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How Land Use Affects Water Quality Characteristics of Stormwater: A Study of Tub Mill Brook

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Abstract

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The Buzzards Bay watershed includes nine coastal communities in southeastern Massachusetts and Cape Cod with swimming beaches and extensive shellfish resources. This area has been the focus of environmental advocacy for the past few decades. Using modern stormwater management equipment, this study focused on detecting pollutants entering stormwater conveyance systems in Buzzards Bay, specifically looking at the watershed of Tub Mill Brook in the Town of Mattapoisett. In attempting to create rules for prioritizing stormwater investigations, four years of stormwater discharge water quality data were evaluated. Models were created in the attempt to quantify relationships between how an area of land is used (i.e., forest, commercial, residential, recreational, saltwater, freshwater, etc.) and the concentration or total load of contaminants found in stormwater conveyance systems. Weak correlations between pollutant discharge and land use were found, but the results were not sufficiently predictive of high contaminant concentrations entering stormwater systems.

In the case study, a systematic monitoring approach was used to identify potential illicit connections and analyze contaminants entering Tub Mill Brook. An inventory of existing stormwater infrastructure was performed, which included inspection and GPS tagging of structures, with most of the stormwater system in good condition. The collected data was used to update an online GIS database for Buzzards Bay Watershed. After five months of sampling water from outfall pipes along the brook and testing them for contaminants, Park Street in the Town of Mattapoisett was identified as a likely area where a nitrate source was polluting the brook. Surfactants and fecal bacteria were also high within the watershed especially along Route 6, one of the most trafficked roads in the area. Recommendations for the Town of Mattapoisett are that they continue monitoring the outfall pipes under dry and wet weather conditions, put a plan into place to inspect certain structures that require more specialized equipment, and use the findings of this study to better focus resources managing stormwater discharges to Tub Mill Brook.

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Table of Contents

List of Figures

List of Tables

Chapter 1: Current State of Stormwater Management

1.1 Introduction to Stormwater Drainage Systems

In a natural landscape, when rain falls onto the land, either the water will be quickly absorbed by the soil, or it will flow overland. This overland “stormwater” would be filtered by the soil and vegetation in the surrounding areas, and then replenish aquifers or other natural bodies of water [1]. When humans start altering landscapes and building infrastructure, stormwater does not infiltrate into the soil but instead travels along impervious surfaces, pools up in low-lying areas (flooding), and/or discharges into receiving waters. Impervious surfaces are those surfaces that prevent water from being absorbed into the soil [2]. These surfaces can be found across the globe, from stretches of paved roads and highways, buildings and rooftops, and large areas used as parking lots. Thus, a problem forms: how to move stormwater runoff across the impervious surfaces towards receiving waters without causing floods and without contaminating those bodies of water, impacting water quality with pollutants generally associated with stormwater runoff, such as fertilizers, hydrocarbons, metals, pathogens, and trash and debris [3].

According to the United States Environmental Protection Agency (USEPA), the primary purpose of stormwater drainage systems is to convey precipitation from pavement and ground surfaces to natural wetlands and other bodies of water [1]. These systems primarily consist of above-ground structures to capture water travelling overland, transferring them to underground pipes and structures which then carry the water to its end destination [4]. This end destination could be a natural body of water or a man-made structure such as a detention or infiltration basin. These basins are designed to detain and/or retain stormwater to decrease flooding, reduce flow rates, and reduce pollutant loads. Municipalities containing an “urbanized area” as defined by the US Bureau of the Census must apply for a Municipal Separate Storm Sewer System permit, commonly referred to as an MS4 permit [4]. Sources of pollution include byproducts of industrial and commercial businesses, soapy water from car washes, excess fertilizers, and even pet waste [5]. These pollutants may enter stormwater systems via direct pipe connections (referred to as illicit stormwater connections) or through surface runoff. These pollutants are thus conveyed to the bodies of water through the stormwater system and may cause impairments to water quality [5].

1.2 Regulations and Governing Plans for Stormwater Management

The US Environmental Protection Agency (EPA) have implemented certain programs into place for cities and towns to adhere to regulations governing stormwater management. The National Pollutant Discharge Elimination System (NPDES) stormwater program details all the steps and processes that need to be followed by municipalities [6]. Municipalities that are required to obtain an MS4 permit must outline and then implement a Stormwater Management Plan to meet the six necessary minimum control measures (MCMs): Public Education and Outreach, Public Participation/ Involvement, Illicit Discharge Detection and Elimination (IDDE), Construction Site Runoff Control, Post-Construction Runoff Control, and Pollution Prevention/ Good Housekeeping [7]. The EPA Office of Water published a series of fact sheets focused on NPDES and MS4 permits, their requirements, and suggested goals to meet the minimum control measures. These measures focus on different important tasks that the municipality must follow to minimize the contamination and pollution of stormwater.

MS4 permit goals focus on specific tasks that must be completed by town officials or contractors working in the municipality, such as implementing a plan to inventory all existing outfalls of stormwater and implementing a plan for Illicit Discharge Detection and Elimination (IDDE). Illicit discharges to a stormwater system are those connections leading to stormwater infrastructure where the material conveyed is not stormwater [9]. One example of an illicit connection would be if a house had a pipe that took water from a washing machine and conveyed that directly to a catchbasin along the street. This “wash water” would not only have dirt and debris from the washed clothes, but also the remains of the detergents and chemicals used to clean the clothes; all these materials would be poured directly into storm drains. This is very different from a sump pump, which is simply used to pump out any ground water or flood water that may get into an individual’s basement. These sump pump connections are not considered illicit connections so long as they only pump out only water accumulated in the basement.

1.3 IDDE Equipment and Techniques

Many pieces of equipment are adapted, developed, or converted for use by municipalities to meet their MS4 obligations. Companies such as Vevor make specialized endoscopes which have a camera attached to the end of a cable which can be uncoiled and used to push the camera along the pipe [10]. The base of the coiled cable also has a camera which allow for the user to view a live feed as the camera is pushed into the pipe or inspection point. These types of cabled cameras allow for visual inspection of areas of pipe, which can be useful for finding cracks or breaks in a pipe that could be leaking, blockages within the pipe, or for potential illicit connection detection. Other experimental equipment is being developed called “vine robots” which use hydraulic fluid or compressed air to extend material outwards from its center to extend the equipment forward [11]. Although experimental, further research has already been conducted into the viability of this type of device in an archaeological environment inaccessible by other equipment [12]. With similar environmental characteristics as those expected in stormwater investigations, this equipment seems to show great potential in the near future.

Municipalities, as mentioned above, must have Stormwater management Plans for their MS4 permit, including routine maintenance. Routine inspection and repair of drains, pipes, manholes, catchbasins,, and outlets of the stormwater system are vital to longevity and efficiency of the system. Many structures of stormwater systems can be visually inspected from the surface without requiring any special equipment. Catchbasins and manholes can easily be inspected by removing their covers with a prybar. Some specialized magnetic lifters are used by municipalities to make lifting easier [13]. These structures are checked to ensure pipes are not blocked and that sediment accumulation at the bottom of these structures does not impede water flow. If an accumulation of sediment is substantial enough (as outlined in municipality’s stormwater management plan or department of public works) then equipment such as a “clam” truck or vacuum are used to remove the sediment.

1.4 Thesis Goals

This thesis explores various techniques and equipment used to monitor stormwater systems in municipalities. Focusing on the Buzzards Bay watershed in Massachusetts, an initial data analysis was performed on historical water quality data collected over the past seven years by the Buzzards Bay National Estuary Program (NEP) to find any potential links between land use variables and concentrations of pollutants. The results of this data analysis could be used in the future for municipalities within Buzzards Bay to predict areas of high pollutant loads, and thus prioritize areas of land for stormwater monitoring. This analysis utilized land use characteristics provided by Massachusetts Bureau of Geographic Information (MassGIS).

The remainder of this project was focused on Tub Mill Brook, located in the town of Mattapoisett. Tub Mill Brook is a small river running from Interstate 195 under Route 6 into Eel Pond. Its headwaters are primarily marshy areas west of North Street. Most of the Tub Mill Brook watershed is residential housing, with some commercial property along Route 6. An analysis of Tub Mill Brook was performed in three parts. An initial delineation of Tub Mill Brook watershed was performed to distinguish catchments associated with each discharge and then to link land use characteristics to each catchment. A catchment is the area of land where all stormwater runoffs will combine and flow into a body of water at a single location, such as an outfall pipe. The second part of the Tub Mill Brook investigation considered existing development and infrastructure within each catchment, including quantifying length of pipes, numbers of catch basins, and manholes within each catchment. Based on this inventory, more focus was put on catchments where there seemed to be a higher likelihood of illicit connections.

While this inventory was ongoing, the final part of this case study was to monitor outfalls by collecting samples of water from each outfall during dry and wet weather events to test them for contaminant concentrations. Samples taken during dry weather would be used to determine possible illicit discharges, as water sources would not be from stormwater runoff. Wet weather samples could contain a combination of illicit discharge and stormwater or just stormwater. Lastly, the information gained from the inventory was used to redefine catchments where appropriate and calculate the water quality volumes of each catchment. The final goals of this study of Tub Mill Brook were to update or confirm existing online GIS information with all stormwater infrastructure information collected. The results of this investigation were reported to the Buzzards Bay National Estuary Program.

Chapter 2: Predicting Stormwater Pollutant Concentrations and Loads from Land Use in the Buzzards Bay Watershed

2.1 Introduction to Buzzards Bay Stormwater Collaborative

The analysis presented here is based on a review of stormwater water quality data collected by the Buzzards Bay Stormwater Collaborative under the guidance of the Buzzards Bay National Estuary Program. The Buzzards Bay National Estuary Program (NEP) is a part of the EPA's National Estuary Program and works with local municipalities to implement the Buzzards Bay Comprehensive Conservation and Management Plan (CCMP). As a science-based non-regulatory organization unit of state government, their work is wide ranging from project development to GIS support, to stormwater remediation, and much more [13]. One goal of the Buzzards Bay Comprehensive Conservation and Management Plan (CCMP) is to "Correct existing stormwater runoff flows to Buzzards Bay and contributing watershed areas that are adversely affecting shell fishing areas, swimming beaches, water quality, and wetlands, or exceeding watershed total pollutant load limits."

Recognizing the relationship between stormwater infrastructure and water quality of Buzzards Bay, the Buzzards Bay NEP began mapping stormwater discharges and catchbasins over 20 years ago, culminating in the first Buzzards Bay Stormwater Atlas, first released in 2003, and last published in 2012. The Stormwater Atlas data enabled the Stormwater Collaborative effort that began in 2016 to quickly implement a stormwater monitoring program, and provided the basis for a strategic monitoring plan, including potential monitoring site locations. Without the previous inventory, the start of the planned stormwater discharge monitoring efforts would have been significantly delayed.

This inventory allowed for easier accessibility to important information necessary to create an online GIS mapping of above-ground infrastructure and discharge locations. Following a systematic approach to verifying locations through GPS tagging, all known stormwater engineering plans and information pertaining to pipes and underground infrastructure of stormwater systems were scanned, geo-referenced, and ultimately integrated into the GIS database using references to above-ground structures. In some cases, field observations disagreed with written plans or previous knowledge; any new field information is currently being used to update the GIS database. This is not the focus of this project, but rather a necessary step in analyzing potential sources of illicit discharges.

To work towards meeting this goal, the Buzzards Bay NEP started taking samples of water within the Buzzards Bay Watershed and testing the samples for contaminants such as nitrates, chlorine, and bacteria. In 2016, Buzzards Bay NEP partnered with the Buzzards Bay Action Committee and the public works departments in Dartmouth, Acushnet, Fairhaven, Mattapoisett, and Wareham. Together, they formed the Buzzards Bay Stormwater Collaborative (BBSC) which to this day serves as the primary group tasked with mapping the stormwater structures and monitor wet and dry weather discharges [14]. In 2018, the BBSC expanded partnership to include the towns of Westport, Marion, and Bourne, and additionally partnered with Massachusetts Maritime Academy (MMA) to continue assessing the impacts of stormwater runoff on shellfish beds in Buzzards Bay. In 2020, MMA became the lead in managing the Stormwater Collaborative with strong support from the municipalities, Buzzards Bay NEP, and Buzzards Bay Action Committee. The accumulation of water quality data has been kept digitally in Excel. The following analysis was focused on using information on how the land in each catchment was used (residential, commercial, industrial, recreational, etc.) to predict contaminant concentration from outfall pipes.

2.2 Available Data

Catchments were characterized by area, and land use categories such as forest, crop, pasture, multi-family residential, high medium and low density residential, commercial, industrial, saltwater sandy beach, marina, nursery, forested wetland, cemetery, and many other categories defined in the MassGIS 2005 Land use dataset [15].[1] A complete list of these land use variables and their definitions is included in Appendix A. These land use variables were reported in square feet but were converted to the percentage of each variable per catchment by dividing the land use variable area by the total catchment area. Appendix A also includes a plot showing the percentage of each catchment covered by land use variables. Other catchment statistics evaluated include impervious surface area, building footprint (referred to as “structures”), and

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[1] 2005 Land Use data was used for this analysis over the 2016 Land Use data available from MassGIS because of technical issues with the 2016 data.

the number of residential and nonresidential units serviced by a sewer or septic system per acre of catchment. Impervious surface area and structures area were also converted to percentage of catchment area of each variable.

The stormwater network water quality data include levels of two forms of bacteria, (*Enterococcus* and fecal coliform), pH, salinity, chlorine content, nitrate content, temperature, conductivity, ammonia content, and levels of surfactants. Surfactants are typically used in detergents and other cleaning products. Salinity data can be used to determine whether there is seawater intrusion in the stormwater network (likely when salinity is greater than 10 parts-per-thousand (ppt). Both forms of bacteria content were reported in units of colony-forming units per 100mL, nitrate, ammonia, and surfactant concentrations were reported as parts-per-million (ppm, approximately equivalent to mg/L), chlorine was reported as parts-per-billion (ppb, approximately equivalent to 1000 mg/L), and temperature was reported in degrees Celsius. The database included other details such as date and time of sampling, sample location with a simplified drawing, weather, type of outlet (pipe, culvert, stream, roadcut, etc.), whether the conditions were wet or dry, town, and station. The month that samples were taken was recorded, and the weather conditions (wet or dry) was also recorded and kept with the data set for analysis.

2.3 Analysis Methods

Using the existing land use and water quality data, initial analysis was performed with the purpose of identifying any potential relationship between land use categories and contaminant levels. Firstly, some values of contaminants were limited by the testing equipment, and as such certain water samples returned values of less than the lower limit of the equipment or greater than the upper limit of the equipment. These test results are referred to as censored data because they are not accurate results, and instead bounded by the operating range of the instruments and equipment used for testing. Based on a 1993 research paper published in *Mathematical Geometry*, censored geochemical data can be modified to allow for more accurate results from statistical analyses. For tests resulting in a “less than ‘specified value’ ” scenario, the “specified value” was multiplied by a factor of 0.55, and for tests resulting in a “greater than ‘specified value’ ” scenario, the “specified value” was multiplied by a factor of 1.7 [16]. After modification of these censored data points, a new category within the water quality data was created labeled

DIN, for dissolved inorganic nitrogen, and calculated as the sum of the concentrations of nitrates and ammonia. Generally, higher concentrations of DIN can lead to more algal growth and potential algal blooms which can have negative effects on the natural ecosystems in water bodies. Using Microsoft Excel pivot tables, data was sorted by catchment, and then separated by weather condition (wet or dry) at time of sampling. For each weather condition, the arithmetic mean of all contaminant concentrations except for bacteria was calculated. Because bacteria levels varied by four orders of magnitude, geometric means were calculated instead of arithmetic means to diminish the weight of extreme values. A combined set of all weather conditions was also analyzed, with the same calculations as described above.

Water quality volume was next calculated as the impervious surface area multiplied by one inch of rainfall, reported in cubic feet. Using this water quality volume, the load of each contaminant was calculated as the concentration multiplied by the water quality volume. This calculation of total contaminant load was completed for each of the three subsets of data (wet weather, dry weather, and combined). This total contaminant load is the estimated total mass of the contaminant that would be conveyed through the stormwater system at that catchment by a storm with average total rainfall of 1 inch. If such a storm occurs, then this calculated load is the best estimate of the total amount of contaminants that would be washed through the stormwater system and introduced to the natural body of water the stormwater system drains into.

After these calculations were complete, the calculated data sets were uploaded into MATLAB and run through a stepwise linear algorithm (stepwiselm.m) to produce a model that would take the land use variables and predict concentrations of each contaminant or total contaminant load at each catchment. For this analysis, the dependent variables were the average concentrations of nitrates, ammonia, surfactants, geometric means of fecal and enterococcus bacteria, and calculated DIN. This algorithm takes each independent variable and performs an t-test to determine if the independent variable has any significance in predicting the contaminant concentration. In this case, we are trying to use the independent variables of land use percentages, number of septic tanks per acre, number of linkages to the sewer system per acre, and all the other variables above not including contaminant concentrations or loads to accurately predict concentrations or total load of each contaminant.

The algorithm starts with a constant value model and performs the t-test on each independent variable. The null hypothesis of this t-test is that the coefficient of each independent variable not in the model is zero, thus saying each has no statistical significance in predicting the concentration of contaminants. The alternate hypothesis is that any one of the variables not already in use in the model function has a coefficient not equal to zero, meaning the variable is significant in predicting the contaminant concentration. The t-test is performed for each possible value for the coefficient of independent variables to calculate the p-value of each scenario. This p-value represents the probability that the change in variance that occurs in the model due to adding this predictor variable is explained purely by chance and not by inclusion of this new predictor variable. If the p-value of the t-test is less than a specified alpha value (0.05 used in this study, which is the common default for this test), then the null hypothesis is rejected, and the predictor variable is added to the model function. This means that there is less than a 5% chance (a statistically small likelihood) this change in variation could occur without some influence of the predictor variable. The model function is more accurate at predicting the concentration of the contaminant with this independent variable included than if it were not included. The variable with the lowest p-value is most significant in increasing accuracy of the model, thus added to the model first. This process is repeated until the point where adding any independent variable, higher order term of independent variable, or combination of independent variables will all be rejected by the t-test.

In addition, at every iteration of creating the model, the algorithm performs a secondary t-test to determine if any variables or combination of variables should be removed. Like the process of adding a new independent variable, the null hypothesis is that the variable coefficient in the model is zero (thus insignificant to predicting the dependent variable). If the t-test calculates a p-value greater than a predefined beta (0.10 for this study), then the null hypothesis cannot be rejected. There is more than a 10% chance the predictor variable is not influential in predicting the contaminant concentration. This means the variable is not significant in increasing the accuracy of the model and is then removed. The final equation for a model would be expressed in the following general form:

$$[Contaminant\ Concentration/Load] = A_0 + \sum_{i=1}^{n} A_i * X_i^{B_i} + \sum_{i=1,j=1,i\neq j}^{n,n} A_{i,j} * X_i^{B_{i,j,i}} * X_j^{B_{i,j,j}}$$

Where:

A_0 is the constant intercept for the model.

X_i and X_j are the ith and jth predictor variables.

A_i and $A_{i,j}$ are constant coefficients associated with predictor variable X_i and with predictor variables X_i and X_j respectively.

B_i, $B_{i,j,i}$, and $B_{i,j,j}$ are the integer exponents associated with X_i, associated with X_i when variables X_i and X_j are multiplied together, and associated with X_j when variables X_i and X_j are multiplied together.

The model equation used to predict Surfactant concentrations under wet weather conditions, with values to four significant digits, is shown below:

$[Surfactants] = 0.6077 + 0.5904 * [\%\ Multi - Family\ Residential] - 0.2378 * [\%\ High\ Density\ Residential] + 12.51 * [\%\ Pasture] + 22.92 * [\%\ Water] + 889.0 * [\%\ Multi - Family\ Residential] * [\%\ Water]$

The output of this algorithm is extensive including a function handle to call the equation created by the algorithm, the names of each predictive variable selected to be included in the model, the coefficient associated with each predictive variable in the model function, the input values of each parameter including known contaminant concentration or load, the predicted output for each sample from the model function, the residuals for each sample, and calculations for mean squared error (MSE), root mean squared error (RMSE) and coefficient of determination (R^2). These later values, especially R^2, were used to determine how useful these models are at predicting the concentrations and loads of each contaminant.

The final analysis of the historical water quality data within the Buzzards Bay Watershed was to separate samples into groups based on the month of the year and statistically analyze if there are major differences between each subset of data. This was done graphically by creating box-and-whisker plots and histograms to visually identify if there may be differences in the mean contaminant concentrations from month to month, as well as analytically by way of the f-test to compare two variances. This test was applied to compare every subset of data to one another (i.e., samples taken during March would be compared to samples taken during April, May, June, etc., samples taken during April would be compared to samples taken during May, June, July, etc., and so on until all subsets of the data set were tested against every other subset). The f-test calculates the variance of each subset of data, the ratio of these two variances (the f-statistic), and then a p-value that is associated with the f-statistic. If this p-value is less than 0.05, then the null hypothesis that the data from both subsets come from a single population with the same variance is rejected. Rejection of the null hypothesis in this case would mean the two subsets of data likely do not come from the same population, but instead represent two separate populations of data.

2.4 Analysis Results

36 models were created with the stepwiselm.m algorithm, 6 for each contaminant, surfactant, nitrate, ammonia, DIN, fecal bacteria, and enterococcus bacteria. One model was created to best predict the concentration of each contaminant under dry weather conditions, a second for wet weather conditions, and a third for all weather condition, dry and wet. A fourth model was created to best predict the total load of each contaminant under dry weather conditions, a fifth for wet weather condition, and a sixth for all weather conditions, dry and wet. Table 2.1 shows the resultant predictive variables and parameters for the model created to predict the concentration under dry conditions of each contaminant. Table 2.2 shows the results for wet weather conditions, and Table 2.3 shows the results for all weather conditions. Table 2.4 shows the predictive variables and parameters associated for the model created to predict the total load of each contaminant under dry conditions. Table 2.5 shows the same results for the models created to predict total load of contaminants under wet conditions, and table 2.6 shows the same results for predicting total load of contaminant under all weather conditions.

In each table, the contaminant listed is the dependent variable of the model. For each dependent variable, predictor variables added to the model are listed. The “estimate” is the coefficient associated with the predictor variable within the model function, “SE” represents the calculated standard error of the “estimate,” “tstat” is the t-statistic value associated with determining whether the predictor variable is significant in predicting contaminant concentration (dependent variable), and “p-value” is the probability of this t-statistic occurring without influence of the predictor variable. As stated above, 0.05 was used as the upper threshold for the p-value to determine if the predictor variable was significant in increasing accuracy of the model. The coefficient of determination, R^2, is associated with the model predicting the dependent variable and represents the amount of total variation within the data that can be explained by the model. Values range from 0 to 1, and higher values of R^2 represent a more accurate model than lower values. For purposes of this study, the following scale was used to characterize model accuracy and usefulness: R^2 less than 0.35 represents no correlation between predictor variables and contaminant concentration, R^2 between 0.35 and 0.65 represents a weak correlation, and R^2 greater than 0.65 represents a strong correlation. Predictor variables shown as “variable 1 * variable 2” are two variables multiplied together to form a single predictor variable in the model.

Table 2.1 Models to Predict Contaminants Concentrations Under Dry Weather Conditions

Contaminant	**Predictor Variable**	**Estimate**	**SE**	**tstat**	**P-value**	**R^2 of model**
DIN	% Structures	-7.127989893	2.812124888	-2.535	1.270E-02	0.2315
	% Transitional	202.3352679	48.63916887	4.160	6.448E-05	
	% Powerline/Utility	36.9690351	17.79914079	2.077	4.020E-02	
NH3	% Saltwater Wetland	77.6131752	7.78158451	9.974	4.892E-17	0.4877
	% Commercial	0.535442008	0.214857425	2.492	1.421E-02	
NO3	% Structures	-8.481477268	2.759600009	-3.073	2.674E-03	0.229
	% Transitional	210.4963699	48.06440019	4.379	2.744E-05	
Surfactants	Non Residential Sewer Connections per Acre	0.814287841	0.282577001	2.882	4.789E-03	0.2176
	% Multi-Family Residential	2.406000008	0.938158319	2.565	1.173E-02	
	% Medium Density Residential	0.706485828	0.254091311	2.780	6.425E-03	
	% Non-Forested Wetland	10.26031537	4.329667744	2.370	1.961E-02	
	% Water Based Recreation	3.930303862	1.916805395	2.050	4.279E-02	
Fecal	% Structures	5.036705863	1.727165474	2.916	4.881E-03	0.2322
	% Water	-531.4828202	164.881665	-3.223	1.995E-03	
	% Marina	7.701333798	2.939275181	2.620	1.096E-02	
Enterococcus	% High Density Residential	0.572786941	0.188533971	3.038	2.980E-03	0.1807
	% Golf Course	-86.99816994	41.58532601	-2.092	3.876E-02	
	% Urban Public/Institutional	-0.848580399	0.412077722	-2.059	4.185E-02	

Table 2.2 Models to Predict Contaminants Concentrations Under Wet Weather Conditions

Contaminant	**Predictor Variable**	**Estimate**	**SE**	**tstat**	**P-value**	**R^2 of model**
DIN	% Multi-Family Residential	2.200488434	0.889093293	2.475	1.443E-02	0.1177
	% Medium Density Residential	0.923373028	0.376656276	2.452	1.537E-02	
	% Forested Wetland	36.97453798	11.18434333	3.306	1.183E-03	
NH3	% Pasture	22.7028674	4.687777326	4.843	3.120E-06	0.2006
	% Water	43.09287694	11.16743587	3.859	1.680E-04	
NO3	% Cropland	16.58697801	8.007205558	2.072	3.999E-02	0.081
	% Forested Wetland	25.45737998	8.254593019	3.084	2.424E-03	
Surfactants	% Multi-Family Residential	0.590350477	0.341774914	1.727	8.620E-02	0.2127
	% High Density Residential	-0.237797896	0.111496365	-2.133	3.459E-02	
	% Pasture	12.51228971	5.045309377	2.480	1.426E-02	
	% Water	22.92047238	12.36170074	1.854	6.571E-02	
	% Multi-Family Residential * % Water	889.0085191	240.6264794	3.695	3.094E-04	
Fecal	% Freshwater Wetlands	-12.60064984	4.689581149	-2.687	9.660E-03	0.2246
	% Participation Recreation	-2.676074756	1.188379154	-2.252	2.858E-02	
Enterococcus	% Forested Wetland	-8.551138655	4.327543689	-1.976	4.996E-02	0.0687
	% Participation Recreation	-1.776211079	0.726679514	-2.444	1.565E-02	

Table 2.3 Models to Predict Contaminants Concentrations Under Dry and Wet Weather Conditions

Contaminant	Predictor Variable	Estimate	SE	tstat	P-value	R^2 of model
DIN	% Transitional	223.3815305	43.65003297	5.118	7.576E-07	0.1902
	% Pasture	31.62273132	11.16131217	2.833	5.108E-03	
	% Forested Wetland	23.01285298	7.063308665	3.258	1.330E-03	
NH3	% Pasture	1.090963903	7.506180876	0.145	8.846E-01	0.2091
	% Water	41.3975182	9.66073051	4.285	2.899E-05	
	% Pasture * % Water	32399.30099	12183.64674	2.659	8.500E-03	
NO3	% Medium Density Residential	0.647249025	0.271728445	2.382	1.822E-02	0.2316
	% Low Density Residential	1.146390102	0.530876468	2.159	3.208E-02	
	% Transitional	240.3730408	39.1643088	6.138	4.860E-09	
	% Forested Wetland	17.30727561	6.500223647	2.663	8.427E-03	
Surfactants	Residential Properties Per Acre	0.199261119	0.0389602	5.114	7.788E-07	0.2105
	% High Density Residential	0.097708729	0.27194118	0.359	7.198E-01	
	% Transportation	4.261477275	1.611228726	2.645	8.871E-03	
	% Non-Forested Wetland	9.210520427	3.317338337	2.776	6.057E-03	
	% High Density Residential * Residential Property Per Acre	-0.240560114	0.062397984	-3.855	1.591E-04	
Fecal	% Saltwater Sandy Beaches	8.101094069	3.631089616	2.231	2.831E-02	0.0977
	% Mining	3.283122618	1.539487784	2.133	3.584E-02	
Enterococcus	% Freshwater Wetlands	-8.435873	2.864168836	-2.945	3.625E-03	0.1159
	% Urban/Public/Institutional	-1.496086975	0.353164147	-4.236	3.525E-05	

Table 2.4 Models to Predict Total Contaminant Load Under Dry Weather Conditions

Contaminant	**Predictor Variable**	**Estimate**	**SE**	**tstat**	**P-value**	**R^2 of model**
DIN	% Transitional	702443820.9	88200964.3	7.964	1.812E-12	0.3849
	% Pasture	107774574.4	50049387.63	2.153	3.351E-02	
NH3	% Transitional	10487088.96	4917766.52	2.132	3.519E-02	0.0397
NO3	% Transitional	707839597.1	81525288.88	8.682	4.253E-14	0.4226
	% Pasture	102576450.3	46258621.88	2.217	2.867E-02	
Surfactants	% Multi-Family Residential	2410909.014	958644.5946	2.515	1.337E-02	0.1484
	% Transitional	113553901.3	31237682.02	3.635	4.256E-04	
Fecal	% Structures	5.416328895	2.279672697	2.376	2.042E-02	0.0788
Enterococcus	% High Density Residential	0.578846175	0.224646024	2.577	1.129E-02	0.0564

Table 2.5 Models to Predict Total Contaminant Load Under Wet Weather Conditions

Contaminant	Predictor Variable	Estimate	SE	tstat	P-value	R^2 of model
DIN	% Cemetery	96677726.49	21985977.75	4.397	2.043E-05	0.1122
NH3	% Cemetery	15026561.22	5303605.429	2.833	5.229E-03	0.0499
NO3	% Medium Density Residential	1019832.659	467988.7638	2.179	3.086E-02	0.1361
	% Cemetery	210002041.5	70445862.25	2.981	3.346E-03	
	% Medium Density Residential * % Cemetery	-312455555.1	146414373.4	-2.134	3.444E-02	
Surfactants	% Multi-Family Residential	698291.5213	428932.9427	1.628	1.056E-01	0.1471
	% Cemetery	8684040.966	9186654.072	0.945	3.460E-01	
	% Multi-Family Residential * % Cemetery	327499925.7	120222508.8	2.724	7.213E-03	
Fecal	% Impervious Surfaces	-2.663623054	0.593193226	-4.490	4.206E-05	0.4206
	% Industrial	92.43722056	32.76276607	2.821	6.841E-03	
	% Forested Wetland	-23.70116261	6.329889095	-3.744	4.682E-04	
	% Mining	2.801330117	1.42028948	1.972	5.411E-02	
Enterococcus	% Saltwater Sandy Beaches	-11.84124935	3.047829923	-3.885	1.530E-04	0.3203
	% Forest	-1.352002936	0.385524565	-3.507	5.983E-04	
	% Cemetery	19.84983276	8.322823492	2.385	1.833E-02	
	% Brushland/Successional	-3.741974555	1.200308504	-3.118	2.187E-03	
	% Brushland/Successional * % Forest	566.858629	284.6796475	1.991	4.827E-02	

Table 2.6 Models to Predict Total Contaminant Load Under Dry and Wet Weather Conditions

Contaminant	**Predictor Variable**	**Estimate**	**SE**	**tstat**	**P-value**	**R^2 of model**
DIN	% Transitional	710480132.8	71759548.93	9.901	6.718E-19	0.3498
	% Cemetery	25925432.66	12067131.09	2.148	3.295E-02	
NH3	None	-	-	-	-	-
NO3	% Transitional	714994346.6	61563570.98	11.614	6.174E-24	0.4139
Surfactants	% Multi-Family Residential	999695.0788	492738.2034	2.029	4.388E-02	0.1238
	% Medium Density Residential	427408.7486	184936.6002	2.311	2.191E-02	
	% Transitional	116167389.1	27076485.55	4.290	2.851E-05	
Fecal	% Structures	4.17866527	1.996473522	2.093	3.933E-02	0.1079
	% Mining	4.658265976	1.752794641	2.658	9.400E-03	
Enterococcus	% Freshwater Wetlands	-10.08055476	3.331977119	-3.025	2.831E-03	0.1596
	% Saltwater Sandy Beaches	-9.186215895	3.216694176	-2.856	4.776E-03	
	% Urban Public/Institutional	-1.081624801	0.407441739	-2.655	8.619E-03	
	% Brushland/Successional	-2.876044216	1.038129494	-2.770	6.161E-03	
	% Mining	3.190145501	1.517696358	2.102	3.689E-02	
	% Freshwater Wetlands * % Urban Public/Institutional	711.9554653	355.664563	2.002	4.675E-02	

The models created to predict contaminant concentrations in wet weather and those for all weather conditions showed R^2 values less than 0.35, meaning none of these models showed significant relationships between the predictive variables and the contaminant concentrations. For dry weather conditions, the only model that showed a significant correlation between the predictive variables and the contaminant concentration was the model used to predict ammonia concentration for each catchment ($R^2 = 0.4877$ signifying a weak correlation). All other models showed no significant correlation between the predictive variables and the contaminant concentration.

For predicting total contaminant load in each catchment based on land use variables, four models showed weak correlations between the predictive variables of each model to their respective contaminant: total DIN load under dry weather conditions ($R^2 = 0.3849$), total nitrate (NO3) load under dry weather conditions ($R^2 = 0.4226$), total fecal coliform load under wet weather conditions ($R^2 = 0.4206$), and total nitrate load under any weather condition dry or wet ($R^2 = 0.4139$). None of the other models showed significant correlation between the predictive variables and contaminant load.

The model to predict ammonia concentrations under dry weather conditions used percentage of catchment area as saltwater wetland and percentage of catchment area as commercial property as predictor variables. Both have positive values for their estimated coefficients in the model, which means both have a positive correlation to the ammonia concentration under dry conditions. It is important to note that these correlations do not necessary mean that the commercial properties or saltwater wetlands themselves are causing increased ammonia concentrations, but these areas remain an area of interest when looking at ammonia pollution in stormwater.

The model to predict total DIN load under dry conditions used percentage of catchment area designated as transitional land and percentage of catchment area used as pastures as the predictive inputs. The same variables were used in the model to predict total nitrate load under dry conditions. For both models, the coefficient estimates were positive and extremely large in magnitude, showing a positive correlation between both predictor variables and nitrates and DIN load. Since they are extremely large in magnitude, on the order of 10^9, relatively small increases in the percentage of land used as pastures or changing use from one category to another might lead to relatively large increases in nitrate and DIN load at each catchment. This suggests that nitrate and DIN total load under dry weather conditions could be very sensitive to certain processes associated to pastures and to processes associated with changing an area of land from one category of use to another. The range for percentage of catchment area as pastureland and transitional land are small, only from about 0 to 0.05 percent. These small ranges of predictor variables likely contribute to such large coefficients.

The model predicting fecal load within a catchment under wet weather conditions used four predictor variables: percentage of impervious area, percentage of industrial area, percentage of forested wetlands, and percentage of mining area. The model coefficients for impervious area percentage and forested wetland area percentage were negative, showing that higher percentages of impervious and forested wetland areas correlated to decreased total fecal coliform load. The model coefficient for land area percentage as industrial and mining, on the other hand, was positive, on the same order of magnitude as the coefficient for percentage of area as impervious. This model showed weak correlation, giving evidence to the overall validity of the model, but not necessarily enough evidence to confirm the accuracy of the model equation.

The final model that showed any significant correlation used the percentage of transitional area to predict the total nitrate load under any weather condition. This model is significant in that while it showed a weak correlation, it was the only model that showed a significant correlation between the predictor variables and any contaminant for any weather condition. It was also the only significant model that used only a single predictor variable. In this case, the percentage of area as transitional land had a positive correlation to total nitrate load on the order of magnitude of 10^8. This seems to suggest total load of nitrates could be very sensitive to the percentage of area within a catchment associated with transitional land, but as before the very small range within predictor variables contributes greatly to these large coefficients.

In all, five models created to predict contaminant concentrations or total contaminant load in stormwater systems were significant. All five models showed weak correlations, with coefficients of determination, R^2, less than 0.50. Based on these values of R^2, these models give enough evidence to show correlations between the predictor variables and contaminants as discussed above, but not enough evidence to confirm the accuracy of the mathematical relationships determined by the models. This level of confidence would be represented by strong correlations among the model. These weak correlations could be a result of not enough evidence to confirm a strong relationship, or from the linear models not being the appropriate model type necessary to evaluate the correlations between the land use variables and contaminant concentrations and total load. Further analysis, especially with more data points from future samples, could yield more accurate and conclusive results.

An additional note is that only five models showed significant correlations out of a total of 36 possibilities. Two were used to predict total load of nitrates (one for dry conditions alone, one for under any weather condition), another to predict total DIN load under dry conditions, a fourth to predict total fecal load under wet weather conditions, and the last to predict ammonia concentration under dry weather conditions. These models, even if taken as extremely accurate, would not be able to predict all the contaminants under dry and wet weather conditions, which would be most useful for prioritizing monitoring efforts. Overall, land use was a poor predictor of stormwater pollutant concentrations in the Buzzards Bay watershed and have little value in prioritizing monitoring efforts. Rather, systematic testing of stormwater discharges, and conducting detailed evaluations where discharges have high pollutant concentrations appears to be the appropriate management approach.

As a final analysis step, water quality data was sorted by the month each sample was taken, and in this way the water quality data was analyzed to determine if contaminant concentrations significantly differed during certain months of the year. Tables 2.7 through 2.12 show the results of the two variance f-tests comparing the concentrations of contaminants sampled during different months of the year. The test compared two months together, analyzing whether the sample results significantly differed between the two months. A value of one signifies that the null hypothesis of the f-test was rejected and so the data taken during those two months have different variances. This suggested that the data taken during the two months are significantly different due to some variable(s) at play. A value of zero from the f-test signifies there is not enough evidence to suggest the data taken on the two separate months were from different population data sets, and so there is not enough evidence to say they are significantly different.

Table 2.7 F-Test Results Comparing Surfactant Contamination from Month to Month Where One Represents a Difference in Variance and Zero Represents a Similar Variance

	April	May	June	July	August	September	October	December
April	0	0	1	1	1	1	1	0
May	0	0	1	1	1	1	1	0
June	1	1	0	1	0	0	0	1
July	1	1	1	0	1	0	1	1
August	1	1	0	1	0	1	0	1
September	1	1	0	0	1	0	1	1
October	1	1	0	1	0	1	0	1
December	0	0	1	1	1	1	1	0

Table 2.8 F-Test Results Comparing Ammonia Contamination from Month to Month Where One Represents a Difference in Variance and Zero Represents a Similar Variance

	April	May	June	July	August	September	October	December
April	0	0	1	1	1	1	1	0
May	0	0	1	1	1	1	1	0
June	1	1	0	1	0	0	0	1
July	1	1	1	0	1	0	1	1
August	1	1	0	1	0	1	0	1
September	1	1	0	0	1	0	1	1
October	1	1	0	1	0	1	0	1
December	0	0	1	1	1	1	1	0

Table 2.9 F-Test Results Comparing Nitrate Contamination from Month to Month Where One Represents a Difference in Variance and Zero Represents a Similar Variance

	April	May	June	July	August	September	October	December
April	0	0	1	1	1	1	1	0
May	0	0	1	1	1	1	1	0
June	1	1	0	1	0	0	0	1
July	1	1	1	0	1	0	1	1
August	1	1	0	1	0	1	0	1
September	1	1	0	0	1	0	1	1
October	1	1	0	1	0	1	0	1
December	0	0	1	1	1	1	1	0

Table 2.10 F-Test Results Comparing DIN Contamination from Month to Month Where One Represents a Difference in Variance and Zero Represents a Similar Variance

	April	May	June	July	August	September	October	December
April	0	0	1	1	1	1	1	0
May	0	0	1	1	1	1	1	0
June	1	1	0	1	0	0	0	1
July	1	1	1	0	1	0	1	1
August	1	1	0	1	0	1	0	1
September	1	1	0	0	1	0	1	1
October	1	1	0	1	0	1	0	1
December	0	0	1	1	1	1	1	0

Table 2.11 F-Test Results Comparing Fecal Coliform Contamination from Month to Month Where One Represents a Difference in Variance and Zero Represents a Similar Variance

	April	May	June	July	August	September	October	December
April	0	0	1	1	1	0	0	0
May	0	0	0	0	0	0	0	0
June	1	0	0	1	0	0	0	0
July	1	0	1	0	0	0	0	0
August	1	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0

Table 2.12 F-Test Results Comparing Enterococcus Coliform Contamination from Month to Month Where One Represents a Difference in Variance and Zero Represents a Similar Variance

	April	May	June	July	August	September	October	December
April	0	0	1	1	1	1	1	0
May	0	0	1	1	1	1	1	0
June	1	1	0	1	0	0	0	1
July	1	1	1	0	1	0	1	1
August	1	1	0	1	0	1	0	1
September	1	1	0	0	1	0	1	1
October	1	1	0	1	0	1	0	1
December	0	0	1	1	1	1	1	0

When looking at the data set as a whole, most samples did not seem to have data for Fecal Coliform, which likely played a role in why the results for Fecal Coliform did not show the same results as the other contaminants. In fact, Tables 2.7 through 2.12 show that the results for f-tests between each combination of months were exactly the same when comparing each contaminant except for Fecal Coliform. The months that seemed to have similar distributions of contamination were the months of April, May, and December. Contamination from these months was significantly different from the contamination seen in every other month. The results when comparing other months of the year were not as clear, but the months of July and September were similar to one another and significantly different from all other months, and the months of June, August, and October had similar variations in contamination that was significantly different than the contamination in all other months.

To visually show the variations in contaminant concentrations from month to month, box and whisker plots are shown below for ammonia. The box and whisker plots show the mean concentration of Ammonia by month labeled as the "x" and the "boxes" represent the range of values encompassed by the median 50% of the data. The "whiskers," or the lines extending from the central box, show the highest and lowest values in the data set that are not outliers. Outliers are marked as individual colored points. Data points are considered outliers when they exceed one and a half times the interquartile range (IQR, difference between 1st and 3rd quartiles) above the 3rd quartile or below the 1st quartile. Take an example data set, which has a minimum value of 2, a maximum value of 52, the 1st quartile is 5, and the 3rd quartile is 21. In this example data set, interquartile range (IQR) is 16, which means any value below -19 or above 45 would be considered an outlier. In the context of statistics, these outliers tend to skew the data set and significantly change the mean value of the data set, especially when all the outliers are positioned on the same extreme of the data range. Figure 2.2 graphs the same box and whisker plot without showing the outliers. This gives a more focused view on the range of values not considered outliers, which clarifies and visualizes the major variations of ammonia concentrations without showing the influence of values that fall on the extreme ends of the data sets.

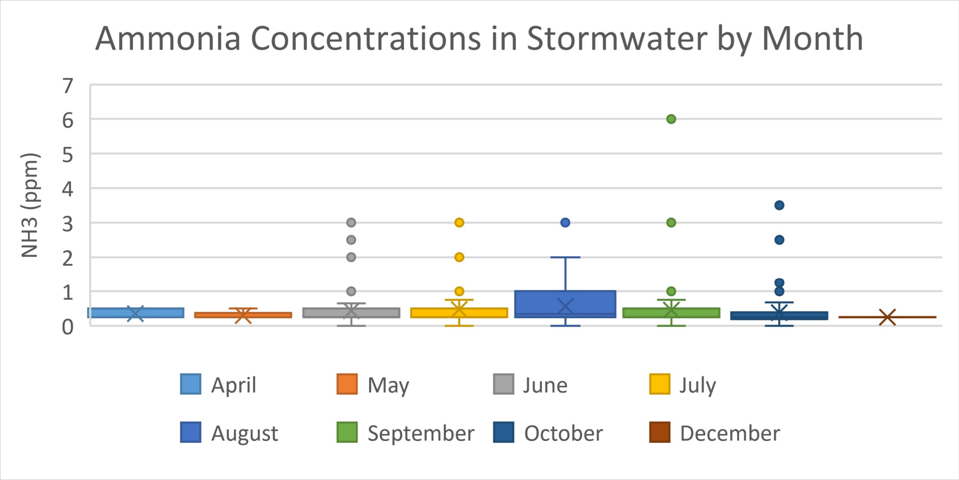

Figure 2.1 Box and Whisker Plot of Monthly Data Trends in Ammonia Concentrations with Outliers Included

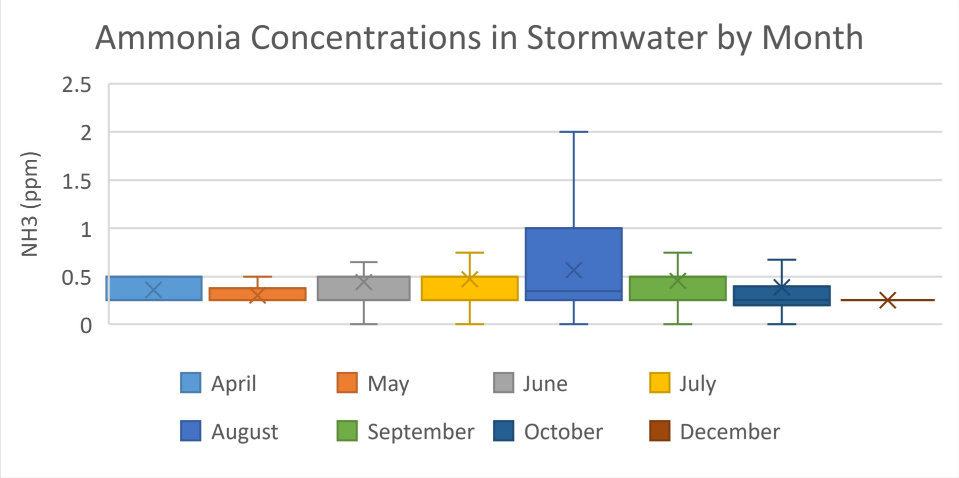

Figure 2.2 Box and Whisker Plot of Monthly Data Trends in Ammonia Concentrations with Outliers Excluded

From viewing both figures, the concentration of ammonia does not vary greatly during the months of April, May, and December, with Figure 2.2 showing that the mean ammonia concentration during each month was close to 0.25 ppm, and the range of values extending from 0.25 ppm to 0.5 ppm. Variations in ammonia concentration during the months of June, July, September, and October were very similar, with these months each having a mean concentration close to 0.5 ppm and ranges of values (excluding outliers) from 0 ppm to approximately 0.5 ppm. The month of August seemed to show the largest range of values (excluding outliers again) from 0 ppm to 2 ppm. When looking at Figure 2.1, where the outliers are included, it is even more apparent how ammonia concentrations are significantly higher during the months of June through October as opposed to April, May, and December. As in Figure 2.2, Figure 2.1 shows that the concentration of ammonia among samples taken during June through October are similar, with values of outliers ranging from 1 ppm to 6 ppm. These graphs confirm the results shown in Tables 2.7 through 2.12, where the concentrations of contaminants are very similar during the months of April, May, and December, and where the concentrations during those months differ greatly from the concentrations of samples taken during the months of June through October. Contaminant concentrations during June through October are similar to one another, but still certain months show key differences, such as the larger range of values between the first and third quartiles during the month of August (about 0.25 ppm to 1 ppm) compared to all the other months (about 0.25 ppm to 0.5 ppm).

By understanding differences in contaminant concentrations from month to month, assuming all other variables acted independently and randomly, those months of the year where contaminants were shown to be significantly higher or vary the most (June through October) are the most important for collecting samples to understand why such high concentration and/or variability occurs. If high contamination or variability among pollutants was found near specific areas, those areas would require additional focus by the municipality to identify the cause of high contamination/variability and then implement actions or education to the public, where applicable, to decrease stormwater pollution. While the focus of this paper is not on monthly variability of contaminated stormwater, future research should be conducted to understand the reasons for significant increases in contamination detected from samples taken during the months of June through October, and how the variability also changes from month to month.

Chapter 3: Case Study of Tub Mill Brook

3.1 Overview of Tub Mill Brook

The Town of Mattapoisett is located along the coast of southeastern Massachusetts, between the towns of Marion and Fairhaven. This community has many waterfront properties, and much of the town's land includes wetlands. The Town of Mattapoisett is currently implementing the Stormwater Management Program (SWMP) to support its MS4 permit, with many goals set to reduce pollutant loads to the town's stormwater infrastructure [17]. One primary goal of the town's SWMP is to inventory all the existing stormwater infrastructure, while another major goal is to monitor all outfalls periodically for contaminant concentrations to prioritize which catchment areas should be repaired and modified to better treat stormwater. Due to high traffic from Interstate 195 and Route 6, along with many businesses along Route 6 and Acushnet Road in Mattapoisett, there are many concerns of polluted stormwater being carried into the nearby Tub Mill Brook from the roadways and businesses. Therefore, the focus of this case study was on Tub Mill Brook. This effort occurred between January and August 2021.

Tub Mill Brook is a stream running through the Town of Mattapoisett, Massachusetts. The stream begins about a mile north of Interstate 195 traveling south past Route 6 and discharging to Eel Pond, which is connected to Mattapoisett Harbor in Buzzards Bay. There are 12 known outfalls directly flowing into Tub Mill Brook, including discharges to 4 culverts that allow the passage of the stream to flow under roadways (name the four roads). Three of those discharges have catchbasins collecting stormwater from along Route 6, a heavily trafficked state road in the region. Due to this high traffic and commercial development along the highway, and uncertainties about potential illicit tie-ins, the Town of Mattapoisett has been concerned about potential illicit discharges and pollution from these discharges.

3.2 Watershed Analysis with Existing Data

Using existing GIS data from Buzzards Bay NEP and BBSC, including 1-ft contours from LiDAR data [18], catchments were defined for each discharge Tub Mill Brook watershed using AutoCAD Civil 3D, and ArcGIS Pro. The GIS data provided had delineations based on older topographic information. These catchments were redefined using the one-foot contours by visual approximation. Because the data analysis earlier did not conclusively show any relationships between land use and pollutant concentrations, no prior determination was possible to determine whether any Tub Mill Brook discharge had a high or low potential for illicit connections. Instead, equal priority was given to inventorying the entire watershed. Figure 3.1 below shoes the initial assessment of catchments.

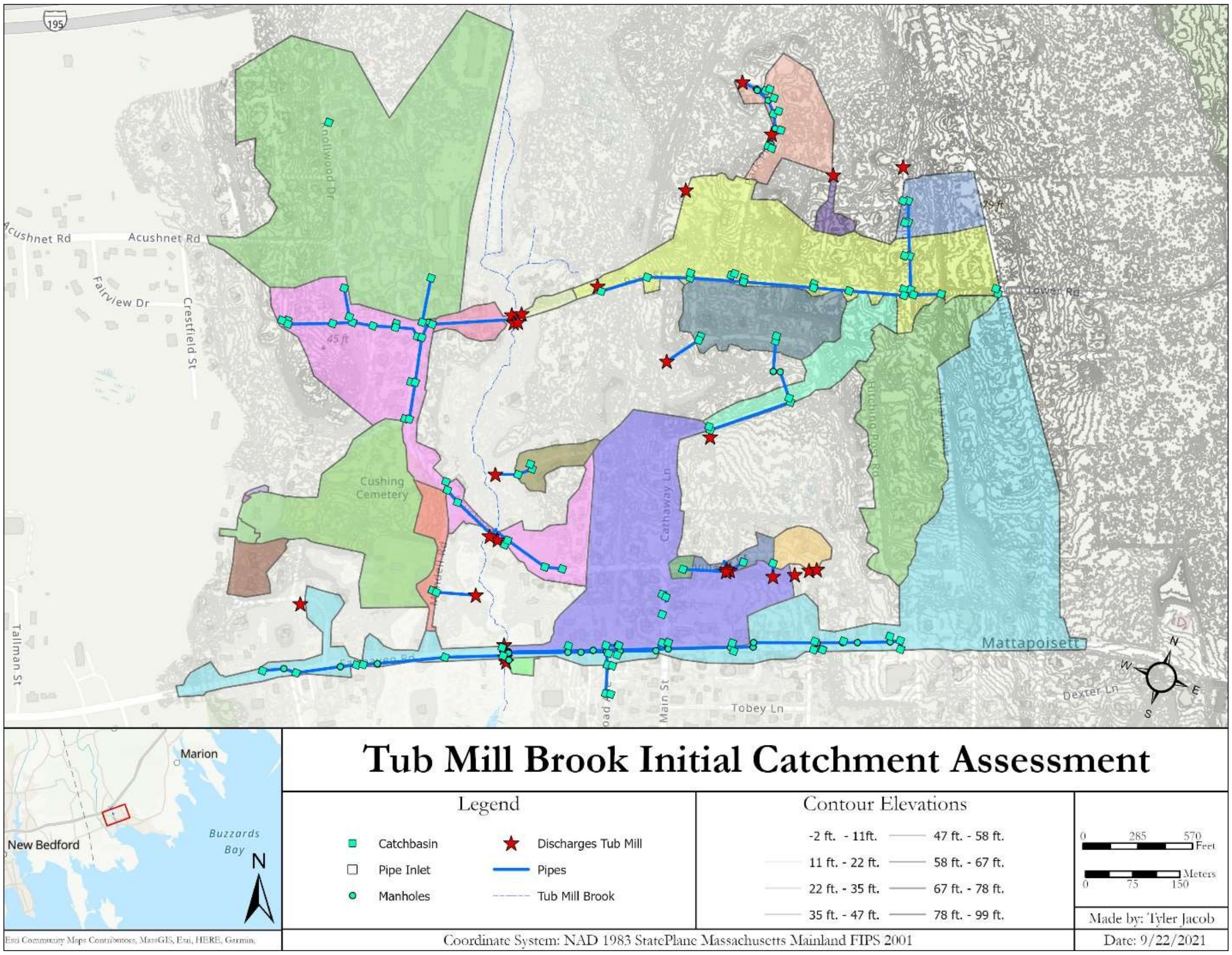

Figure 3.1 Initial Assessment of Catchment Areas of Tub Mill Brook with Catchment Areas Marked in Different Colors

3.3 Inventory of Tub Mill Brook

A stormwater infrastructure inventory and tie-in investigation of the stormwater discharges to Tub Mill Brook was performed with the Buzzards Bay Stormwater Collaborative Illicit Discharge Investigation Trailer. This trailer, built and maintained by Buzzards Bay NEP and the Stormwater Collaborative, has equipment to investigate potential illicit discharges and undocumented tie-ins to the municipal stormwater network s. While most towns and municipalities have various types of equipment for stormwater network investigations, the advantage of this trailer is that it conveniently provides in one location all the equipment necessary to conduct these investigations. Trailer equipment includes a manhole hook, magnetic lid lifter with steel dolly, utility magnetic locator, clam shovel, 200-foot measuring tape, safety cones, drainpipe inspection camera, smoke machine, and PPE [19]. The complete list of equipment is listed in Appendix B.

Stormwater investigations were conducted during the weeks of April 26 and July 19, 2021. It was mostly dry during this period with some occasional scattered showers during the night. The inventory team included Buzzards Bay NEP personnel, Massachusetts Maritime Academy cadets, a member of the Town of Mattapoisett Highway Department, and me. The team split into two groups, each of which received a copy of the maps for the week which show approximate locations for structures (catchbasins, stormwater manholes, outfall pipes, etc.) including landmarks and street names. One team (comprised of cadets) used one or two pairs of iPads and Geodes GPS unit to capture location data of each structure. The Geode GPS is reported to be accurate to within one meter [19], which is meets the goals of the Stormwater Collaborative. The software used allows user to input data relevant to the stormwater facility being inventoried.

As the first team moved from structure to structure collecting GPS data, the second team collected and recorded the rest of the necessary data. Starting at the outfall pipe, one person hand drew a map of his/her location and the relative locations of structures in comparison to one another and to landmarks such as addresses of nearby houses. The highway department worker would open the structure cover to allow visual inspection inside the structure. Notes were taken at each structure of their relative condition, recommended repairs, presence of any standing or flowing water, the direction of flowing water if present, and notes on sensory details. These sensory notes were focused on details not ordinary to stormwater, such as odor of feces, discolored water, and any sheen on the surface of standing water. Information on the pipes connecting structures was recorded, including the pipe material, pipe diameter, and invert height of each pipe in the structure. If a pipe was found in a structure, but there did not seem to be any nearby structure in the direction that the pipe pointed, then the drainpipe inspection camera was pushed into the pipe from the opened structure to visually inspect if the pipe was capped, led to another structure, or linked directly into another pipe. Someone else took the magnetic utility locator and walked in the direction the pipe pointed towards to try to identify any above structures buried just under the surface.

In many cases, the camera, linked by wire to the video screen, could only be moved into the pipe approximately 10 meters before it could no longer be pushed forward. While the camera had a cover with rollers, the rollers were too small and heavy to be pushed forward beyond 10 meters. The design was modified by attaching a 2-liter plastic bottle to the camera. This design improved travel within the pipe slight, but generally the camera could still not reach the next structure. The limitation in the camera design was supplemented by the magnetic utility locator, which proved to be the most useful device in finding adjacent structures and pipes. Where neither of these methods were unsuccessful, the smoke test blower was often helpful in finding adjacent structures and tie-ins.

The inventory data sheet used in the Tub Mill Brook investigation is included in Appendix C. Appendix D shows maps of the GIS data after completion of the inventory. Since Route 6 is designated a state road, a permit from the state, and a police detail are required open structures on Route 6. The permit and costs were not approved in time for this study, so investigations on Route 6 were limited , and the mapped infrastructure was taken from engineering plans.

In general, the inventory identified structures that need to be cleaned and other structures that need repair, but much of the stormwater network was in good condition, and no illicit connections were found. Structures along Park Place, Church Street, and Baptist Street need to be cleaned due to debris accumulation. The structures at the end of Barlow Lane are in poor condition, but this street is privately owned, so the town would only be able to try to compel the owners to repair and clean the stormwater catchment. Sump pump drains were found in areas of

Driscoll Lane leading directly to catchbasins, but no flowing water was detected and no immediate evidence of illicit discharge from those connections were detected. Some manholes along Driscoll Lane were covered by concrete covers and could not be inspected, but all other structures were in good condition and showed no signs of illicit discharges. One pipe could not be found, TMR1282PI which was believed to be on Village Court. Interconnection between the town stormwater infrastructure and the State of Massachusetts stormwater network on Route 6 was confirmed at Railroad Avenue and is suspected at Upland Way/Hitching Post Road.

The major areas of concern are places of uncertainty that could not be accessed at the time of the inventory, such as one end of the stormwater network on Upland Way and Hitching Post Road. This area included some reported blocked pipes that were attempted to be unblocked using equipment from the IDDE trailer to no avail. The pipes leading south out of the network either connect directly to Route 6 as an interconnection, or travel below the state road and connect further south. Information from the highway department suggested there is an interconnection at Route 6, and no information obtained from the inventory could verify or refute the existence of an interconnection. An interconnection is likely, and all available information from design drawings of stormwater drainage along Route 6 show a disconnect at Barstow Street. Therefore, structures along North Street, Upland Way, and Hitching Post Road are likely connected to Route 6, east of Tub Mill Brook, but follow the stormwater conveyance system south at Barstow Street. Consequently, these structures require further investigation to confirm these suspicions, but are excluded from further analysis in this study.

3.4 Stormwater Sampling and Monitoring

During and after the inventory was completed, outfall pipes were sampled for water quality testing. Samples were taken during dry and wet weather conditions. During dry weather conditions, lack of rainfall would mean pollutants would not be entering the system along road surfaces and catchbasins. Any high contaminant concentrations would more likely originate from a point source within the catchment area associated with the outfall pipe. Wet weather conditions would include stormwater entering from catchbasins and roadcuts, allowing contaminants to enter from any surface along the watershed. This would mean that dry weather samples would be better suited to locate relative locations of contaminant point sources while wet weather samples would be better suited to analyze total contaminant sources from catchments areas.

3.4.1 Water Sampling Procedure

Water samples were taken on site with field observations recorded on the Buzzards Bay Stormwater Collaborative – Water Quality Sampling Sheet. Nitrile examination gloves were used throughout the sampling process, gloves being replaced between samples to reduce the likelihood of cross-contamination of samples. A single “daily use” sample cup was used to first collect a sample from a single outfall. Using the Hach Pocket Pro, Multi 2 tool, the salinity of the sample was tested on site to confirm that the sample is freshwater (salinity less than 0.5 ppt) and not mixed with a saltwater source (where salinity is usually seen in concentrations higher than 1 ppt). Once the sample was confirmed by salinity to be freshwater, then two more samples were taken each from a sealed, sterile specimen container until both containers were full of sample water. The latter two samples were closed and promptly placed into a cooler with blue ice packs.

All necessary information about site arrival time, location, weather conditions, type of flow, facility ID, and sketches of site conditions were recorded on the water quality sampling sheet (blank sheet included in Appendix C). Field testing using the equipment described in Table 3.1 was conducted and results recorded. All equipment was promptly cleaned with deionized water. Labels detailing the sample ID, date and time of sampling, laboratory analysis to be conducted, and name(s) of collector(s) were then placed on each of the sample containers in the cooler, one labeled for “MMA” analysis (to be saved for indoor analysis as described in Table 3.2) and one labeled “Fecal” for fecal bacteria analysis. Once field observations and testing were completed, the “daily use” cup was emptied and cleaned using deionized water and replaced for use at the next site. After all site samples were collected, field observations were recorded, and on-site testing was complete, all sample containers designated for fecal coliform testing were delivered to the laboratory and custody of samples were signed off. Finally, the samples labelled “MMA” were brought to Massachusetts Maritime Academy campus and tested for concentrations of nitrates and surfactants using the equipment and techniques outlined in Table 3.2. Proper personal protective equipment (nitrile examination gloves, safety glasses, and masks/face protection) was used, and analysis methods followed the manufacturer’s guidelines for each respective equipment. All chemicals were properly disposed of according to Massachusetts Maritime Academy guidelines, and all equipment cleaned.

3.4.2 Summary of Analysis Methods

Water samples were tested for eight different parameters, which were indicators of potential illicit connections or other sources of contamination. The water quality data collection effort consisted of three components: field observations and testing for ammonia, conductivity, salinity, temperature, and pH, indoor analysis of nitrates and surfactants, and certified laboratory testing for fecal coliform. The basic methods and equipment for each component is described below in Tables 3.1, 3.2, and 3.3. For testing using equipment in Tables 3.1 and 3.2, the manufacturer’s procedures for testing were followed.

Table 3.1 Field Testing Equipment

Parameter	**Equipment**	**Operating Range**	**Resolution**	**Accuracy**
Ammonia	Hach Test Strips	0-6 ppm	0.25 ppm	+/- one half of a color block
Conductivity	Hach Pocket Pro, Multi 2	0-200 µS/cm or 2.00-19.9 mS/cm (auto-range)	0.01mS/0.1µS/1.0uS (range dependent)	±1.0%
Salinity	Hach Pocket Pro, Multi 2	0-10 ppt	0.01 ppt	±1.0%
Temperature	Hach Pocket Pro, Multi 2	0-50°C (32 to 122°F)	0.1°C	±0.5°C
pH	Hach Pocket Pro, Multi 2	0.0-14.0	0.01	0.02

Table 3.2 Indoor Analysis Equipment

Parameter	**Equipment**	**Operating Range**	**Resolution**	**Accuracy**	**Holding Time**
Surfactants (detergents as MBAS)	CHEMetrics L-9400	0-3 ppm	+ 1 color standard increment	+ 30 % error	48 hours
Nitrates	LaMotte Nitrate-Nitrogen test kit (3615-01)	0.00 to 1.00 ppm	0.1 ppm	0.1 ppm	24 hours

Table 3.3 Laboratory Analysis Method and Field Processing Requirements

Parameter	Sample Container	Field Processing	Method	Units	Holding Time
Fecal Coliform	100 mL sterilized polyethylene	Collect, label, store in blue ice	Membrane Filtration, wastewater, SM9222D, 21st Edition 2005	CFU/100 mL	6 hours

3.4.3 Sample Results and Analysis

Dry weather samples were taken on March 24, May 11, May 12, and May 13, 2021, while wet weather samples were taken on April 16, May 29, and July 9, 2021. Dry weather samples consisted of samples taken directly along the river at culverts. Wet weather samples consisted of samples taken at outfall pipes directly along the river and samples taken from the same culvert sites as during dry weather sample events. The water samples taken on May 29 were outside of the normal hours of the laboratory where fecal coliform testing was done, so there is no fecal coliform data for sampling on that date. Testing results for samples taken on dry weather conditions are shown in Table 3.4 and results for samples taken in wet weather conditions are shown in Table 3.5.

Table 3.4 Results of Dry Weather Sampling Along Tub Mill Brook

Site Visit ID	**Facility ID**	**Sample Type**	**Sample Date**	**Sample Time**	**pH**	**Temperature (℃)**	**Conductivity (*μ*S/cm)**	**Salinity (ppt)**	**Ammonia (ppm)**	**Chlorine (ppb)**	**Nitrate (ppm)**	**Surfactants (ppm)**	**Fecal Coliform (CFU/100 mL)**
MT24MAR01	TMR1068PI	Dry	24-Mar-21	10:45 AM	5.98	11.20	461.00	0.38	0.25	63.00	0.88	0.25	< 2
MT24MAR02	TMR1067PI	Dry	24-Mar-21	11:07 AM	7.27	11.80	398.00	0.18	0.25	140.00	8.80	0.50	< 2
MT24MAR03	TMR1077PI	Dry	24-Mar-21	11:41 AM	5.53	11.00	310.00	0.15	0.25	105.00	1.76	0.50	< 2
MT24MAR04	TMR1092PI	Dry	24-Mar-21	11:55 AM	5.41	12.10	306.00	0.15	0.25	60.00	1.76	0.50	< 2
MT24MAR05	TMR1094PI	Dry	24-Mar-21	12:16 PM	6.10	13.40	244.00	0.12	0.25	199.00	2.64	0.25	< 2
MT11MAY01	TMR1068PI	Dry	11-May-21	8:49 AM	7.45	16.10	733.00	0.35	0.25	0.00	0.00	1.50	60
MT11MAY02	TMR1067PI	Dry	11-May-21	9:41 AM	7.44	16.60	313.00	0.14	0.00	45.00	0.00	0.25	90
MT11MAY03	TMR1077PI	Dry	11-May-21	10:20 AM	6.16	16.40	262.00	0.12	0.25	7.00	0.00	3.00	40
MT11MAY04	TMR1092PI	Dry	11-May-21	10:55 AM	6.11	17.30	255.00	0.12	0.00	4.00	0.88	3.00	26
MT11MAY05	TMR1094PI	Dry	11-May-21	11:25 AM	6.42	17.50	213.00	0.10	1.00	0.00	1.76	0.75	12
MT12MAY01	TMR1068PI	Dry	12-May-21	9:00 AM	6.67	14.40	295.00	0.14	0.25	0.00	0.88	2.50	34
MT12MAY02	TMR1067PI	Dry	12-May-21	9:23 AM	7.09	15.40	359.00	0.17	0.25	0.00	3.52	0.50	28
MT12MAY03	TMR1077PI	Dry	12-May-21	9:46 AM	6.02	14.50	275.00	0.13	0.00	53.00	0.88	1.88	58
MT12MAY04	TMR1092PI	Dry	12-May-21	10:10 AM	5.75	14.50	271.00	0.13	0.00	0.00	0.88	1.88	76
MT12MAY05	TMR1094PI	Dry	12-May-21	10:34 AM	6.40	15.20	240.00	0.12	0.25	0.00	1.76	2.00	4
MT13MAY01	TMR1068PI	Dry	13-May-21	8:40 AM	6.35	15.30	276.00	0.13	0.00	0.00	0.88	7.50	34
MT13MAY02	TMR1067PI	Dry	13-May-21	9:00 AM	7.41	15.80	379.00	0.18	0.25	10.00	3.52	0.75	38
MT13MAY03	TMR1077PI	Dry	13-May-21	9:45 AM	5.95	15.50	278.00	0.14	0.00	27.00	0.88	2.00	14
MT13MAY04	TMR1092PI	Dry	13-May-21	10:10 AM	5.80	16.90	271.00	0.13	0.00	0.00	0.88	2.00	6
MT13MAY05	TMR1094PI	Dry	13-May-21	10:45 AM	6.38	19.60	213.00	0.10	0.00	0.00	1.76	3.00	< 2

Table 3.5 Results of Wet Weather Sampling Along Tub Mill Brook

Site Visit ID	Facility ID	Sample Type	Sample Date	Sample Time	pH	Temperature (℃)	Conductivity (μS/cm)	Salinity (ppt)	Ammonia (ppm)	Chlorine (ppb)	Nitrate (ppm)	Surfactants (ppm)	Fecal Coliform (CFU/100 mL)
MT16APR01	TMR1076PI	Wet	16-Apr-21	8:38 AM	8.61	9.20	143.20	0.08	0.25	0.00	0.88	0.50	56
MT16APR02	TMR1070PI	Wet	16-Apr-21	9:16 AM	8.22	9.10	69.20	0.04	0.25	48.00	0.00	0.50	128
MT16APR03	TMR1067PI	Wet	16-Apr-21	9:50 AM	7.49	10.10	106.90	0.05	0.25	30.00	1.76	0.50	1330
MT16APR04	TMR1117RC	Wet	16-Apr-21	10:50 AM	7.64	9.60	26.30	0.01	0.25	28.00	0.00	0.50	256
MT16APR05	TMR1092PI	Wet	16-Apr-21	11:18 AM	6.56	10.60	333.00	0.16	0.25	44.00	0.88	3.00	316
MT29MAY01	TMR1070PI	Wet	29-May-21	8:12 AM	9.17	10.80	442.00	0.27	0.25	7.00	0.88	0.50	-
MT29MAY02	TMR1068PI	Wet	29-May-21	8:30 AM	7.86	10.40	243.00	0.13	0.25	12.00	0.88	1.50	-
MT29MAY03	TMR1067PI	Wet	29-May-21	8:49 AM	7.55	10.30	117.20	0.06	0.25	17.00	1.76	0.75	-
MT29MAY04	TMR1076PI	Wet	29-May-21	9:26 AM	7.58	13.40	60.90	0.03	0.25	12.00	0.88	1.50	-
MT29MAY05	TMR1077PI	Wet	29-May-21	9:48 AM	6.12	13.70	218.00	0.10	0.00	15.00	1.76	3.00	-
MT29MAY06	TMR1092PI	Wet	29-May-21	10:12 AM	5.65	13.80	210.00	0.10	0.25	18.00	0.88	5.00	-
MT29MAY07	TMR1094PI	Wet	29-May-21	10:39 AM	6.14	14.60	171.90	0.08	0.25	0.00	1.76	3.75	-
MT09JUL01	TMR1070PI	Wet	9-Jul-21	8:30 AM	8.90	24.20	265.00	0.14	0.25	2.00	0.88	0.50	> 25000
MT09JUL02	TMR1068PI	Wet	9-Jul-21	9:05 AM	7.45	23.40	400.00	0.20	1.00	0.00	1.76	0.75	3900
MT09JUL03	TMR1067PI	Wet	9-Jul-21	9:40 AM	7.74	22.10	157.40	0.08	1.00	4.00	1.76	1.50	23000
MT09JUL04	TMR1076PI	Wet	9-Jul-21	10:15 AM	7.30	23.50	37.00	0.02	0.00	0.00	0.88	1.50	> 25000
MT09JUL05	TMR1077PI	Wet	9-Jul-21	10:40 AM	6.38	21.60	296.00	0.15	0.00	30.00	1.76	1.50	7700
MT09JUL06	TMR1092PI	Wet	9-Jul-21	11:04 AM	6.44	21.50	285.00	0.14	0.25	33.00	1.76	0.25	7900
MT09JUL07	TMR1117RC	Wet	9-Jul-21	11:30 AM	6.47	23.60	77.80	0.04	1.00	11.00	0.88	0.50	8100
MT09JUL08	TMR1284PI	Wet	9-Jul-21	12:00 PM	6.48	23.20	79.20	0.04	0.50	7.00	0.88	0.25	25600
MT09JUL09	TMR1094PI	Wet	9-Jul-21	12:26 PM	6.40	23.00	77.60	0.04	3.00	11.00	0.88	0.25	12700

According to Illicit Discharge Detection and Elimination (IDDE) Guidance Manual by the Center for Watershed Protection and University of Alabama (with funding by the EPA) [20], the most reliable parameters that could detect an illicit discharge are ammonia and surfactants. Nitrates and fecal coliform are also important factors used to consider the type of illicit discharge if suspected. Therefore, emphasis was put on the fecal coliform, nitrate, ammonia, and surfactant concentrations. Threshold concentrations of each parameter were established as 0.50 ppm for ammonia, 0.25 ppm for surfactants, and 0.44 ppm for nitrates. The number of parameters above their respective thresholds in conjunction with the fecal coliform level was used to determine the potential for illicit discharge within a catchment area. In the case of fecal coliform, if the maximum recorded concentration was below 50 CFU/100mL, then the bacteria level showed "low" bacterial concern, if above 10,000 CFU/100mL bacteria level showed "elevated" bacterial concern, and if between 50 and 10,000 CFU/mL showed "some" bacterial concern. Table 3.6 shows the classification of illicit discharge potential used in analyzing the water quality data.

Table 3.6 Illicit Discharge Classification

Illicit Discharge Potential	**Bacteria (CFU/100mL)**		**Water Quality Parameters**
Elevated	> 10,000	and/or	3 parameters above threshold
Some	50 – 10,000	and/or	2 parameters above threshold
Low	< 50	and	1 or fewer parameter above threshold

The data was sorted by FacilityID (identifier for each outfall pipe) and then separated into dry and wet weather analyses. The arithmetic means of each parameter (except for fecal coliform) was calculated, and the maximum value of fecal coliform was recorded. These were then used to analyze the potential for illicit discharge at each outfall pipe. Table 3.7 shows the average parameter values (and maximum fecal coliform level) for the dry weather samples, separated by FacilityID. Table 3.8 shows the same parameter information for wet weather samples. Highlighted values are above their respective thresholds, and these highlighted values were used to determine the illicit discharge potential.

Table 3.7 Dry Weather Sampling Data Analysis Results with Asterisked (*) Values Above Thresholds

Facility ID	pH	Temperature (C)	Conductivity (µS/cm)	Salinity (ppt)	Ammonia (ppm)	Chlorine (ppb)	Nitrate (ppm)	Surfactants (ppm)	Max. Fecal Coliform (CFU/100mL)	Illicit Discharge Potential
TMR1067PI	7.3025	14.9	362.25	0.1675	0.1875	48.75	3.96*	0.5*	90	Some
TMR1068PI	6.6125	14.25	441.25	0.25	0.1875	15.75	0.66*	2.9375*	60	Some
TMR1077PI	5.915	14.35	281.25	0.135	0.125	48	0.88*	1.84375*	58	Some
TMR1092PI	5.7675	15.2	275.75	0.1325	0.0625	16	1.1*	1.84375*	76	Some
TMR1094PI	6.325	16.425	227.5	0.11	0.375	49.75	1.98*	1.5*	12	Some

Table 3.8 Wet Weather Sampling Data Analysis Results with Asterisked (*) Values Above Thresholds

Facility ID	pH	Temperature (C)	Conductivity (µS/cm)	Salinity (ppt)	Ammonia (ppm)	Chlorine (ppb)	Nitrate (ppm)	Surfactants (ppm)	Max. Fecal Coliform (CFU/100mL)	Illicit Discharge Potential
TMR1067PI	7.593	14.16	127.17	0.063	0.5	17	1.76*	0.917*	23000*	Elevated
TMR1068PI	7.655	16.9	321.5	0.165	0.625*	6	1.32*	1.125*	3900	Elevated
TMR1070PI	8.763	14.7	258.73	0.15	0.25	19	0.5867*	0.5*	25000*	Elevated
TMR1076PI	7.83	15.36	80.37	0.043	0.1667	4	0.88*	1.167*	25000*	Elevated
TMR1077PI	6.25	17.65	257	0.125	0	22.5	1.76*	2.25*	7700	Some
TMR1092PI	6.216	15.3	276	0.13	0.25	31.67	1.173*	2.75*	7900	Some
TMR1094PI	6.27	18.8	124.75	0.06	1.625*	5.5	1.32*	2*	12700*	Elevated
TMR1117RC	7.055	16.6	52.05	0.025	0.625*	19.5	0.44	0.5*	8100	Some
TMR1284PI	6.48	23.2	79.2	0.04	0.5	7	0.88*	0.25	25600*	Elevated

As tabulated in Table 3.7, none of the samples taken during dry weather events showed high concentrations of ammonia or fecal bacteria. The levels of nitrates and surfactants, however, were consistently higher than their respective acceptable levels in both dry and wet weather conditions. Table 3.8 seems to show that the highest levels of surfactants were found in samples taken along Park Street (TMR1092PI and TMR1094PI), at both locations where Tub Mill Brook crosses the street. There is a boat storage and repair facility on Park Street, near that area of Tub Mill Brook. It is quite possible that the facility regularly washed their boats and equipment, which may have contributed to a higher surfactant concentration in that area of the river. There was a similarly high concentration of surfactants from the outfall pipe along Acushnet Road (TMR1077PI), just downstream of the Park Street culverts. This similarly high concentration likely came from the same source as that of Park Street. Samples taken further downstream, at Mendell Road (TMR1076PI) and along Route 6 (TMR107PI, TMR1068PI, and TMR1070PI) were 50% less concentrated. While still above the threshold stated above, these concentrations were much closer to the acceptable levels.

Important to note is that TMR1067PI, an outfall pipe with catchbasins running along Route 6, is regularly submerged within the natural water line of Tub Mill Brook, so contaminants from upstream sources likely mix in with the stormwater flow from those Route 6 catchbasins (east of the Route 6 culvert at Tub Mill Brook). TMR1070PI, on the other hand, is an outfall pipe that is always above the natural water level of Tub Mill Brook, and so any contaminant concentrations are solely from the catchbasins west of the Route 6 culvert. As seen in Table 3.8, the wet weather samples show much lower surfactant concentrations for outfall pipes that are not regularly submerged, namely TMR1070PI (just described), TMR1284PI (with catchbasins along the northwestern section of Acushnet Road and Park Street, and the road cut at Park Street (TMR1117RC). Wet weather sample results for nitrate concentrations also showed higher concentrations in water samples taken from culverts and submerged pipes, with nitrate concentrations of 1.25 part per million (ppm or mg/L) or greater, whereas all other samples had average nitrate concentrations between 0.44 and 0.917 ppm. The smallest difference between these groups is about 25%. This may suggest that contaminants are being introduced to the stream naturally, or in areas upstream of where these outfall pipes and culverts are located.

A final important section to analyze is the bacteria concentrations. The concentrations of fecal coliform were very low during dry weather sample events; the highest fecal coliform level recorded during dry weather was 90 CFU/100mL. In comparison, only one recorded value of fecal coliform during a wet weather event was less than 100 CFU/100mL (56 CFU/100mL on April 16, 2021, at Mendell Road, TMR1076PI). All other samples showed much greater levels of fecal coliform during wet weather than dry weather. This seems to suggest that the material(s) that entered the stormwater system which increased bacteria levels are from overland sources being carried by stormwater. This can be seen during the most recent wet weather sampling, on July 9, 2021. Rainfall data from nearby New Bedford Regional Airport showed that less than one inch of rainfall occurred that day, with about 2.5 inches of rainfall occurring during the three-day period of July 1-3, 2021. Rainfall Data for the months of March to July 2021 is included in Appendix E. It is expected that a large rain event would wash many contaminants off the streets and into storm drains, but due to the higher rainfall earlier in the week, most of the contaminants likely would have been washed away before July 9. Yet, the data shows that on July 9, the samples taken from outfall pipes with catchbasins had significantly higher bacteria concentrations than along Tub Mill Brook itself. Most of the outfall pipes recorded bacteria levels three times higher than those from the culverts. This strong evidence points to overland sources of contamination being introduced to the stormwater system in multiple locations.

3.5 Catchment Delineations and Infrastructure Summary

After the inventory of the structures in the Tub Mill Brook watershed were completed, the catchment areas associated with each outfall pipe were updated. Figure 3.2 shows the updated catchment areas in the watershed, with each color corresponding to a different catchment. This final analysis showed the relative changes of the catchment areas due to the updated information from the inventory. The largest change was that of Upland Way, Hitching Post Road, and North Street south of Park Street, which were all deemed to convey stormwater south along Barstow Street as opposed to conveying water along Route 6 as previously understood. The next largest changes were that of the catchment associated with Park Street (outfall pipe labelled TMR1284PI), which increased drastically, while the catchment area associated with Acushnet Road (outfall pipe labelled TMR1077PI) diminished. All other changes were minor and relatively small in comparison. Information about each catchment, including outfall pipe, general location, area of catchment, and water quality volume, are summarized in Table 3.9. Catchments are shown in greater detail in Appendix D.

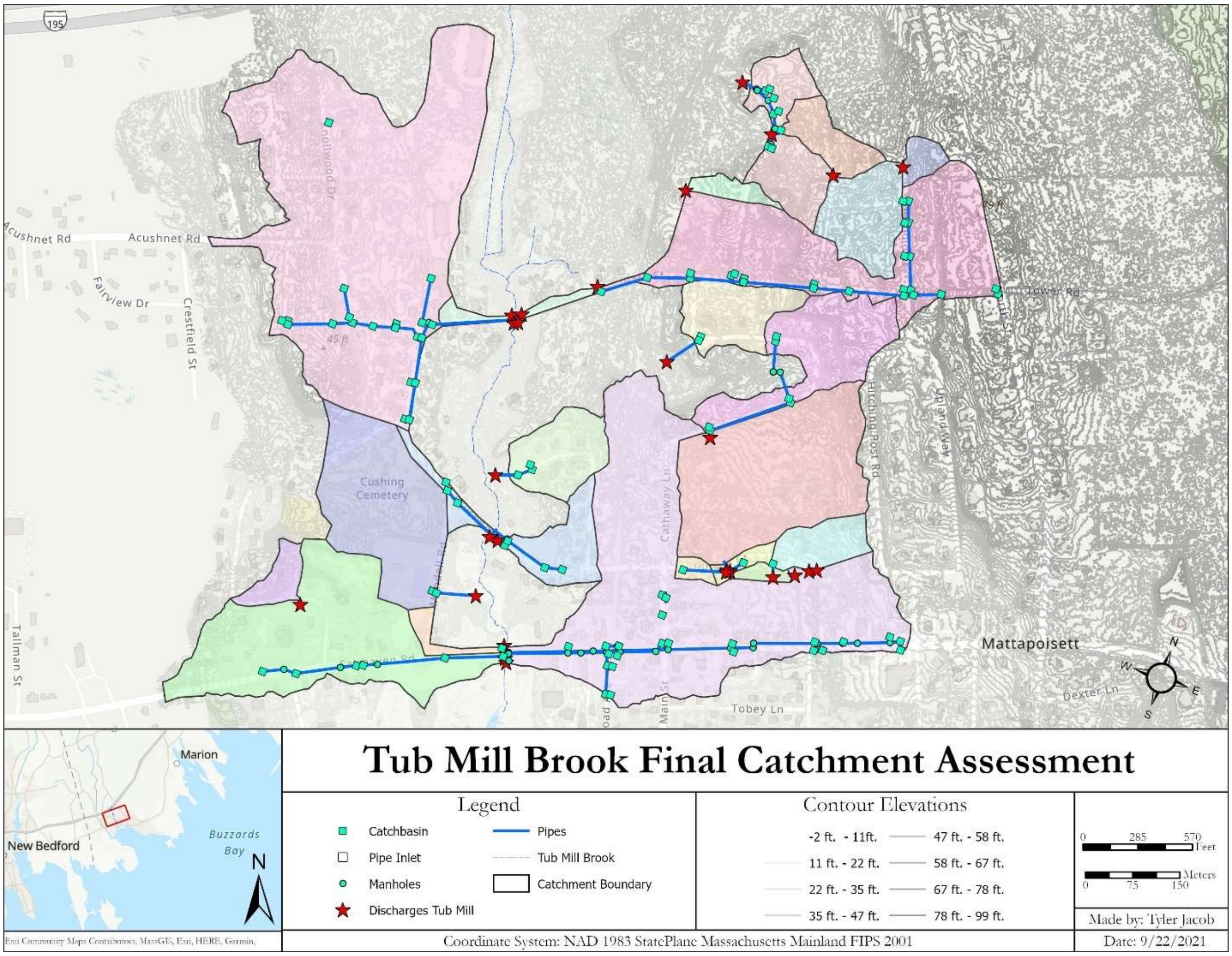

Figure 3.2 Final Assessment of Catchment Areas in Tub Mill Brook with Catchment Areas Marked in Different Colors

The inventory performed on the catchments in Tub Mill Brook showed that there were some structures that were not found or inaccessible. These areas, namely manholes along Driscoll Lane covered by concrete covers, unknown location of discharge pipe TMR1282PI, and the older rugged stormwater structures in and around Church and Main Street, required further investigation by the Town of Mattapoisett and Buzzards Bay Stormwater Collaborative.

Table 3.9 Catchment Information Including Calculated Water Quality Volume (WQV in ft^3)

FacilityID	**Location**	**Number of Inlets**	**Number of Manholes**	**Total Pipe Length (ft)**	**Catchment Area (ft^2)**	**Impervious Road Surface (ft^2)**	**Impervious Other (ft^2)**	**1-inch WQV (ft^3)**
TMR1067PI	Route 6 East of Tub Mill Brook	23	19	3,736.1	1,361,157.6	129,012.2	111,280.7	20,024.4
TMR1068PI	Route 6 West and Culvert	6	3	1,340.5	702,918.2	79,651.1	31,276.6	9,244.0
TMR1070PI	Route 6 and Mendell Rd.	1	1	17.0	34,906.9	15,591.5	480.9	1,339.4
TMR1072PI, TMR1099RC, TMR1100RC	Village Ct. Cul-de-Sac	1	0	69.8	105,878.8	8,430.4	18,048.5	2,206.6
TMR1074PI	Village Ct. West of Cul-de-Sac	1	0	82.4	29,162.1	7,325.3	1,864.4	765.8
TMR1075PI	Catchment South of Driscoll Ln.	1	0	45.3	647,248.1	0.0	29,676.3	2,473.0
TMR1076PI	Mendell Rd. Catchment	2	0	229.7	474,924.7	120,849.0	14,628.5	11,289.8
TMR1077PI, TMR1104RC	Acushnet Rd. Culvert and Roadcut	7	0	860.5	189,078.3	40,607.1	8,778.8	4,115.5
TMR1081PI	Driscoll Ln. East Catchment	6	2	887.0	309,957.8	25,938.6	27,908.7	4,487.3
TMR1083PI	Barlow Ln. Catchment	3	0	223.0	176,604.6	15,570.6	13,407.7	2,414.9
TMR1087PI	Driscoll Ln. West Catchment	2	0	221.3	171,187.6	15,918.3	17,292.0	2,767.5
TMR1092PI	Park St. West Culvert	1	0	45.7	-	-	-	-
TMR1094PI	Park St. East Culvert	24	0	2,546.4	741,394.1	81,406.2	45,278.0	10,557.0

FacilityID	Location	Number of Inlets	Number of Manholes	Total Pipe Length (ft)	Catchment Area (ft^2)	Impervious Road Surface (ft^2)	Impervious Other (ft^2)	1-inch WQV (ft^3)
TMR1102PI	Park Pl. Catchment	8	6	650.4	220,596.9	20,638.4	17,386.0	3,168.7
TMR1281PI	Park Pl. Culvert	1	0	53.0	104,678.3	0.0	2,914.0	242.8
TMR1282PI	Village Ct. Adjacent to Acushnet Rd.	1	0	224.3	21,277.2	4,025.4	978.6	417.0
TMR1283PI	Culvert South of Village Ct.	1	0	23.6	21,350.0	0.0	678.6	56.6
TMR1284PI	Park St. West	20	1	2,258.2	1,713,616.7	167,956.0	137,600.7	25,463.1
TMR1103RC	Wildwood Ter.	-	-	-	63,243.7	12,731.6	5,864.7	1,549.7
TMR1116RC, TMR1117RC	Park St. Roadcuts Near West Culvert	-	-	-	43,812.0	12,900.9	168.7	1,089.1
TMR1124RC	Hawthorne St. and Naushon St.	-	-	-	194,510.3	15,668.9	14,850.1	2,543.2
TMR1125RC	Gosnold St.	-	-	-	40,968.6	3,814.2	480.8	357.9
TMR1127RC	Park Pl. Roadcut	-	-	-	41,984.7	8,933.5	0.0	744.5

Based on the inventory performed and the data analysis of water quality samples taken along Tub Mill Brook, no illicit connections were found in any of the stormwater networks. This means either illicit connections were difficult to find, or pollutants are conveyed overland into catch basins. Based on the dry weather sampling, there is likely a source of nitrates and surfactants discharging into Tub Mill Brook near where it flows under Park Street. While it is unclear exactly where this source may be, one potential source is Interstate 195, which has many catchments and pipes with outfalls leading to headwaters of Tub Mill Brook, but which could not be investigated in this study. Another potential source is the adjacent boatyard on Park Street. Whether the interstate highway or that particular property are the actual sources requires further investigation. Other sources of surfactants may be present along Acushnet Road or along Route 6, but nitrate testing seemed to show the concentration of nitrates decreasing as water travelled further downstream (away from Park Street). These decreasing nitrate concentrations signifies that the primary source of nitrate pollution would be around Park Street.

Based on wet weather samples, Route 6 requires the most investigation into sources of pollution in stormwater, since samples showed consistently high bacteria content, high nitrate concentrations, and high surfactant concentrations. Some evidence of high ammonia content was present along Route 6 catchments as well which requires investigation. The Mendell Road catchment showed high bacteria content and high surfactant concentrations and requires further investigation into those sources of pollution. Since this catchment includes the highway department building and parking area, some investigation should be done to see if the highway department may be a high contributor to these pollutants. If that is the case, policies in the highway department may be changes to reduce transport of these contaminants to stormwater systems, such as washing vehicles in grassy areas. Acushnet Road and Park Street catchments require investigations into high nitrate and surfactant concentrations. Park Street also has high bacteria content and ammonia content. After investigations into potential sources of contamination, effluent may be appropriately treated before draining into Tub Mill Brook and Buzzards Bay.

Chapter 4: Conclusions

Based on the analysis shown in Chapter 2, land use and development indicators are a poor predictor of pollutant concentrations in stormwater in the Buzzards Bay Watershed. This trend is likely localized to the Buzzards Bay Watershed, as most non-point sources of pollution are directly related to land use. Non-point sources of pollution require surface runoff to collect and transport pollutants into bodies of water. As discussed in the case study of Tub Mill Brook, wet weather sampling allows for collection of data which can be analyzed to find non-point sources of stormwater pollution, yet when analyzing wet weather samples to find potential connections between land use variables and pollution, no linear models could accurately be produced to quantify any such connection within Buzzards Bay Watershed.

There are many potential land use variables that could conceivably affect stormwater pollutant loads, and some of those are listed in the conclusion of Chapter 2, but those pollutant loads likely vary among municipalities and depends upon patterns of development, age of infrastructure (e.g., catch basin cleaning), and no doubt numerous other factors. As more samples of stormwater are taken and tested by the Stormwater Collaborative, a future analysis using more sophisticated multivariate statistical techniques might be more productive to help establish priorities for stormwater network investigations. Until then, the practice of collecting systematic assessments of all discharges under an MS4 permit, followed by more intensive investigations of discharges with high pollutant loads remains the most effective management approach.

There is little data on illicit connections in the Buzzards Bay watershed, and few have been found by the Stormwater Collaborative; the apparent reasons for those connections were site specific. Illicit connections are found by visual inspection of stormwater networks. While high contaminant concentration can be a potential indicator of illicit connections, few illicit connections to Buzzards Bay stormwater network have been found by the Stormwater Collaborative even where pollutant concentrations were high. These high pollutant concentrations in stormwater discharges could be explained by point or non-point sources entering the system via overland stormwater runoff, or by undocumented and hard to find illicit tie-ins. The Tub Mill Brook Watershed case study showed that even with comprehensive field investigations and discharge monitoring, it is difficult to find the sources of pollutants to stormwater networks. The field investigations found no evidence of any illicit connections. There are known sump pump connections to stormwater networks in this town, but these sump pump connections are quite common in southeastern Massachusetts where basements may be regularly flooded from rain events and a high water table; they do not show any signs of contamination.

The inventory of Tub Mill Brook did uncover some stormwater structures that do require maintenance soon, but the majority of the catchbasins, manholes, and pipes seemed to be clear of debris and easily allow water to travel through the structures to Tub Mill Brook. Some manholes along Driscoll Lane were covered by concrete covers and could not be inspected; one discharge pipe could not be found, TMR1282PI, which was believed to be on Village Court. Interconnection between the town stormwater infrastructure and the State of Massachusetts stormwater network on Route 6 was confirmed at Railroad Avenue. Upland Way and Hitching Post Road are suspected interconnections along Route 6, but do not connect to the pipes that lead to outfalls on Tub Mill Brook. These areas need further investigation. Future investigations of the Route 6 stormwater infrastructure will require a state permit and requires the presence of a police detail. As for the structures on Barlow Lane, the citizens owning that private roadway and land would need to be compelled to find and repair the infrastructure buried in the ground.

Some of these areas needing further investigation could benefit from greater equipment and technology. Commercially available self-propelled camera systems would be a more effective tool for the Stormwater Collaborative investigations trailer, but even systems of this design can be limited by the shapes and diameters of pipes. In addition, debris in pipe would pose a challenge for any camera system. As new technology and equipment become commercially available, their viability in real-life scenarios should continuously be evaluated for municipalities and groups such as the Stormwater Collaborative to have the most capable equipment available to overcome the challenges faced in the field.

From the water samples taken along Tub Mill Brook, high concentrations of nitrates and surfactants seemed to enter the river near Park Street during both dry and wet weather conditions. This evidence suggests that there may have been a nearby point source of contamination that should be found and eliminated. The most obvious place to investigate likely would be any businesses along Park Street, including Triad Boatyard. No other areas of the watershed seemed to show evidence of an apparent pollution source, and higher pollutant concentrations in other catchments may have many sources (see Appendix D). The town could consider hiring an environmental firm to investigate the findings of this study.

Stormwater conveyance is an essential function to prevent flooding of roads and private property. The treatment of stormwater to reduce pollutants, and practices that reduce the conveyance of pollutants to stormwater networks is essential for maintaining healthy ecosystems in the surrounding areas. Illicit discharge detection and elimination as required by MS4 permits, coupled with stormwater infrastructure to reduce non-point pollutant loads, is vital for ensuring reduced pollutant discharges to aquatic ecosystems. Illicit connections and point source discharges to stormwater networks may not be nearly as common now as they may have been in the past. In the Buzzards Bay Watershed, the ongoing inventory effort by the Buzzards Bay Stormwater Collaborative have only recently found a single instance of an illicit discharge connection in the eight municipalities that participate in the program. While this is a positive result, the Stormwater Collaborative has primarily focused on small stormwater networks close to the coast, and these communities have not fully completed inventories of their stormwater structures, including some of the most heavily urbanized areas along Route 6 in each municipality. These areas have a greater potential for illicit connections, but only further investigations will determine if illicit connections are an important source to stormwater pollution to Buzzards Bay, or if most of that pollution represent so-called non-point sources that will require the construction of stormwater treatment systems.

The case study of Tub Mill Brook showed that it takes time and resources to fully analyze an area for contamination of stormwater. While sampling was scheduled to take place during the months of March through August of 2021, only two rain events occurred in that time frame with enough total volume and at a time during the week where samples could be brought to a lab for certified testing for bacteria. During this time, other rain events occurred in the middle of the night, or with such little total volume that stormwater samples could not practically be collected at times when most people are awake. Unfortunately, sampling during nighttime may not always be practicable due in large part to the lack of light and the possible dangers of where sampling occurs. In most rural towns, such as was the case with Mattapoisett, many outfalls are in wooded areas with areas of dense shrubs and trees lining sloped grades leading down into the water body the stormwater flows into. Taking out nighttime sampling then, and limited by rainfall events, it is much more practicable and advisable to spend multiple years when possible gathering sample data for a comprehensive analysis of pollution sources within a watershed. Having teams of multiple people going out to multiple locations at the same time would allow for more outfall pipes and areas to be sampled simultaneously. This is especially true for larger watersheds, areas with larger stormwater networks, and networks with more numerous outfalls. Only after accurately analyzing the conditions of the stormwater network, understanding the major pollutants, and how those pollutants enter stormwater can municipalities treat stormwater and decrease pollution to our waterways.

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Appendix A: Definition of Land Use Variables [15]

Land Use Variable	Definition and Description
Cropland	Generally tilled land used to grow row crops. Boundaries follow the shape of the fields and include associated buildings (e.g., barns). This category also includes turf farms that grow sod.
Pasture	Fields and associated facilities (barns and other outbuildings) used for animal grazing and for the growing of grasses for hay.
Forest	Areas where tree canopy covers at least 50% of the land. Both coniferous and deciduous forests belong to this class.
Non-Forested Wetland	DEP Wetlands (1:12,000) WETCODEs 4, 7, 8, 12, 23, 18, 20, and 21.
Mining	Includes sand and gravel pits, mines, and quarries. The boundaries extend to the edges of the site's activities, including on-site machinery, parking lots, roads, and buildings.
Open Land	Vacant land, idle agriculture, rock outcrops, and barren areas. Vacant land is not maintained for any evident purpose, and it does not support large plant growth.
Participation Recreation	Facilities used by the public for active recreation. Includes ball fields, tennis courts, basketball courts, athletic tracks, ski areas, playgrounds, and bike paths plus associated parking lots. Primary and secondary school recreational facilities are in this category, but university stadiums and arenas are considered Spectator Recreation. Recreation facilities not open to the public such as those belonging to private residences are mostly labeled with the associated residential land use class not participation recreation. However, some private facilities may also be mapped.
Spectator Recreation	University and professional stadiums designed for spectators as well as zoos, amusement parks, drive-in theaters, fairgrounds, racetracks and associated facilities and parking lots.
Water-Based Recreation	Swimming pools, water parks, developed freshwater and saltwater sandy beach areas and associated parking lots. Also included are scenic areas overlooking lakes or other water bodies, which may or may not include access to the water (such as a boat launch). Water-based recreation facilities related to universities are in this class. Private pools owned by individual residences are usually included in the Residential category. Marinas are separated into code 29.
Multi-Family	Duplexes (usually with two front doors, two entrance pathways, and sometimes two driveways), apartment

Land Use Variable	Definition and Description
Residential	buildings, condominium complexes, including buildings and maintained lawns.
High Density Residential	Housing on smaller than 1/4 acre lots. See notes below for details on Residential interpretation.
Medium Density Residential	Housing on 1/4 - 1/2 acre lots. See notes below for details on Residential interpretation.
Low Density Residential	Housing on 1/2 - 1 acre lots. See notes below for details on Residential interpretation.
Saltwater Wetland	DEP Wetlands (1:12,000) WETCODEs 11 and 27.
Commercial	Malls, shopping centers and larger strip commercial areas, plus neighborhood stores and medical offices (not hospitals). Lawn and garden centers that do not produce or grow the product are also considered commercial.
Industrial	Light and heavy industry, including buildings, equipment, and parking areas.
Transitional	Open areas in the process of being developed from one land use to another (if the future land use is at all uncertain). Formerly identified as "Urban Open".
Transportation	Airports (including landing strips, hangars, parking areas and related facilities), railroads and rail stations, and divided highways (related facilities would include rest areas, highway maintenance areas, storage areas, and on/off ramps). Also includes docks, warehouses, and related land-based storage facilities, and terminal freight and storage facilities. Roads and bridges less than 200 feet in width that are the center of two differing land use classes will have the land use classes meet at the center line of the road (i.e., these roads/bridges themselves will not be separated into this class).
Waste Disposal	Landfills, dumps, and water and sewage treatment facilities such as pump houses, and associated parking lots. Capped landfills that have been converted to other uses are coded with their present land use.
Water	DEP Wetlands (1:12,000) WETCODEs 9 and 22.

Land Use Variable	**Definition and Description**
Cranberry bog	Both active and recently inactive cranberry bogs and the sandy areas adjacent to the bogs that are used in the growing process. Impervious features associated with cranberry bogs such as parking lots and machinery are included. Modified from DEP Wetlands (1:12,000) WETCODE 5.
Powerline/Utility	Powerline and other maintained public utility corridors and associated facilities, including power plants and their parking areas.
Saltwater Sandy Beach	DEP Wetlands (1:12,000) WETCODEs 1, 2, 3, 6, 10, 13, 17 and 19
Golf Course	Includes the greenways, sand traps, water bodies within the course, associated buildings, and parking lots. Large forest patches within the course greater than 1 acre are classified as Forest (class 3). Does not include driving ranges or miniature golf courses.
Marina	Include parking lots and associated facilities but not docks (in class 18)
Urban Public/Institutional	Lands comprising schools, churches, colleges, hospitals, museums, prisons, town halls or court houses, police, and fire stations, including parking lots, dormitories, and university housing. Also, may include public open green spaces like town commons.
Cemetery	Includes the gravestones, monuments, parking lots, road networks and associated buildings.
Orchard	Fruit farms and associated facilities.
Nursery	Greenhouses and associated buildings as well as any surrounding maintained lawn. Christmas tree (small conifer) farms are also classified as Nurseries.
Forested Wetland	DEP Wetlands (1:12,000) WETCODEs 14, 15, 16, 24, 25 and 26.
Very Low Density Residential	Housing on > 1 acre lots and very remote, rural housing. See notes below for details on Residential interpretation.
Junkyard	Includes the storage of car, metal, machinery, and other debris as well as associated buildings as a business.
Brushland/Successional	Predominantly (> 25%) shrub cover, and some immature trees not large or dense enough to be classified as forest. It also includes areas that are more permanently shrubby, such as heath areas, wild blueberries, or mountain laurel.

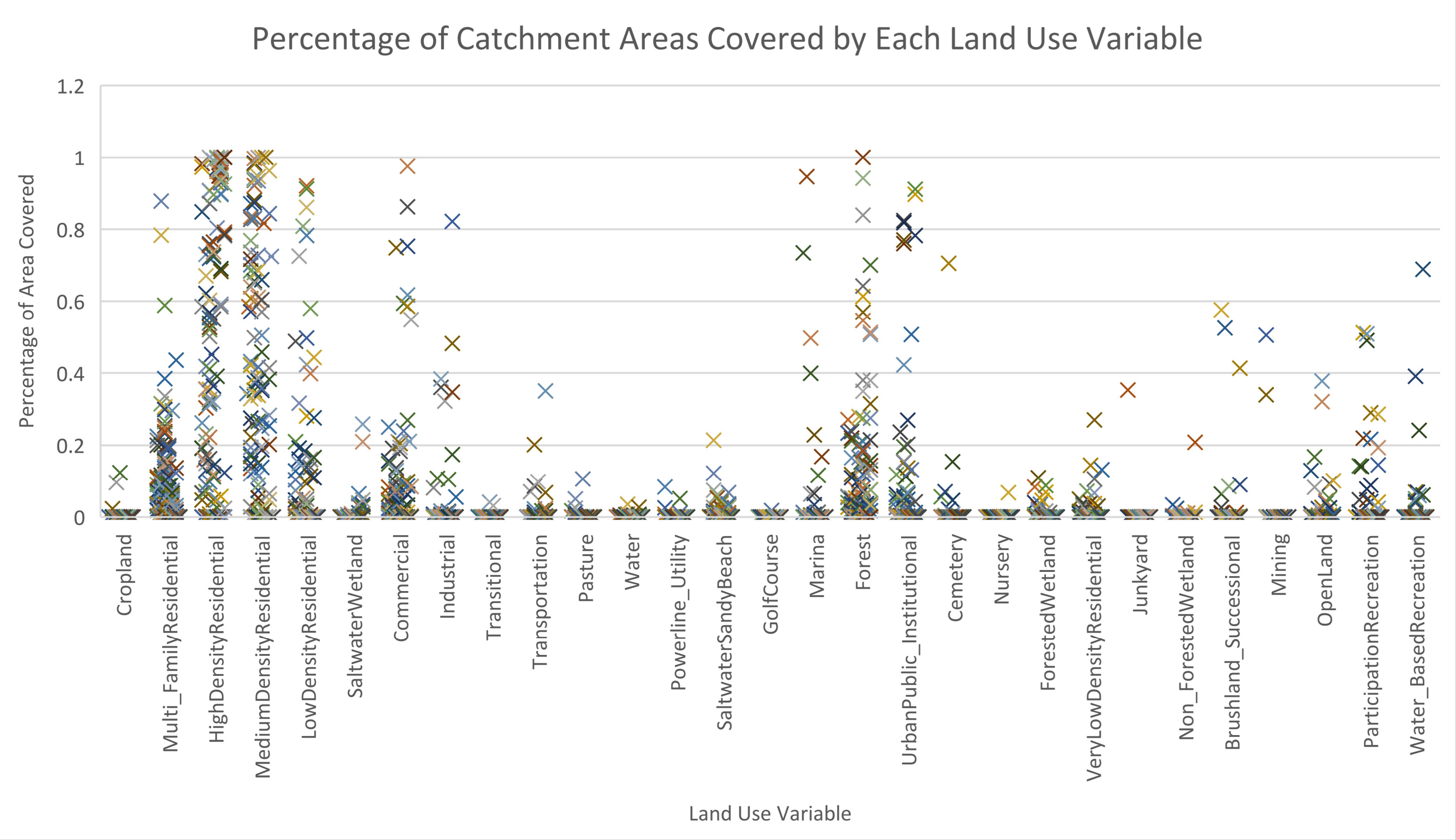


Figure A.1: Percentage of Area Covered by Land Use Variables, with Each Catchment Marked in a Different Color

Appendix B: Equipment List for BBSC Discharge Investigation Trailer

1. Adjustable Ball mount w/ clip, trailer ball, jack block, and (2) wheel wedges
2. Tote: (2) Spotlight assemblies
3. Tote: Spare parts
4. Tote: Liquid Supplies:
    a. Diluted Tracer Dye
    b. Gas Can
    c. Marking Paint – white and red
    d. Small Engine Oil
5. Hydrant Connection: backflow preventer assembly, hydrant wrench, pipe wrench, and supports
6. Laser Pointer, Laser Cradle, and safety glasses
7. Drop light
8. Smoke Test Blower and Smoke Candles – 60 second (12 pack)
9. Tracer Dye – full strength
10. Electric Generator with short cord
11. (2) 50-foot Extension Cords and (1) 15-foot Extension Cord
12. Drainpipe Inspection Video Camera
13. Pipe Snake (100 foot)
14. Ridgid KJ-3100 Water Jetter
15. (8) Filled Sandbags
16. Garden Hoses (1) 75-foot, (1) 50-foot, and (3) 10-foot
17. Electric dewatering pump with Drain Hose
18. Small utility pump – for dye and waste
19. Water Tank (35 gallon) – for dye and waste
20. 6 Gallon Water Tote
21. (2) 32 Gallon Barrels
22. (4) 5 Gallon Buckets
23. Tarps and rope

24. Magnetic Lid Lifter Steel Dolly
25. Yard Tools - Rake, Spade, Flat blade shovel, Push Broom, Loppers, and Clam Shovel
26. 48” Pry Bar, 24” Pry Bar, Manhole hook, and 10-lb Hammer
27. Hand Tools: sockets, wrenches, plyers, screwdrivers, pentagon socket
28. Hand Tools: pry bar assortment, pipe wrench, 3-lb hammer, adjustable wrench
29. 200-foot Tape Measure
30. Measuring Wheel
31. Survey level, tripod, and pole
32. Survey supplies – measuring tape, chalk line, stakes, plumb bob, masonry nails, and flagging
33. Utility Magnetic Locator
34. PVC Guide Pipe Set
35. Tote: Confined Space Harness, tripod winch
36. Confined Space Tripod
37. Confined Space Gas Detector
38. Safety Cones
39. PPE – Hard Hats, Work Gloves, Face Shield or Safety Googles
40. Staple Items: trash bags, duct tape, Teflon tape, cable ties, rags, nitrile gloves

Appendix C: Blank Inventory and Sampling Sheets

Catchment ID: **Date/Time:**

Location:

Inspector: **Town:**

Sketch:

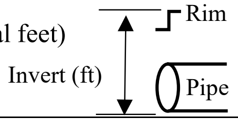
Conditions: 1)All Good 2)Needs Cleaning 3)Needs Repair 4) Blockages 5)Immediate Hazard

6)Standing Water 7)Dry Weather Flow 8)Tidal Intrusion 9)Leaf Debris 10)Trash 11)Odor 12)Suds

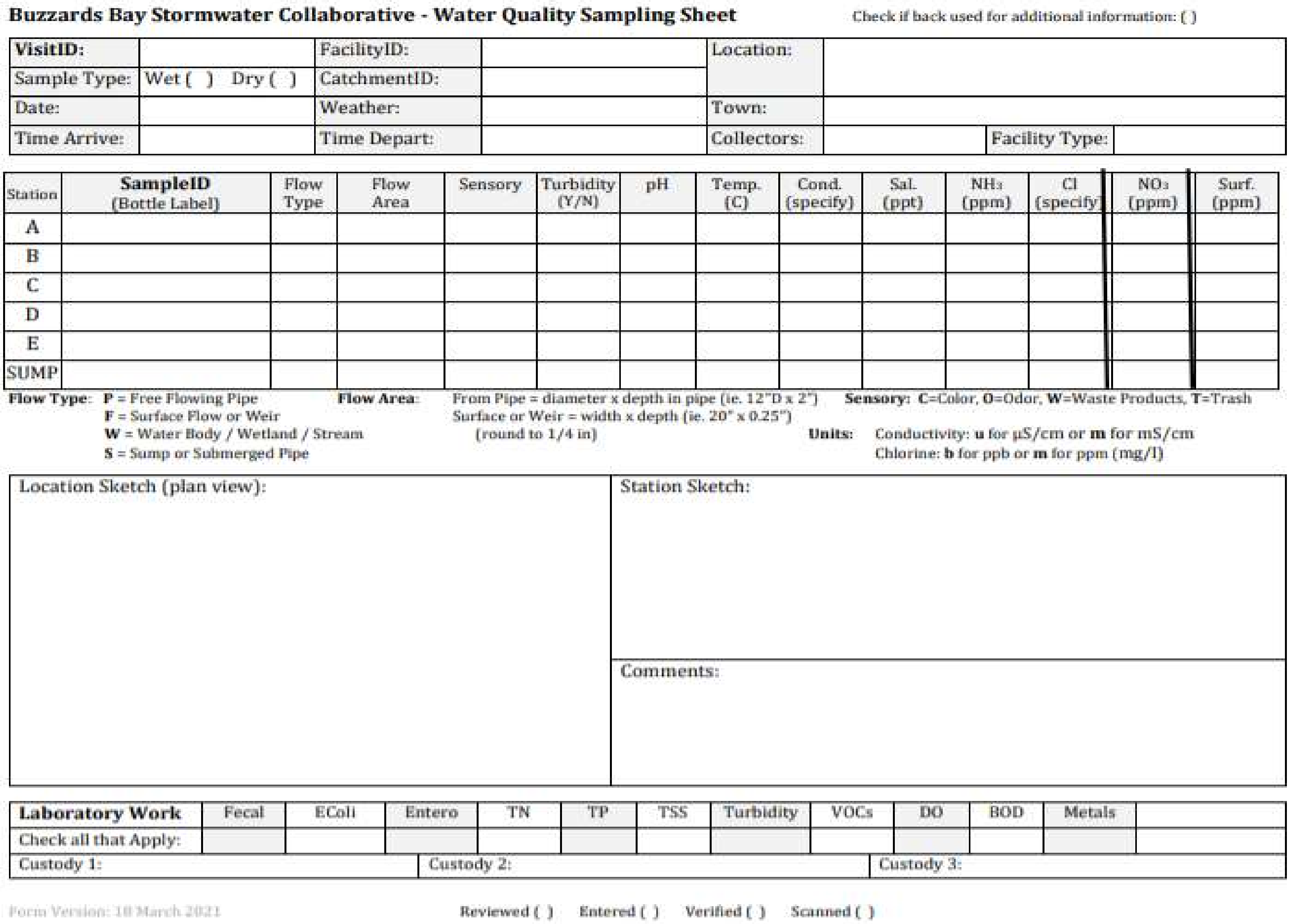
13)Organic Sheen 14)Petroleum Sheen 15)Unknown Sheen 16)Sewage 17)Bleaching 18)Unnatural Color

Comments:

Instructions:
1. Show structures in proximity with connections – plan view
2. Sketch each pipe with relevant notes
3. Indicate: direction, size (inches), material, invert (decimal feet)
4. Indicate invert to bottom of sump (decimal feet)
5. Indicate number for all conditions that apply



Abbreviations: V = Clay
C = Concrete
M = Corrugated Metal
P = PVC
H = HDPE
I = Cast or Ductile Iron



Buzzards Bay Stormwater Collaborative - Water Quality Sampling Sheet

Check if back used for additional information: ( )

VisitID:		FacilityID:		Location:			
Sample Type:	Wet ( ) Dry ( )	CatchmentID:					
Date:		Weather:		Town:			
Time Arrive:		Time Depart:		Collectors:		Facility Type:	

Station	**SampleID** (Bottle Label)	Flow Type	Flow Area	Sensory	Turbidity (Y/N)	pH	Temp. (C)	Cond. (specify)	Sal. (ppt)	NH_3 (ppm)	Cl (specify)	NO_3 (ppm)	Surf. (ppm)
A													
B													
C													
D													
E													
SUMP													

Flow Type: **P** = Free Flowing Pipe
F = Surface Flow or Weir
W = Water Body / Wetland / Stream
S = Sump or Submerged Pipe

Flow Area: From Pipe = diameter x depth in pipe (ie. 12"D x 2")
Surface or Weir = width x depth (ie. 20" x 0.25")
(round to 1/4 in)

Sensory: **C**=Color, **O**=Odor, **W**=Waste Products, **T**=Trash

Units: Conductivity: **u** for µS/cm or **m** for mS/cm
Chlorine: **b** for ppb or **m** for ppm (mg/l)

Location Sketch (plan view):

Station Sketch:

Comments:

Laboratory Work	Fecal	EColi	Entero	TN	TP	TSS	Turbidity	VOCs	DO	BOD	Metals	
Check all that Apply:												

Custody 1:

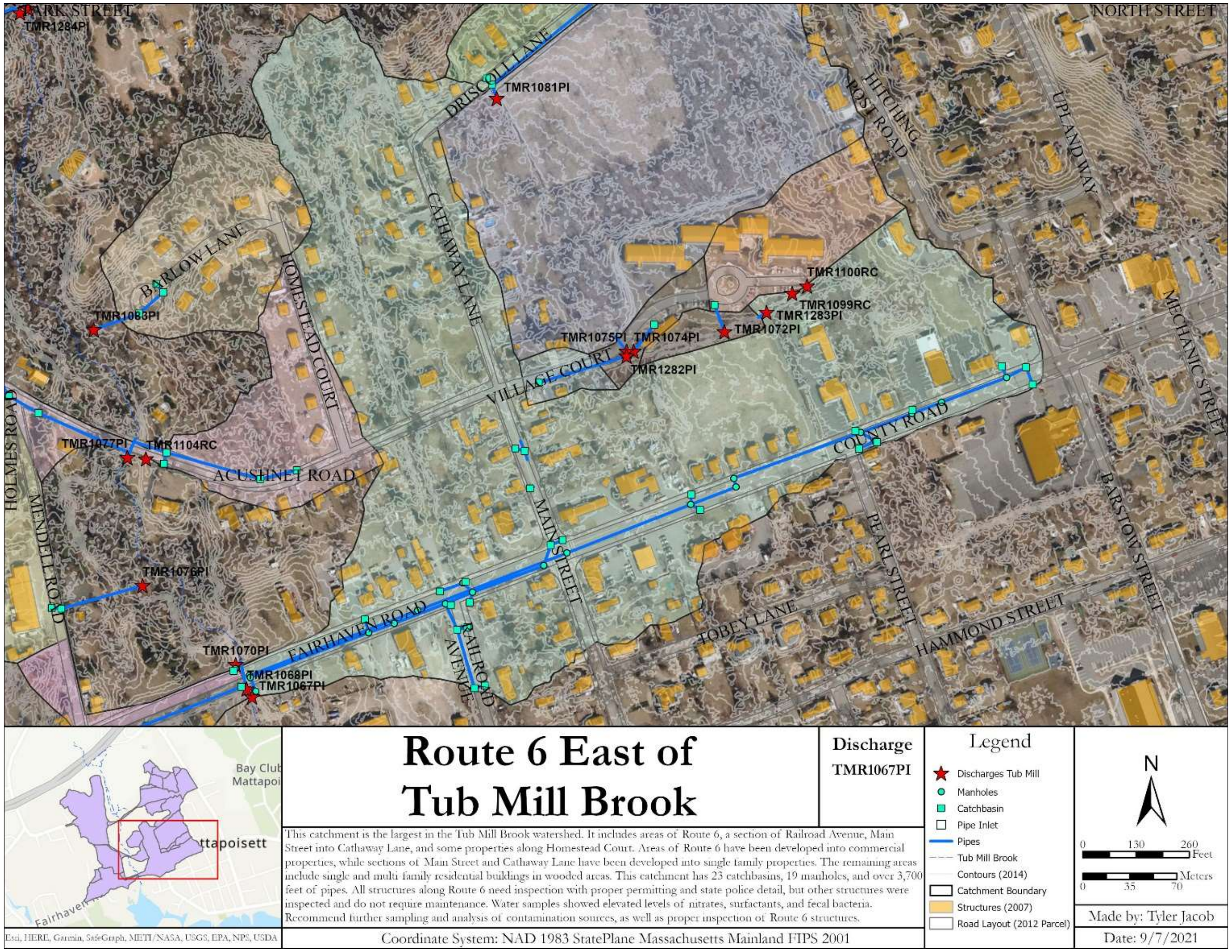
Custody 2:

Custody 3:

Form Version: 18 March 2021

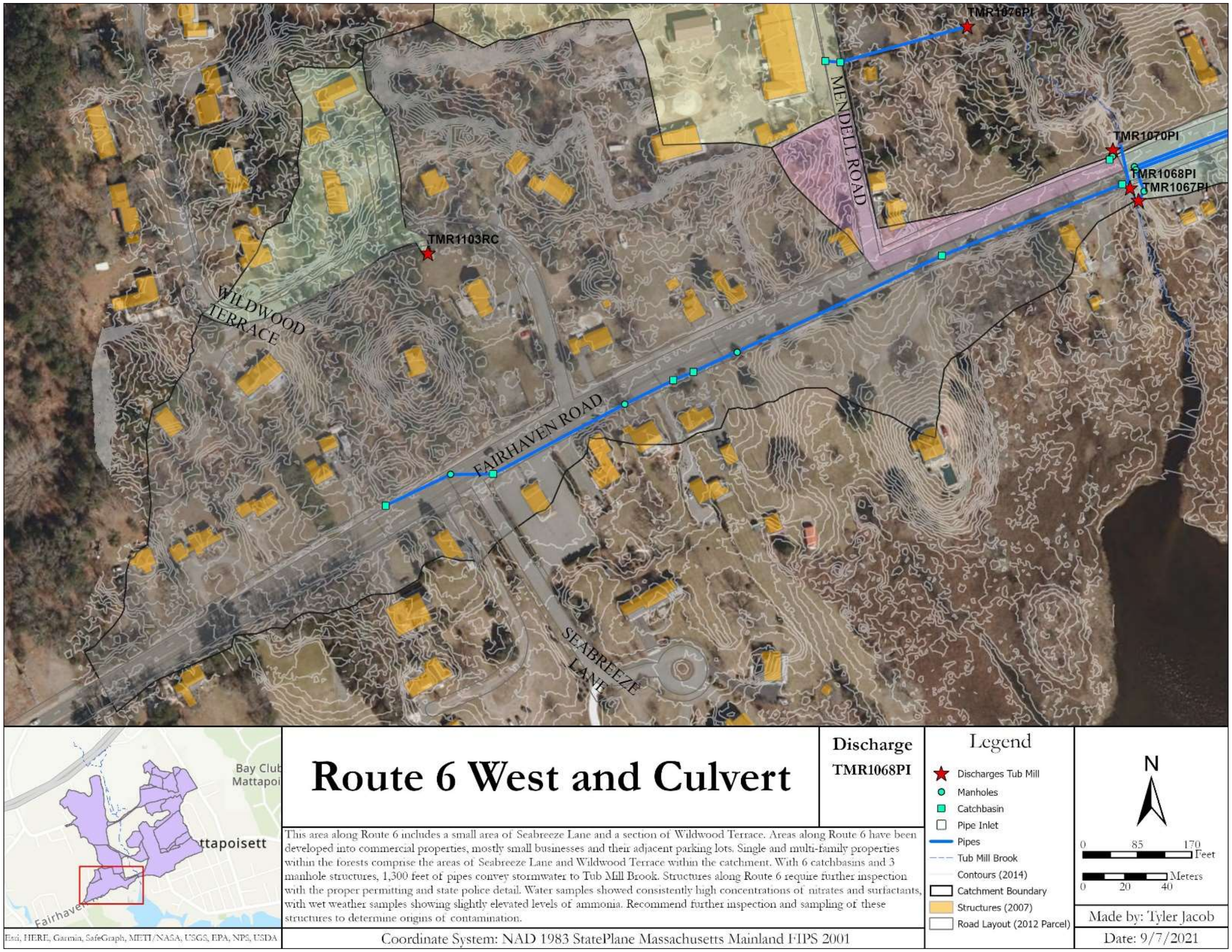
Reviewed ( ) Entered ( ) Verified ( ) Scanned ( )

Appendix D: Tub Mill Brook Catchments with Summary Information



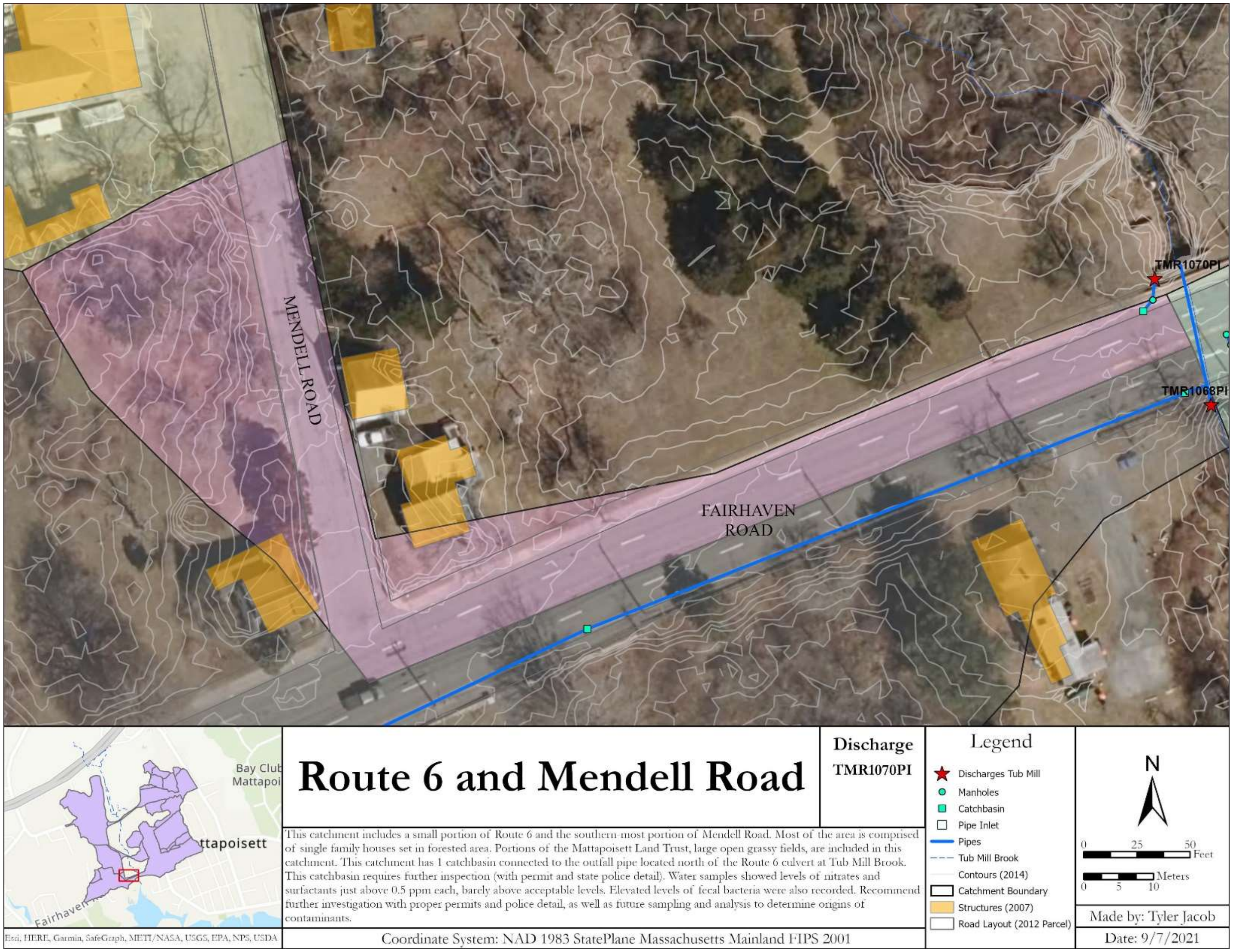
This catchment is the largest in the Tub Mill Brook watershed. It includes areas of Route 6, a section of Railroad Avenue, Main Street into Cathaway Lane, and some properties along Homestead Court. Areas of Route 6 have been developed into commercial properties, while sections of Main Street and Cathaway Lane have been developed into single family properties. The remaining areas include single and multi-family residential buildings in wooded areas. This catchment has 23 catchbasins, 19 manholes, and over 3,700 feet of pipes. All structures along Route 6 need inspection with proper permitting and state police detail, but other structures were inspected and do not require maintenance. Water samples showed elevated levels of nitrates, surfactants, and fecal bacteria. Recommend further sampling and analysis of contamination sources, as well as proper inspection of Route 6 structures.

Figure D.1: Route 6 East of Tub Mill Brook



This area along Route 6 includes a small area of Seabreeze Lane and a section of Wildwood Terrace. Areas along Route 6 have been developed into commercial properties, mostly small businesses and their adjacent parking lots. Single and multi-family properties within the forests comprise the areas of Seabreeze Lane and Wildwood Terrace within the catchment. With 6 catchbasins and 3 manhole structures, 1,300 feet of pipes convey stormwater to Tub Mill Brook. Structures along Route 6 require further inspection with the proper permitting and state police detail. Water samples showed consistently high concentrations of nitrates and surfactants, with wet weather samples showing slightly elevated levels of ammonia. Recommend further inspection and sampling of these structures to determine origins of contamination.

Figure D.2 : Route 6 West and Culvert



Route 6 and Mendell Road

Discharge
TMR1070PI

This catchment includes a small portion of Route 6 and the southern-most portion of Mendell Road. Most of the area is comprised of single family houses set in forested area. Portions of the Mattapoisett Land Trust, large open grassy fields, are included in this catchment. This catchment has 1 catchbasin connected to the outfall pipe located north of the Route 6 culvert at Tub Mill Brook. This catchbasin requires further inspection (with permit and state police detail). Water samples showed levels of nitrates and surfactants just above 0.5 ppm each, barely above acceptable levels. Elevated levels of fecal bacteria were also recorded. Recommend further investigation with proper permits and police detail, as well as future sampling and analysis to determine origins of contaminants.

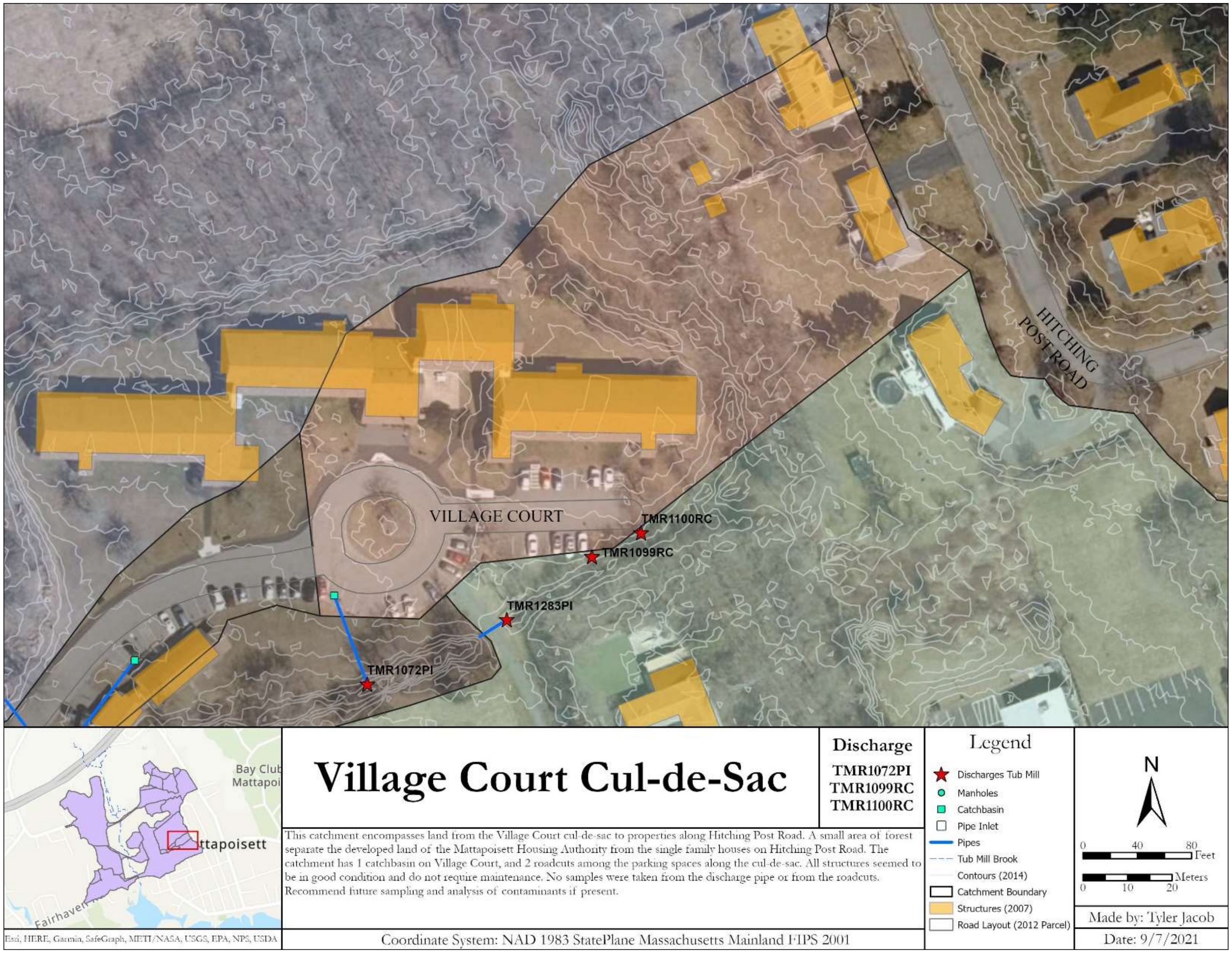
Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA

Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001

Made by: Tyler Jacob

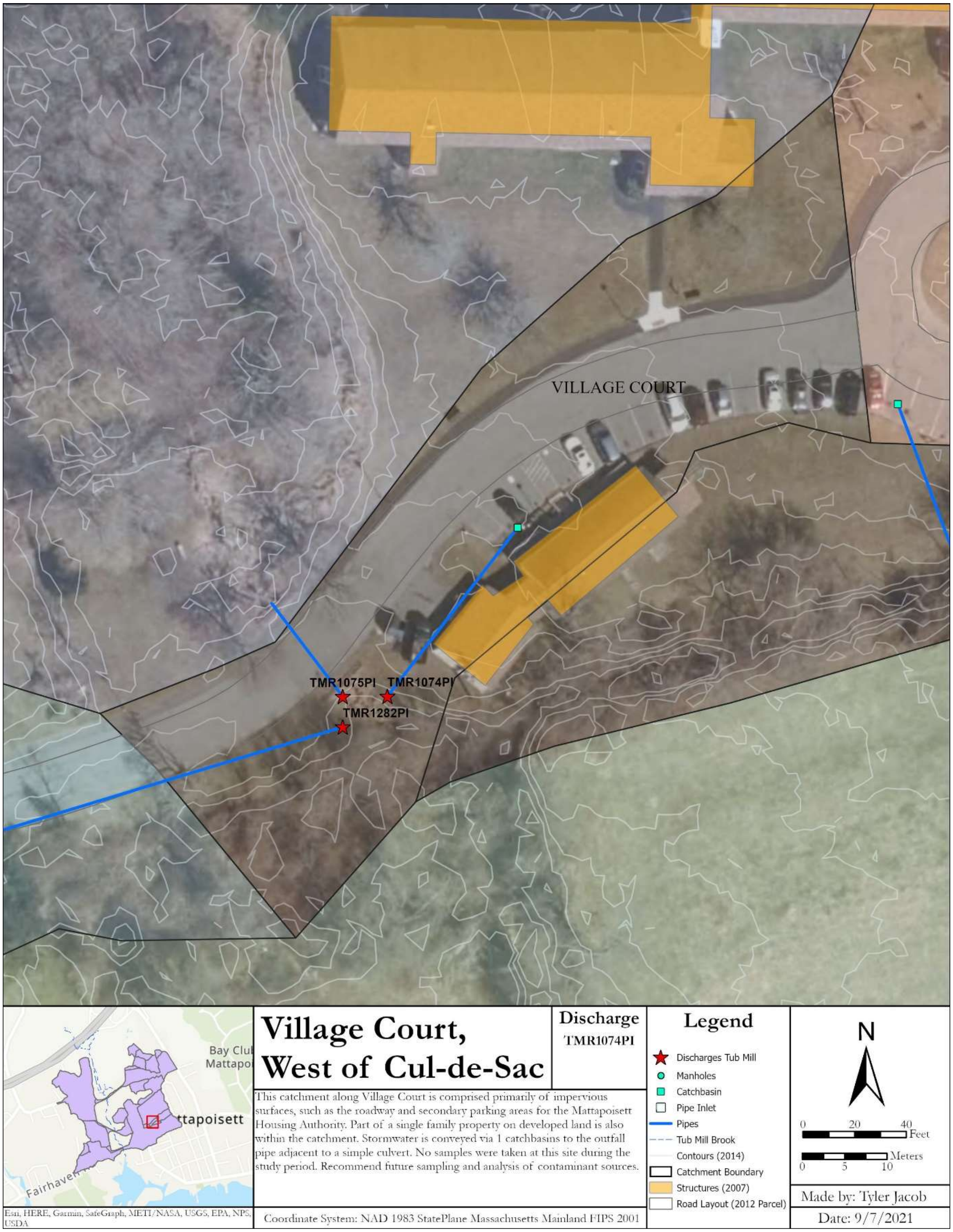
Date: 9/7/2021

Figure D.3: Route 6 and Mendell Road



This catchment encompasses land from the Village Court cul-de-sac to properties along Hitching Post Road. A small area of forest separate the developed land of the Mattapoisett Housing Authority from the single family houses on Hitching Post Road. The catchment has 1 catchbasin on Village Court, and 2 roadcuts among the parking spaces along the cul-de-sac. All structures seemed to be in good condition and do not require maintenance. No samples were taken from the discharge pipe or from the roadcuts. Recommend future sampling and analysis of contaminants if present.

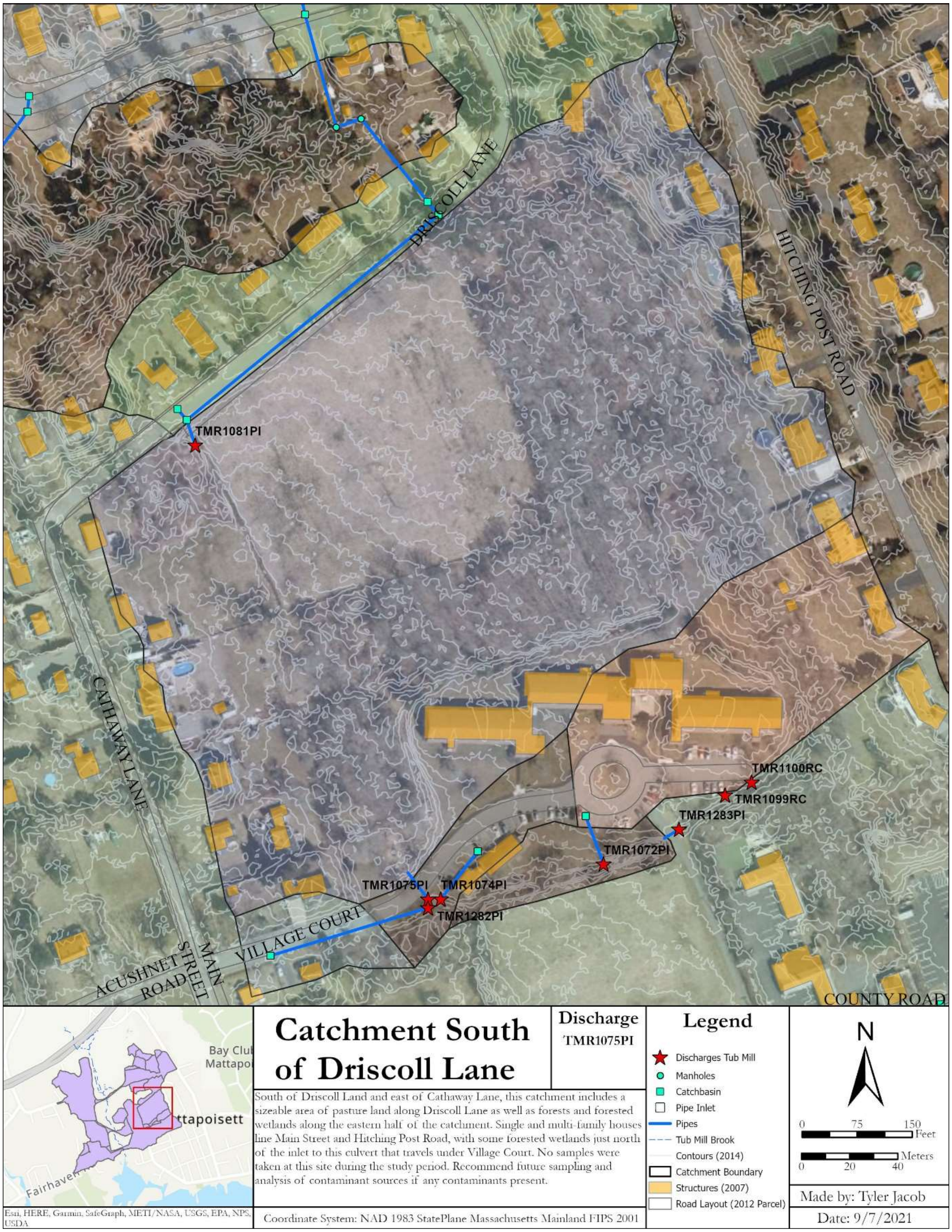
Figure D.4: Village Court Cul-de-Sac



Village Court, West of Cul-de-Sac

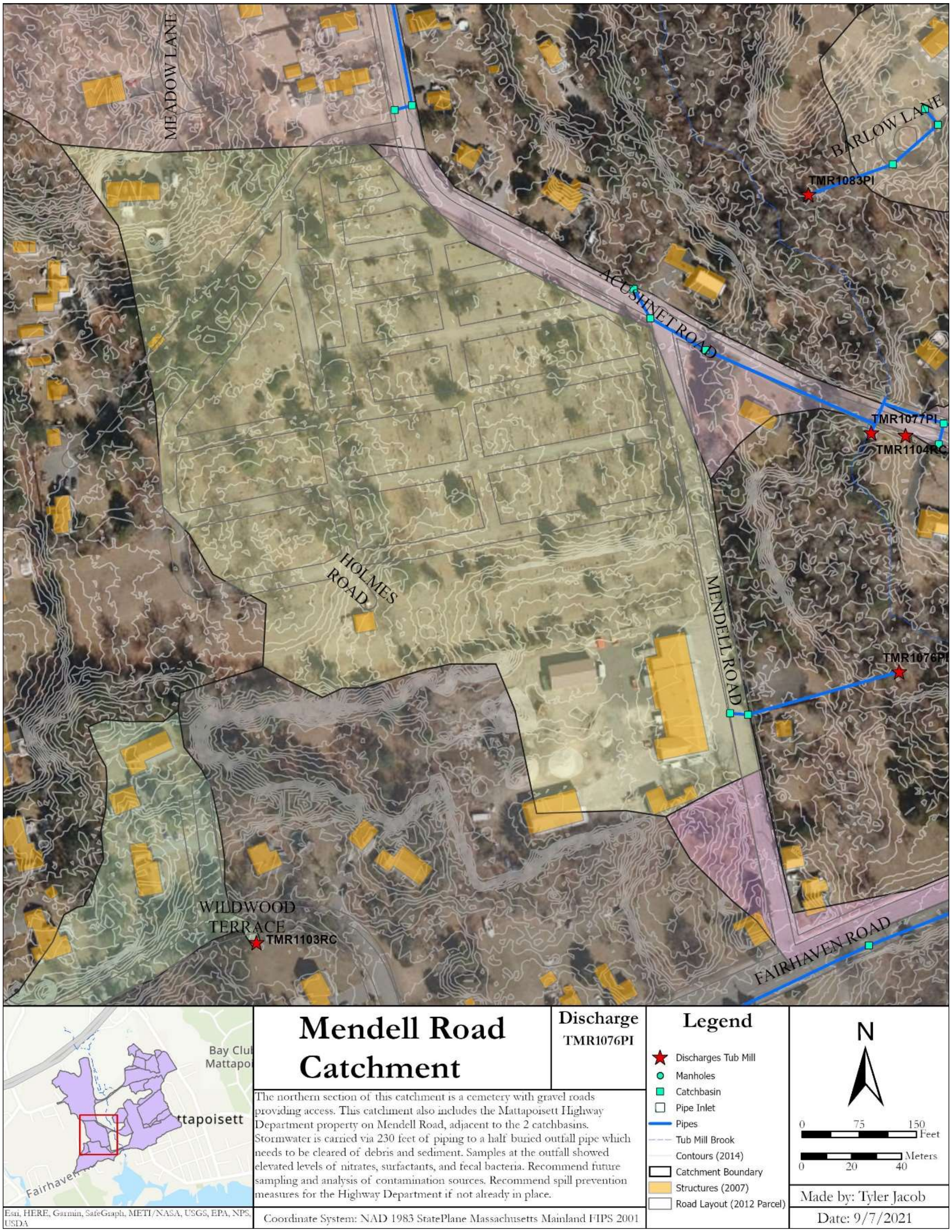
This catchment along Village Court is comprised primarily of impervious surfaces, such as the roadway and secondary parking areas for the Mattapoisett Housing Authority. Part of a single family property on developed land is also within the catchment. Stormwater is conveyed via 1 catchbasins to the outfall pipe adjacent to a simple culvert. No samples were taken at this site during the study period. Recommend future sampling and analysis of contaminant sources.

Figure D.5: Village Court, West of Cul-de-Sac



South of Driscoll Land and east of Cathaway Lane, this catchment includes a sizeable area of pasture land along Driscoll Lane as well as forests and forested wetlands along the eastern half of the catchment. Single and multi-family houses line Main Street and Hitching Post Road, with some forested wetlands just north of the inlet to this culvert that travels under Village Court. No samples were taken at this site during the study period. Recommend future sampling and analysis of contaminant sources if any contaminants present.

Figure D.6: Catchment South of Driscoll Lane



Mendell Road Catchment

The northern section of this catchment is a cemetery with gravel roads providing access. This catchment also includes the Mattapoisett Highway Department property on Mendell Road, adjacent to the 2 catchbasins. Stormwater is carried via 230 feet of piping to a half buried outfall pipe which needs to be cleared of debris and sediment. Samples at the outfall showed elevated levels of nitrates, surfactants, and fecal bacteria. Recommend future sampling and analysis of contamination sources. Recommend spill prevention measures for the Highway Department if not already in place.

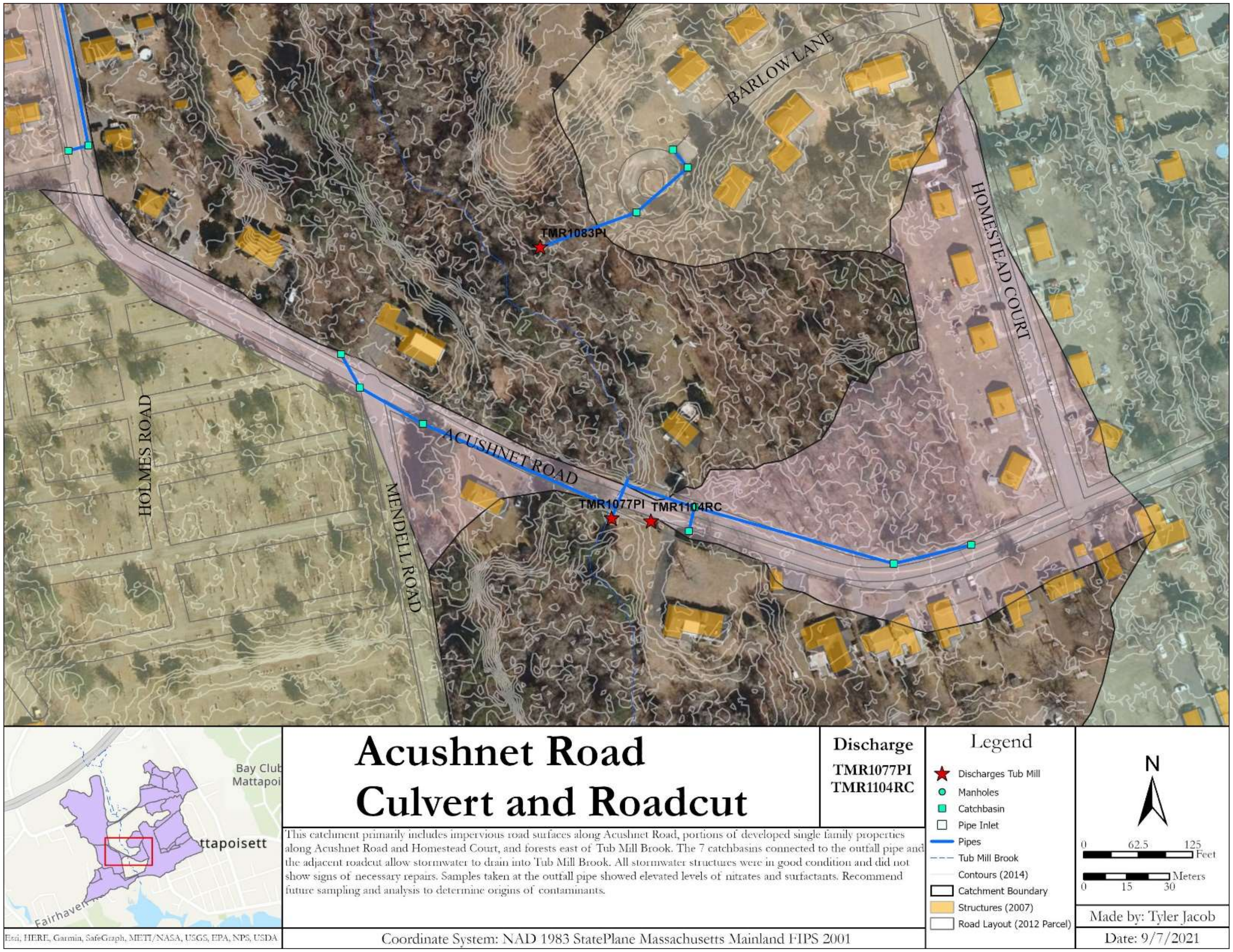
Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA

Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001

Made by: Tyler Jacob

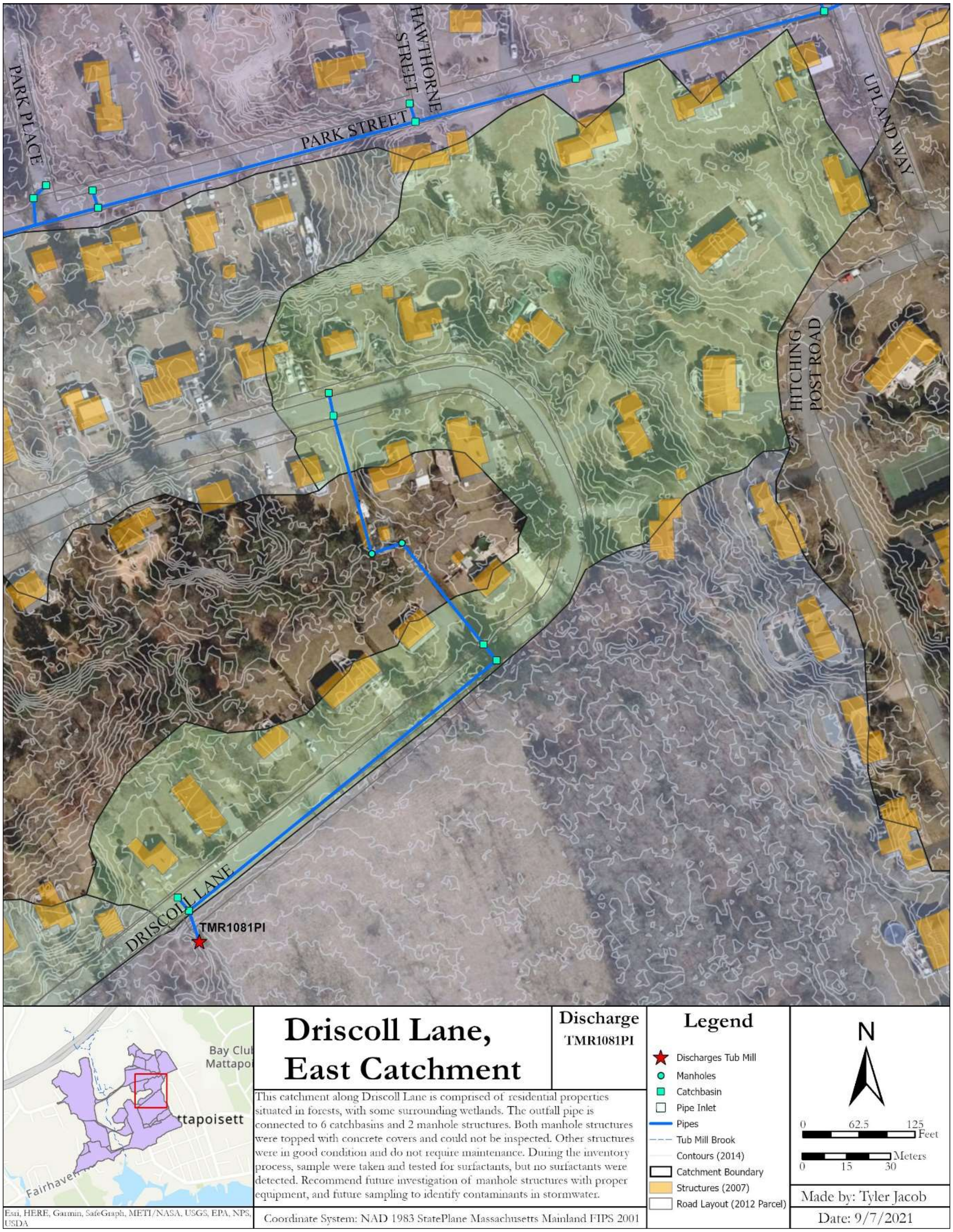
Date: 9/7/2021

Figure D.7: Mendell Road Catchment



This catchment primarily includes impervious road surfaces along Acushnet Road, portions of developed single family properties along Acushnet Road and Homestead Court, and forests east of Tub Mill Brook. The 7 catchbasins connected to the outfall pipe and the adjacent roadcut allow stormwater to drain into Tub Mill Brook. All stormwater structures were in good condition and did not show signs of necessary repairs. Samples taken at the outfall pipe showed elevated levels of nitrates and surfactants. Recommend future sampling and analysis to determine origins of contaminants.

Figure D.8: Acushnet Road Culvert and Roadcut

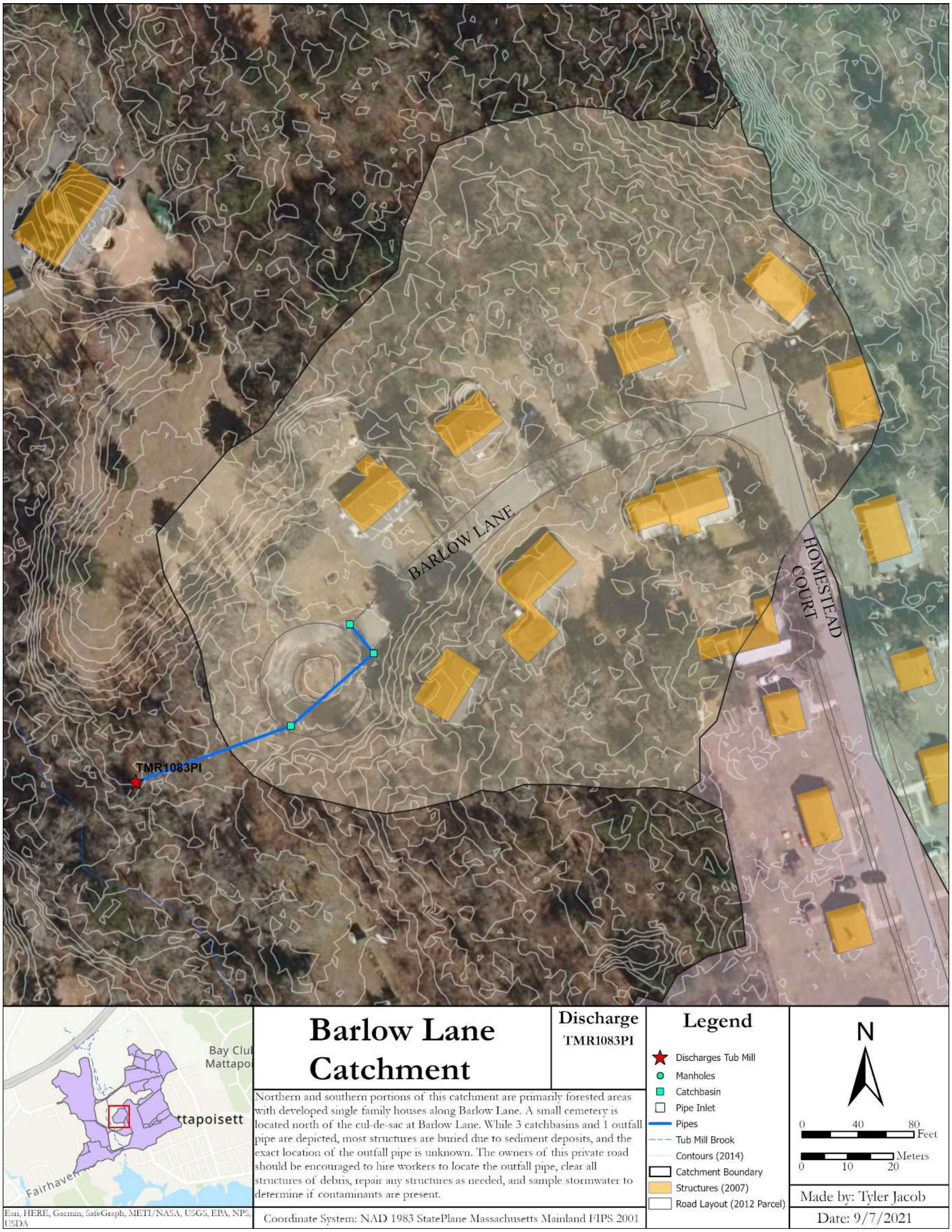


Driscoll Lane, East Catchment

This catchment along Driscoll Lane is comprised of residential properties situated in forests, with some surrounding wetlands. The outfall pipe is connected to 6 catchbasins and 2 manhole structures. Both manhole structures were topped with concrete covers and could not be inspected. Other structures were in good condition and do not require maintenance. During the inventory process, sample were taken and tested for surfactants, but no surfactants were detected. Recommend future investigation of manhole structures with proper equipment, and future sampling to identify contaminants in stormwater.

Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001

Figure D.9 Driscoll Lane, East Catchment



Barlow Lane Catchment

Discharge
TMR1083PI

Legend

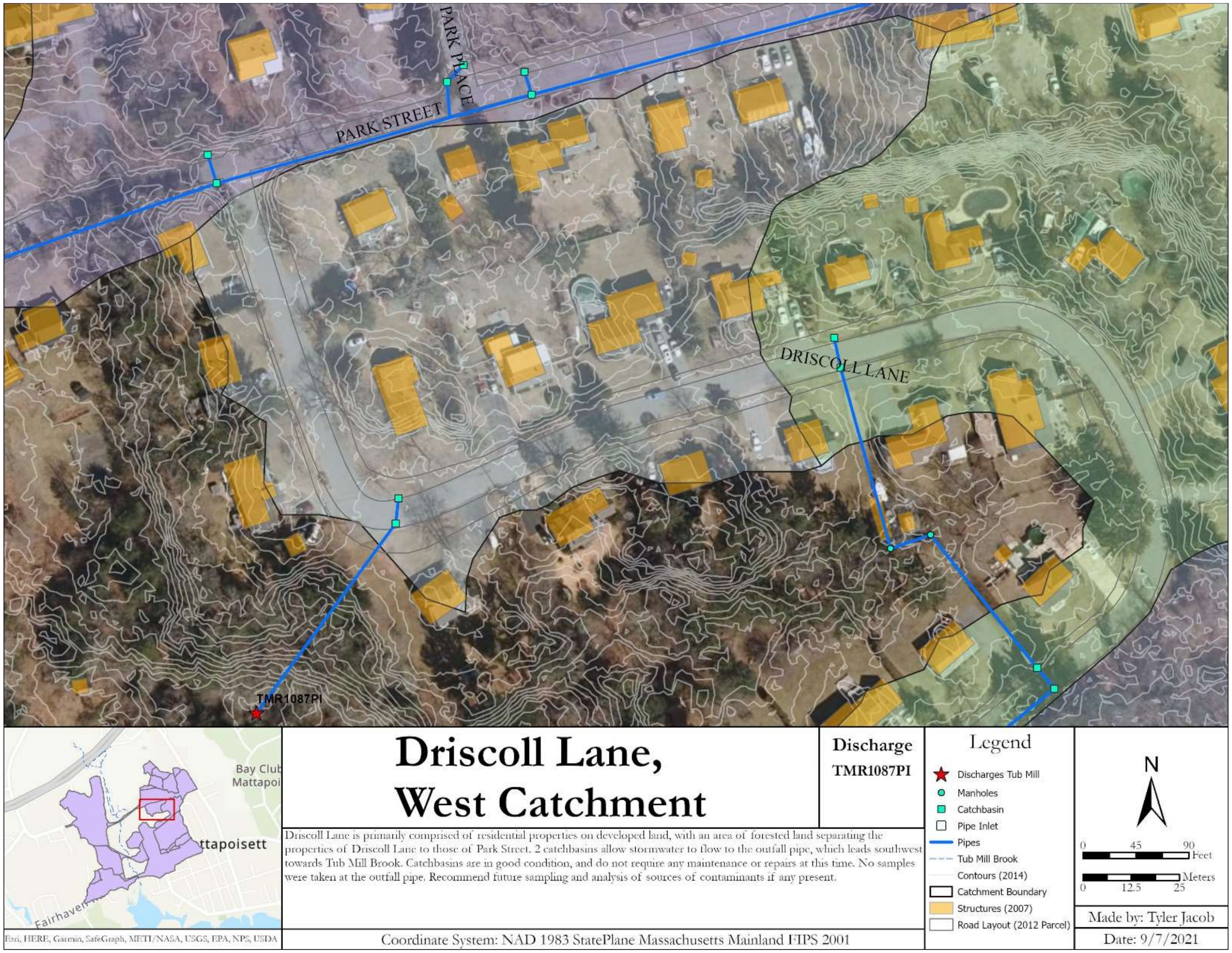
Northern and southern portions of this catchment are primarily forested areas with developed single family houses along Barlow Lane. A small cemetery is located north of the cul-de-sac at Barlow Lane. While 3 catchbasins and 1 outfall pipe are depicted, most structures are buried due to sediment deposits, and the exact location of the outfall pipe is unknown. The owners of this private road should be encouraged to hire workers to locate the outfall pipe, clear all structures of debris, repair any structures as needed, and sample stormwater to determine if contaminants are present.

Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001

Made by: Tyler Jacob

Date: 9/7/2021

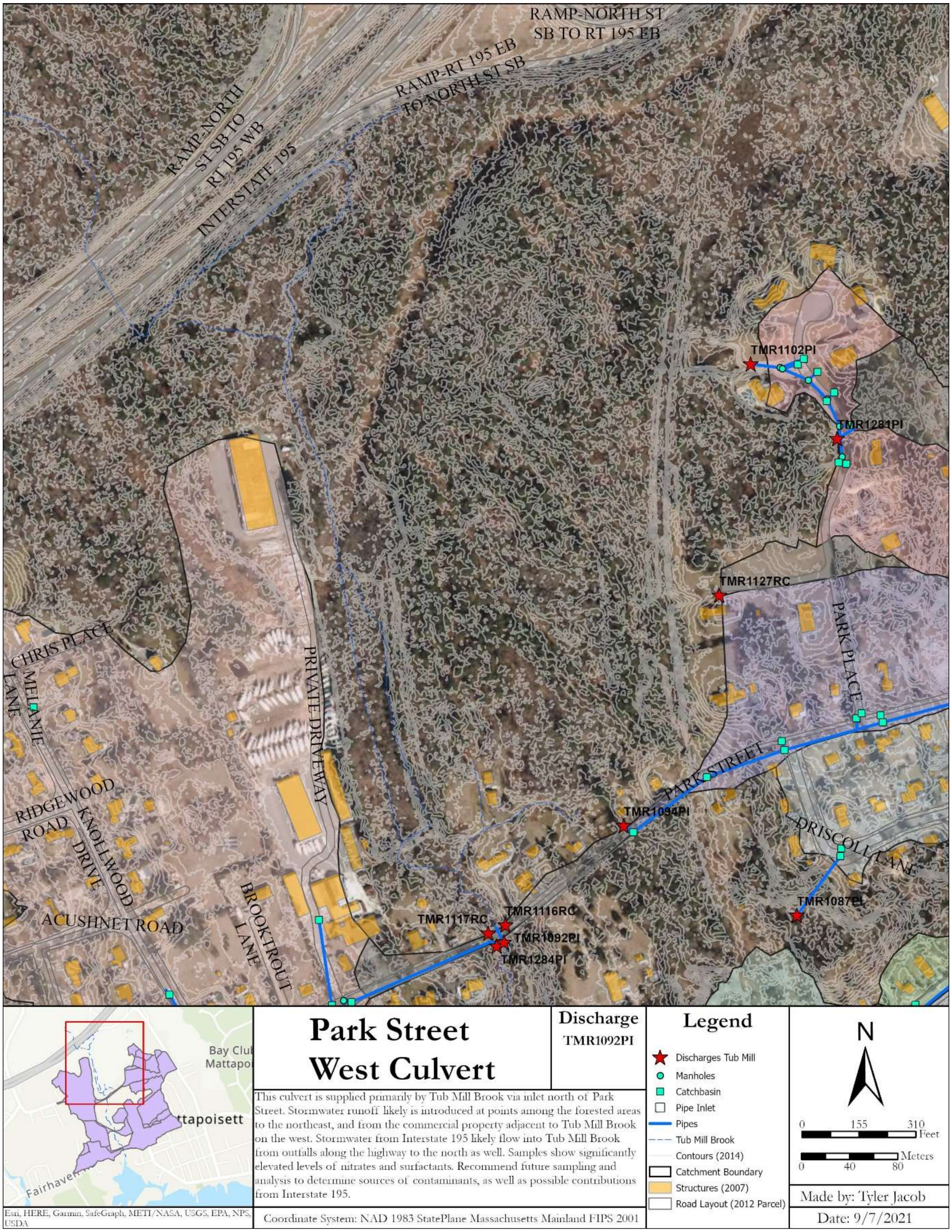
Figure D.10: Barlow Lane Catchment



Driscoll Lane, West Catchment

Driscoll Lane is primarily comprised of residential properties on developed land, with an area of forested land separating the properties of Driscoll Lane to those of Park Street. 2 catchbasins allow stormwater to flow to the outfall pipe, which leads southwest towards Tub Mill Brook. Catchbasins are in good condition, and do not require any maintenance or repairs at this time. No samples were taken at the outfall pipe. Recommend future sampling and analysis of sources of contaminants if any present.

Figure D.11: Driscoll Lane West Catchment



Park Street West Culvert

Discharge
TMR1092PI

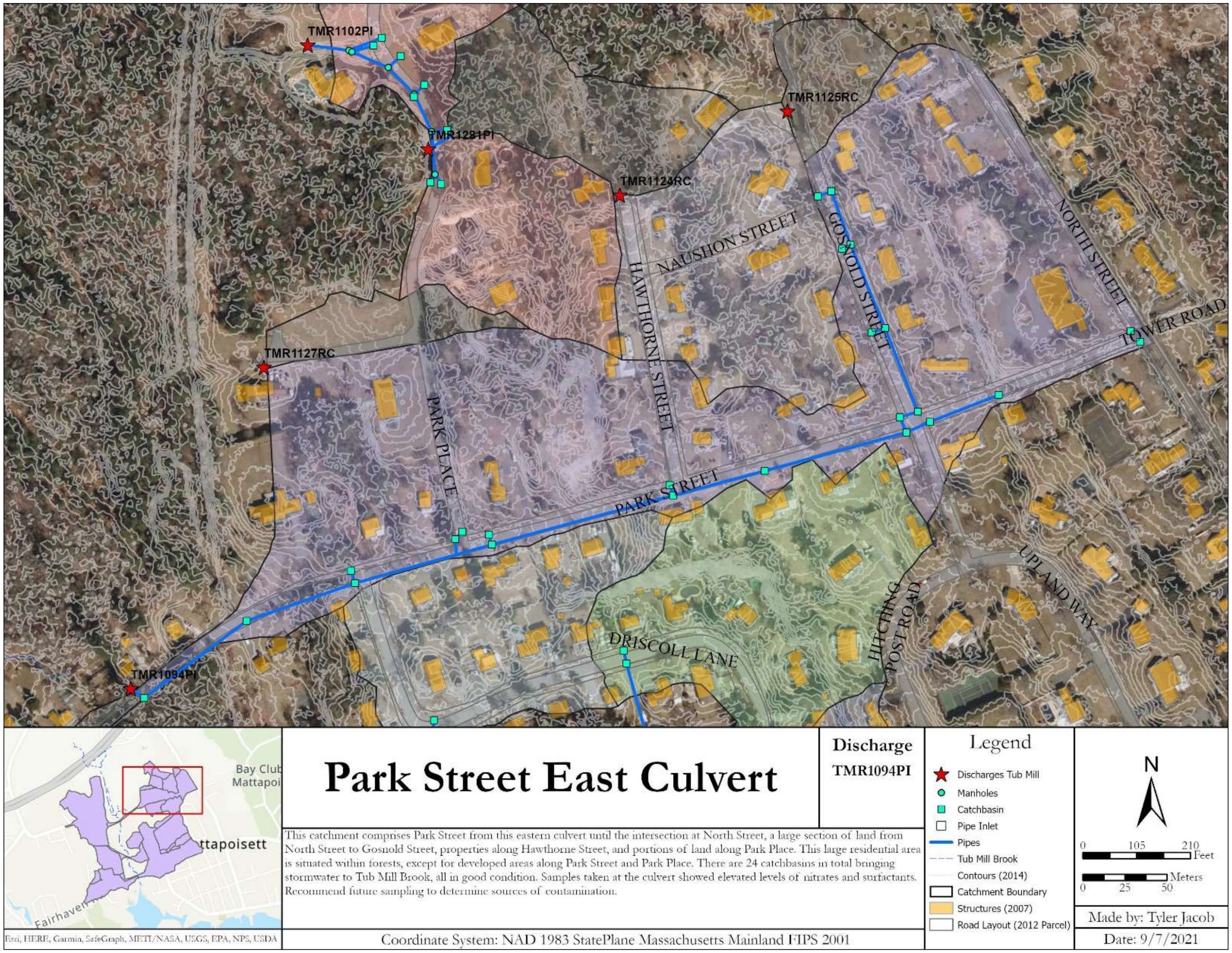
This culvert is supplied primarily by Tub Mill Brook via inlet north of Park Street. Stormwater runoff likely is introduced at points among the forested areas to the northeast, and from the commercial property adjacent to Tub Mill Brook on the west. Stormwater from Interstate 195 likely flow into Tub Mill Brook from outfalls along the highway to the north as well. Samples show significantly elevated levels of nitrates and surfactants. Recommend future sampling and analysis to determine sources of contaminants, as well as possible contributions from Interstate 195.

Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001

Legend
★ Discharges Tub Mill
○ Manholes
🟩 Catchbasin
☐ Pipe Inlet
— Pipes
--- Tub Mill Brook
— Contours (2014)
☐ Catchment Boundary
🟧 Structures (2007)
☐ Road Layout (2012 Parcel)

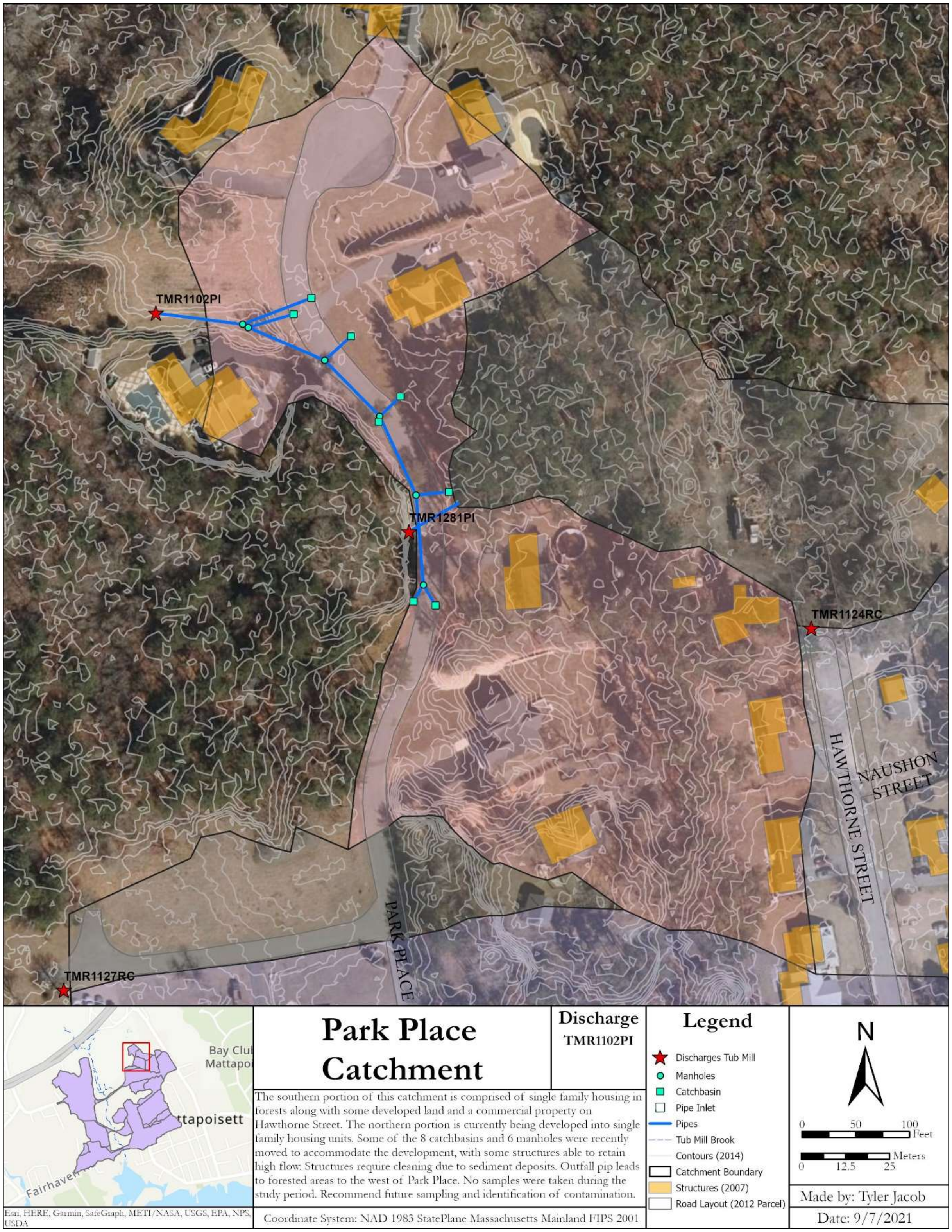
Made by: Tyler Jacob
Date: 9/7/2021

Figure D.12: Park Street West Culvert



This catchment comprises Park Street from this eastern culvert until the intersection at North Street, a large section of land from North Street to Gosnold Street, properties along Hawthorne Street, and portions of land along Park Place. This large residential area is situated within forests, except for developed areas along Park Street and Park Place. There are 24 catchbasins in total bringing stormwater to Tub Mill Brook, all in good condition. Samples taken at the culvert showed elevated levels of nitrates and surfactants. Recommend future sampling to determine sources of contamination.

Figure D.13: Park Street East Culvert

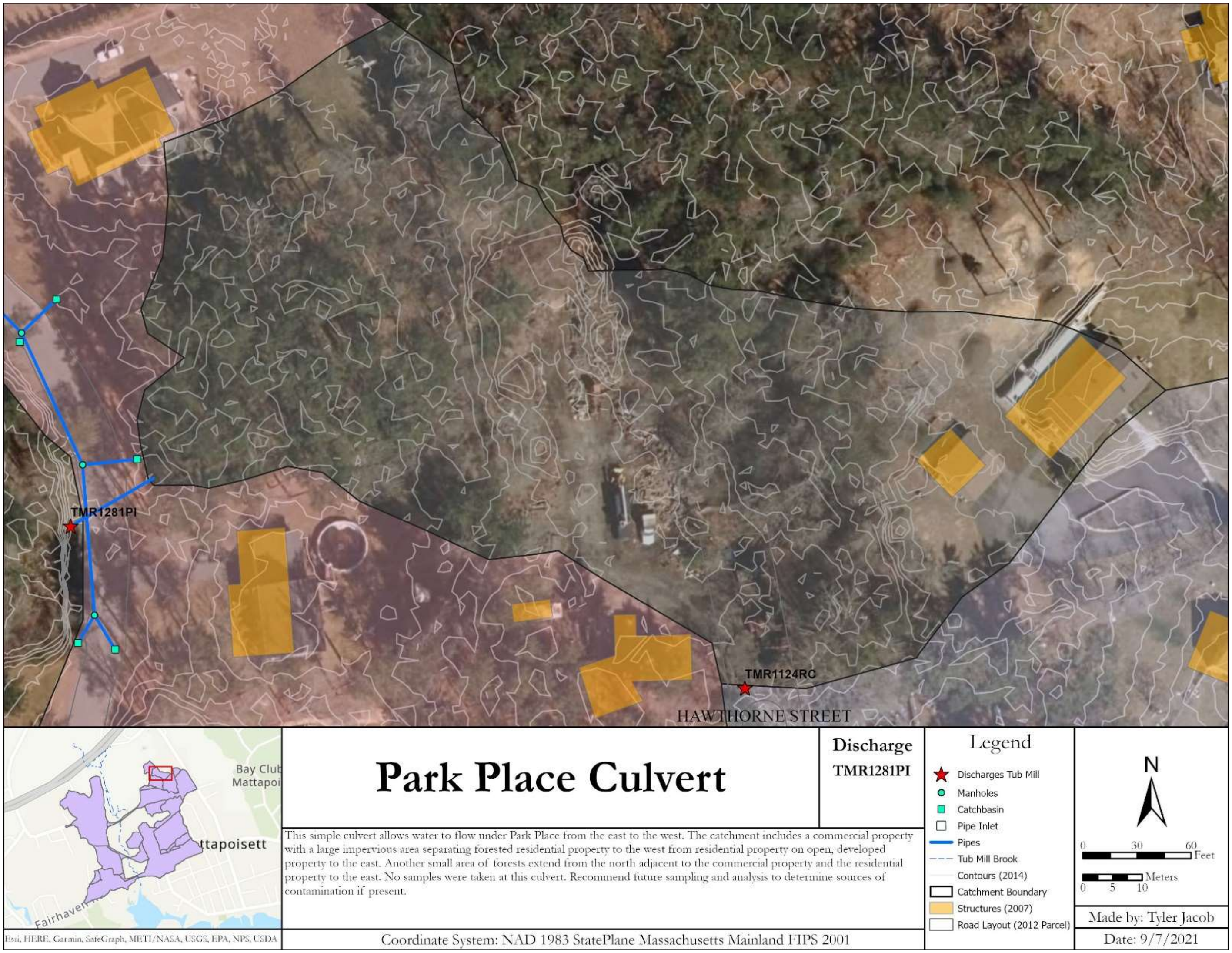


Park Place Catchment

The southern portion of this catchment is comprised of single family housing in forests along with some developed land and a commercial property on Hawthorne Street. The northern portion is currently being developed into single family housing units. Some of the 8 catchbasins and 6 manholes were recently moved to accommodate the development, with some structures able to retain high flow. Structures require cleaning due to sediment deposits. Outfall pip leads to forested areas to the west of Park Place. No samples were taken during the study period. Recommend future sampling and identification of contamination.

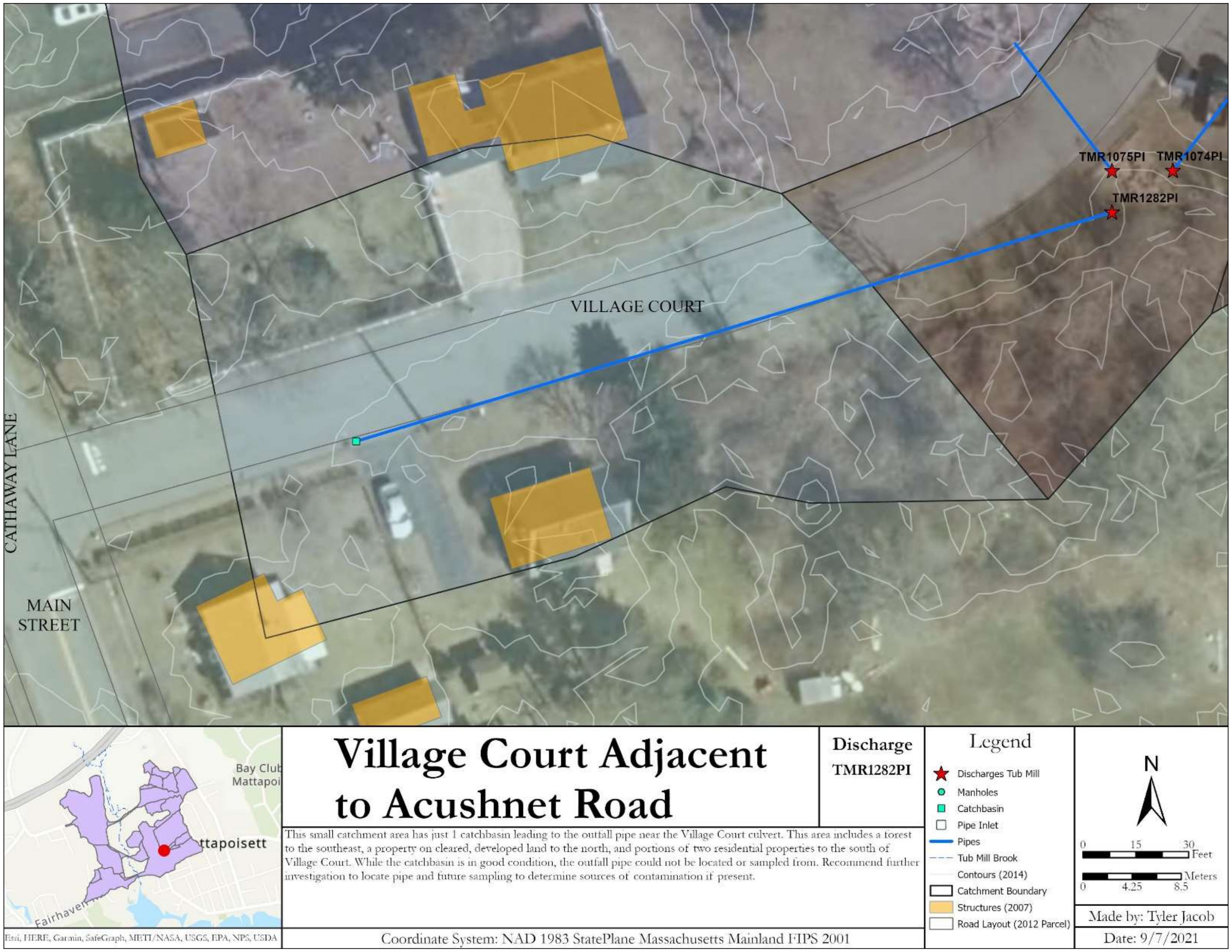
Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001

Figure D.14: Park Place Catchment



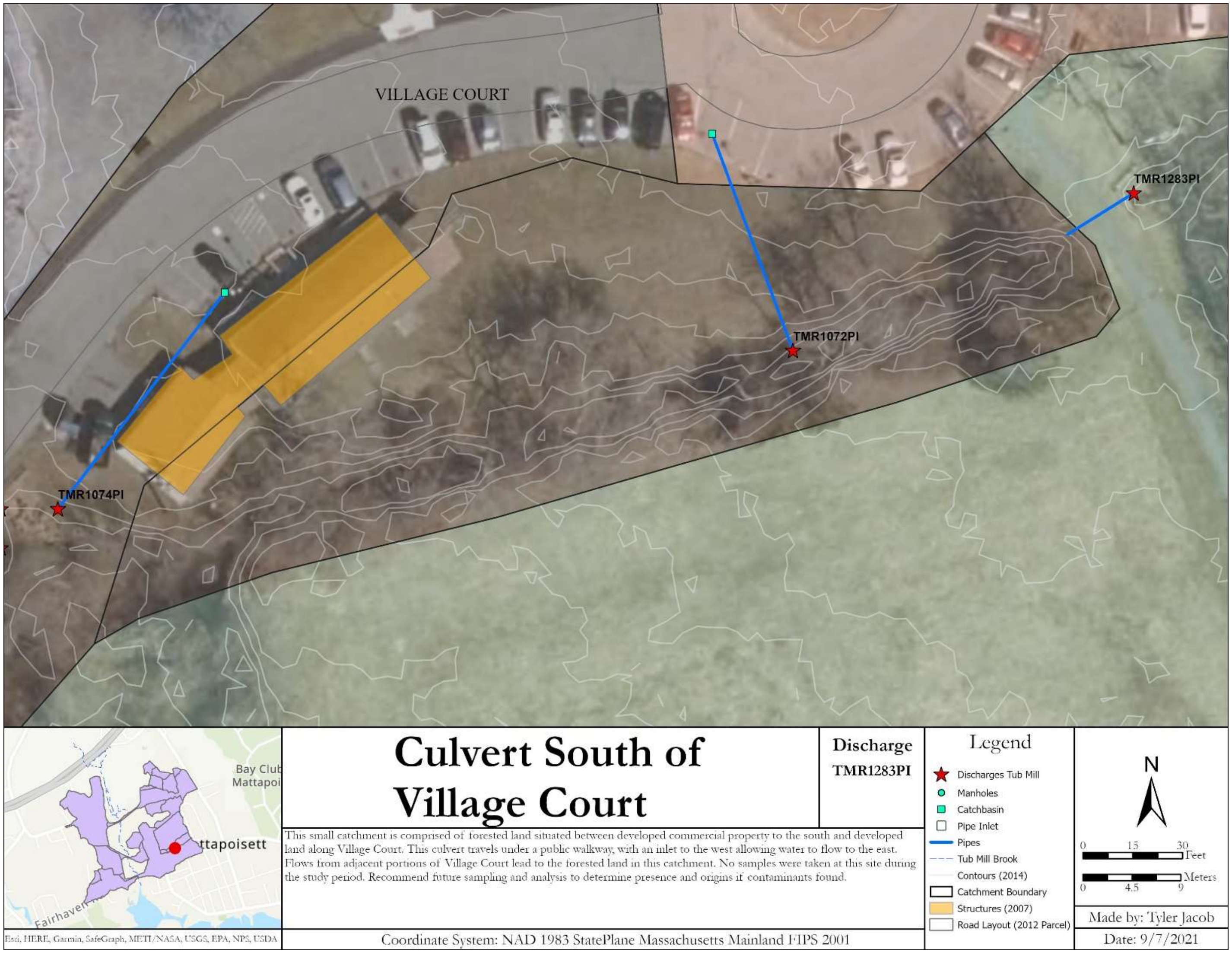
This simple culvert allows water to flow under Park Place from the east to the west. The catchment includes a commercial property with a large impervious area separating forested residential property to the west from residential property on open, developed property to the east. Another small area of forests extend from the north adjacent to the commercial property and the residential property to the east. No samples were taken at this culvert. Recommend future sampling and analysis to determine sources of contamination if present.

Figure D.15: Park Place Culvert



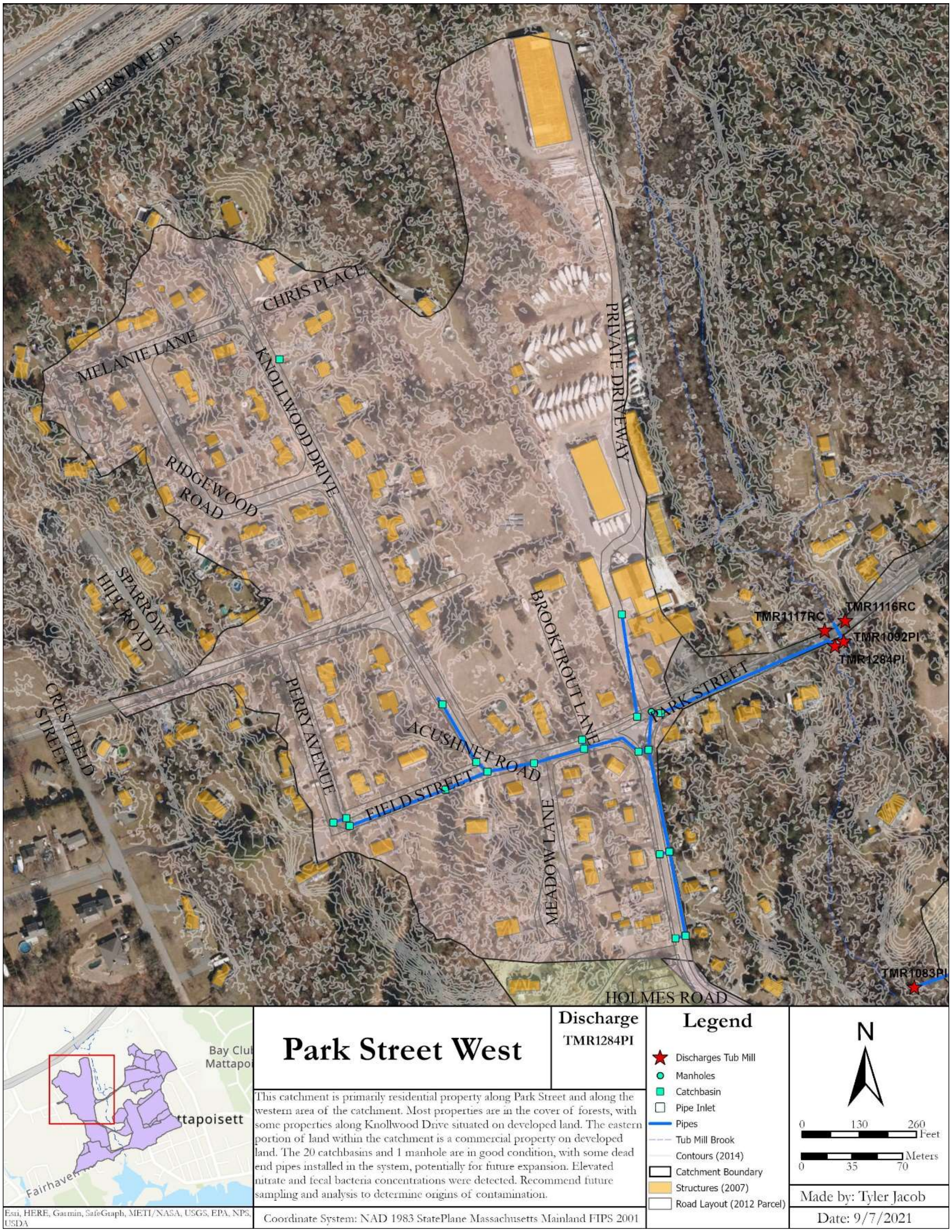
This small catchment area has just 1 catchbasin leading to the outfall pipe near the Village Court culvert. This area includes a forest to the southeast, a property on cleared, developed land to the north, and portions of two residential properties to the south of Village Court. While the catchbasin is in good condition, the outfall pipe could not be located or sampled from. Recommend further investigation to locate pipe and future sampling to determine sources of contamination if present.

Figure D.16: Village Court Adjacent to Acushnet Road



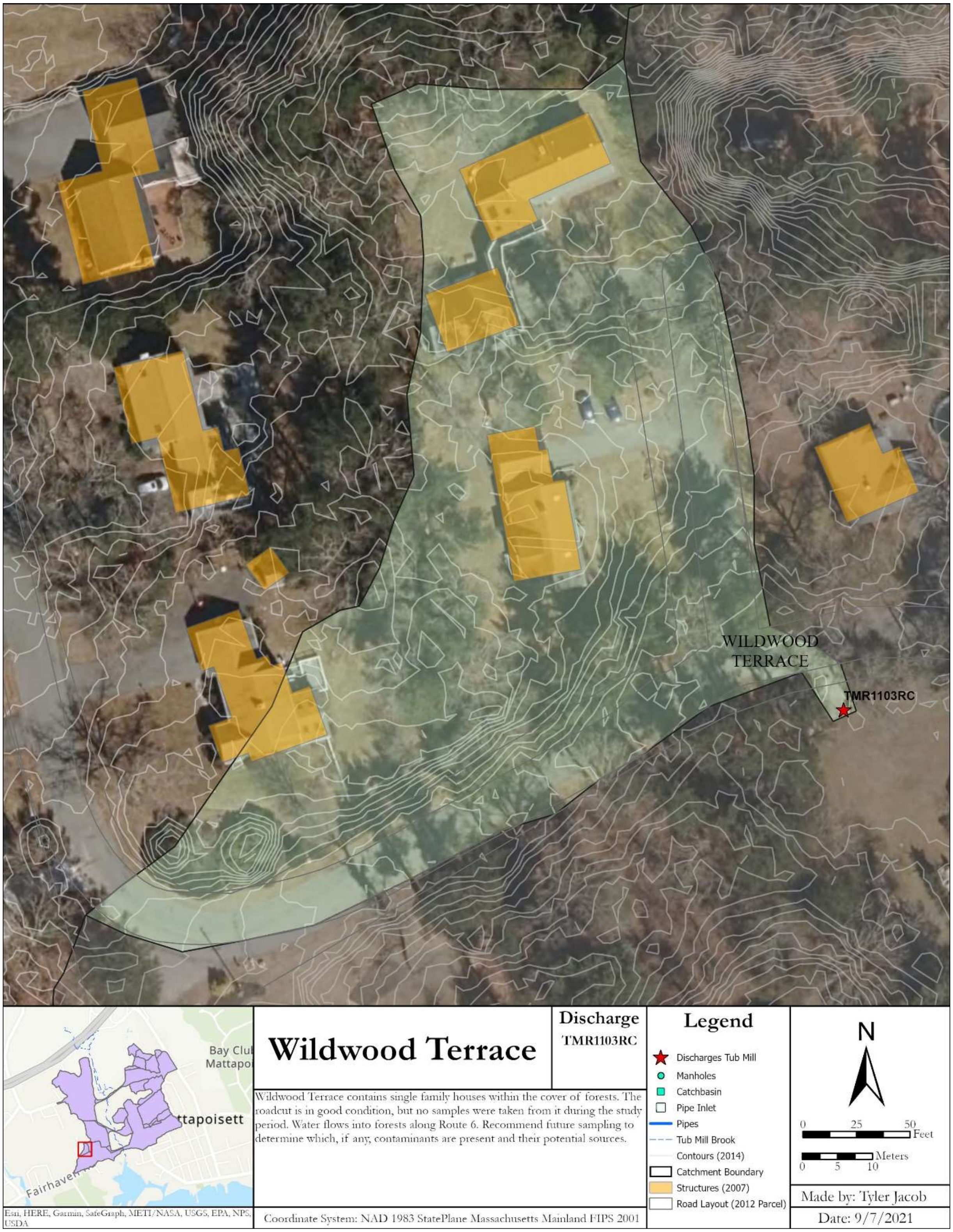
This small catchment is comprised of forested land situated between developed commercial property to the south and developed land along Village Court. This culvert travels under a public walkway, with an inlet to the west allowing water to flow to the east. Flows from adjacent portions of Village Court lead to the forested land in this catchment. No samples were taken at this site during the study period. Recommend future sampling and analysis to determine presence and origins if contaminants found.

Figure D.17: Culvert South of Village Court



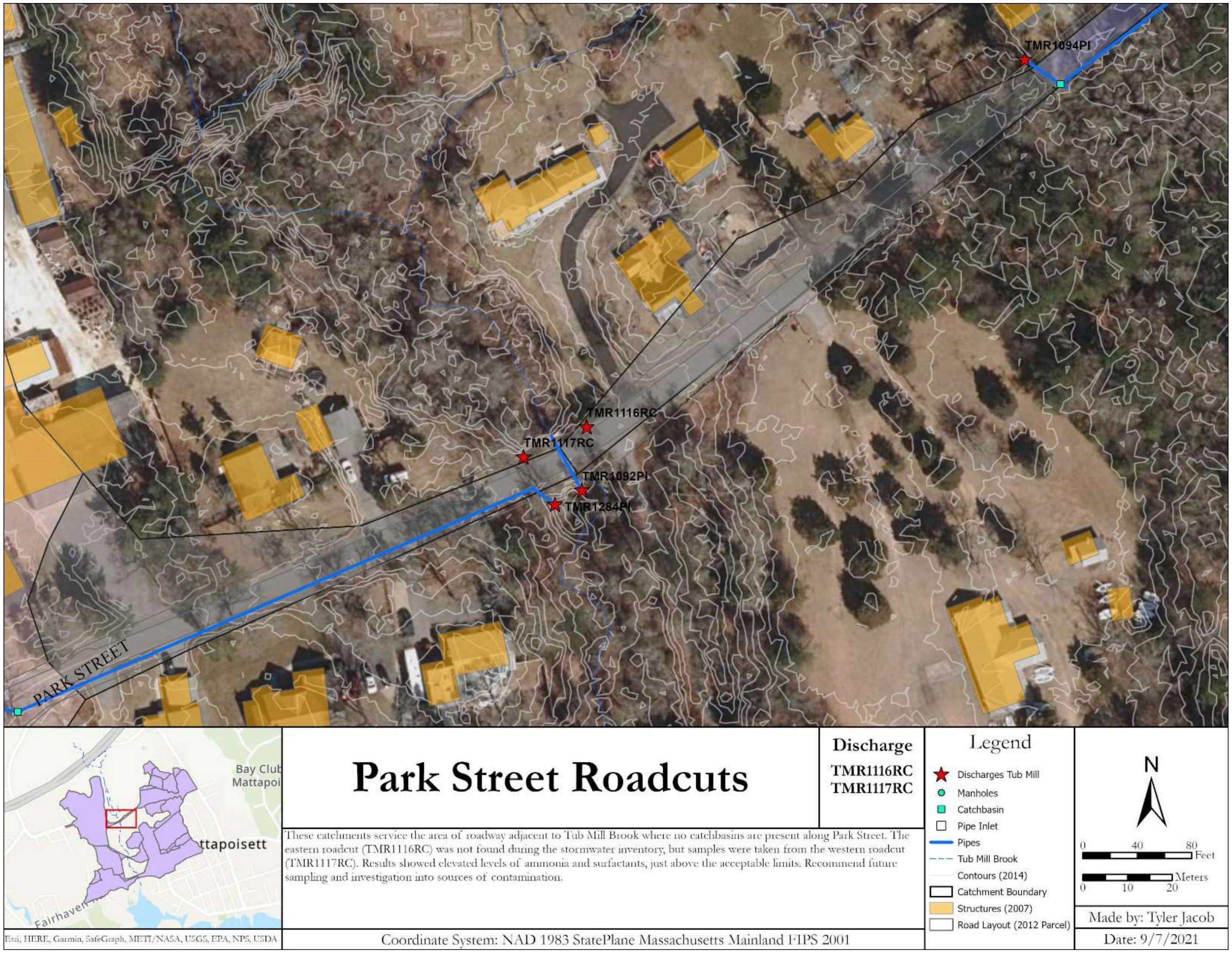
This catchment is primarily residential property along Park Street and along the western area of the catchment. Most properties are in the cover of forests, with some properties along Knollwood Drive situated on developed land. The eastern portion of land within the catchment is a commercial property on developed land. The 20 catchbasins and 1 manhole are in good condition, with some dead end pipes installed in the system, potentially for future expansion. Elevated nitrate and fecal bacteria concentrations were detected. Recommend future sampling and analysis to determine origins of contamination.

Figure D.18: Park Street West



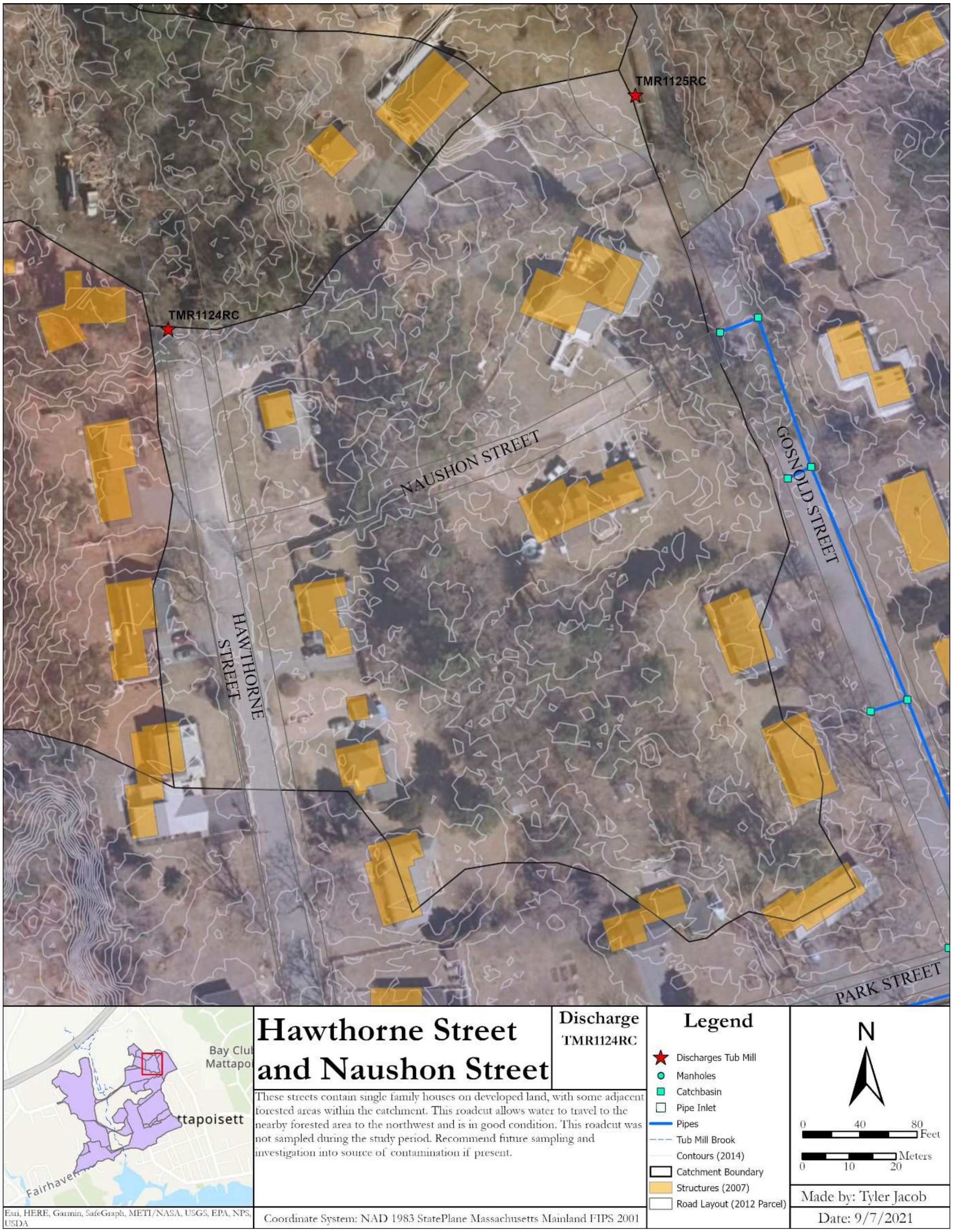
Wildwood Terrace contains single family houses within the cover of forests. The roadcut is in good condition, but no samples were taken from it during the study period. Water flows into forests along Route 6. Recommend future sampling to determine which, if any, contaminants are present and their potential sources.

Figure D.19: Wildwood Terrace



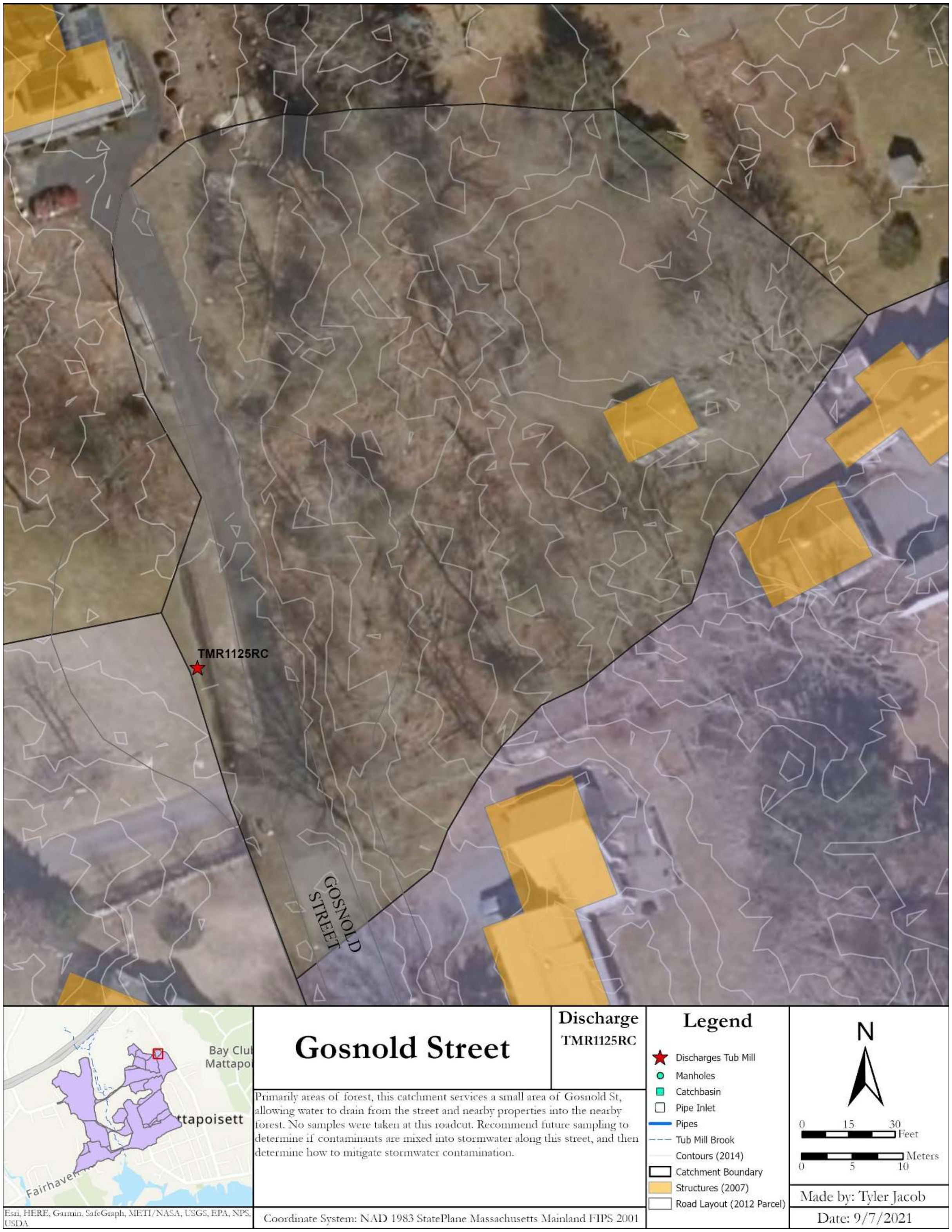
These catchments service the area of roadway adjacent to Tub Mill Brook where no catchbasins are present along Park Street. The eastern roadcut (TMR1116RC) was not found during the stormwater inventory, but samples were taken from the western roadcut (TMR1117RC). Results showed elevated levels of ammonia and surfactants, just above the acceptable limits. Recommend future sampling and investigation into sources of contamination.

Figure D.20: Park Street Roadcuts Near West Culvert



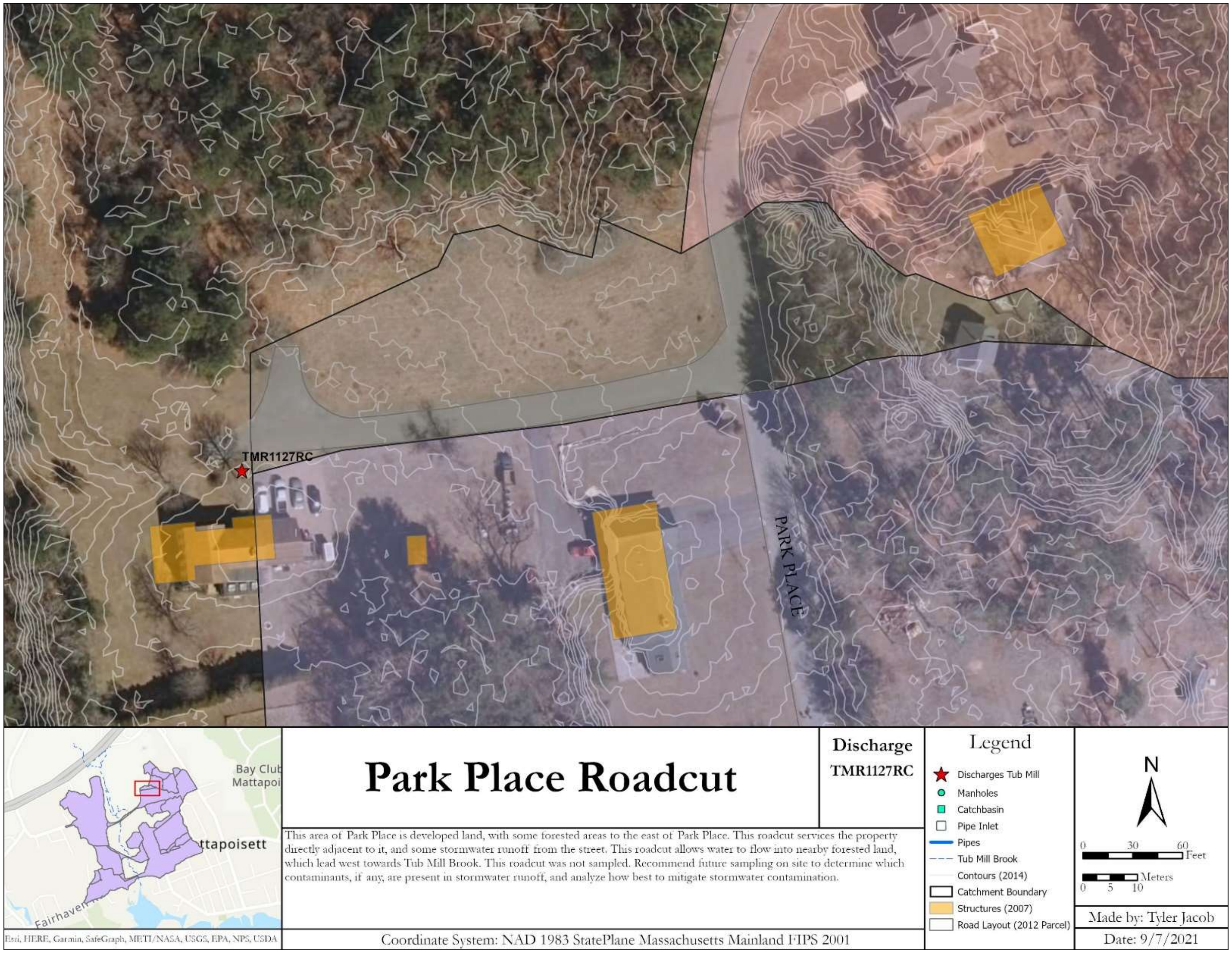
These streets contain single family houses on developed land, with some adjacent forested areas within the catchment. This roadcut allows water to travel to the nearby forested area to the northwest and is in good condition. This roadcut was not sampled during the study period. Recommend future sampling and investigation into source of contamination if present.

Figure D.21: Hawthorne Street and Naushon Street



Primarily areas of forest, this catchment services a small area of Gosnold St, allowing water to drain from the street and nearby properties into the nearby forest. No samples were taken at this roadcut. Recommend future sampling to determine if contaminants are mixed into stormwater along this street, and then determine how to mitigate stormwater contamination.

Figure D.22: Gosnold Street



Park Place Roadcut

Discharge

TMR1127RC

This area of Park Place is developed land, with some forested areas to the east of Park Place. This roadcut services the property directly adjacent to it, and some stormwater runoff from the street. This roadcut allows water to flow into nearby forested land, which lead west towards Tub Mill Brook. This roadcut was not sampled. Recommend future sampling on site to determine which contaminants, if any, are present in stormwater runoff, and analyze how best to mitigate stormwater contamination.

Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001

Made by: Tyler Jacob

Date: 9/7/2021

Figure D.23: Park Place Roadcut

Appendix E: Precipitation Data for Months March through July 2021

Table E.1 Daily Precipitation at New Bedford Regional Airport March-July 2021 [21]
Latitude: 41.67639, Longitude: -70.9583

Date	Precipitation (in)	Date	Precipitation (in)
March 01	0.37	April 03	0
March 02	0	April 04	0
March 03	0	April 05	0
March 04	0	April 06	0
March 05	0	April 07	0
March 06	0	April 08	0
March 07	0	April 09	0
March 08	0	April 10	0
March 09	0	April 11	0
March 10	0	April 12	0
March 11	0	April 13	0
March 12	0	April 14	0
March 13	0	April 15	0.35
March 14	0	April 16	1.54
March 15	0	April 17	0.06
March 16	0	April 18	0
March 17	0	April 19	0
March 18	1.1	April 20	0
March 19	0.08	April 21	0.01
March 20	0	April 22	0
March 21	0	April 23	0
March 22	0	April 24	0
March 23	0	April 25	0.54
March 24	0	April 26	0
March 25	0.01	April 27	0
March 26	0	April 28	0.01
March 27	0	April 29	0.1
March 28	0.73	April 30	0.05
March 29	0.08	May 01	0.08
March 30	0	May 02	0.02
March 31	0.18	May 03	0.11
April 01	0.43	May 04	0.62
April 02	0	May 05	0.14

Date	Precipitation (in)	Date	Precipitation (in)
May 06	0	June 21	0
May 07	0	June 22	0.25
May 08	0	June 23	0.02
May 09	0.05	June 24	0.03
May 10	0.99	June 25	0.21
May 11	0	June 26	0
May 12	0	June 27	0
May 13	0	June 28	0
May 14	0	June 29	0
May 15	0	June 30	0
May 16	0	July 01	0.84
May 17	0.15	July 02	0.27
May 18	0.01	July 03	1.23
May 19	0	July 04	0.01
May 20	0	July 05	0
May 21	0	July 06	0.16
May 22	0	July 07	0
May 23	0.09	July 08	0
May 24	0	July 09	1.09
May 25	0	July 10	0
May 26	0	July 11	0
May 27	0.01	July 12	0.05
May 28	0	July 13	0
June 03	0.1	July 14	0
June 04	0.02	July 15	0
June 05	0	July 16	0
June 06	0	July 17	0.03
June 07	0	July 18	0
June 08	0	July 19	0.26
June 09	0	July 20	0
June 10	0	July 21	0
June 11	0	July 22	0
June 12	0.28	July 23	0
June 13	0	July 24	0
June 14	0.33	July 25	0.06
June 15	0	July 26	0
June 16	0	July 27	0
June 17	0	July 28	0.02
June 18	0	July 29	0.61
June 19	0.2	July 30	0
June 20	0	July 31	0

The data set from New Bedford Regional Airport did not have rainfall data for the days of May 29 through June 2, 2021 [21]. For those days, rainfall data are shown in Figure E.1, taken from USGS gage 414204071091700 (Fall River Precipitation Gage, in Fall River, MA) [21].

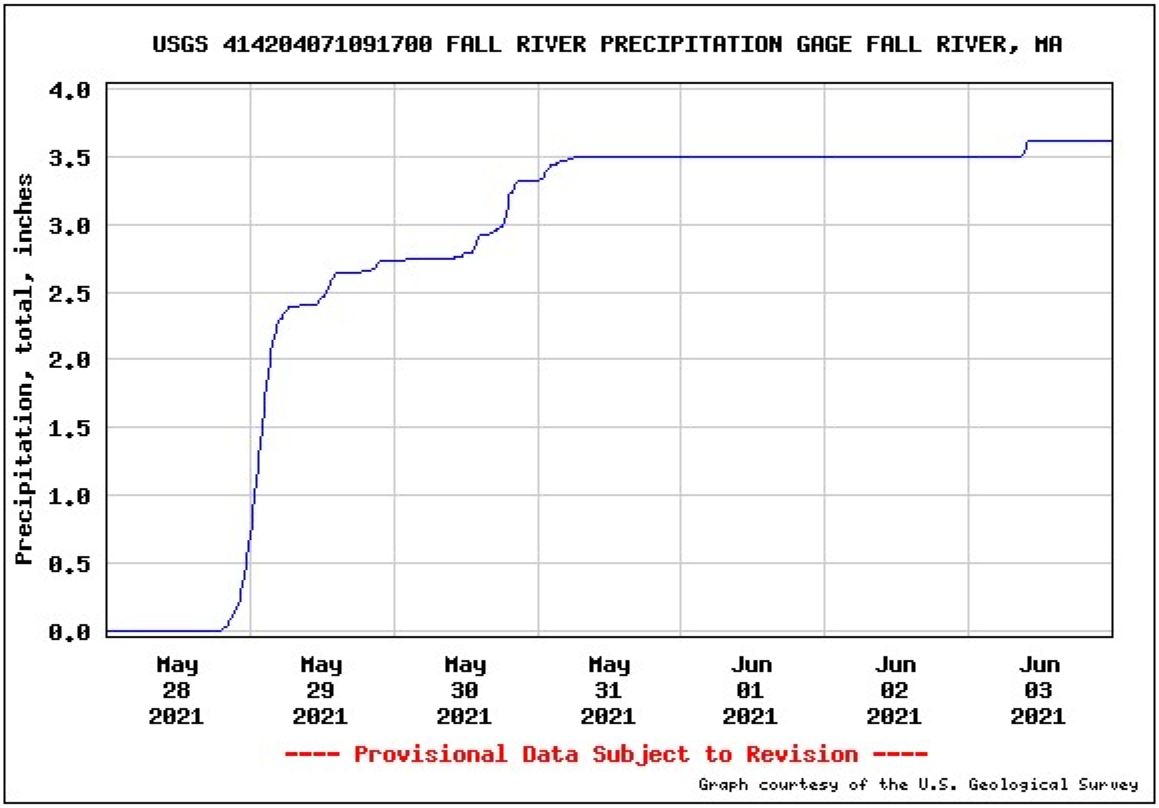


Figure E.1 Precipitation Data for May 28, 2021, Through June 3, 2021, in Fall River, MA