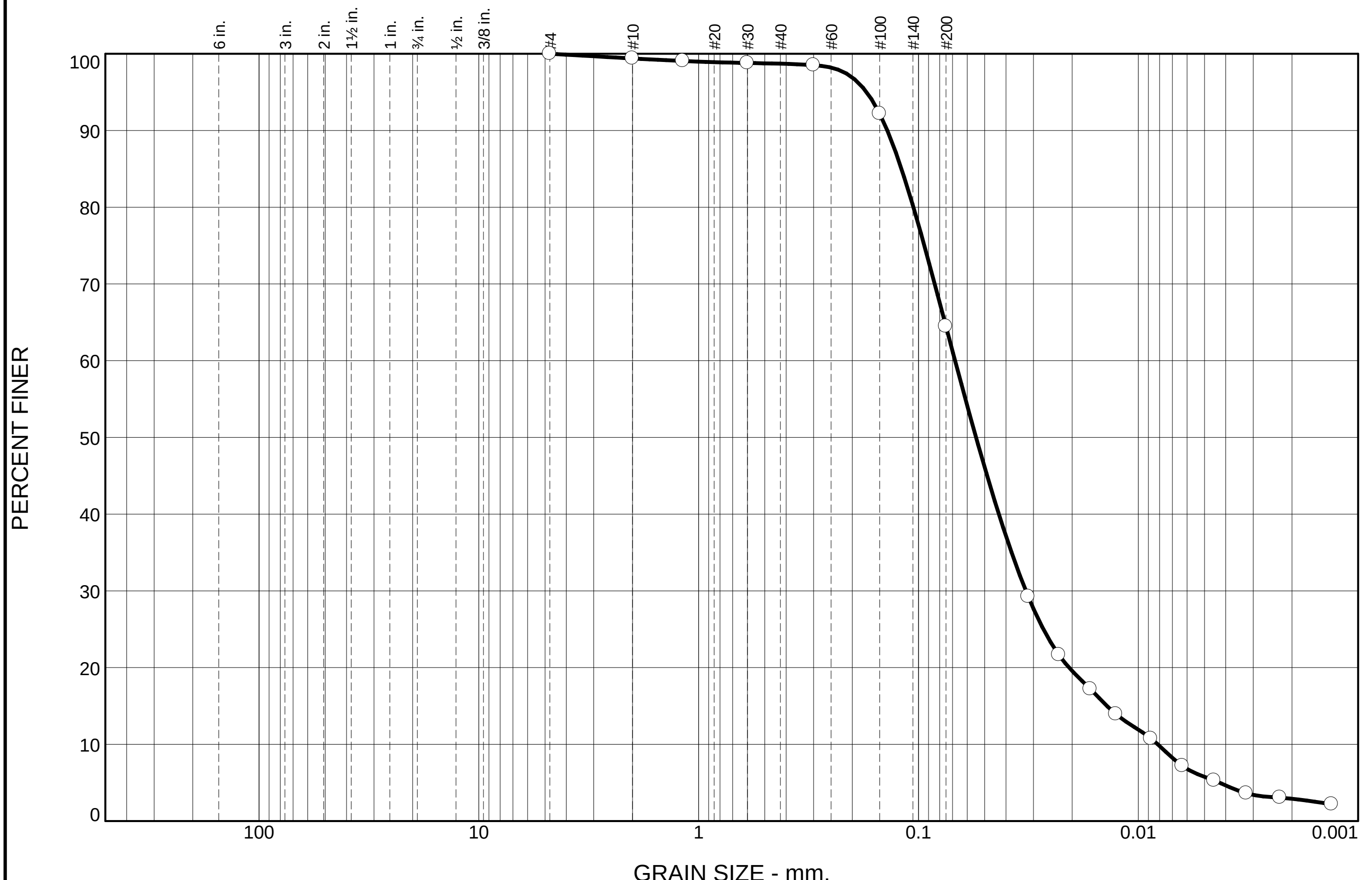
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.6	0.7	34.2	58.7	5.8

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1195	0.0682	0.0547	0.0325	0.0139	0.0082	1.89	8.36

Material Description	USCS	AASHTO
○ Sandy SILT	ML	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** WR9 **Sample Number:** S1

Remarks:

○Hartwell

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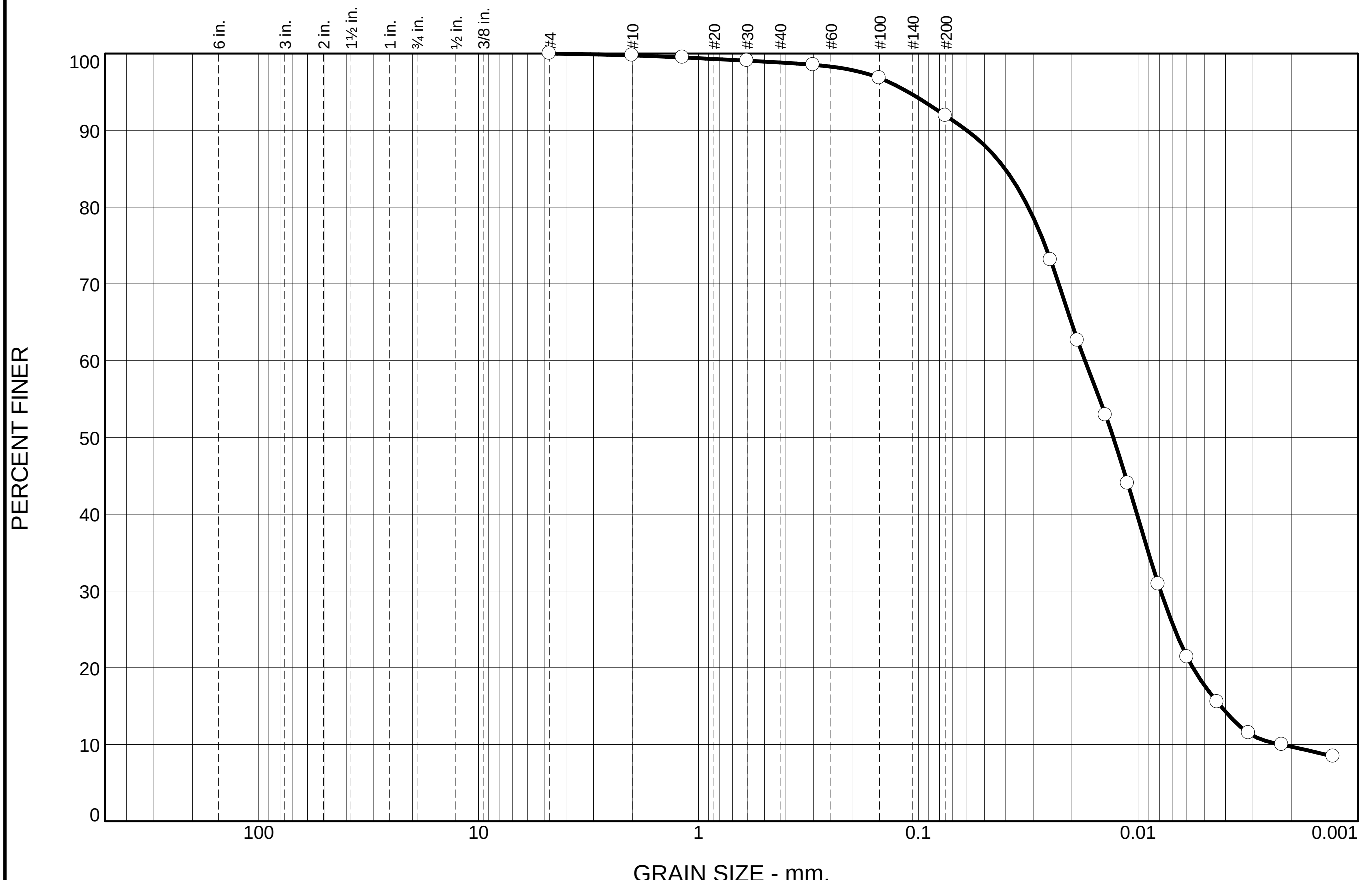
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.2	1.0	6.9	74.2	17.7

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.0403	0.0174	0.0130	0.0079	0.0042	0.0022	1.60	7.80

Material Description	USCS	AASHTO
○ SILT	ML	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** WR9 **Sample Number:** S2

Remarks:

○Hartwell

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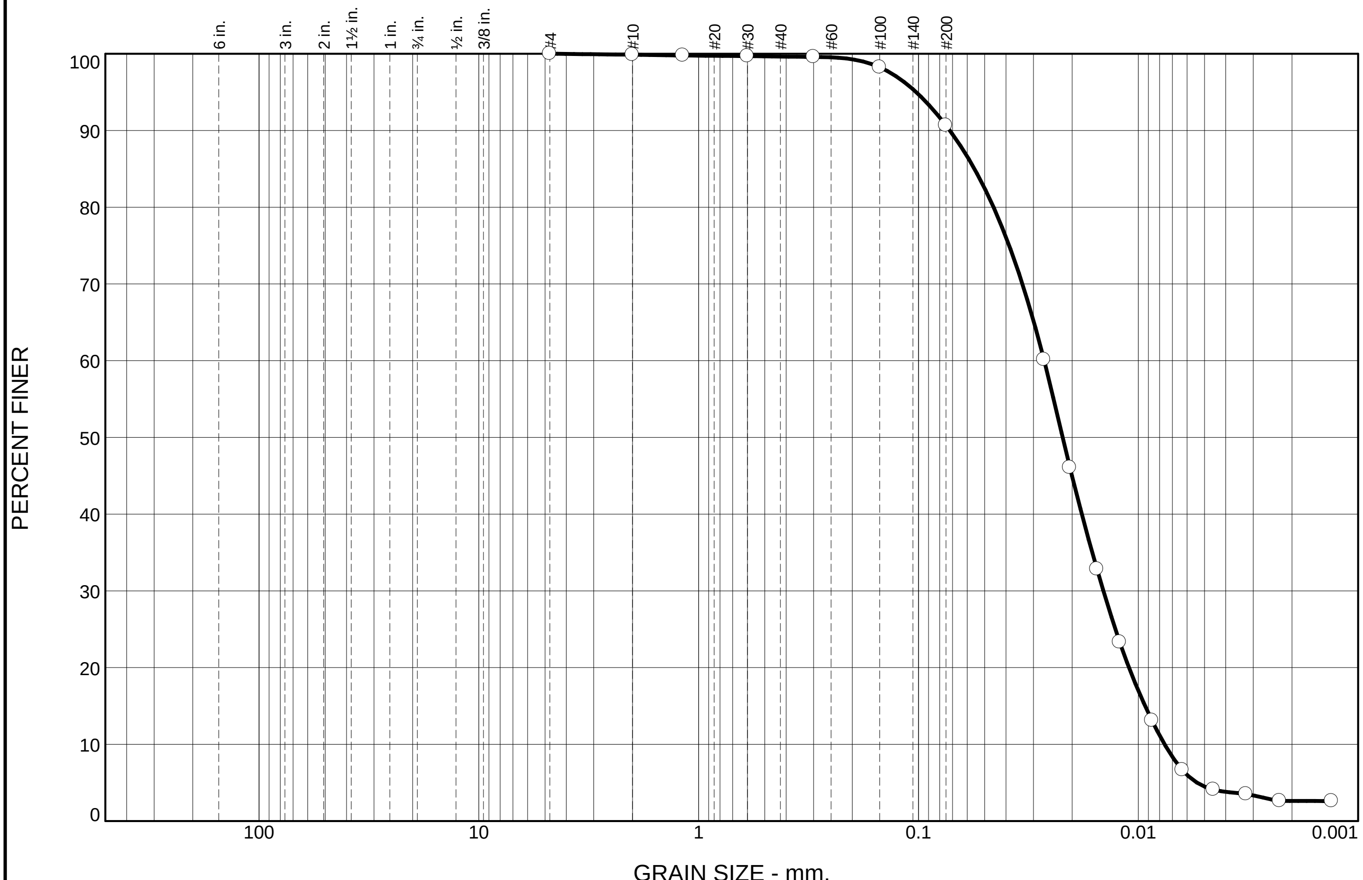
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.1	0.3	8.9	86.2	4.5

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.0557	0.0268	0.0221	0.0144	0.0093	0.0076	1.02	3.53

Material Description	USCS	AASHTO
○ SILT	ML	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** WR9 **Sample Number:** S3

Remarks:
○Hartwell

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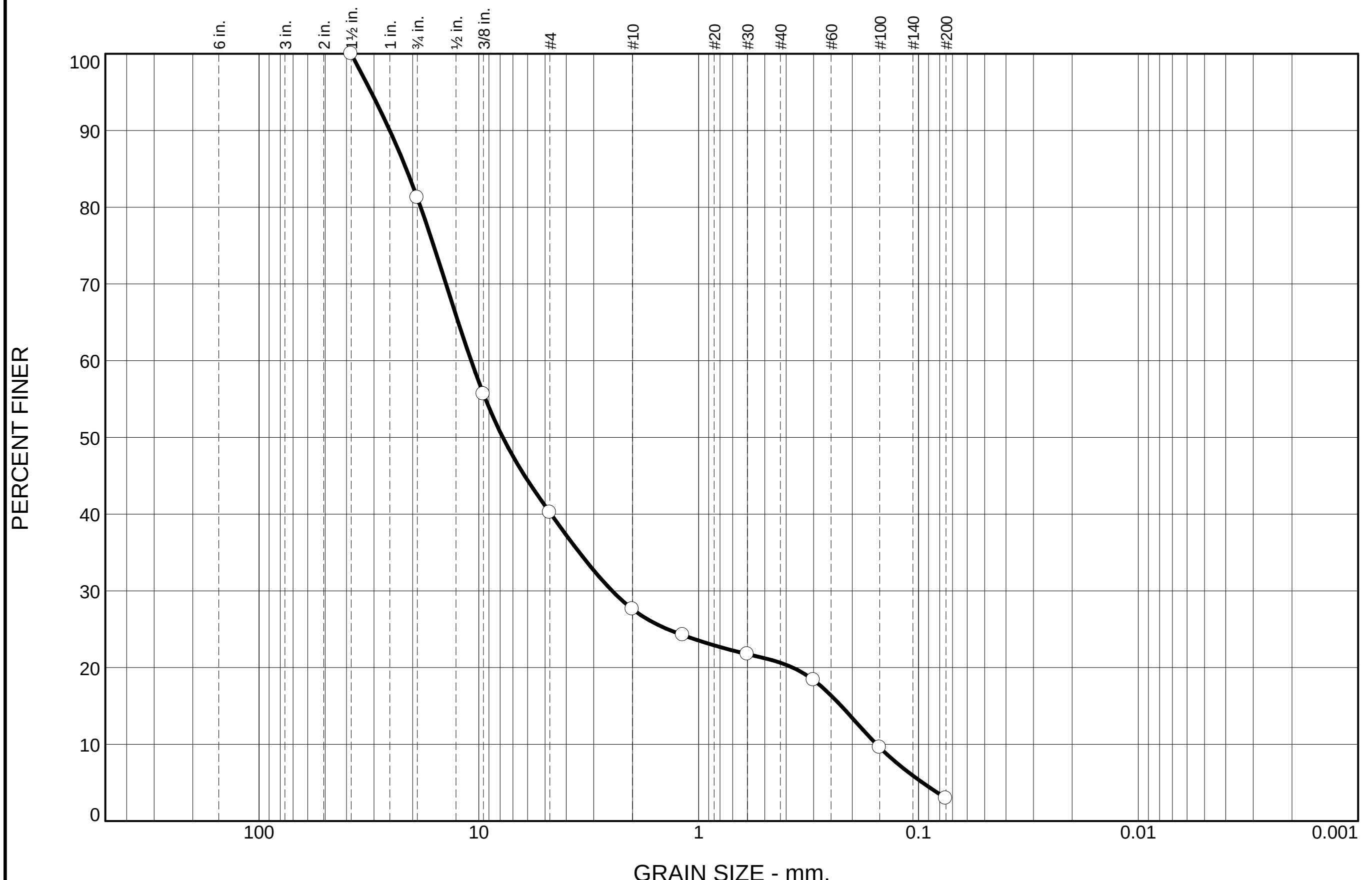
Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	18.8	41.0	12.6	7.0	17.6	3.0	

╳	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	21.3886	10.8400	7.7773	2.4739	0.2245	0.1551	3.64	69.91

Material Description	USCS	AASHTO
○ Narrowly Graded GRAVEL with Sand	GP	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** B1 **Sample Number:** S1

Remarks:
○Lipfert

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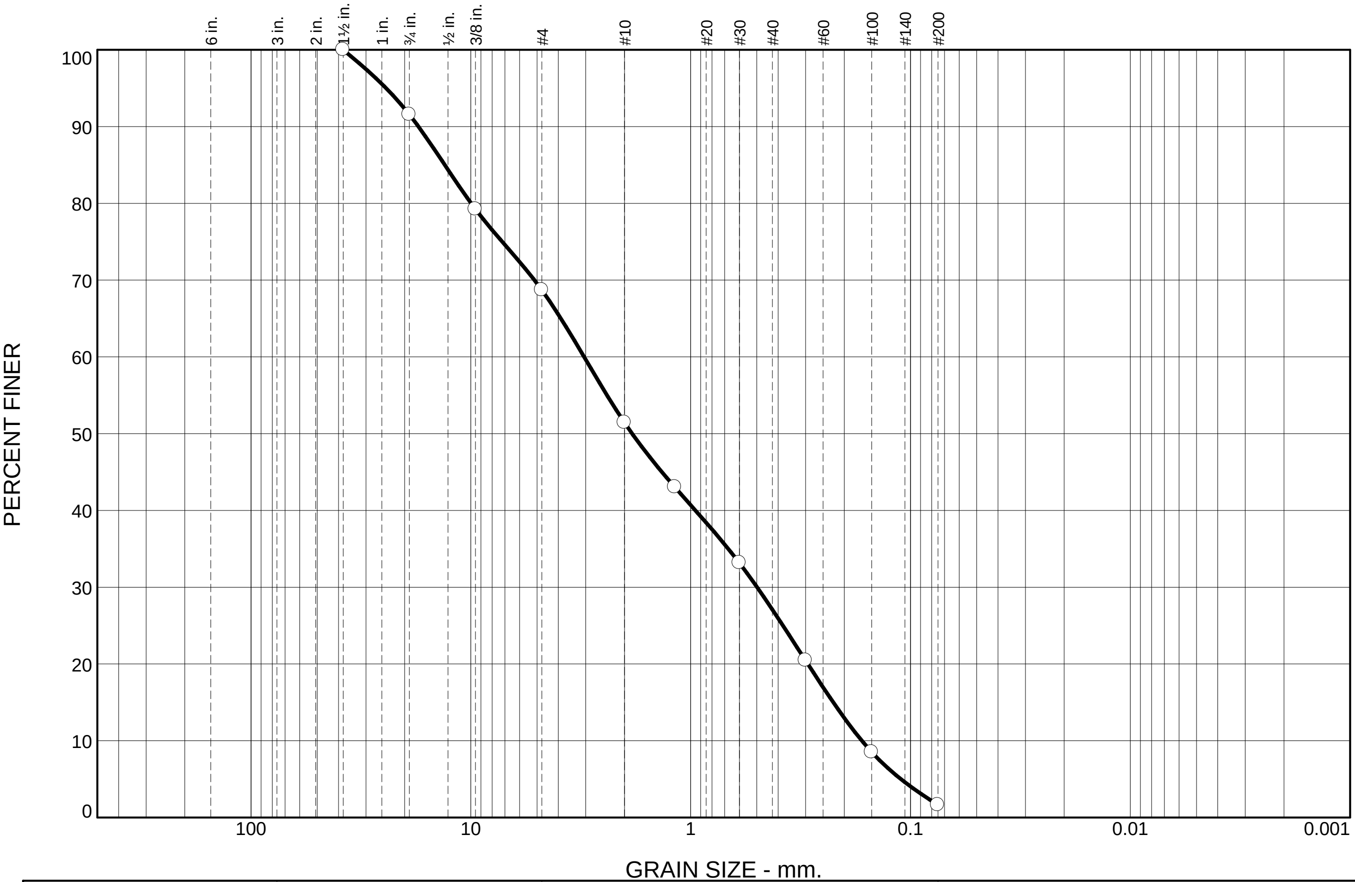
Woburn, MA 01801

Figure

Tested By: JG **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	8.4	22.9	17.3	24.3	25.5	1.6	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	13.1408	3.0529	1.8460	0.4987	0.2244	0.1664	0.49	18.35

Material Description	USCS	AASHTO
○ Narrowly graded SAND with gravel	SP	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** B1 **Sample Number:** S2

Remarks:

○Lipfert

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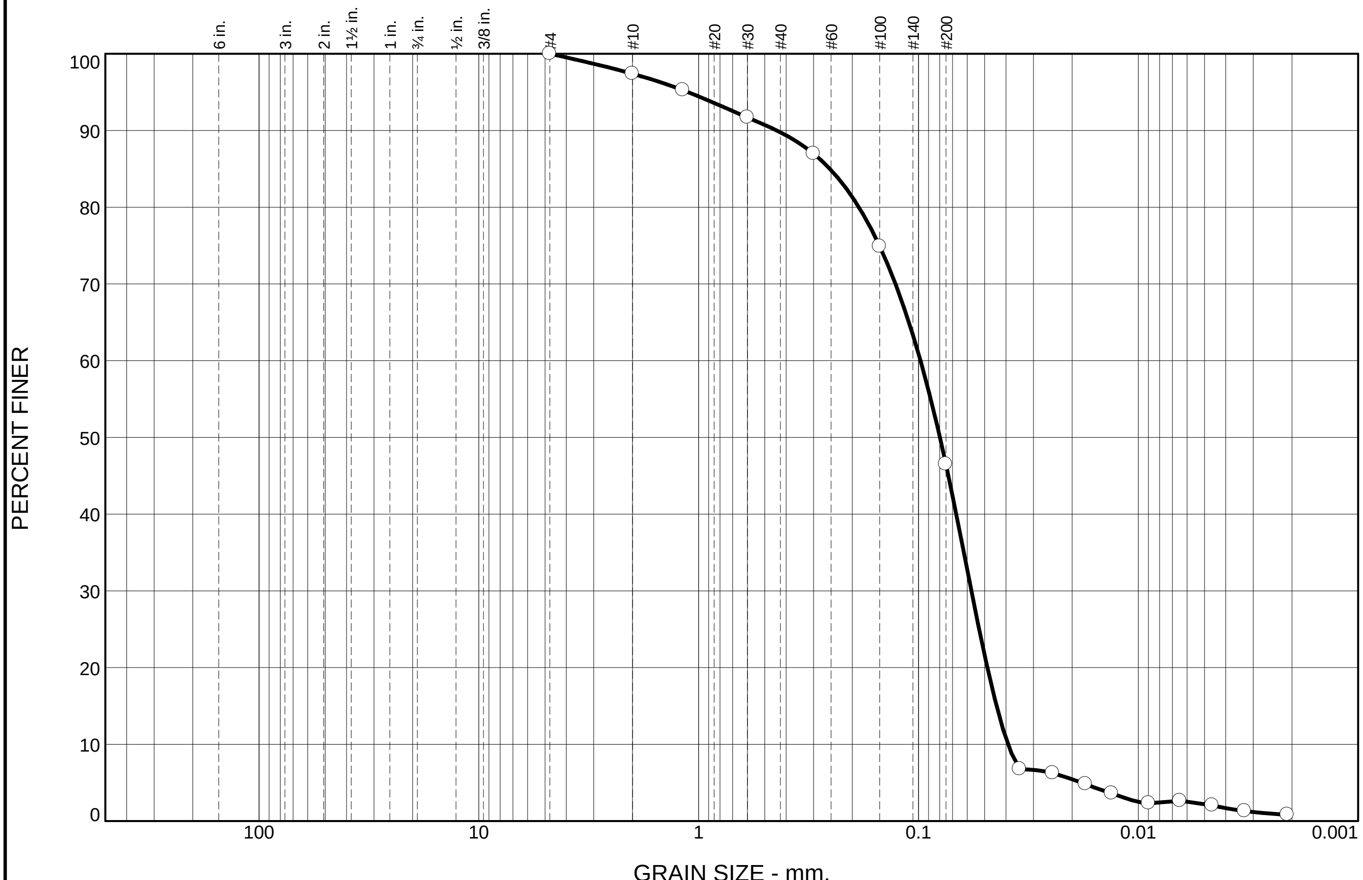
Woburn, MA 01801

Figure

Tested By: DJA **Checked By:** NM

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	2.6	7.6	43.3	44.3	2.2

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.2529	0.0979	0.0798	0.0574	0.0441	0.0391	0.86	2.50

Material Description	USCS	AASHTO
○ SILTY SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** B1 **Sample Number:** S3

Remarks:

○Lipfert

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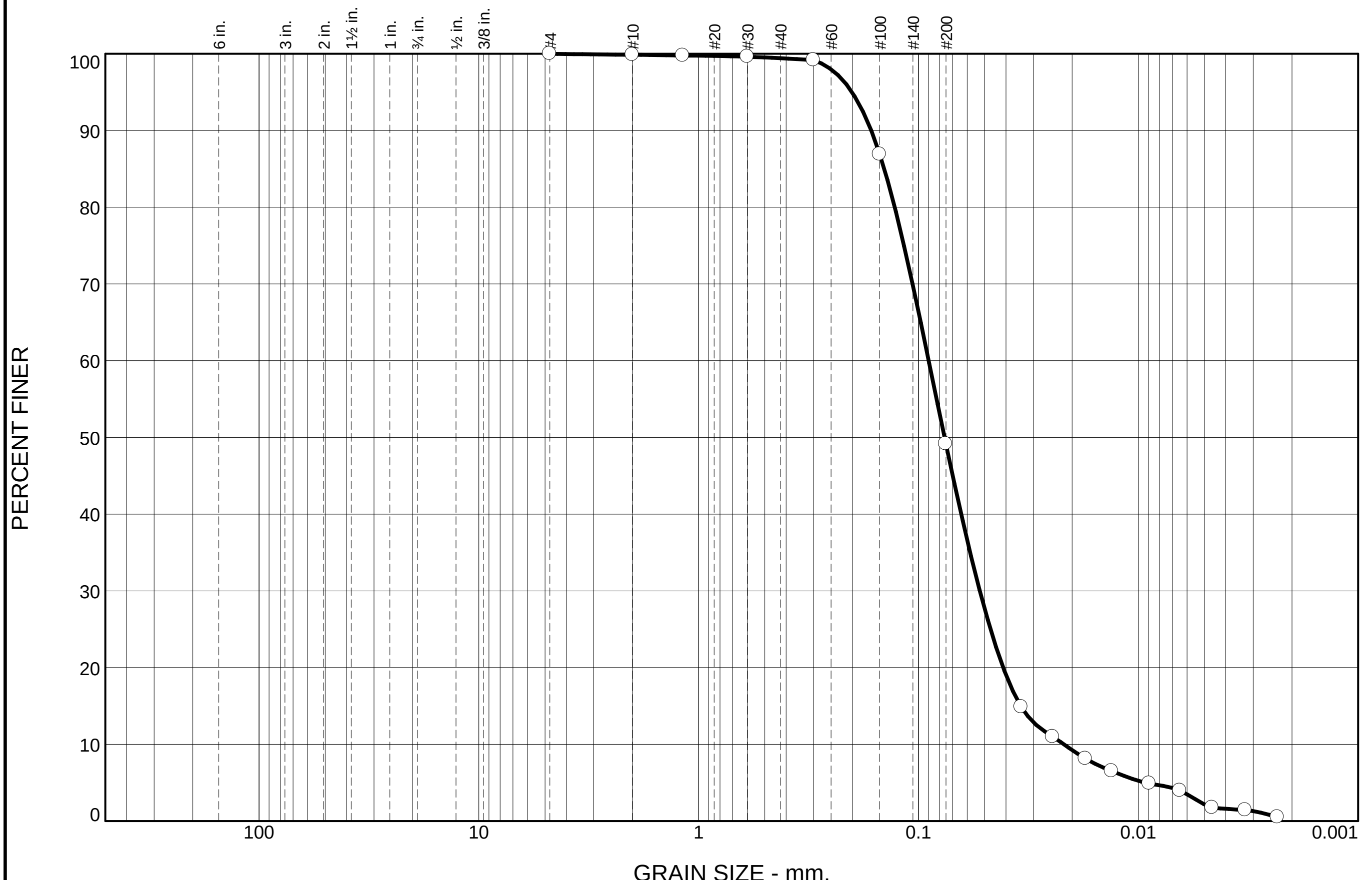
Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.1	0.5	50.3	46.9	2.2

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1431	0.0899	0.0761	0.0526	0.0343	0.0218	1.41	4.12

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** B3 **Depth:** El. 290.11 ft **Sample Number:** S1

Remarks:

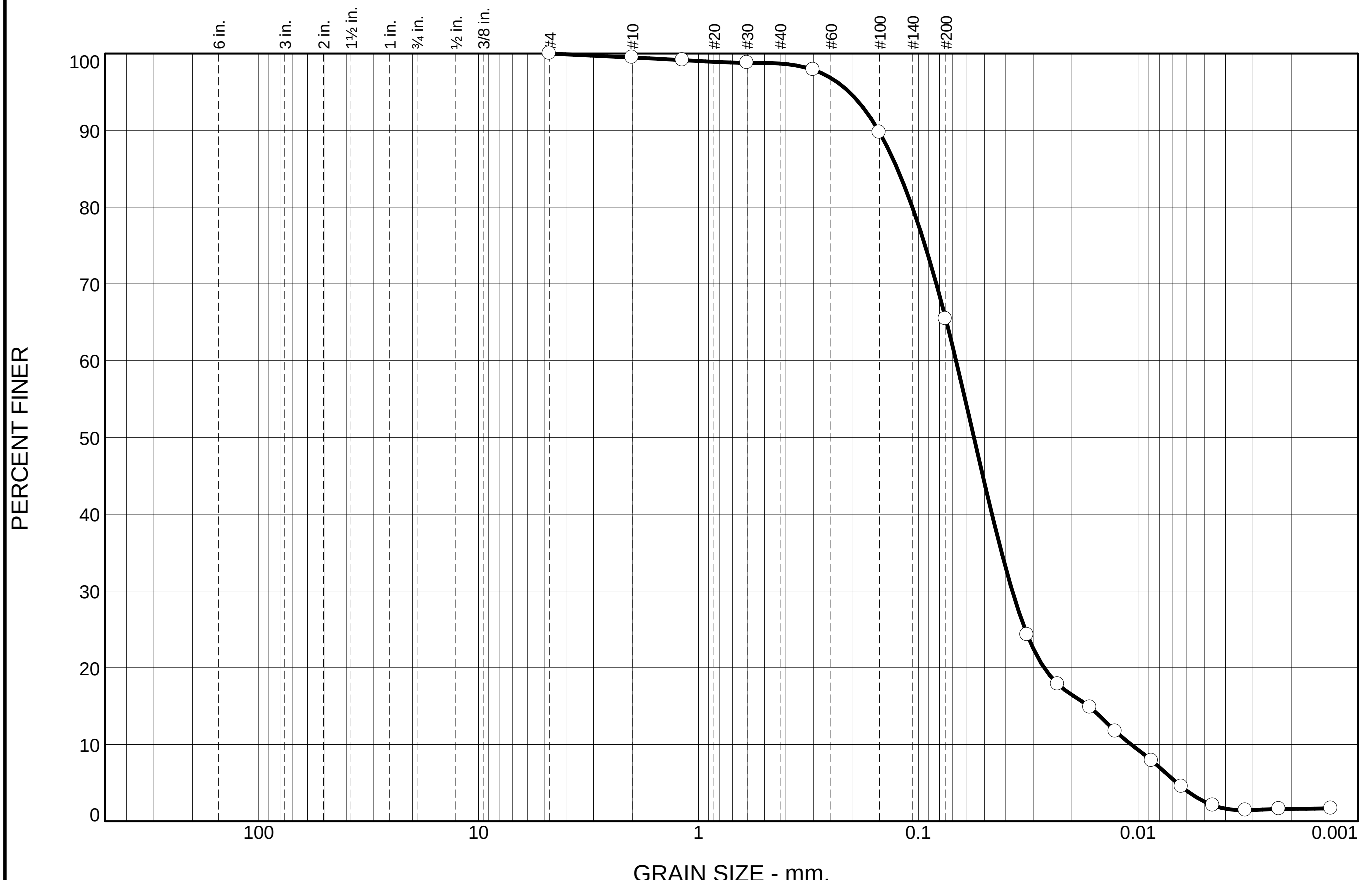
○Jarvis Island

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF/NM **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.5	0.8	33.3	62.8	2.6

⨯	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1245	0.0673	0.0558	0.0373	0.0168	0.0107	1.93	6.27

Material Description	USCS	AASHTO
○ Sandy SILT	ML	-

Project No. 1402390 **Client:** Great River Hydro
Project: Erosion Study

○ **Source of Sample:** B3 **Depth:** El. 291.66 ft **Sample Number:** S2

Remarks:
○Jarvis Island

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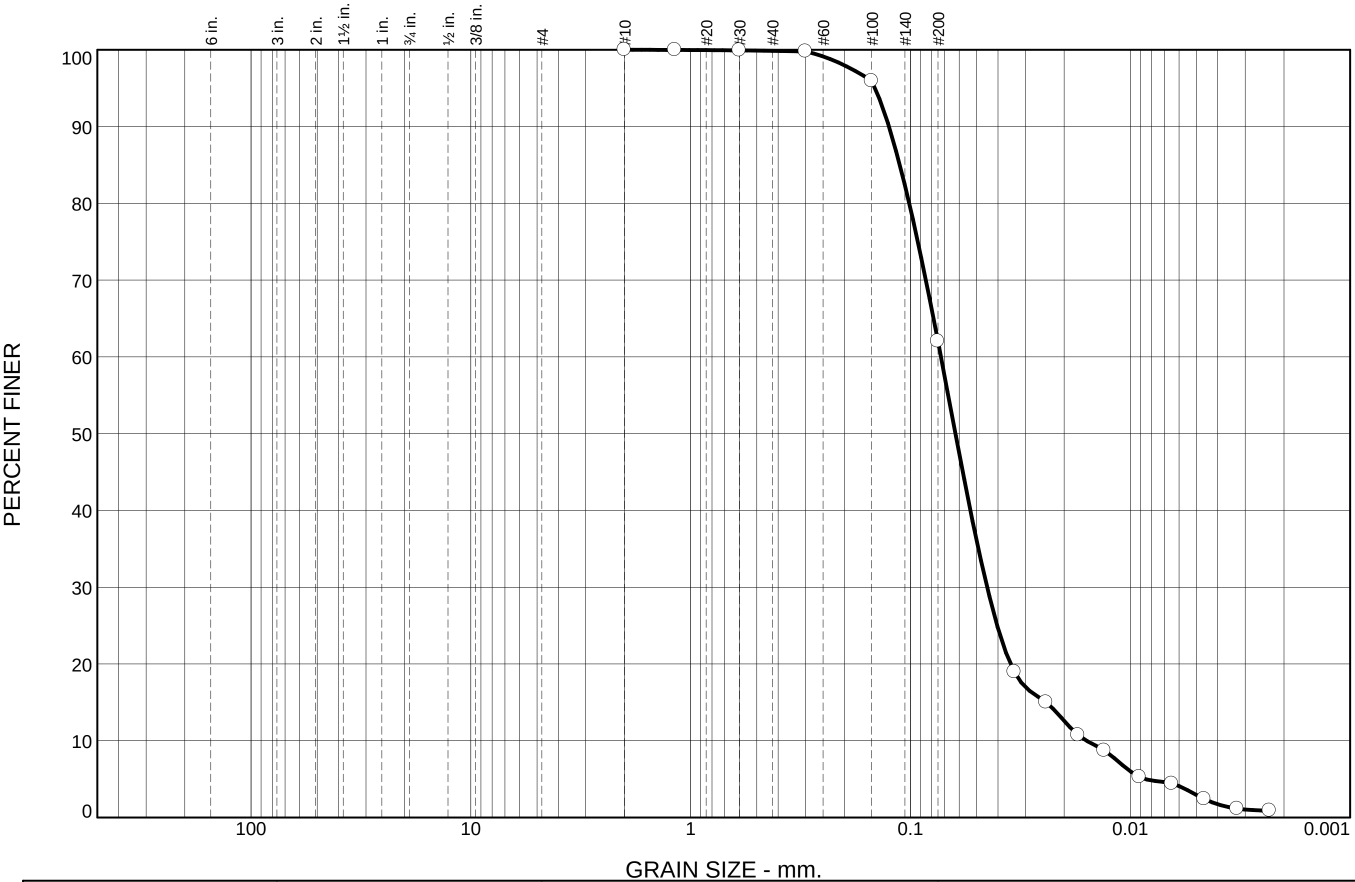
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



% +3"	% Gravel Coarse	% Gravel Fine	% Sand Coarse	% Sand Medium	% Sand Fine	% Fines Silt	% Fines Clay
0.0	0.0	0.0	0.0	0.1	37.9	59.1	2.9

LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
-	-	0.1118	0.0727	0.0624	0.0448	0.0241	0.0158	1.75	4.60

Material Description	USCS	AASHTO
Sandy SILT	ML	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

Source of Sample: B7 **Depth:** El. 289.7 ft **Sample Number:** S1

Remarks:
Charlestown

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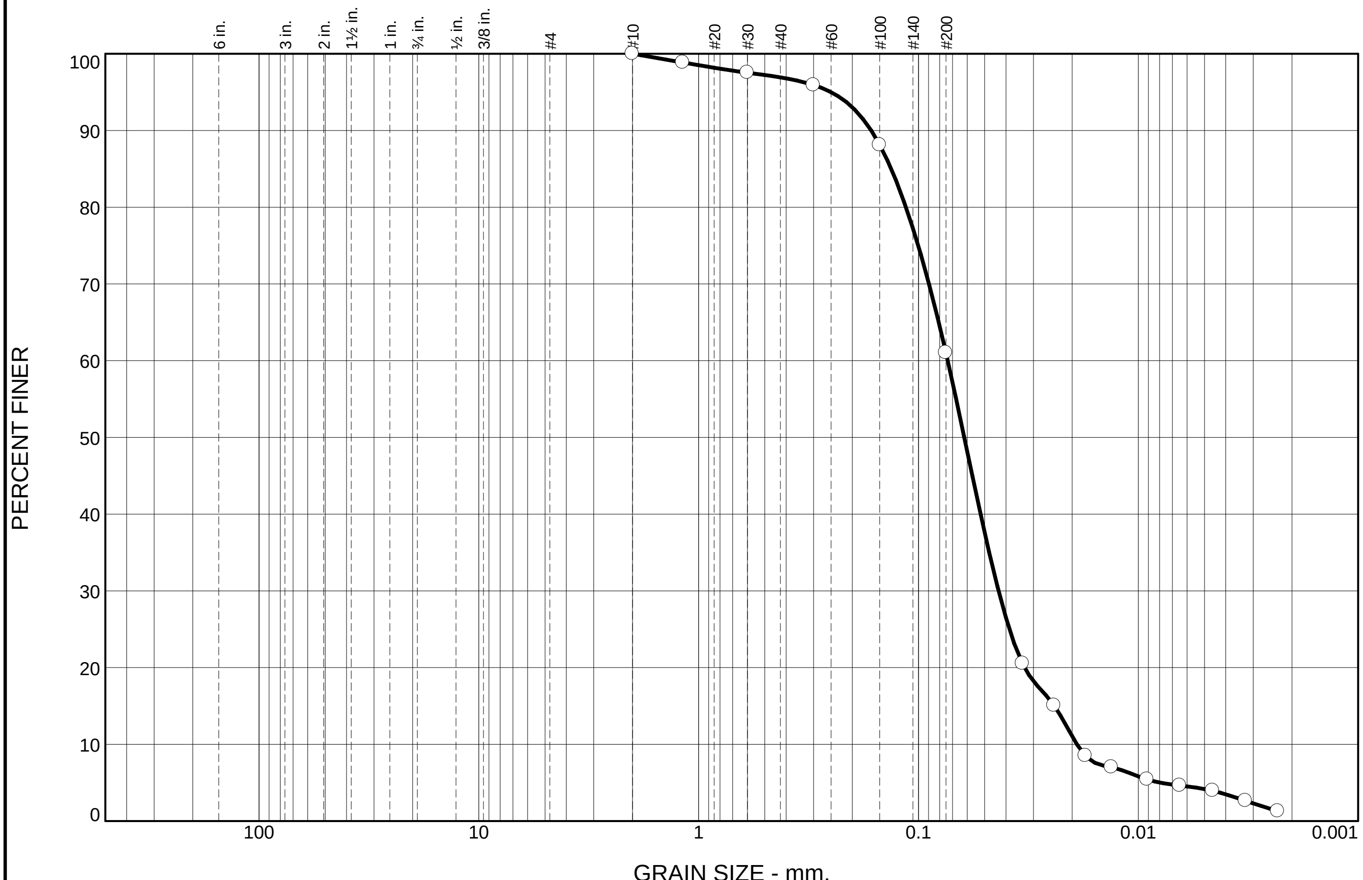
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: NM **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.0	3.1	35.9	56.8	4.2

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1331	0.0736	0.0619	0.0432	0.0241	0.0190	1.33	3.87

Material Description	USCS	AASHTO
○ Sandy SILT	ML	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** B7 **Depth:** El. 290.3 ft **Sample Number:** S2

Remarks:

○Charlestown

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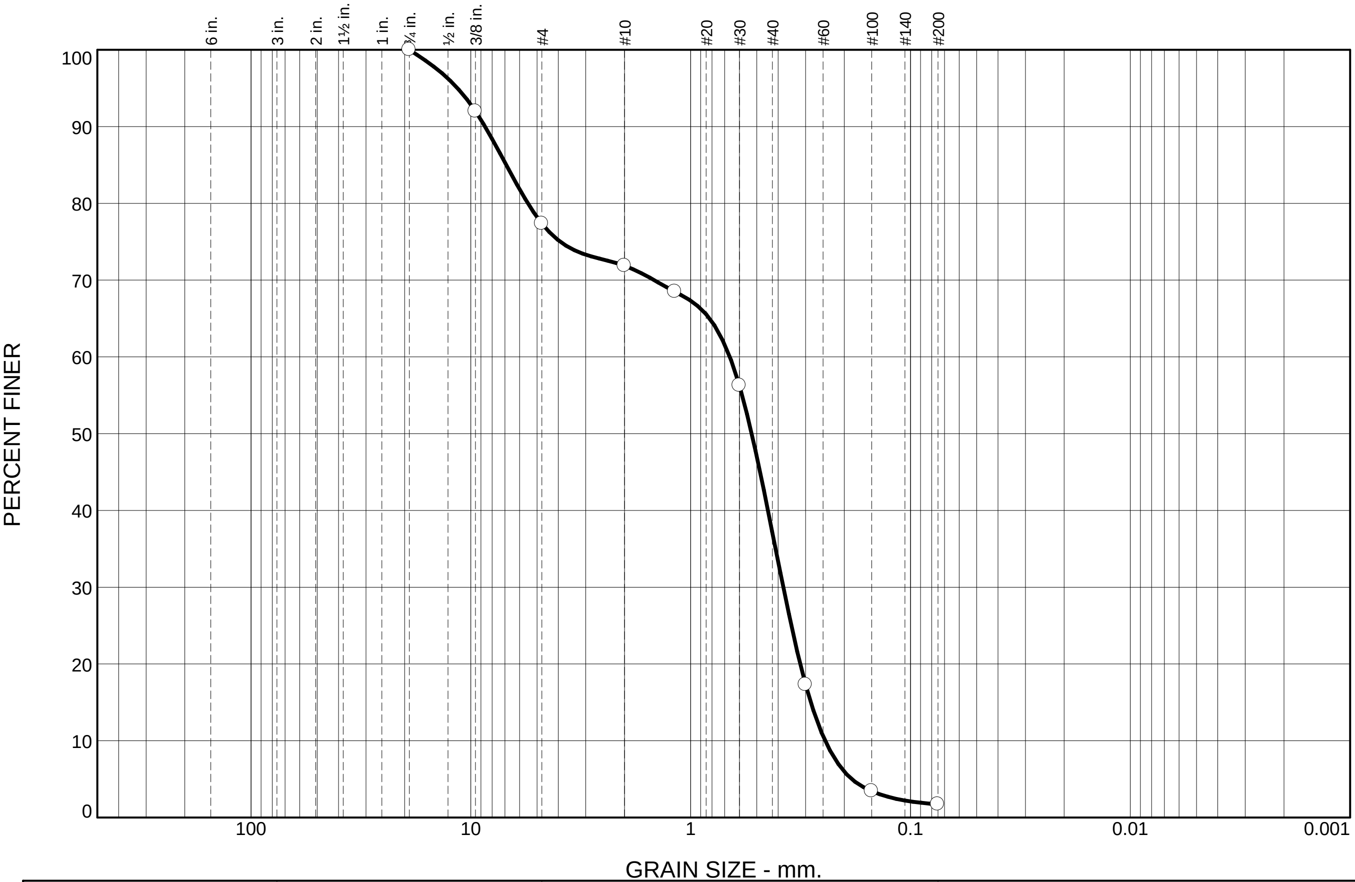
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: NM **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	22.7	5.4	34.8	35.4	1.7	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	6.9009	0.6632	0.5276	0.3788	0.2842	0.2444	0.89	2.71

Material Description	USCS	AASHTO
○ Narrowly Graded SAND with Gravel	SP	-

Project No. 1402390 **Client:** Great River Hydro
Project: Erosion Study

○ **Source of Sample:** B9 **Depth:** El. 289.7 ft **Sample Number:** S1

Remarks:
○North Walpole

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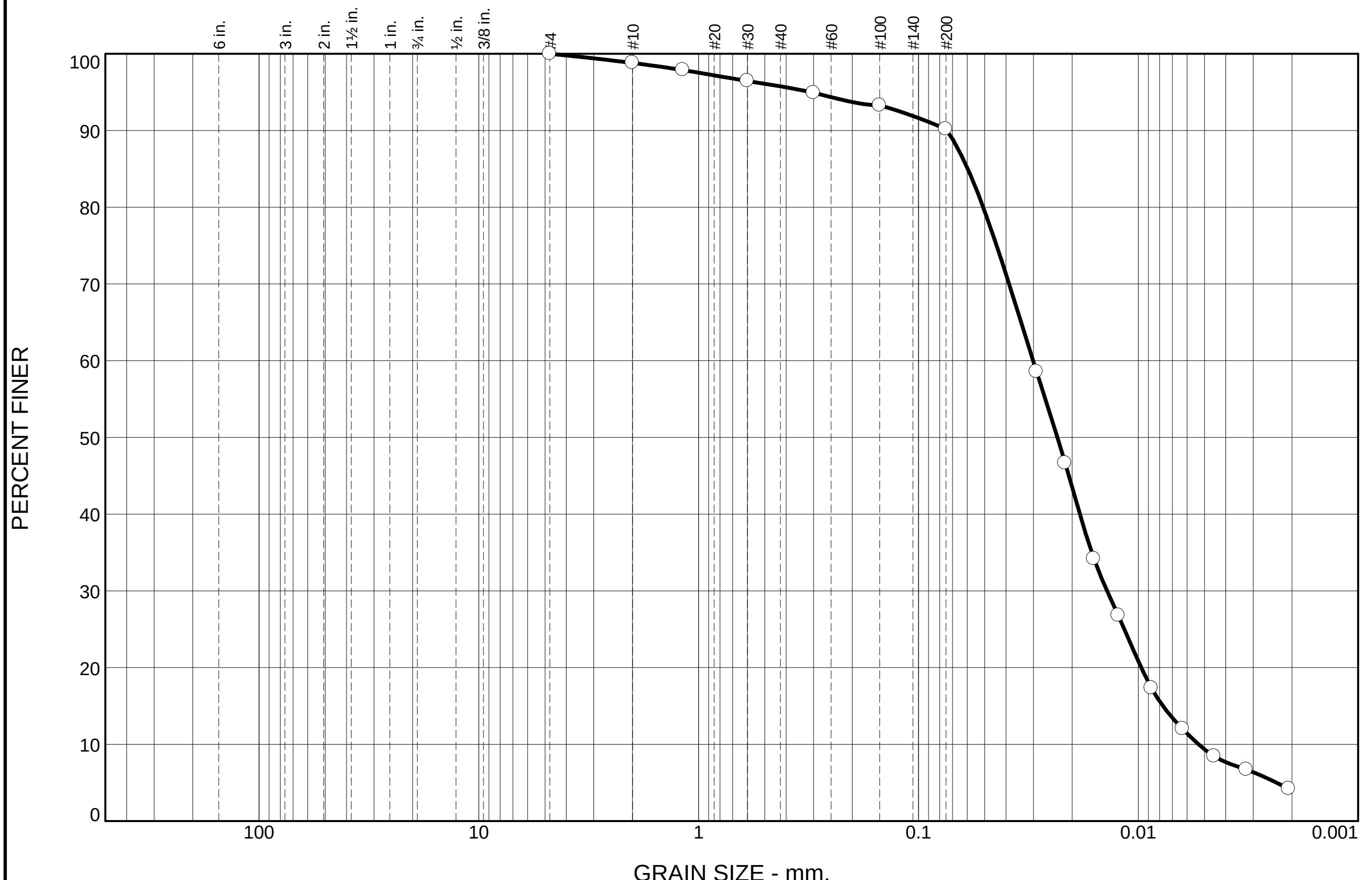
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	1.2	3.0	5.6	80.9	9.3

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.0597	0.0301	0.0233	0.0139	0.0077	0.0053	1.20	5.66

Material Description	USCS	AASHTO
○ SILT	ML	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** B9 **Sample Number:** S2

Remarks:
○North Walpole

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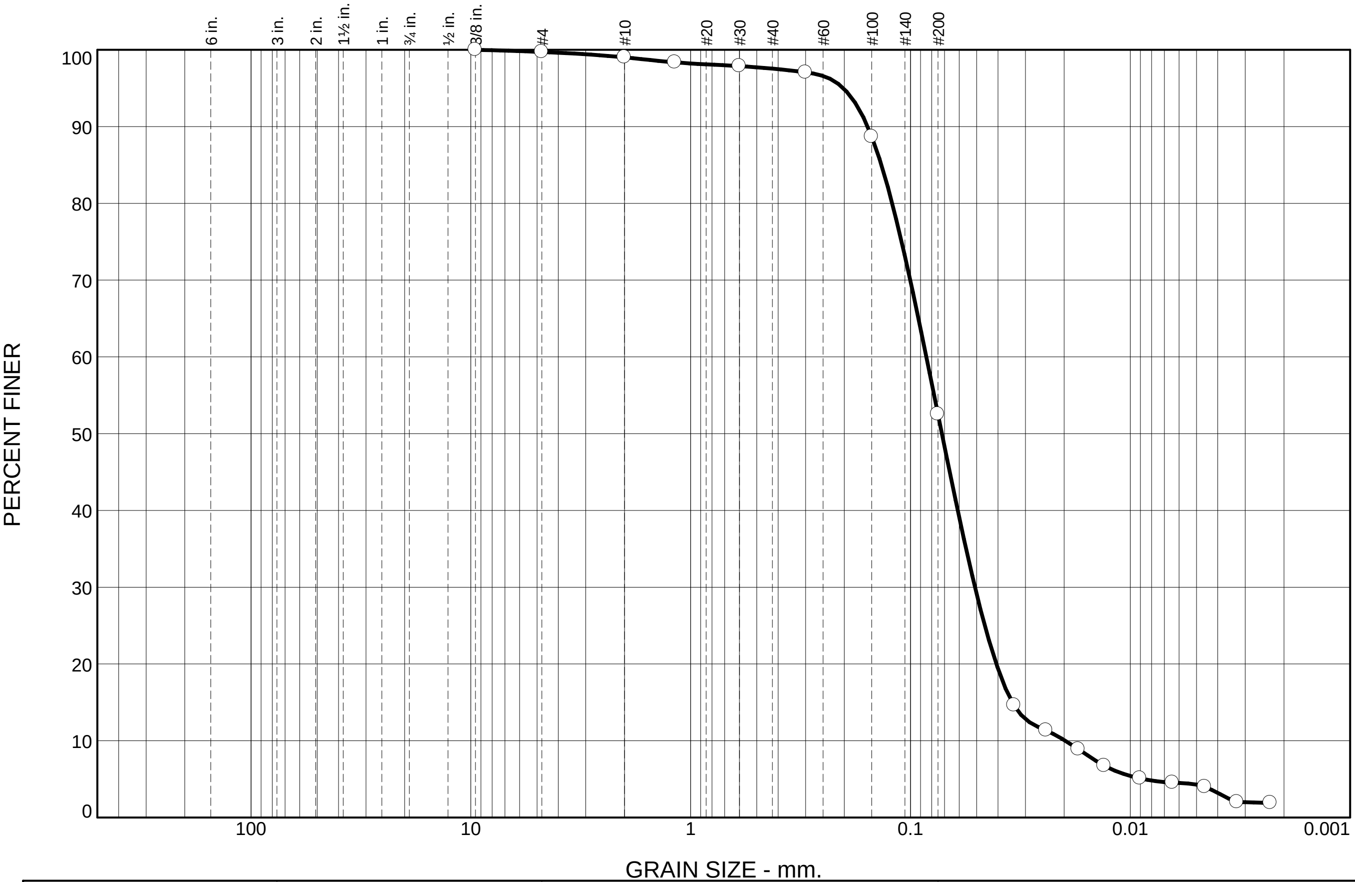
Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.3	0.7	1.5	45.0	48.2	4.3

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1356	0.0847	0.0720	0.0509	0.0344	0.0198	1.55	4.28

Material Description	USCS	AASHTO
○ Sandy SILT	ML	-

Project No. 1402390 **Client:** Great River Hydro
Project: Erosion Study

○ **Source of Sample:** BR1 **Sample Number:** S1

Remarks:
○Walpole Beach

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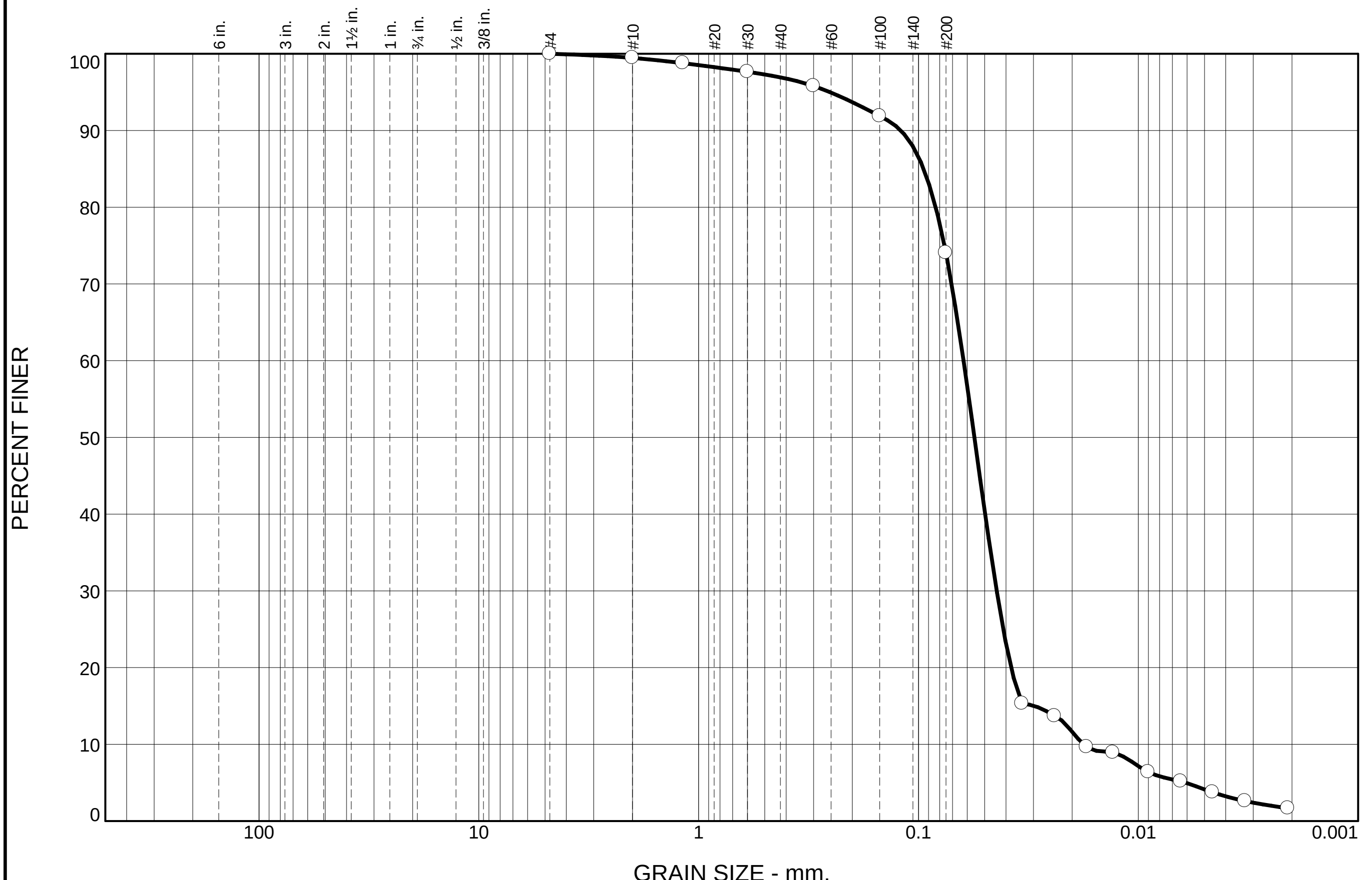
Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.5	2.6	22.9	69.9	4.1

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.0948	0.0624	0.0557	0.0441	0.0298	0.0178	1.75	3.51

Material Description	USCS	AASHTO
○ SILT with Sand	ML	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** BR1 **Sample Number:** S2

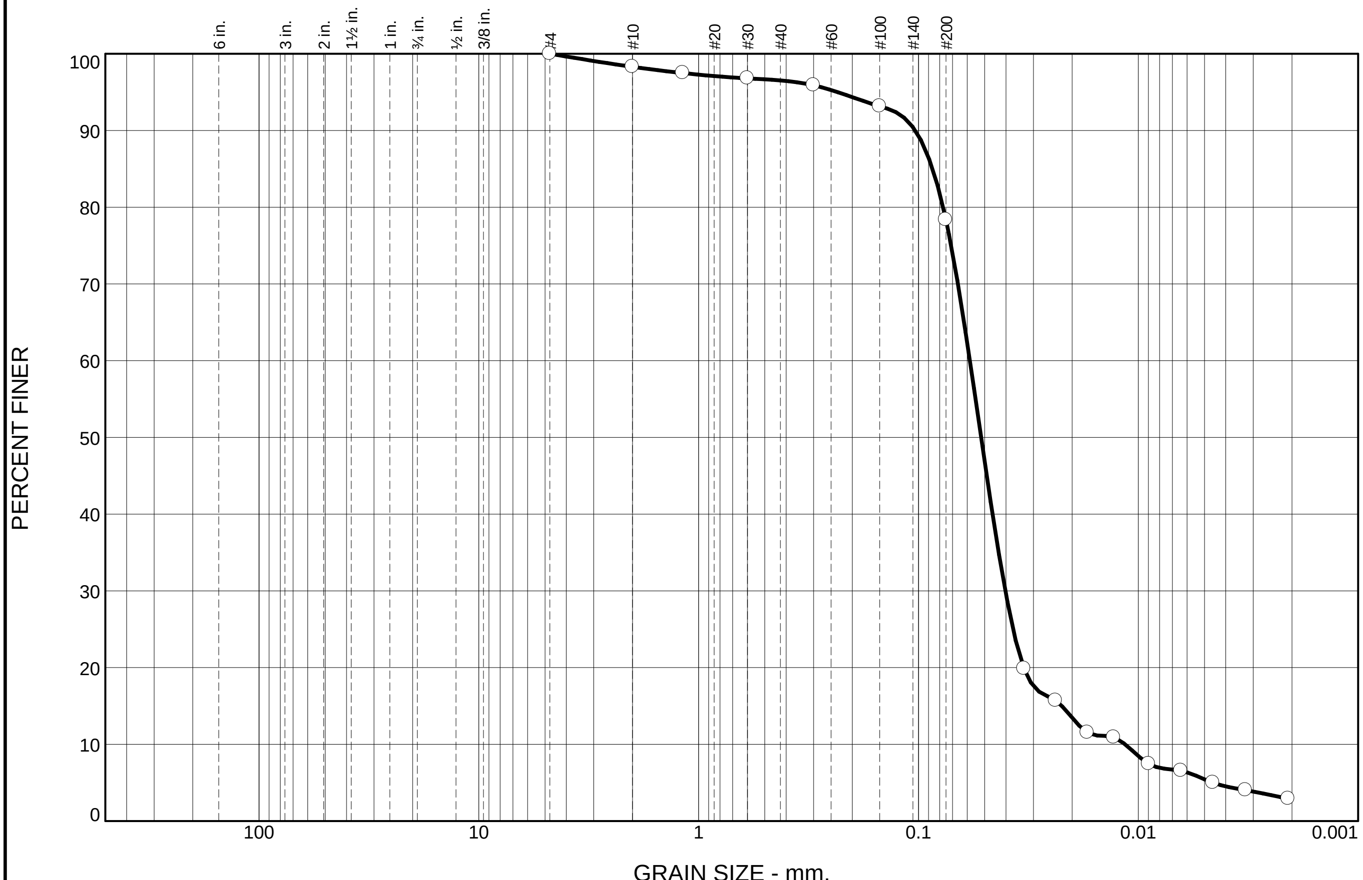
Remarks:
○Walpole Beach

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	1.7	1.8	18.1	73.0	5.4

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.0863	0.0584	0.0519	0.0403	0.0223	0.0115	2.42	5.08

Material Description	USCS	AASHTO
○ SILT with Sand	ML	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** BR1 **Sample Number:** S3

Remarks:
○Walpole Beach

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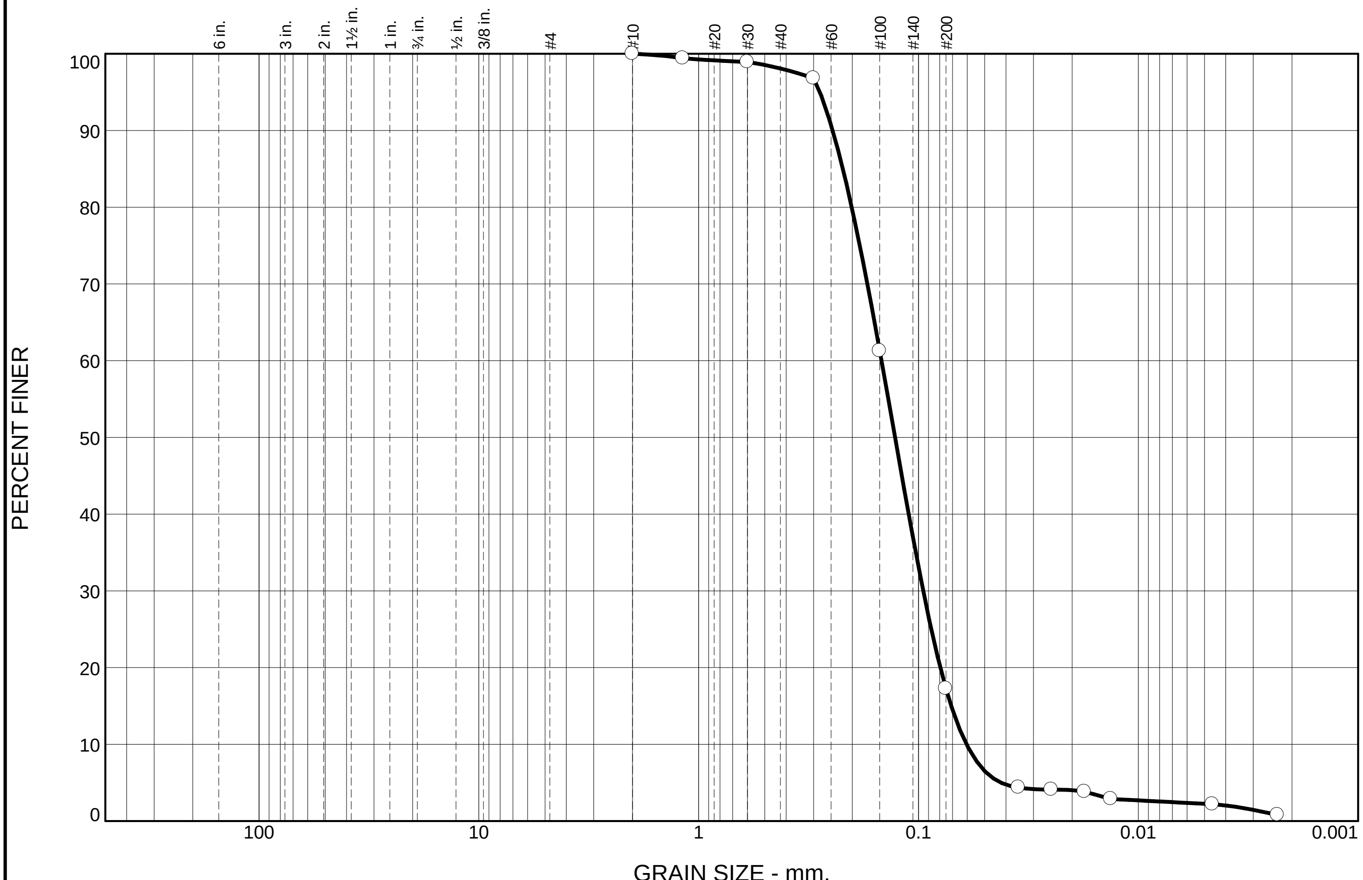
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.0	1.9	80.8	15.0	2.3

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.2208	0.1473	0.1278	0.0951	0.0709	0.0604	1.02	2.44

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** BR5 **Depth:** El. 219.18 **Sample Number:** S1

Remarks:
○Malnati

GEI Consultants, Inc.
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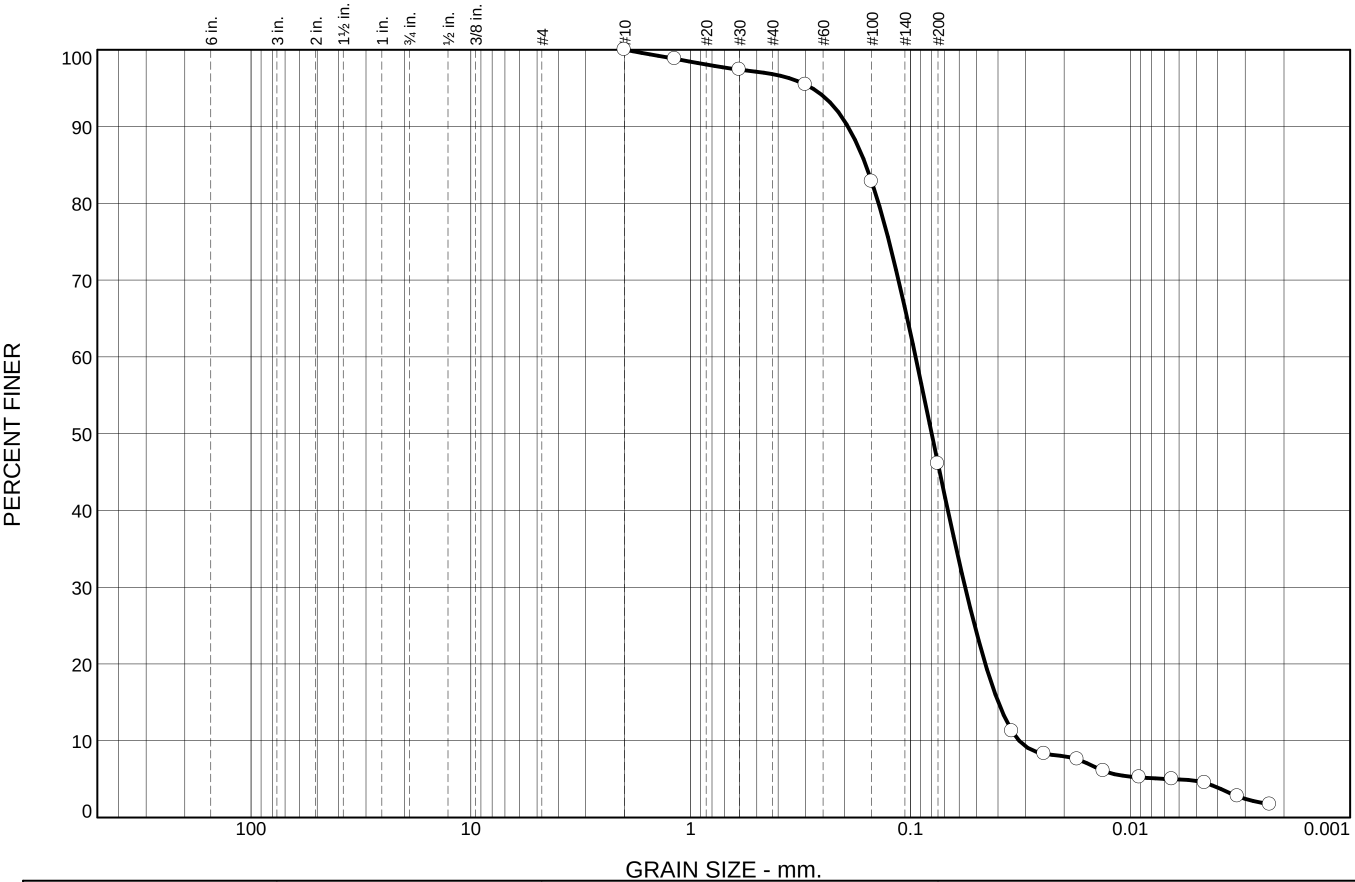
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.0	3.2	50.7	41.3	4.8

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1597	0.0948	0.0801	0.0564	0.0398	0.0320	1.05	2.97

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** BR5 **Depth:** El. 221.5 **Sample Number:** S2

Remarks:

○Malnati

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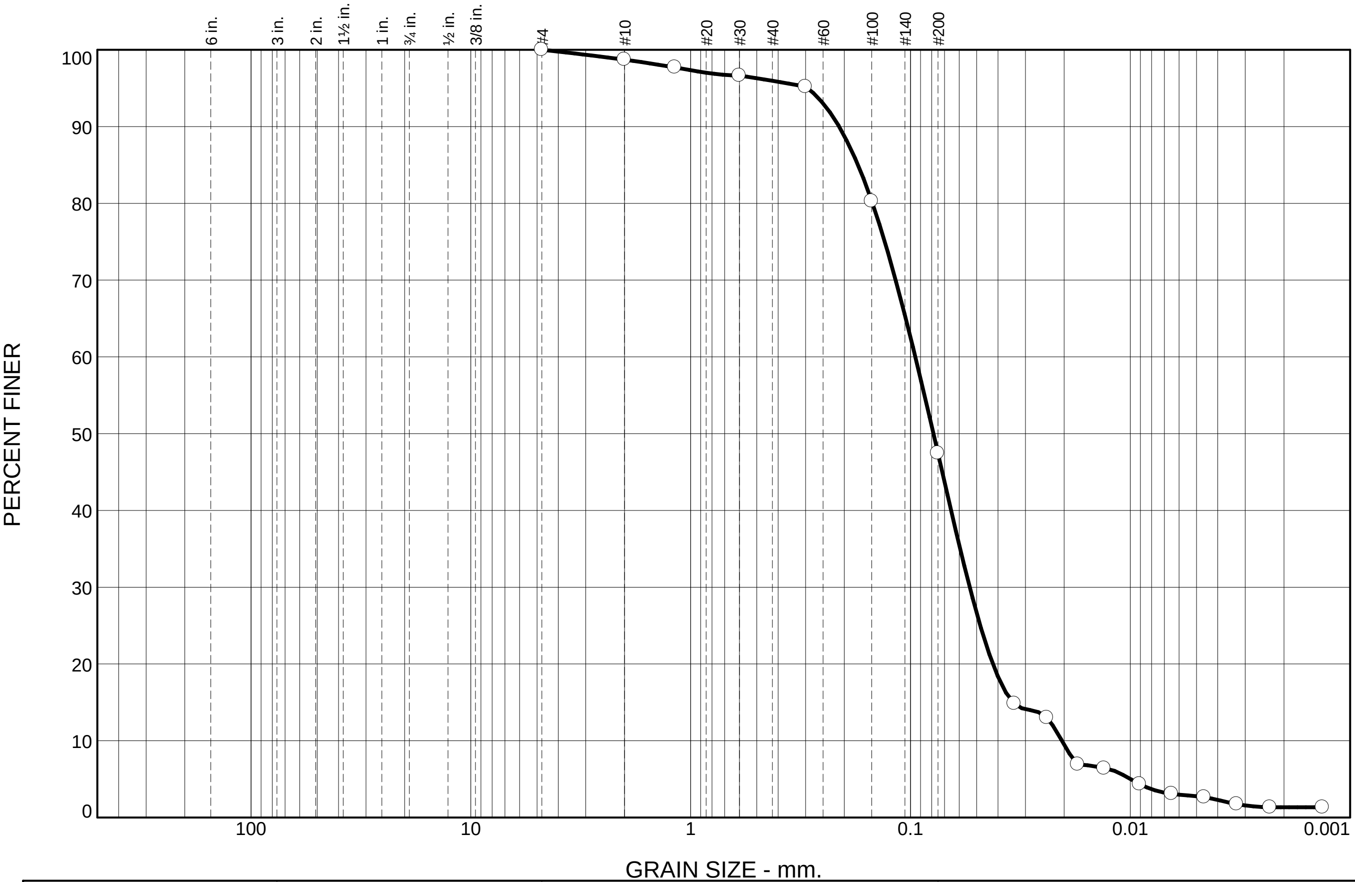
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	1.3	2.7	48.5	44.7	2.8

☒	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1733	0.0951	0.0786	0.0538	0.0341	0.0205	1.48	4.64

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** BR5 **Sample Number:** S3

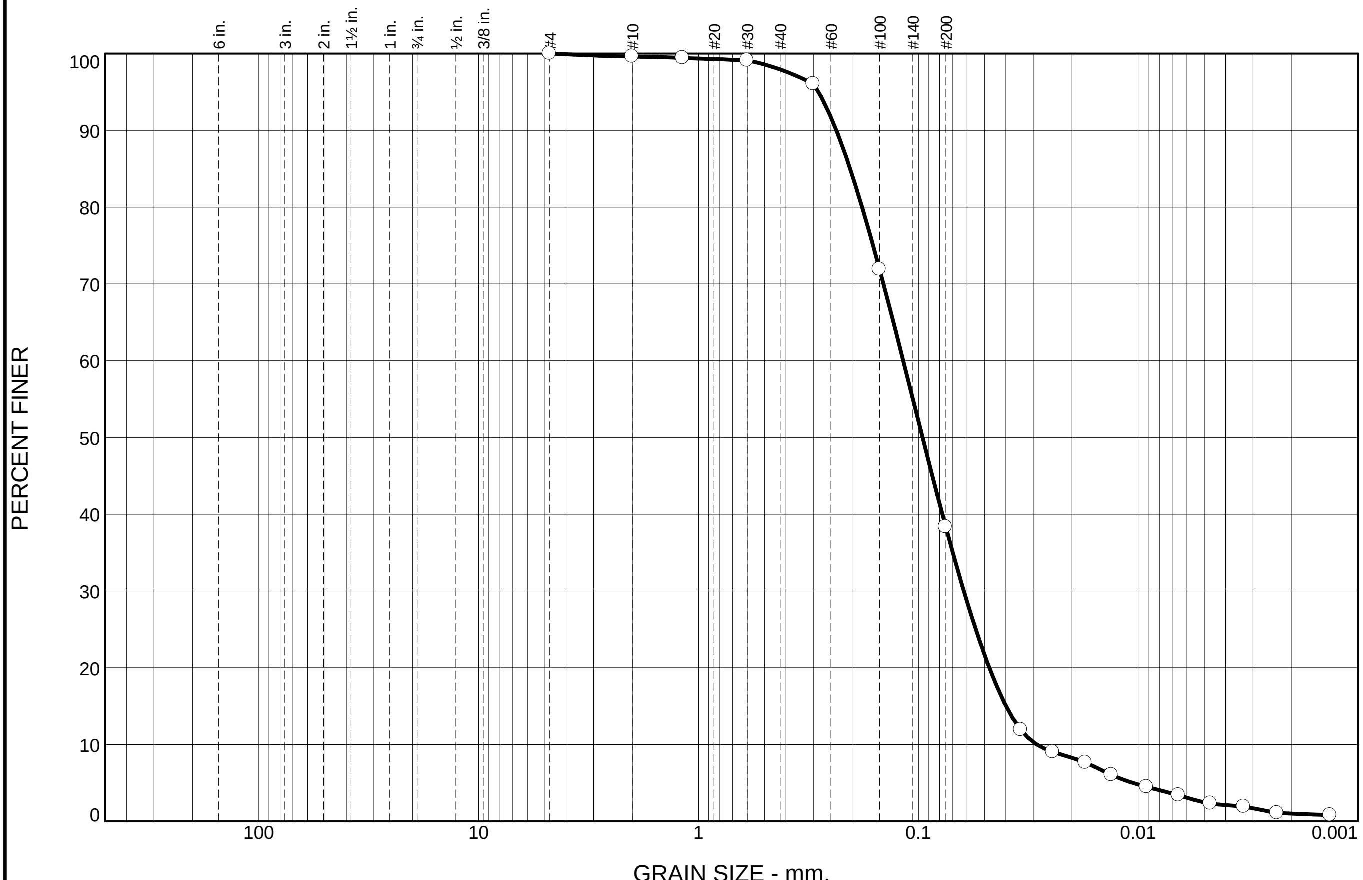
Remarks:
○Malnati

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.4	1.7	59.5	35.9	2.5

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.2042	0.1171	0.0956	0.0621	0.0399	0.0289	1.14	4.06

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** V2 **Depth:** El. 220.09 ft

Remarks:
○Riverview Farm U/S

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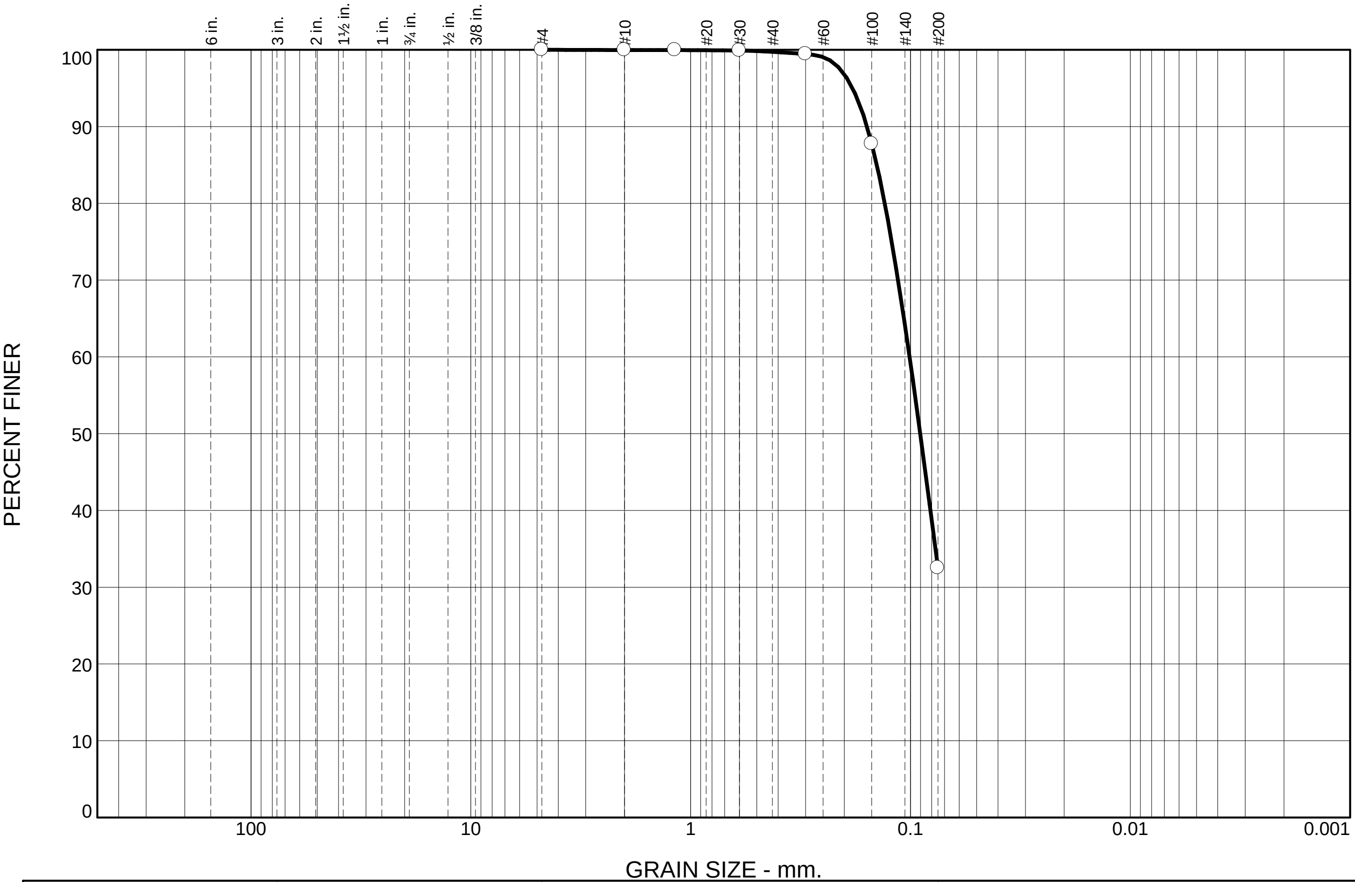
Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.0	0.3	67.2	32.5	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1422	0.1010	0.0903					

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** V2 **Depth:** El. 218.21 ft **Sample Number:** S2

Remarks:

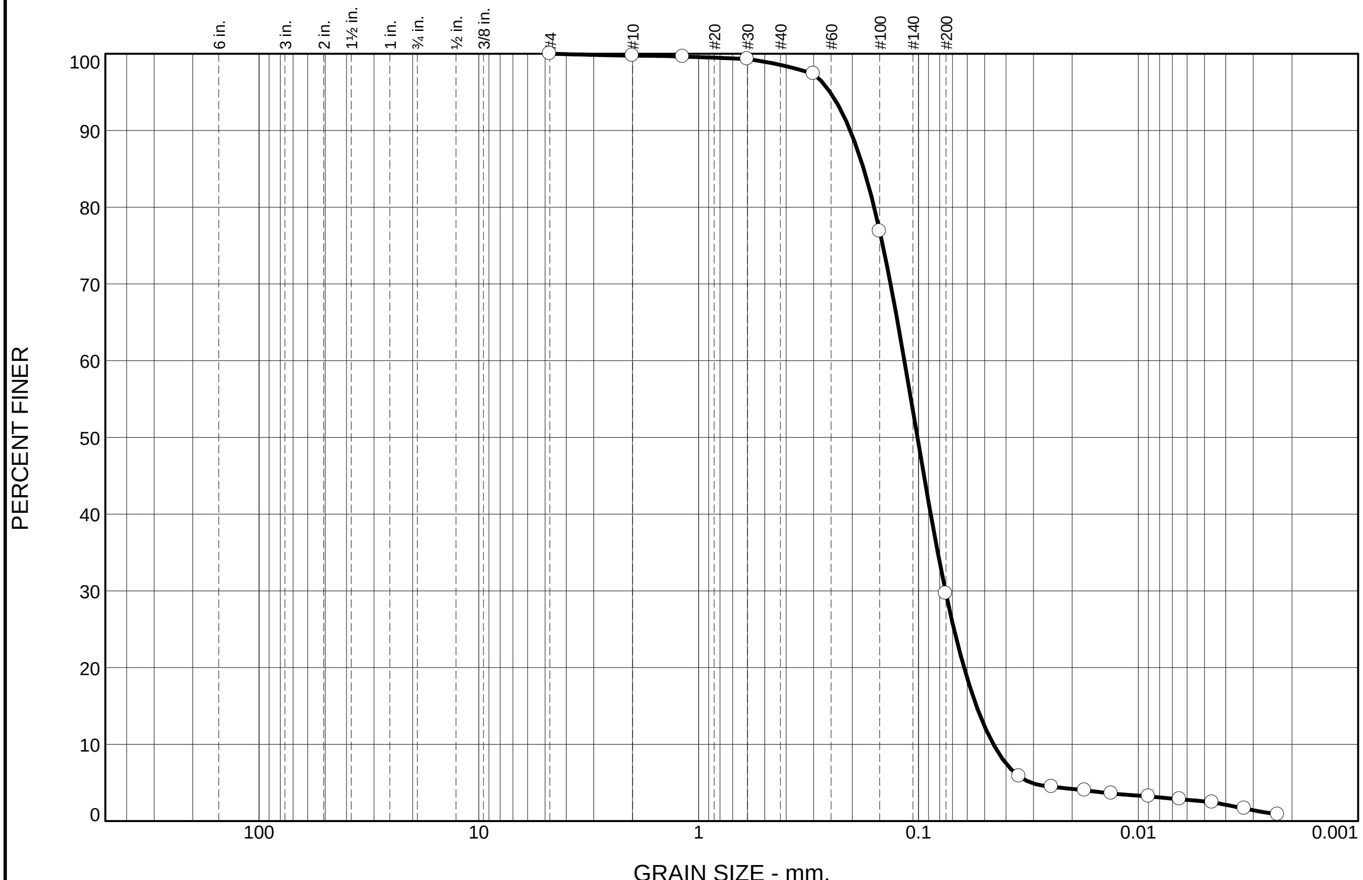
○Riverview Farm U/S

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: JG **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.2	1.3	68.8	27.1	2.6

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1775	0.1159	0.1011	0.0754	0.0545	0.0456	1.08	2.54

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** V3 **Sample Number:** S1

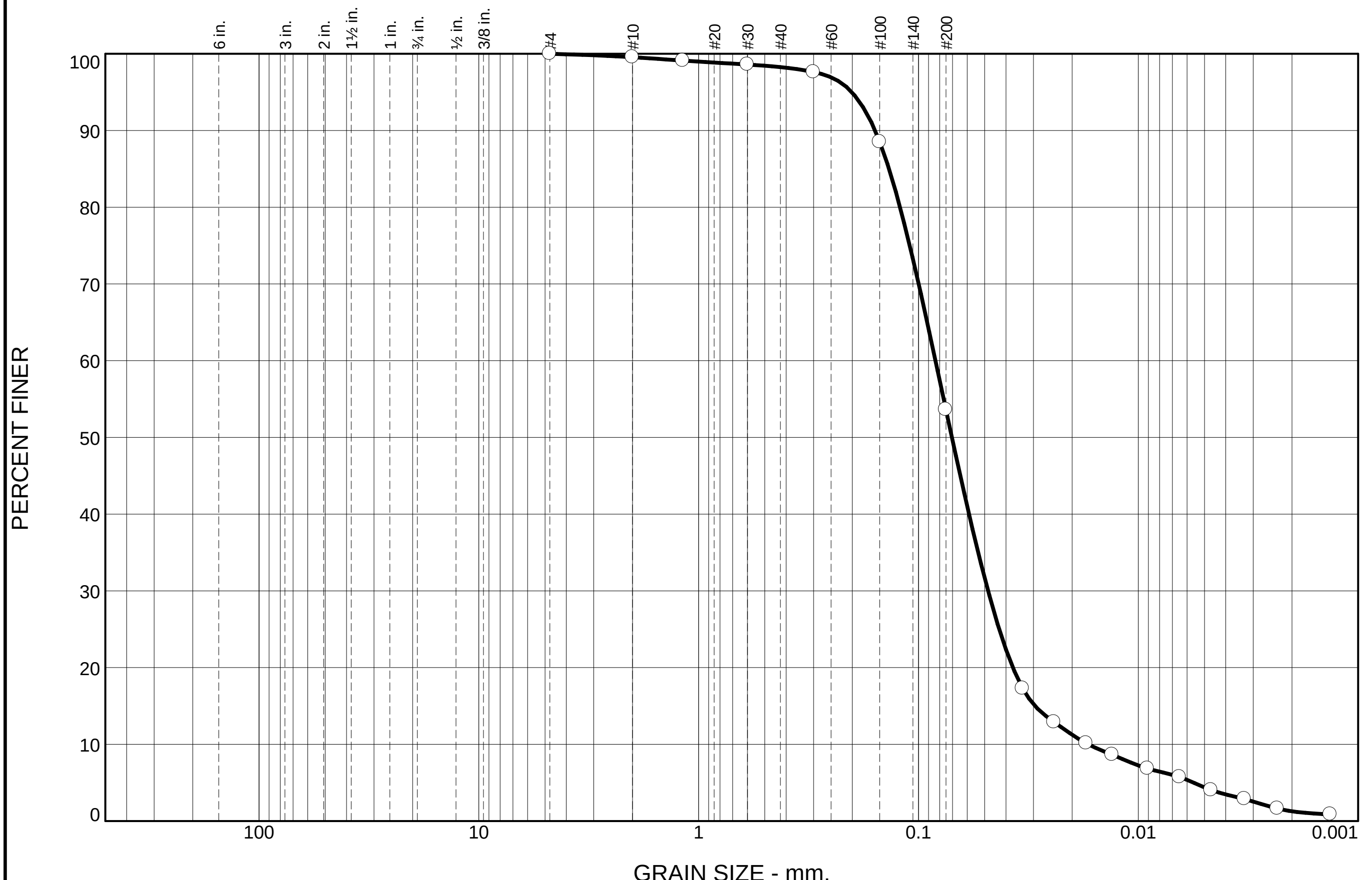
Remarks:
○Riverview Farm D/S

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.4	1.3	44.7	49.2	4.4

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	0.1361	0.0837	0.0705	0.0482	0.0295	0.0169	1.65	4.96

Material Description	USCS	AASHTO
○ Sandy SILT	ML	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** V3 **Sample Number:** S2

Remarks:

○Riverview Farm D/S

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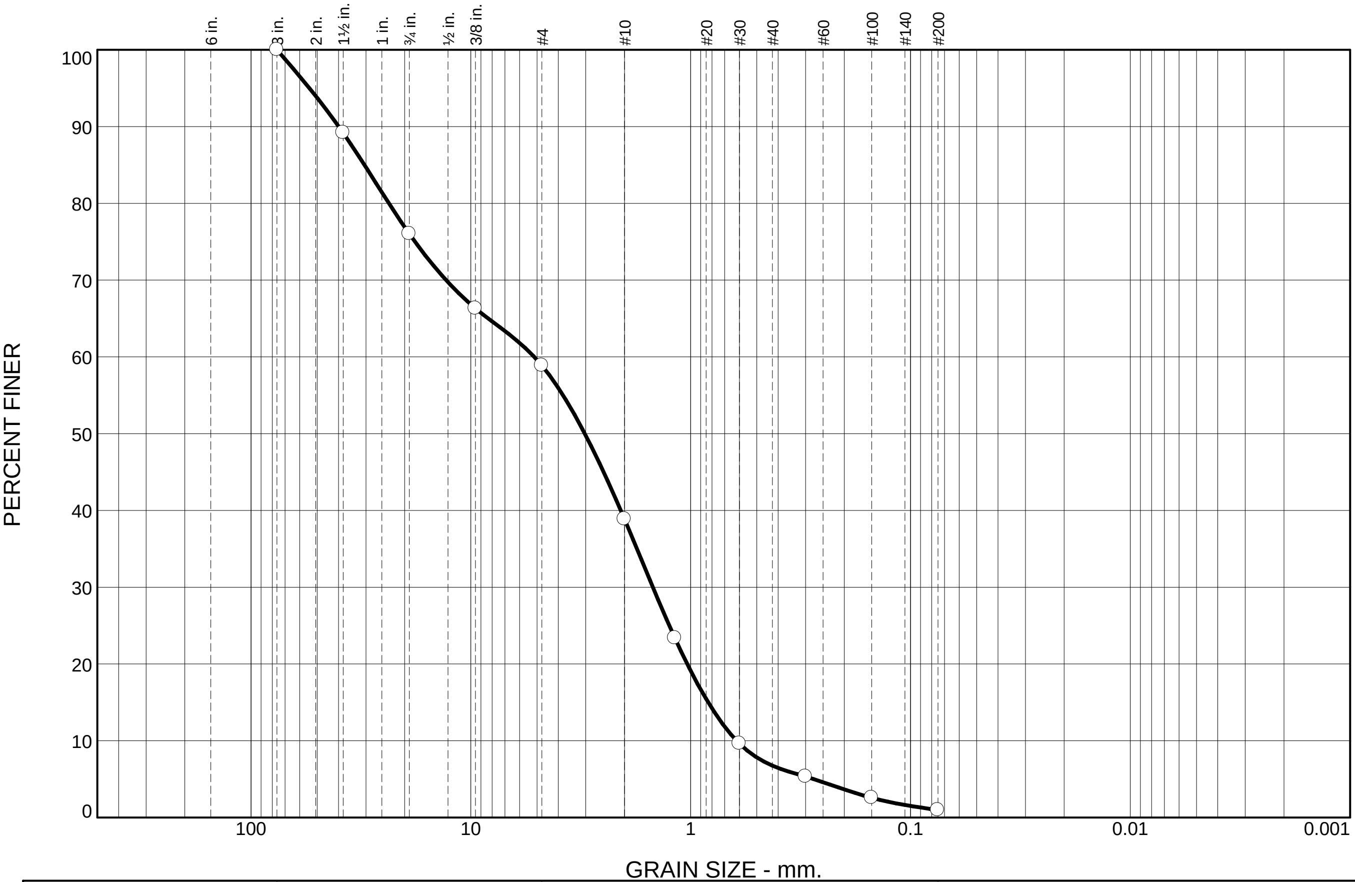
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	24.0	17.1	20.0	32.1	5.8	1.0	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	30.4925	5.1501	3.0297	1.4859	0.8317	0.6174	0.69	8.34

Material Description	USCS	AASHTO
○ Narrowly Graded SAND with Gravel	SP	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** V6 **Depth:** Beach **Sample Number:** S1

Remarks:

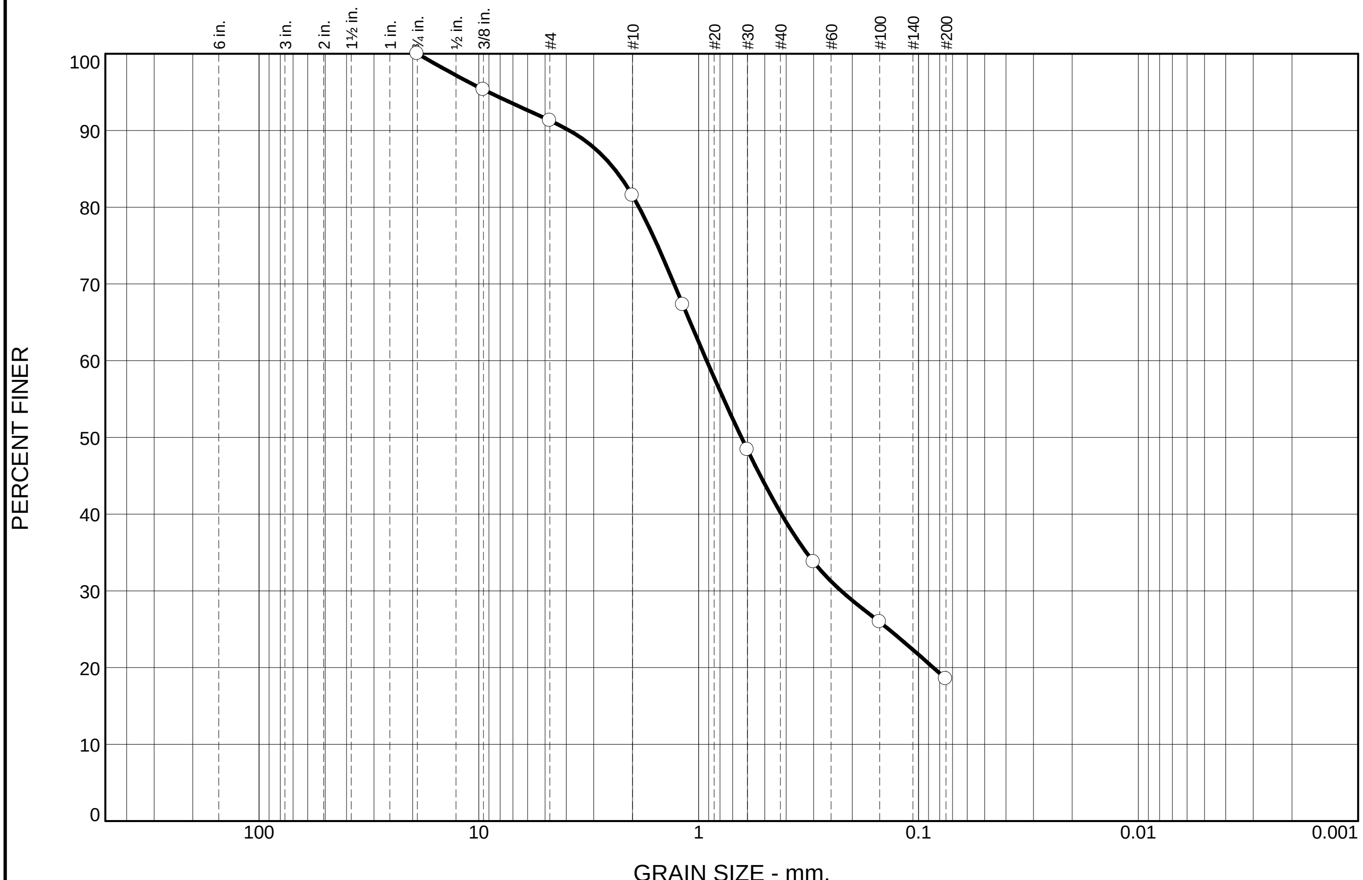
○LaCroix

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: NM **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	8.7	9.8	41.3	21.7	18.5	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	2.4180	0.9190	0.6387	0.2248				

Material Description	USCS	AASHTO
○ Silty SAND	SM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** V6 **Sample Number:** S2

Remarks:

○LaCroix

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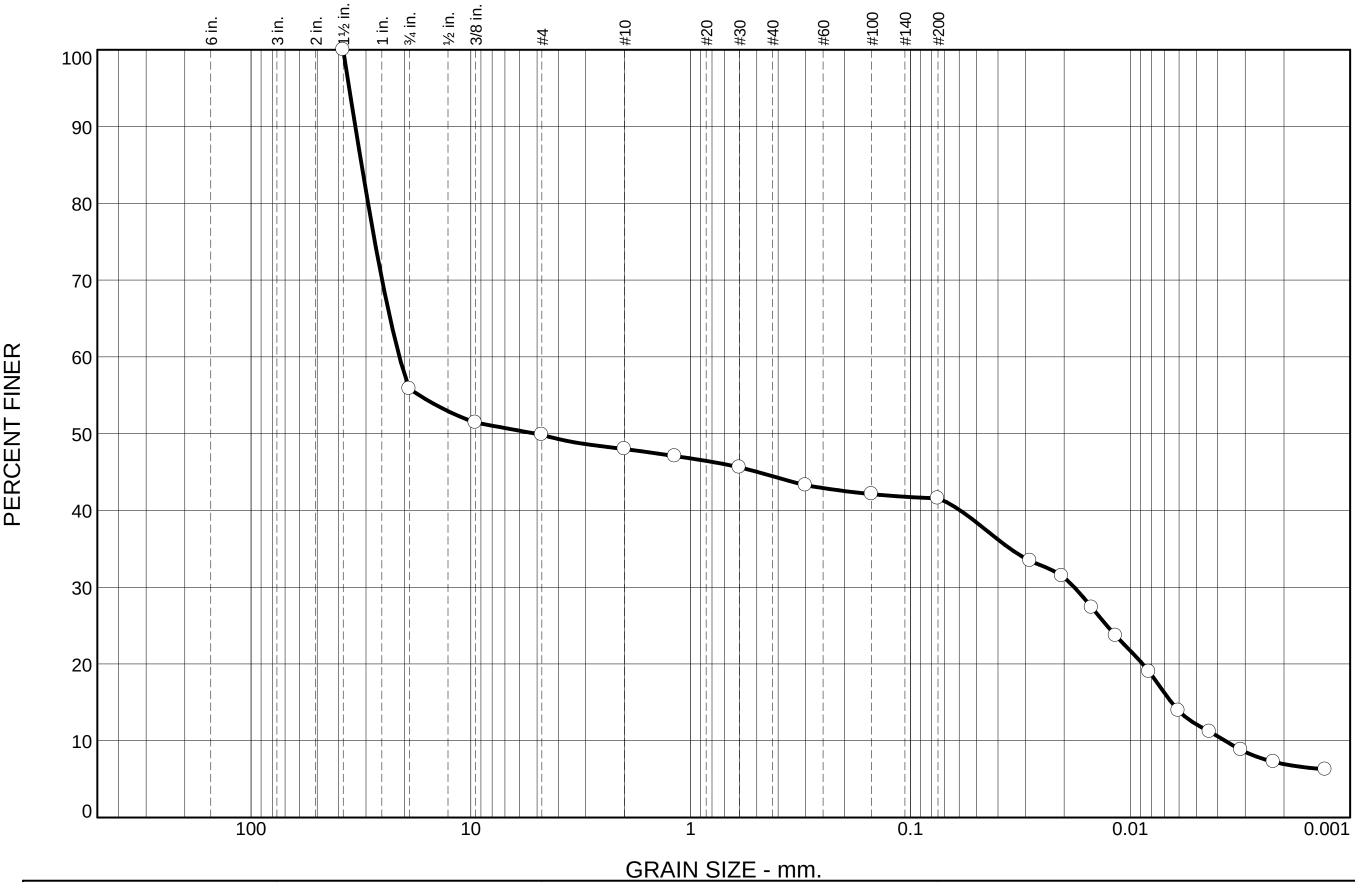
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: JG **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	44.1	6.0	1.9	3.5	2.9	29.5	12.1

╳	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	31.4019	21.1320	5.0579	0.0180	0.0065	0.0037	0.00	5708.15

Material Description	USCS	AASHTO
○ Silty GRAVEL	GM	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** VR1 **Depth:** El. 181.7 ft **Sample Number:** S1

Remarks:

○Vernon Bank

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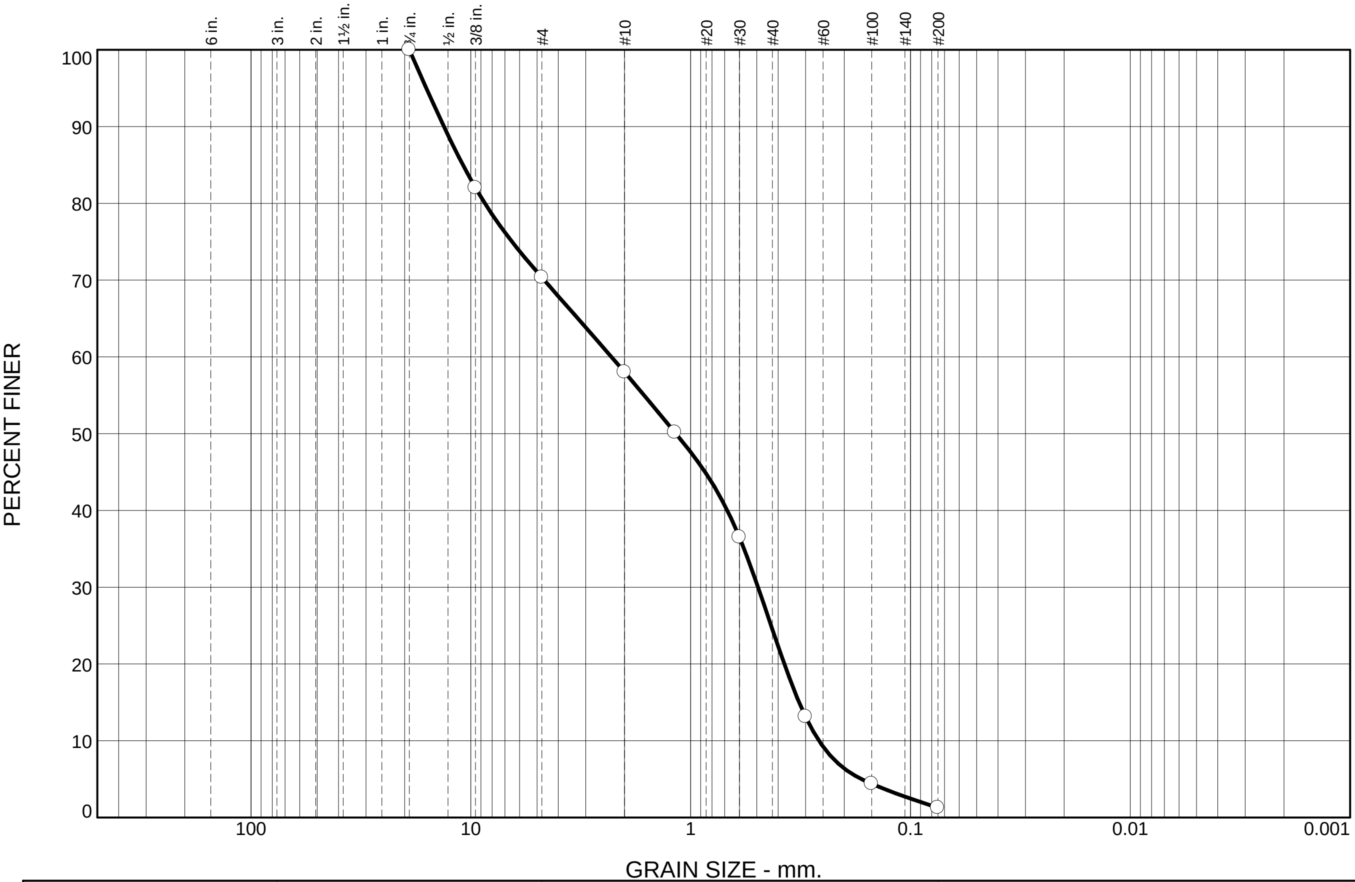
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	29.7	12.3	33.5	23.2	1.3	

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	-	-	10.8680	2.2931	1.1681	0.4938	0.3211	0.2607	0.41	8.80

Material Description	USCS	AASHTO
○ Narrowly Graded SAND with Gravel	SP	-

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** VR1 **Depth:** El. 184.41 ft **Sample Number:** S2

Remarks:

○Vernon Bank

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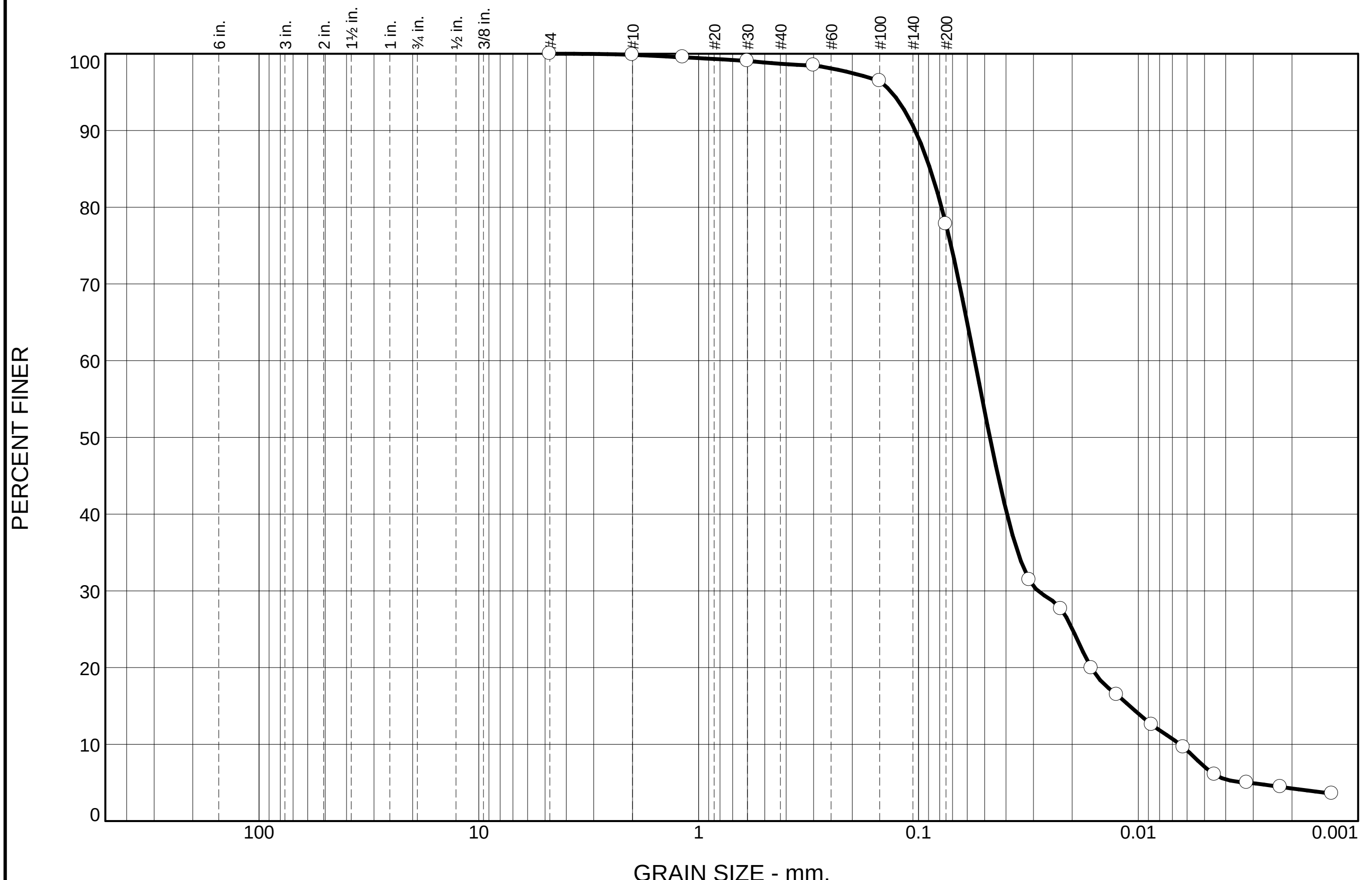
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: JG **Checked By:** EF

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.1	1.2	20.9	70.7	7.1

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	NV	NP	0.0885	0.0555	0.0473	0.0286	0.0109	0.0065	2.28	8.59

Material Description	USCS	AASHTO
○ SILT with Sand	ML	A-4(0)

Project No. 1402390 **Client:** Great River Hydro

Project: Erosion Study

○ **Source of Sample:** VR2 **Sample Number:** S1

Remarks:

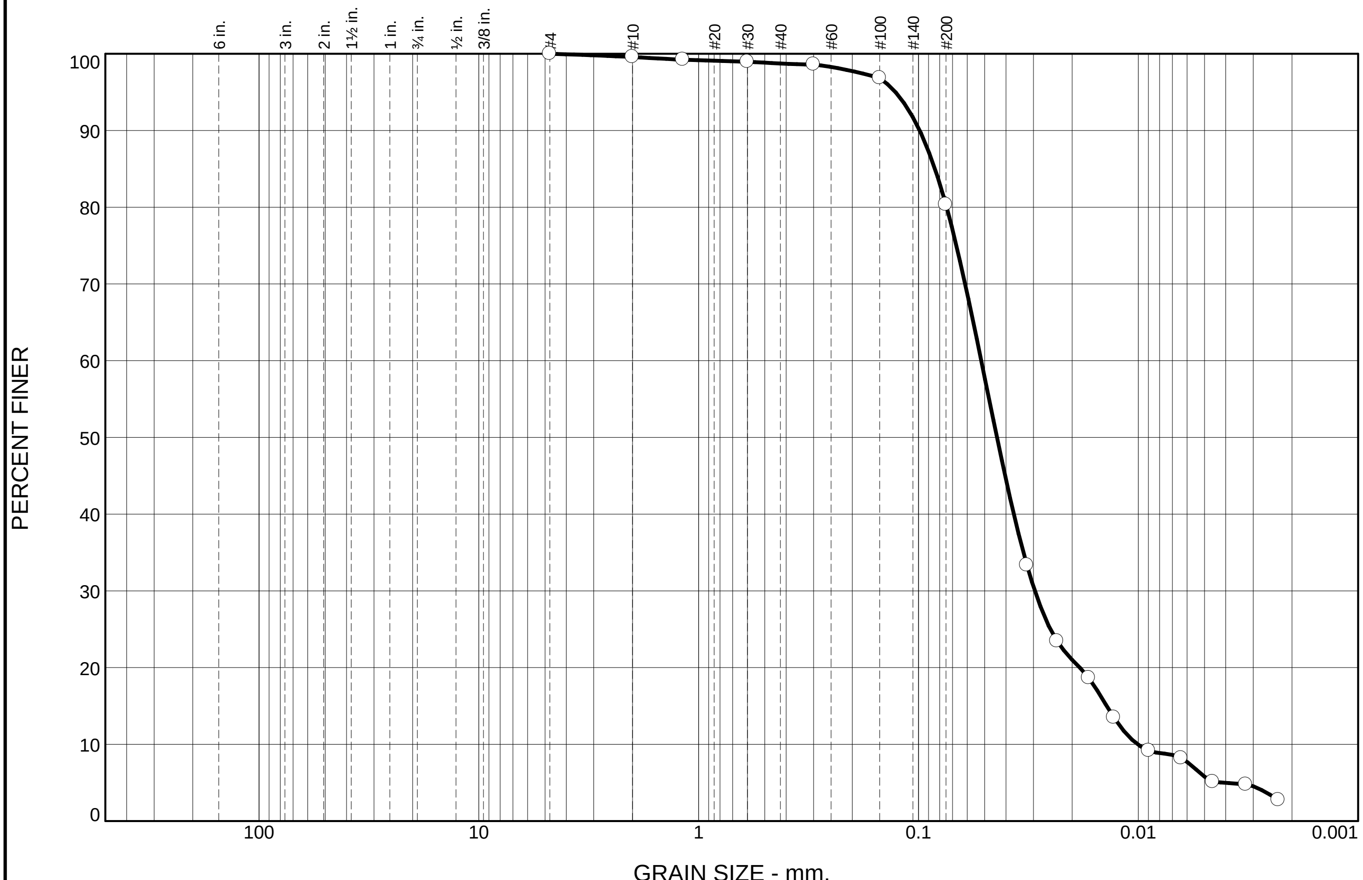
○Stebbins Island

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.4	0.9	18.4	74.5	5.8

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	NV	NP	0.0841	0.0518	0.0439	0.0296	0.0139	0.0101	1.67	5.14

Material Description	USCS	AASHTO
○ SILT with Sand	ML	A-4(0)

Project No. 1402390 **Client:** Great River Hydro
Project: Erosion Study

○ **Source of Sample:** VR2 **Depth:** El. 186.5 ft **Sample Number:** S2

Remarks:
○Stebbins Island

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400 Unicorn Park Drive
Woburn, MA 01801

Figure

Tested By: EF **Checked By:** DJA

APPENDIX C

Hydraulic Modeling Report

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GEI Consultants

Consulting Engineers and Scientists

November 2, 2017
Project 1402390

VIA EMAIL: jragonese@greatriverhydro.com

Mr. John Ragonese
Great River Hydro, LLC
112 Turnpike Road, Suite 202
Westborough, MA 01581

Dear John:

Re: Erosion Study 2-Dimensional Modeling
Connecticut River
New Hampshire and Vermont

Great River Hydro, LLC retained GEI Consultants, Inc. to perform 2-Dimensional (2D) modeling and run operational flow scenarios to estimate velocity and shear stress at 21 erosion monitoring sites on the Connecticut River in New Hampshire and Vermont. This work is based on the 1-Dimensional (1D) hydraulic model that was developed as part of relicensing under Integrated Licensing Process (ILP) Study 4, Hydraulic Modeling Study (GEI, 2016).

Background

As part of ILP Study 4, GEI created a 1D hydraulic model to simulate routing of river flow on the main stem of the Connecticut River in support of Federal Energy Regulatory Commission (FERC) relicensing efforts by Great River Hydro, formerly TransCanada Hydro Northeast Inc., for the Wilder Hydroelectric Project (FERC Project No. 1892), Bellows Falls Hydroelectric Project (FERC No. 1855) and the Vernon Hydroelectric Project (FERC No. 1904). The purpose of the 1D hydraulic model in ILP Study 4 was, along with the Operations Modeling (Study 5), to inform resource consultants about the effects of project operations on aquatic, terrestrial, and geologic resources. Figure 3-1 in Study 4 shows the hydraulic model study area and Figures 4-5a and 4-5b show the level logger locations, also referred to as the erosion monitoring sites associated with Erosion Studies 2/3.

These 21 erosion monitoring sites were evaluated in the 2D hydraulic model and are located at the river stations and hydraulic model node locations shown in Table 1. Individual 2D model flow areas were set up for each of the erosion monitoring locations, however two riverine erosion monitoring sites downstream of Vernon dam were relatively close to one another and were able to share the same 2D model flow area, resulting in 20 flows areas in total.

Model Development

GEI performed 2D modeling to estimate near-bank velocity and shear stress for a range of operational flows and water surface elevations at the downstream dam. We developed the 2D hydraulic model using the USACE 2D HEC-RAS model (USACE, 2016a) and an unsteady flow

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207.797.8901 fax: 207.797.4704

analysis for a mixed flow regime with computation interval of 10 seconds. At this computation interval and a model cell size of 10 ft by 10 ft, the courant number was kept below 5 in accordance with the HEC-RAS 2D User's Manual (USACE, 2016b). Model routing uses the 2D diffusion wave equation set, the default for HEC-RAS 2D.

Model Terrain

The 2D model terrain was based on the same digital elevation model developed for the 1D hydraulic model, which combined both topographic and bathymetric surveys. Topography refers to the elevations of land above the water surface while bathymetry refers to elevations of land below the water surface. Upstream of Vernon dam, topographic data was developed by Normandeau from high resolution LiDAR data acquired by U.S. Imaging between April 26 and May 8, 2013 (U.S. Imaging, 2013) and bathymetry data was acquired by Normandeau from July through September 2013 (Normandeau Associates, 2015a). Downstream of Vernon dam, topographic data from LiDAR was provided by U.S. Imaging (U.S. Imaging, 2013) and bathymetric data was provided by FirstLight.

The LiDAR survey was performed over an approximately 1-mile-wide swath that centered on the study reach of the Connecticut River. To perform the LiDAR survey, the river system was flown for 34.2 hours at a height of approximately 1,066 meters above ground level and at a speed of 120 knots traveling from south to north. The LiDAR system settings and flight parameters yielded a density of 3.8 points per square meter on a single flight line with 35 percent overlap for a resulting density of about 5 points per square meter.

Bathymetric surveys were needed to record elevations of land underwater that are not able to be recorded by LiDAR surveys. A more detailed description of the Normandeau bathymetry survey is provided in the ILP Study 7 Final Report (Normandeau Associates, 2015b). Information about the FirstLight bathymetric data is provided in FirstLight Relicensing Study 3.2.2, Hydraulic Study of Turners Falls Impoundment, Bypass Reach and Below Cabot (Gomez and Sullivan, March 2015).

The terrain included detailed bathymetry for all 21 erosion monitoring sites except for four sites where detailed bathymetry was not available and one site where bathymetry existed for the right channel (looking downstream) but was unavailable for the left channel. At these sites, the channel developed for the 1D model was "burned" into the terrain using standard methods outlined in the HEC-RAS 2D Modeling User's Manual (USACE, 2016c). A sensitivity analysis was performed using the same burning technique on a 2D flow area that had detailed bathymetry. The results indicated no significant reduction in the detail of the model results. In other words, the results for the sites with burned channels indicated velocities within 0.2 ft/s of the detailed bathymetry. Given safety and access issues related to collecting certain bathymetry data, as well as the time-sensitivity associated with responding to FERC's additional information request, GEI concluded that the burned channel method, which is standard modeling practice where detailed bathymetry is not available, was an appropriate approach for this project at the locations where detailed bathymetry was not available.

2-Dimensional Flow Areas

We imported the terrains into the HEC-RAS model using RAS Mapper and developed 2D flow areas for each monitoring location with a grid size of 10 ft by 10 ft. We developed 20 flow areas, one area for each monitoring location with the two monitoring locations downstream of Vernon dam that are relatively close together sharing the same 2D flow area.

The flow areas extended at least 0.5 miles upstream and downstream of the monitoring locations and in some cases 1 mile upstream and downstream. The model was run for the flows and downstream impoundment water surface elevations, and resulting water levels at the monitoring locations were checked against the 1D model to confirm the 2D models were producing consistent results with the 1D calibrated model.

Manning's n-values

Manning's n-values were entered as the same values as the calibrated 1D hydraulic model (GEI, 2016) across each flow area.

Dam Operating Conditions

The operational flows and downstream dam water surface elevations were input to the 2D model based on information provided by Great River Hydro. Flow and downstream dam water surface elevation inputs for the 2D model are summarized in Table 2. Simulated water surface elevations at the 2D flow areas along the reach are typically a function of the river flow. In the case of the impoundment or non-riverine sections, the simulated water surface elevations at the 2D flow areas are a function of both river flow and the water surface elevation at the downstream dam. For this reason, there are low, medium and high downstream dam water surface elevations for 2D areas located in the pool or non-riverine sections. There is typically only one downstream dam water surface elevation for the 2D flow areas in the riverine sections as shown in Table 2 as the downstream dam water surface elevation effect is de minimis and it is more of a function of discharge from upstream dam.

Boundary Conditions

For each of the model runs, the boundary condition at the upstream end of each 2D flow area was set to the range of low, medium and high operational flows provided by Great River Hydro (Table 2). The boundary condition at the downstream end of the 2D areas was set to the water surface elevation at the downstream end of the 2D area indicated in the 1D hydraulic model for the given flow and the water surface elevation at the downstream dam.

The water surface elevation in the 2D model results were checked for agreement with the calibrated 1D model for similar water surface elevations at the monitoring locations. There was a total of 153 model runs made for the 21 erosion monitoring locations. Water surface elevations in the 2D model compared very favorably with the 1D model and were within about 0.1 ft for 151 of the 153 runs. The two exceptions occurred for the low flow (2,000 cfs), low water surface elevation (175.6 ft) run for sites VR-01 and VR-02 located downstream of Vernon Dam. The combination of these two minimum conditions resulted in a water surface elevation difference between the 2D model and the 1D model of about 0.6 ft (2D minus 1D) at these two erosion monitoring locations. Water surface elevations for all other flow and downstream water surface elevations at these two erosion monitoring locations compare favorably with the 1D model.

This difference may be due to more detail captured in the 2D terrain than was captured in the 1D cross sections for the low flow scenario.

Results

The 2D model results provide information on velocity and shear stress at 21 erosion monitoring sites on the Connecticut River in New Hampshire and Vermont. This work was performed using the USACE HEC-RAS model in 2D, unsteady state along individual 2D areas at each of the 21 erosion monitoring locations. GEI ran the model to estimate velocity and shear stress at the 21 monitoring locations based on the flows and impoundment elevations shown in Table 2.

The model results were provided to Field Geology Services (Field Services) for their use in evaluating whether the operational flows and downstream dam water surface elevations result in velocities and shear stress at the near bank of the erosion monitoring locations that would exceed published thresholds for permissible velocity and critical shear stress of channel sediments. Model results of velocities and shear stress that are below published thresholds would suggest no potential for sediment mobilization from operational flows and downstream dam water surface elevations.

Model results were provided to Field Services in the form of the HEC-RAS files, which enable Field Services to view and analyze the results using the mapping and graphic tools internal to HEC-RAS Mapper.

Limitation

This report presents the modeling results for operation conditions identified by Great River Hydro using terrain data surveyed by U.S. Imaging and developed by Normandeau Associates and FirstLight. The model results are based on information provided by others. The results are also based on our judgement in model development.

The results of this analysis should only be used to estimate velocity and shear stress at the erosion monitoring locations. Actual flows, water surface elevations, velocities and shear stress may vary from those estimated by the model but in our judgement, provide a reasonable estimate based upon an appropriate estimation method. This analysis does not consider debris, or unforeseen gate blockage, the presence of which may affect the results.

Reuse of this report for any other purposes, in part or in whole, is at the sole risk of the user.

Sincerely,

GEI CONSULTANTS, INC.

Lissa Robinson, P.E. (ME, NH, VT)
Senior Civil Engineer, Hydrogeologist, Land Planner

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Attachments

Y:\PROJECTS\2014\1402390 TransCanada Hydraulic Model\2D Modeling Erosion Study\GEI_2D_Modeling_Rpt_11022017.docx

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Tables

Table 1: Erosion Monitoring Locations

Logger ID	River Station	Node	Hydraulics
02-W02	113.468	1166	pool
02-W03	110.171	1143	pool
02-W07	96.907	1040	pool
02-W09	91.611	999	pool
02-W10	89.809	985	pool
02-W12	81.919	919	pool
02-WR01	77.415	864	riverine
02-WR05	71.012	801	riverine
02-WR08	62.963	730	riverine
02-WR09	60.380	703	riverine
02-B01	58.717	686	pool
02-B03	52.634	632	pool
02-B07	41.168	552	pool
02-B09	35.959	523	pool
02-BR01	33.976	496	riverine
02-BR05	31.165	460	riverine
02-V02	21.658	377	pool
02-V03	21.300	373	pool
02-V06	10.236	194	pool
02-VR01	2.318	42	riverine
02-VR02	1.306	17	riverine

Table 2: Flows and Downstream Impoundment Water Surface Elevations

Erosion Monitoring Location	Downstream Impoundment WSEL (ft NAVD88)	Flow (cfs)
W_02	379.6	700
		5000
		12000
W_02	382.6	700
		5000
		12000
W_02	384.6	700
		5000
		12000
W_03	379.6	700
		5000
		12000
W_03	382.6	700
		5000
		12000
W_03	384.6	700
		5000
		12000
W_07	379.6	700
		5000
		12000
W_07	382.6	700
		5000
		12000
W_07	384.6	700
		5000
		12000
W_09	379.6	700
		5000
		12000
W_09	382.6	700
		5000
		12000
W_09	384.6	700
		5000

Erosion Monitoring Location	Downstream Impoundment WSEL (ft NAVD88)	Flow (cfs)
		12000
W_10	379.6	700
		5000
		12000
W_10	382.6	700
		5000
		12000
W_10	384.6	700
		5000
		12000
W_12	379.6	700
		5000
		12000
W_12	382.6	700
		5000
		12000
W_12	384.6	700
		5000
		12000
WR_01	290.2	700
		5000
		12000
WR_05	290.2	700
		5000
		12000
WR_08	290.2	700
		5000
		12000
WR_09	290.2	700
		5000
		12000
B_01	288.2	2000
		5000
		12000
B_01	290.2	2000
		5000
		12000
B_01	291.2	2000
		5000
		12000
B_03	288.2	2000
		5000
		12000
B_03	290.2	2000
		5000
		12000
B_03	291.2	2000
		5000

Erosion Monitoring Location	Downstream Impoundment WSEL (ft NAVD88)	Flow (cfs)
		12000
B_07	288.2	2000
		5000
		12000
B_07	290.2	2000
		5000
		12000
B_07	291.2	2000
		5000
		12000
B_09	288.2	2000
		5000
		12000
B_09	290.2	2000
		5000
		12000
B_09	291.2	2000
		5000
		12000
BR_01	217.6	2000
		5000
		12000
BR_05	217.6	2000
		5000
		12000
V_02	216.6	2000
		6000
		15000
V_02	217.6	2000
		6000
		15000
V_02	219.6	2000
		6000
		15000
V_03	216.6	2000
		6000
		15000
V_03	217.6	2000
		6000
		15000
V_03	219.6	2000
		6000
		15000
V_06	216.6	2000
		6000
		15000
V_06	217.6	2000
		6000
		15000

Erosion Monitoring Location	Downstream Impoundment WSEL (ft NAVD88)	Flow (cfs)
V_06	219.6	2000
		6000
		15000
VR_01	175.6	2000
		6000
		15000
VR_01	180.6	2000
		6000
		15000
VR_01	184.6	2000
		6000
		15000
VR_02	175.6	2000
		6000
		15000
VR_02	180.6	2000
		6000
		15000
VR_02	184.6	2000
		6000
		15000