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Cooperative GIS Mapping for Massachusetts Communities and the MassDOT

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Abstract

The 2016 Massachusetts Small MS4 General Permit requires that Municipal Separate Storm Sewer Systems (MS4s) be mapped. With MS4s interconnected across properties, maps are developed by different organizations which makes it difficult to determine where stormwater runoff is collecting and how stormwater infrastructure is managed. Through interviews and geospatial data analysis, we developed recommendations for facilitating the collaboration and integration of geospatial data between Central Massachusetts Regional Stormwater Coalition communities and the Massachusetts Department of Transportation.

Acknowledgments

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Authorship

Christian Chadwick was the lead for the stormwater sections of the Background (2.1), including 2.1.1 The Importance of Stormwater Management, 2.1.2 Municipal Separate Storm Sewer Systems (MS4s) and 2.1.3 CMRSWC and Its Purpose. He was also responsible for the 2.6 Summary, 3.5 Data Analysis, 4.1 MassDOT Overview, and 4.5 DCR Overview.

Fernand Gay was the lead for the GIS sections of the Background (2.3), including 2.3.1 An Application of GIS Mapping, 2.3.2 GIS Mapping & Stormwater Management, and 2.3.3 GIS Mapping Initiatives in Massachusetts. He was also responsible for the Executive Summary, 2.5 Past Stormwater Initiatives Involving GIS, 2.1.3a Municipalities of Interest, 3.6 Project Deliverables, 4.3 The City of Framingham, 4.4 The Town of Holden, 6.0 Conclusion, and co-wrote 5.0 Recommendations.

Zoe Mahoney was the lead for Introduction (1.0) and the stormwater regulation sections of the Background (2.2). Specifically, she wrote 2.1.4 MassDOT and Stormwater Management, 2.1.5 About the DCR, 2.2.1 The History of the EPA's Stormwater Regulation, 2.2.2 Phase II & Massachusetts Small MS4 Regulation, 2.2.2a The Six Minimum Control Measures of Small MS4, and 2.4 Interorganizational Sharing of Geospatial Data. She was also the lead for the Methodology sections (3.0-3.4), 4.2 The Town of Auburn, 4.6 Thematic Analysis of Findings, 4.7 Summary, 5.4 Summary, and co-wrote 5.0 Recommendations.

Executive Summary

Introduction & Background

Contaminated stormwater runoff is a major source of water pollution in urban areas. When precipitation or storm events occur, it is possible for the resulting stormwater to run along impervious surfaces, collect numerous harmful pollutants, and even discharge these pollutants into large bodies of water. Contaminated stormwater runoff can have adverse public health effects and cause both environmental and economic detriment. Because of the possibility of flooding from heavy rainfall, drainage systems are needed to redirect the stormwater runoff. However, drainage systems can be a gateway for pollutants to enter water bodies. Municipal Separate Storm Sewer Systems (MS4s) are meant to help control and manage the flow of stormwater runoff.

The 2016 Massachusetts Small MS4 General Permit specifies the requirements for operating a small MS4 in Massachusetts. The Massachusetts regulation for small MS4s falls under Phase II of the federal mandate - the NPDES stormwater program. The permit requires compliance with six minimum control measures. Under the third minimum control measure - Illicit Discharge Detection and Elimination - operators of small MS4s are required to map their MS4 so infrastructure can be identified and located. By producing a map of an MS4, municipalities and MS4 operators can better address how and where to treat stormwater, further reducing its possible adverse effects on public health, the environment, and the economy.

The Central Massachusetts Stormwater Coalition (CMRSWC) is a group of municipalities that work together to more effectively manage stormwater in Central Massachusetts. The CMRSWC also works toward public education and outreach on stormwater in efforts to gain more support in stormwater management efforts.

MS4 infrastructure is interconnected across town borders, state roads, and properties in the CMRSWC municipalities. Municipalities must collaborate with state agencies who own, manage, and map the interconnected infrastructure to create a fully comprehensive map of their MS4. Of the state agencies that the CMRSWC municipalities may work with, the Massachusetts Department of Transportation (MassDOT) is of most interest because of the number of state roads that run through Central Massachusetts.

Methodology

The goal of our project was to facilitate the collaboration and integration of geospatial data between CMRSWC municipalities and the MassDOT. We created a document for the CMRSWC municipalities that provides recommendations for improving their relationship and data integration with the MassDOT in meeting the requirements of the 2016 Massachusetts Small MS4 General Permit. We worked at the goal for our project through four main objectives.

1. Identify the degree of information included in the municipalities' and MassDOT's geospatial data and how it is managed
2. Identify how geospatial data is shared between organizations
3. Identify what data gaps or constraints exist in the integration of stormwater sewer system geospatial data
4. Develop an approach to address data gaps and to facilitate interorganizational collaboration

In a case study methodology approach, we focused on three municipalities within the CMRSWC (Auburn, Framingham, and Holden).

First, we obtained maps from the three CMRSWC municipalities and the MassDOT to identify and establish the base level of geospatial data included in the MS4 maps. Next, we interviewed key staff members involved in MS4 mapping from the three municipalities, the MassDOT, and the Department of Conservation and Recreation (DCR) to determine the specifics of their mapping methodologies and how MS4 geospatial data is shared between organizations. We then analyzed both the geospatial data provided and the qualitative data obtained in our interviews to, ultimately, identify and address data gaps or interorganizational constraints in the integration of MS4 geospatial data. In carrying out our four objectives, we were able to compile our findings and make recommendations included in the guidance document.

Findings & Results

Through the thematic analysis of both the MS4 geospatial data acquired and the qualitative data obtained by interviews, we determined several hindrances in the stormwater management operations of municipalities and the MassDOT that impede the ability to optimally integrate data. To start, a major finding was limited funding. MS4 regulation is a federally unfunded mandate, meaning that municipalities must scramble within their budget or taxation to enact basic stormwater management efforts. Limited funding is the direct cause of another major finding: limited staffing. There is an ongoing issue of limited staffing for the stormwater management departments in the three municipalities we interviewed and the MassDOT. Most of the responsibilities that come with MS4 mapping are often placed on an existing staff member because designated stormwater staff is not hired.

Another finding was the relationship between the three municipalities and the MassDOT. The municipalities we interviewed have essentially had little to no contact with the MassDOT in past years in terms of MS4 mapping efforts, obstructing the process of integrating maps. The municipalities were also unaware of GeoDOT - the MassDOT's public GIS geodatabase. GeoDOT contains useful resources for municipalities including the MassDOT's drainage data. With Hung Pham (Stormwater Program Coordinator) as the primary contact for the MassDOT's MS4 mapping efforts, GeoDOT will need to be utilized by municipalities to minimize any unnecessary contact with the MassDOT.

When analyzing mapping methodologies and MS4 geospatial data, we found that the three municipalities' maps are more detailed in comparison to the MassDOT's. The MassDOT's data is condensed and standardized. With its choice in both symbology and color scheme, the MassDOT's map provides a viewer with a quick understanding because of its clear discernment of infrastructure.

Recommendations

We developed three categories of recommendations for a benefitting a future collaborative relationship between CMRSWC municipalities and the MassDOT. The first recommendation is improving readability and integration of MS4 maps. To make the process of improving readability and integration of MS4 maps easier, we recommend that the CMRSWC municipalities follow the MassDOT's standards for map symbology, condense infrastructure classes, adopt a color scheme to identify ownership, and consider two tiers of attributes. The second recommendation we developed targets improving the communicative relationship between CMRSWC municipalities and the MassDOT. Municipalities must first know who to contact in the organization and how to use GeoDOT to minimize unnecessary communication that may overwhelm a point contact. Lastly, future considerations for limited staffing and funding were developed as the third recommendation. Our third recommendation discusses the possibility for volunteer or intern programs and initiatives with universities, community colleges, K-12 schools, companies, organizations, or watershed associations to lessen the workload that comes with MS4 compliance placed on municipalities. While this recommendation may be an option for municipalities, educating volunteers or interns about stormwater infrastructure and how to use GIS can be time consuming. To assist in developing an educational program for a volunteer or intern program is why additional educational resources are provided with this recommendation.

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1.0 Introduction

Contaminated stormwater runoff has the potential to damage human health, the environment, and the economy. Stormwater runoff is heavy precipitation that hits the ground and flows over impervious surfaces. It can become contaminated when it picks up various pollutants along the way (i.e., oil, trash, fertilizers). Eventually, stormwater runoff gets discharged directly into large bodies of water and is one of the major causes of polluted waters in the United States. It is responsible for the impairment of 5,000 square miles of estuaries, 1.4 million acres of lakes, and 30,000 miles of rivers (EPA, 2015). The effects of contaminated stormwater runoff are concerning, provided that approximately 77% of drinking water in the United States is acquired from surface-water resources (Ryan, 2019). When stormwater is improperly managed, the general public may be exposed to a variety of negative health effects stemming from contaminated drinking water. Infrastructure and road repairs can also become more frequent due to erosion caused by contaminated stormwater runoff (Tuler et al., 2016).

Regulation has been enacted federally by the United States Environmental Protection Agency (EPA) to mitigate pollutants and to protect the nation's waters. In 1987, amendments were made to the Clean Water Act of 1972 to specifically target the regulation of Municipal Separate Storm Sewer Systems (MS4s). MS4s are systems of stormwater infrastructure that collect and drain stormwater runoff into large bodies of water. In Phase II of the two-phase national stormwater program, small MS4s are covered in the regulation, meaning that stormwater discharges in urbanized areas of municipalities with populations less than 100,000 must comply (Franzetti, n.d.). In Massachusetts, the current regulation for Phase II is covered under the 2016 Massachusetts Small MS4 General Permit.

A requirement of the 2016 Massachusetts Small MS4 General Permit is system mapping to identify the MS4's key infrastructure, like catch basins, pipes, and outfalls. The identification of key infrastructure is useful for maintaining effective system operation and designating where stormwater runoff is collected and discharged. MS4 maps and data are generally managed using geographic information system (GIS) software packages. Within GIS software packages, geospatial data creates layers of information, including location and attributes, to identify trends in land use or social trends. GIS provides efficient tools for managing stormwater infrastructure.

Throughout Massachusetts, coalitions have been formed to confront pollution due to stormwater runoff. Thirty-one municipalities in Central Massachusetts have formed the Central

Massachusetts Regional Stormwater Coalition (CMRSWC). As the thirty-one municipalities work collaboratively, they are able to protect their shared resources and aim to meet the requirements of the MS4 permit in a manner that is both efficient and cost-effective.

With MS4 infrastructure interconnected across both town borders and state properties, MS4 maps are developed by different organizations. It would be beneficial to municipalities if the geospatial data associated with the MS4 maps was integrated properly because, otherwise, it becomes difficult to create a comprehensive map, determine where stormwater runoff is collecting in certain areas, and determine how stormwater infrastructure is being managed. A significant concern for the municipalities in the CMRSWC are the highways that run through the municipalities because the MS4s along these highways are mapped by the Massachusetts Department of Transportation (MassDOT). A major contribution to limited integration is that the CMRSWC municipalities face the challenge of maintaining an interorganizational relationship with the MassDOT. Because of the evident harm that contaminated stormwater runoff can cause, municipalities should follow guidelines or standards for mapping and maintaining integration with other organizations' maps. Because maps are developed separately, it is possible that municipalities and organizations have different methods of mapping, such as the GIS software packages used and the identification of infrastructure in their MS4 maps. The disparities in MS4 mapping methodologies are the leading concern when municipalities are attempting to make a cohesive, interconnected map.

The goal of this project was to develop an approach for facilitating the collaboration and integration of geospatial data between the CMRSWC communities and MassDOT to meet the requirements of the 2016 Massachusetts Small MS4 General Permit by developing a guidance document providing recommendations for organizing the data. To accomplish the goal of this project, we interviewed key staff members involved in MS4 mapping from the Town of Auburn, the City of Framingham, the Town of Holden, the MassDOT and the Department of Conservation and Recreation (DCR). The municipalities' and organizations' MS4 geospatial data was acquired and analyzed to determine the current status and condition of the MS4 maps. Through interviews, an understanding was gained regarding the specifics of their mapping methodologies and if geospatial data is currently being shared, if at all. By synthesizing and thematically analyzing qualitative data, recommendations were made to address the data gaps and improve interorganizational collaboration. Through our efforts, the results of our project intend to continue to further promote stormwater management and gain support from the municipalities in the CMRSWC.

2.0 Background

Due to the rapidly changing world, stormwater runoff has become a major cause of pollutant discharge into large bodies of water. The used oil from one vehicle's oil change carried by stormwater can pollute up to 1,000,000 gallons of freshwater (EPA, n.d.). Federal and state regulations aim to control these pollutants to keep water bodies clean.

In the following paragraphs, we will discuss the detrimental effects of stormwater runoff, the federal and state regulations for stormwater runoff, geographic information system (GIS) mapping and its purpose in stormwater management, and prior research on stormwater management and GIS data integration, respectively.

2.1 Stormwater

Stormwater is precipitation in the form of either heavy rain or snowfall that pools together (Oxford Languages, 2021). As stormwater flows over impervious surfaces, it can become contaminated. When stormwater comes in contact with the ground, it is at risk of becoming tainted when it picks up nonpoint source pollution (NSP) - a type of pollution that cannot be traced back to a single source. NSP includes contaminants like pesticides and fertilizers in agricultural communities, oil and other toxins left on the roads by cars, bacteria from pet waste, and leftover sediment from construction zones (EPA, 2020e). The chemicals that are inadvertently leaked into their surrounding ecosystems can be detrimental to every aspect of a community.

2.1.1 The Importance of Stormwater Management

NSP in stormwater runoff is easily spread throughout the environment. Stormwater runoff's adverse impacts can be categorized into three types of impacts: public health impacts, economic impacts, and environmental impacts.

The general public can be exposed to many contaminants as a result of poor stormwater management. Stormwater runoff can seep into drinking water, affecting an entire population. It can also cause standing water - water that does not drain properly and is a breeding ground for bacteria and disease. Public health, however, is not the only thing negatively affected by stormwater runoff.

The public also must deal with economic disruptions due to drainage issues. Building and road repairs are expedited from the eroding effects of the chemicals in the already erosive water. Accelerated wear on physical structures could result in increased property insurance costs. Business revenues take hits from contaminated aquatic life and the cost of removing blockage from drainage ways could increase (Tuler et al., 2016).

An unclean beach is just one example of habitat destruction caused by runoff. Both aquatic and land-based habitats can be destroyed. Drinking water does not just apply to the people living in any given area, it also affects the local animal population. Contaminated stormwater runoff has a substantial impact on everyday life for all living creatures.

2.1.2 Municipal Separate Storm Sewer Systems (MS4s)

Municipal Separate Storm Sewer Systems (MS4s) were designed to counter the outdated Combined Sewer System (CSS). MS4s are a conveyance system for stormwater designed to be more efficient and environmentally conscious than the CSS systems (EPA, 2020d). In Figure 2.1, the process of an MS4 vs. a CSS is displayed to show the different sewer systems utilized by municipalities.

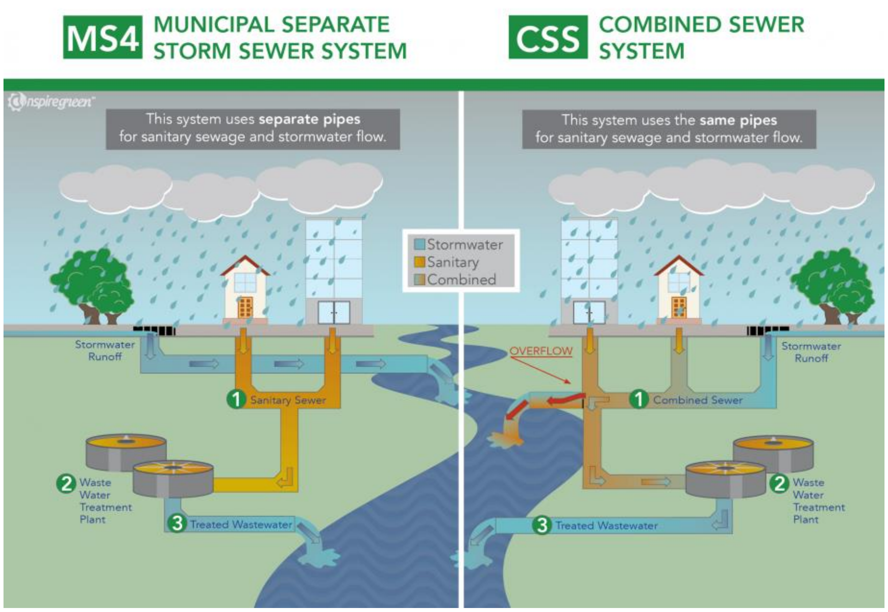

Figure 2.1 - *Municipal Separate Storm Sewer System (MS4) & Combined Sewer System (CSS)*
Note: Provides a visual representation of MS4s vs CSSs (Nspiregreen, n.d.).

As depicted in Figure 2.1, the CSS combines the "sanitary" stormwater with uncleaned sewage at its overflow and has its outlet in a nearby body of water. The MS4 system, which separates the two, is much better for all aspects of daily life. Specifically, MS4s collect and discharge untreated and polluted stormwater into local bodies of water and consist of three major components: catch basins, pipes, and outfalls. As stormwater flows over impervious surfaces, it enters the MS4 through the catch basins or storm drains. The stormwater then flows through pipes attached to the catch basin to an outfall - the location of stormwater discharge into a body of water or a detention or retention pond. The area of land where stormwater collects, flows, and drains to a common outfall is known as a catchment basin or drainage basin.

2.1.3 CMRSWC & Its Purpose

The Central Massachusetts Regional Stormwater Coalition (CMRSWC) is a collaborative of over thirty municipalities in Central Massachusetts that work together on municipal stormwater management. The CMRSWC was originally formed in 2012 with 13 towns: Auburn, Charlton, Dudley, Holden, Leicester, Millbury, Oxford, Paxton, Shrewsbury, Spencer, Sturbridge, Webster, and West Boylston (CMRSWC, 2020). As a completely voluntary coalition, the municipalities work to protect shared resources and to meet the requirements of the MS4 permit in an efficient and cost-effective manner. Additionally, the CMRSWC spreads awareness and promotes projects, like our own, related to stormwater runoff. Their overarching goal is to spread awareness for and work to promote good stormwater management practices.

2.1.4 MassDOT & Stormwater Management

The Massachusetts Department of Transportation (MassDOT) has set out to ensure that Massachusetts' transportation infrastructure is secure, dependable, and durable (MassDOT, n.d.). With their mission comes the responsibility of managing highway runoff discharges into “impaired” waters (Tetratech, n.d.). Currently, Tetra Tech - an engineering consulting firm - is in a “$1 million, multiyear” contract with the MassDOT to help the organization maintain compliance with the National Pollutant Discharge Elimination System (NPDES) permit by completing watershed assessments to “determine stormwater best management practice (BMP) requirements, geographic information systems (GIS) mapping and database management, topographic survey, BMP engineering and design, and environmental permitting services” (Tetratech, n.d., para. 2).

2.1.5 About the DCR

The Department of Conservation and Recreation (DCR) in Massachusetts is responsible for managing the state’s parks and protecting the state’s natural, cultural, and recreational resources. The land that the DCR oversees consists of over 450,000 acres, including forests, watersheds, bodies of water, etc. Through its mission, the DCR aims to ultimately improve the necessary connection between humans and the natural world (DCR, n.d.).

2.2 Stormwater Regulation

The United States Environmental Protection Agency (EPA) has enacted several regulations to help mitigate the negative effects of pollution to preserve the natural world. More specifically, they have set out to protect the United States' precious resource - water. Water is a necessary factor in supporting the existence and prosperity of life and is a resource that supports several recreational activities, industrial and agricultural processes, and a plethora of other pursuits.

Because MS4s discharge untreated and polluted stormwater into local bodies of water, EPA regulations purposely aim to improve water quality, to protect wetlands and aquatic and wildlife habitats, to conserve water resources, to protect public health, and to control flooding in the United States (EPA, 2020b). Stormwater regulations aim to reduce the amount of pollutants that stormwater carries from impervious surfaces into MS4s following precipitation or storm events. Stormwater regulations date back to the year 1972 and have transformed throughout the years since to mandate regulation over small MS4s in Phase II of the national stormwater program.

2.2.1 The History of the EPA's Stormwater Regulation

To protect the United States' bodies of water from pollution, shortly after it was born, the EPA passed the Federal Clean Water Act in 1972 in collaboration with the United States Congress. Within this act, the NPDES was created to control pollutants by requiring the permitting of their sources (City of Durham, n.d.). In other words, the act prohibited all pollutant discharges from a point source unless authorized by a NPDES permit. Throughout the 1970s and 1980s several minor revisions were made to the Clean Water Act (Franzetti, n.d.).

Under the Clean Water Act, amendments were made to it within the Water Quality Act of 1987. The amendments built the foundation for stormwater regulation that is known today. Amendments, known as Phase I, were made to the Water Quality Act of 1987 in 1990. Phase I of the two-phase national stormwater program required stormwater discharges from several sources (medium and large MS4s) to acquire the NPDES permitting. These sources included several types of large industrial facilities, construction sites, and municipalities with a population in excess of 100,000 (Douglas County Government, 2019). Not even a decade later, in 1999, Phase II was introduced expanding the NPDES permit requirement to small MS4s. Phase II included more industrial and construction sites and activities and urbanized areas, designated by the US Bureau of the Census, in municipalities with populations less than 100,000 (Franzetti, n.d.). More specifically, urbanized areas are designated by the most recent decennial census to determine heavily developed and densely populated areas (EPA, 2020e).

2.2.2 Phase II & Massachusetts Small MS4 Regulation

The states that form the United States can vary drastically in landscape and climate, ranging from desert-like to arctic-like conditions. Because of the disparity in landscape and climate across the United States, state environmental policy takes precedence over the EPA's federal standards and law of environmental protection. However, this notion is dependent on that the state law is at least as demanding as the federal law. The current regulation for Phase II in Massachusetts is the 2016 Massachusetts Small MS4 General Permit (EPA, 2020a). The permit went into effect on July 1st of 2018 and modifications in 2020 make up the small MS4 regulation known today in Massachusetts. The Massachusetts regulation applies to the permitting necessary to obtain to release stormwater discharges from small MS4s in the thirty-one municipalities that make up the CMRSWC. Areas in Massachusetts that fall under this regulation are indicated in Figure 2.2.

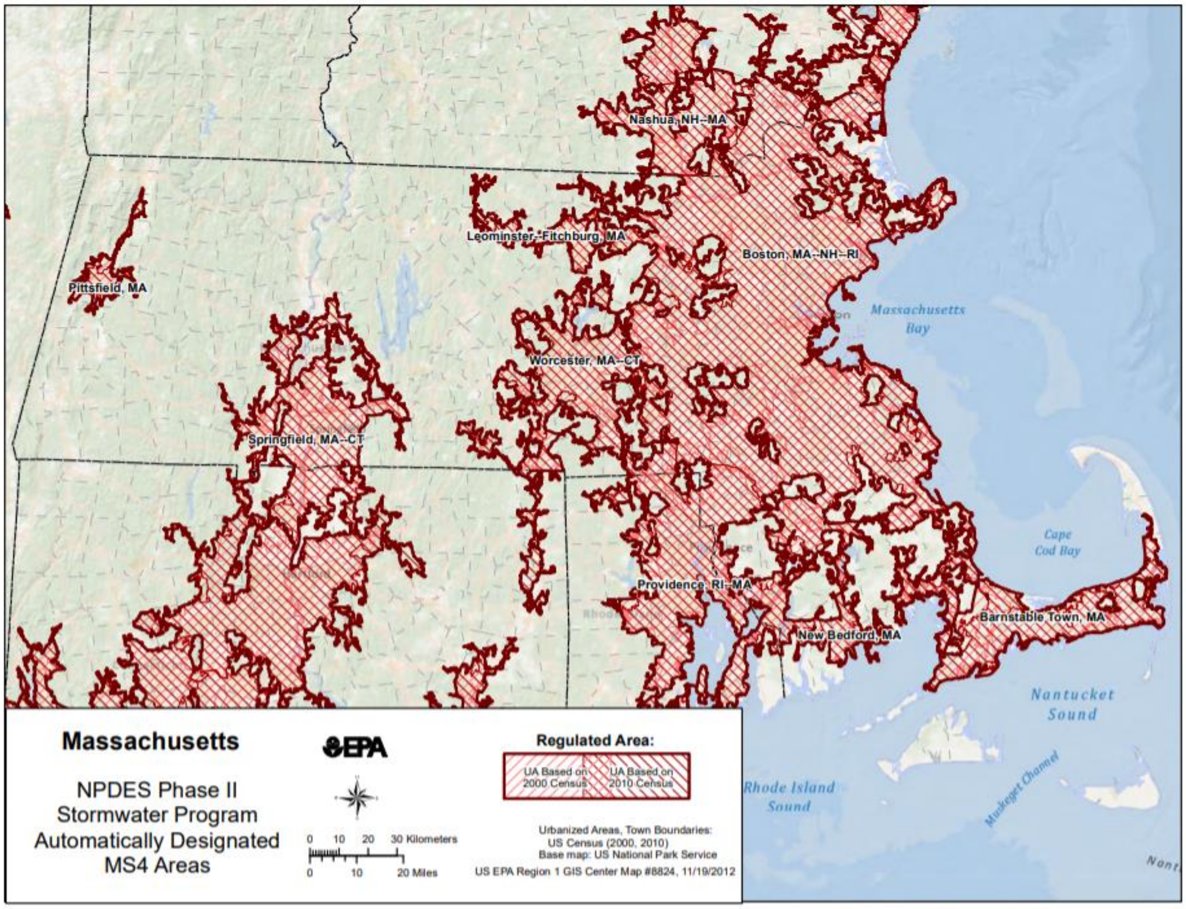

Figure 2.2 - *Massachusetts Phase II Automatically Designated Area*

Note: Urbanized areas designated by the U.S. Census in Massachusetts that are subject to MS4 regulation under Phase II in Massachusetts (EPA, 2020c).

Under the second phase of the national stormwater program, operators of small MS4s are expected to mitigate stormwater pollutants to the "maximum extent practicable" and to protect water quality by fulfilling all demands of the EPA's Clean Water Act (EPA, 2020e). Because Phase II is an unfunded federal mandate, municipalities must find the means within their budget or taxation to support the program. The limited funding has put a strain on a lot of municipalities trying to understand the complexity of the permit and comply with it. An effect of this limited funding is the great disparity in the degree of mapping that has been completed from one municipality to the next.

As part of the regulation, the municipalities must obtain a permit from the NPDES. A Notice of Intent (NOI) is used as the NPDES permit application. The NOI must include the identification of best management practices (BMPs) and quantifiable goals for each of the permit's six minimum control measures (EPA, 2020e). To alleviate a municipality's MS4 pollutant discharge, municipalities are also required to create a Stormwater Management Plan (SWMP). A SWMP is a document produced by a municipality that details the execution of BMPs that will promote compliance with the requirements of the permit and the six minimum control measures (EPA, 2020d). The document is expected to be regularly updated as conditions of the permit change.

2.2.2a The Six Minimum Control Measures of Small MS4s

The successful execution of the six minimum control measures is expected to significantly reduce the discharge of polluted stormwater into bodies of water. These six minimum control measures are known as Public Education and Outreach, Public Participation/Involvement, Illicit Discharge Detection and Elimination, Construction Site Runoff Control, Post-Construction Runoff Control, and Pollution Prevention/Good Housekeeping (EPA, 2020e, pp. 2).

As part of the MS4 program, under the first minimum control measure, permittees are required to educate their citizens with educational materials about the negative impacts to water quality that may occur due to polluted stormwater discharge into bodies of water (EPA, 2020e). Under the second minimum control measure, the public must have the opportunity to participate in the development and execution of the MS4 program (i.e. notification of public hearings, acquisition of citizen representatives on stormwater management pursuits) (EPA, 2020e).

The third minimum control measure requires permittees to formulate and execute a system that not only detects but aims to eliminate illicit discharges into the MS4 (EPA, 2020e). A crucial factor of this control measure, as mandated by Phase II, is system mapping. The purpose of system mapping is to create a depiction of the MS4 in the permit area that would allow a quick understanding of the MS4 and identify key infrastructure for effective system operation. Under the Massachusetts regulation, the mapping is completed in two phases. The first phase of the program is required to be completed within two years of the permit issuance and must provide components of an MS4 system including but not limited to outfalls, interconnections with other MS4s, and the identification of water bodies (EPA, 2020a). The second phase of the program requires that the system map be updated annually, that it is to be completed within ten years of the permit issuance and must include several components including but not limited to outfall spatial location, pipes, and manholes (See Appendix A)

(EPA, 2020a). While system mapping can be performed by hand, a type of powerful software that is often used is geographical information systems (GIS).

For construction activities disturbing an area of land greater than one acre, the formulation and execution of an erosion and sediment control program is necessary under the fourth minimum control measure (EPA, 2020e). Under the fifth minimum control measure, the formulation and execution of a post-construction program to control any stormwater runoff discharge that may occur due to new development is required (EPA, 2020e). The formulation and execution of a pollutant runoff program for municipal operations is required for permittees under the final minimum control measure (EPA, 2020e).

Compliance with the terms and conditions of the permit are essential to avoiding a violation, enforcement action, penalties, or an injunctive relief. A major challenge faced by the CMRSWC is the integration of system mapping where drainage systems are interconnected across municipal boundaries, watersheds, and with highways managed by MassDOT. Previous efforts to resolve this sort of issue exist but are limited, leaving a gap in research. Closing the gap is crucial to municipalities' compliance with the MS4 permit as well as maintaining effective stormwater infrastructure and mitigating polluted stormwater runoff discharge into bodies of water.

2.3 GIS Mapping & Geospatial Data

A geographical information system (GIS) is the primary tool used for mapping utilities like stormwater sewer systems. GIS is an integration tool that turns geospatial data into 2D, 3D, and even 4D layers. Geospatial data is data that combines location, attribute, and temporal information. Specifically, the geographic coordinates, characteristics, and time or life span of an object or event can be synthesized (Stock & Guesgen, 2016). GIS acts as the framework for gathering, integrating, and analyzing geospatial data that can help solve a wide variety of issues, from the spread of diseases to critical habitat destruction (Azad & Wiggins, 1995). Mapping allows users to identify social trends, analyze land use trends, formulate predictions, and illustrate scenarios. Data layers can be manipulated and analyzed to reveal deeper perspectives into data, such as patterns, relationships, and situations (Esri, n.d.). Analyzing and fixing pollution issues, such as stormwater runoff, become a much more manageable task with the introduction of GIS.

2.3.1 An Application of GIS Mapping

GIS is applicable to a lot of different industries but is prominently impactful in sustainability and wildlife protection. At the moment, there is a digital map of the ocean that is three dimensional. The map is sorted by global water masses into 37 distinct volumetric regions, also known as ecological marine units (EMUs). Units are defined by properties considered most crucial to ecosystem health and recovery (Esri, n.d.). They are crucial for helping reduce the risk of critically damaging and exhausting marine resources or wildlife.

GIS offers a unique approach towards tackling the growing issues of pollution and is applied to the world of stormwater management to preserve the habitats contaminated stormwater runoff may damage (Esri, n.d.). The three-dimensional capabilities certain GIS interfaces can provide may also be helpful in visualizing certain stormwater infrastructure.

2.3.2 GIS Mapping & Stormwater Management

There are several GIS software packages on the market that can be utilized to map stormwater systems. For example, one of the most commonly used software packages in the industry is provided by Esri and is known as ArcGIS (Vezina, 2020). In ArcGIS, a feature called the Stormwater Utility Network Foundation is useful for creating subnetworks of stormwater sewer systems. Included in this foundation is a stormwater data model. The model processes the utility network to include all feature classes, asset groups, asset types, rules, and other network properties necessary for a full interpretation of a utility network. Utility network tracing capabilities make it possible to analyze paths in a network. With this capability, many crucial trace types are provided by using the trace geoprocessing tool. Within these trace types are the subnetwork, subnetwork controllers, upstream/downstream, isolation, connected, loops, and shortest path trace tools. The trace tools can then be configured to address stormwater specific technological and business needs (Vezina, 2020). ArcGIS is the industry standard for GIS mapping; however, it is just one of the many GIS software packages available on the market. In correlation with MS4 regulations, municipalities in the CMRSWC use different methods for developing their stormwater system maps. It is likely that most municipalities use Esri products like ArcGIS, but it is possible that other GIS software packages are used or their mapping is done by hand. In Figure 2.3, an example of a map created to address and manage stormwater is shown of Milton, MA. Specifically, this map depicts various stormwater outfalls, catch basins, and sewer pipes in the area.

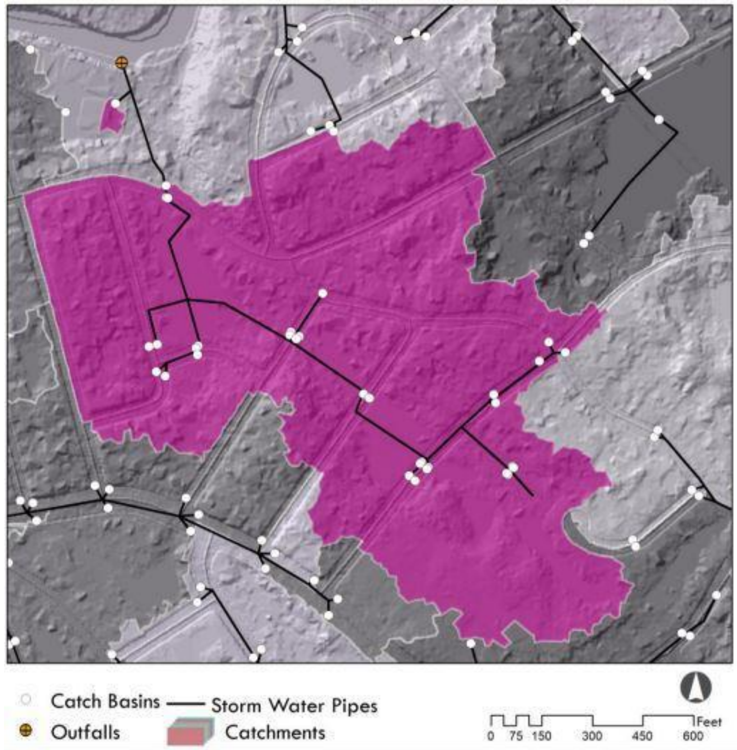

Figure 2.3 - *Outfall Catches in Milton, MA*

Note: The graphic above depicts various stormwater outfall catch basins and sewer pipes (EPA, n.d.).

2.3.3 GIS Mapping Initiatives in Massachusetts

In Massachusetts, initiatives for integrating mapping related to stormwater management have already started. Maps for vulnerable wetland stormwater management planning have become useful planning tools for MS4 municipalities. The maps are used to identify areas in six prime communities where phosphorus reduction efforts in the Charles River and pathogen reduction efforts in the Neponset River could be most effective (MassDEP, 2020). As part of a Wetland Program Development Grant through the EPA, the Massachusetts Department of Environmental Protection (MassDEP) developed a project that defined, analyzed, and mapped wetlands deemed "vulnerable" existing in the nearby communities. Throughout this project, stormwater management tools were discovered for municipalities subject to the 2016 Massachusetts Small MS4 General Permit. Technical assistance to the communities was provided to more efficiently help protect the wetlands from stormwater runoff pollution going forward. The MassDEP then produced individual vulnerable wetland GIS maps for these communities. They also provided technical training and outreach to communities on how to utilize the GIS maps in stormwater management plans. Due to the capabilities and successes of GIS on the project, the MassDEP received a "follow-on" grant from the EPA to generate YouTube videos and training modules for those who wish to get involved in mapping-related issues surrounding stormwater management (MassDEP, 2020).

2.4 Interorganizational Sharing of Geospatial Data

A challenge faced by the CMRSWC is the lack of interorganizational connection with the MassDOT in sharing geospatial data related to MS4 mapping. Accessing and understanding the MassDOT's geospatial data is imperative to municipalities' successful execution of a stormwater management program, compliance with the MS4 permit, and creating a comprehensive map of their MS4 permit area.

Geospatial data can be applied to analyze trends in a variety of issues - from drug use and trafficking to global climate change (Azad & Wiggins, 1995). Sharing available geospatial data is important because it increases the ability to analyze and address the issues in which geospatial data is applicable. Because of the time, resources, and knowledge that it takes to acquire geospatial data, withholding such information is uneconomical (Azad & Wiggins, 1995). Sharing geospatial data may seem simple, however, there lie many technical, financial, and behavioral impediments to sharing geospatial data. When developing an approach for sharing geospatial data between organizations, it is important to provide the organizations with a share in the design. While overcoming technical impediments is achievable, the challenge of an interorganizational relation (IOR) lies primarily within the organizations' lack of willingness to cooperate due to behavioral or institutional factors. A critical issue that turns organizations away from IORs in sharing geospatial data is a loss of autonomy. Organizations are sometimes hesitant to engage in an IOR because some independence may be lost and time, money, and resources will have to be reserved to maintain an IOR. Other factors that affect an IOR include sharing classes, project environment, need for shared data, opportunity to share data, willingness to share data, incentive to share data, impediments to sharing, technical capability for sharing, and resources for sharing (Kevaney, 2015, pp. 81). However, there are benefits to an IOR, including geospatial data compatibility and capital gain. IORs can help resolve the inefficient processes, gaps, and tautology that ensue from multiple independent organizations carrying out GIS work under a kindred pursuit (Pinto & Onsrud, 1995).

A successful case of a GIS IOR was with the Boston Central Artery project. The scale of the project required dozens of construction managers and consulting firms to work on it. Because different GIS software packages were being used by different firms, a move to create a GIS digital base map was made. Agreements were made on the accuracy and standards of the base map to ensure that the geospatial data could be transferred from one system to the next.

2.5 Past Stormwater Management Initiatives Involving GIS Mapping

Three years ago, at WPI's Water Resource Outreach Center (WROC), students addressed the issue of chronic pollution in the nearby Salisbury Pond in Worcester, MA. The team developed a list of eight prime variables in stormwater management. They used these variables, along with GIS mapping to display locations on campus where various stormwater management devices could be placed for optimal efficiency in reducing WPI's contributions to polluted wastewater issues (Marsan et al., 2018). The IQP team's design board can be seen in Figure 2.4.

Figure 2.4 - *Design Board for Past WROC Team*

Note: The graphic above depicts this mentioned IQP team's design board which utilized GIS Mapping to introduce possible "green" infrastructure initiatives for Boynton Hill (Marsan, et al.).

As fellow students of WPI, the research conducted by this previous IQP should be observed, analyzed, and applied to propel our project forward. Their team addressed the issue of polluted water, taking a geographical approach, just as our project will.

In Jingting Sun's internship report in conjunction with the City of Columbia Utilities and Engineering Department and the University of South Carolina, he verified and completed the mapping of stormwater infrastructure for two sub basins in the Congaree River Watershed. The existing mapping for the watershed was fragmented, unverified, and incomplete in its GIS data collection. Sun consulted available plan drawings, collected GPS data in the field, verified maps, and added and edited data in a stormwater database. Through his project, Sun accomplished identifying gaps in the data and finding a solution to integrate data and track pollution sources.

The problem that the Congaree River Watershed faced is similar to the problem currently being faced by the CMRSWC. Many drainage systems are interconnected across multiple municipal boundaries, watersheds, and state-owned properties and their maps may be developed by different organizations. The maps are often not considered to be easily integratable.

2.6 Summary

It is clear that contaminated stormwater runoff is a leading cause of pollution contributing to several public health, environmental, and economic issues. As the world's population continues to grow, urbanize, and demand more resources, stormwater runoff is bound to increase due to the abundance of impervious surfaces. By identifying gaps in geospatial data and integrating data among municipal and state properties, municipalities have a greater chance at knowing the effectiveness of their stormwater systems and are on a better path to fighting pollutants. Specifically, one of the driving factors in wanting to integrate MS4 geospatial data from municipalities with the MassDOT data is to improve upon the accuracy in the data used in creating catchments. The more accurately delineated a catchment is for an outfall, the greater the chance municipalities and the MassDOT have in making the correct decisions about types of treatment. The increase in the accuracy of this data will allow municipalities and the MassDOT to determine how much land area is contributing. Conclusively, there are various components to consider when facilitating the collaboration of geospatial data between local and state entities.

3.0 Methodology

The goal of this project was to develop an approach for facilitating the collaboration and integration of geospatial data between the Central Massachusetts Regional Stormwater Coalition (CMRSWC) municipalities and the Massachusetts Department of Transportation (MassDOT), while meeting the requirements of the 2016 Massachusetts Small MS4 General Permit. We developed recommendations for enabling a partnership between the municipalities and the MassDOT and guiding them in integrating their MS4 mapping efforts through the analysis of three case studies. Our efforts promote safe and effective stormwater management and support compliance with the Massachusetts' small MS4 regulations. To accomplish the goal of this project, we established the following objectives:

1. Identify the degree of information included in the municipalities' and MassDOT's geospatial data and how it is managed
2. Identify how geospatial data is shared between organizations
3. Identify what data gaps or constraints exist in the integration of stormwater sewer system geospatial data
4. Develop an approach to address data gaps and to facilitate interorganizational collaboration

Our project focused on studying the stormwater system mapping approaches for three CMRSWC municipalities - Auburn, Framingham, and Holden. Because of the detrimental effects stormwater runoff can have on public health, the environment, and the economy, it is important to know what stormwater infrastructure exists as part of a stormwater sewer system, where that infrastructure is located, where stormwater is collected, and where it is discharged to to help mitigate illicit discharges into MS4s. State roads and highways that run through the CMRSWC's municipalities are managed by the MassDOT and MS4s along these roads are mapped by the MassDOT, separately from the municipalities' maps.

The long-term goal of the MassDOT is to have a complete map of all the municipalities' MS4s in Massachusetts. However, we understand that mapping stormwater infrastructure is a costly venture and, since the MS4 permit is an unfunded mandate, it is important to know that the integration process will not be instantaneous, nor simple. Because municipalities will have to fund the operation themselves or allocate a fraction of their town's budget to MS4 compliance, accumulating the funding or resources for reaching their system mapping goals of creating comprehensive maps will take time.

Over a time span of seven weeks, the data we analyzed came primarily from the organizations' MS4 geospatial data and from a series of semi-structured interviews with key staff members involved in MS4 mapping from these organizations. While conducting interviews, it is important to understand that they were consensual. The individuals interviewed were not being interrogated; they were providing information voluntarily and were not forced to answer a question they did not wish to answer or participate at all. The interviewees were provided with the details of our project prior to the interview, so they were aware of how their responses would be used and where.

The Gantt chart outlines the schedule our team had set for accomplishing the goals of this project (See Appendix I). The timeline consisted of six tasks to be completed over a course of seven weeks including conducting semi-structured interviews with key staff members involved in MS4 mapping, conducting comparative data analysis of MS4 geospatial data, developing a process for integrating data and interorganizational collaboration, developing a guidance document, creating a supplementary video, and compiling the findings into a final report.

The principal stakeholders in this project were the three municipalities and the MassDOT, but the outcomes of this project will likely affect how other municipalities in the CMRSWC approach their MS4 mapping integration with the MassDOT. In the following sections, the methods pertinent to each of our project objectives are described and discussed.

3.1 Identify the Degree of Information Included in the Municipalities' and MassDOT's Geospatial Data and How It Is Managed

Because of the size of the CMRSWC, we used a case study methodology throughout this project. The purpose of a case study is to conduct an in-depth study of a particular group to gather an understanding of a more complex problem. Case study methodologies are often used in social sciences to conduct qualitative research by interviews or observation (Nedović-Budić & Pinto, 2000). Key members of the Massachusetts Department of Environmental Protection (MassDEP), MassDOT, and CMRSWC involved in MS4 mapping helped us identify the three municipalities suitable for this project and important contacts within these municipalities involved in MS4 mapping. The key members of these organizations (our sponsors) involved in our project were:

- Andrea Briggs: MassDEP Central Regional Office, Deputy Regional Director-BAS
- Hung Pham: MassDOT, Environmental Analyst III (Stormwater Program Coordinator)
- Kerry Reed: City of Framingham, CMRSWC Co-Chair, Senior Stormwater & Environmental Engineer
- Juliet Swigor: MassDEP, Geographic Information System Program
- Laura Schifman: MassDEP, Statewide Stormwater Coordinator

The three CMRSWC municipalities - Auburn, Framingham, and Holden - were identified as the most willing to take part in our project and possess considerable GIS mapping efforts. The identification of suitable municipalities was essential because of the limited time frame that our project was conducted under. We chose these specific municipalities to help us develop a substantial approach to fixing geospatial data integration problems with the MassDOT that may arise for other municipalities in CMRSWC.

The Town of Auburn is comprised of land that, at one point, was outlying sections of Worcester, Leicester, Sutton and Oxford and is located close to the WPI campus, in Worcester County. The City of Framingham, a diverse community located in Middlesex County at nearly 72,000 inhabitants, is the hub of the MetroWest region of Massachusetts (City of Framingham, n.d.). Both of the municipalities expressed interest in our project and possess a significant collection of MS4 geospatial data. As previously mentioned, besides these two municipalities, we considered the Town of Holden. Holden is located in Central Massachusetts, is slightly north of Worcester, and encompasses about 36 square miles that are primarily made up of protected open space, watershed areas, and recreational land (Town of Holden, n.d.). Holden is a municipality we observed to make a note of the challenges that may come with operating as a municipality in the CMRSWC while possessing a fair amount of DCR regulated land.

We used two phase semi-structured interviews to determine the current status of the chosen municipalities' mapping progress and to gain insight into how they create, update, and manage their system mapping. As our project's objectives build on one another, the identification of these factors was essential to understanding each stakeholder's vision and to, ultimately, developing recommendations and a guidance document for the municipalities of the CMRSWC that facilitates the integration of the MassDOT's mapping efforts.

3.1.1 Understanding the Current Standing

A vital aspect in developing a guidance document for the CMRSWC municipalities was to understand the current standing of our case study municipalities' and the MassDOT's MS4 mapping. Our recommendations provide certain organizational and technical measures municipalities should take to effectively integrate the MassDOT's data with their own and support the CMRSWC in executing their long-term goals in stormwater management.

We interviewed the three municipalities' and the MassDOT's key staff members involved in MS4 mapping efforts to understand and acquire their present state of MS4 mapping (See Appendix H). The interviews were conducted in a semi-structured fashion, recorded, and later transcribed. Semi-structured interviews encourage the use of open-ended questions that facilitate discussion. Due to the idiosyncratic nature of the data, group interviews were conducted by organization and included two phases of questions. Lasting approximately thirty minutes, the first phase of questions in the interviews revealed the exact approaches the organizations take to fulfill their mapping requirements, such as what GIS software packages are used, if their GIS work is outsourced, and how often their maps are updated (See Appendices B-G).

3.2 Identifying How Geospatial Data is Shared Between Organizations

The second phase of our semi-structured interviews was used to determine how geospatial data is shared between the three CMRSWC municipalities and the MassDOT to develop an understanding of the municipalities' and MassDOT's intra-organizational and interorganizational structures and functions. Acquiring this qualitative data was crucial in effectively determining the current relationship held between the municipalities and the MassDOT. Our acquisition of this qualitative data helped us detect any aspects of the interorganizational relationship and MS4 mapping methods that could be improved upon, while allowing the organizations to input ideas and have a stake in our design for developing an approach that supports effective geospatial data integration.

3.2.1 Understanding the Relationship Between Municipalities and the MassDOT

The second phase of our interviews of the three municipalities' and the MassDOT's key staff members involved in the MS4 mapping efforts (i.e. a GIS coordinator, town engineer) allowed us to acquire information on their stormwater management departments' organizational structures and functions. We also interviewed key staff members from the DCR to gain additional understanding on how municipalities may interact with another state agency in complying with the MS4 mapping requirements. Lasting approximately thirty minutes, the questions in the second phase of the interviews revealed the relationship that the two organizations have developed, their organizational structures, employed policies, events that are key to their geospatial data sharing history, and processes by which data is requested or shared, as seen in Table 3.2 (See Appendices B-G).

Table 3.2 - *Geographic Information Sharing Factors*

Note: Thirty suggested geographic information sharing factors to consider when developing a sharing structure (Kevaney, 1995).

Geographic Information Sharing Factors
Sharing Classes
1 Classes of sharing arrangements
Project Environment
2 Number of organizations involved
3 Organizational goal/mission
4 Organization relationships
5 Current general relations between/among organizations
6 Historic relations between/among organizations
7 GIS relationships between/among organizations
8 Control of information
9 Growth rate for service area
10 Leadership politics/ego
Need for Shared Data
11 Adequacy of internal data and data resources
12 Data of another organization is needed
13 Need data that can best be developed or maintained jointly
14 Level of dependence from sharer perspective
Opportunity *To Share Data*
15 Organization(s) in the area have needed data
16 Organizations in the area have resources to share development/ maintenance costs
Willingness To Share Data
17 Organization owning data willing to share
18 Organization offers/willing to share cost of *data* development/ maintenance
19 Level of dependence from *lead* organization perspective
Incentive To Share Data
20 Governmental program or regulations that require or encourage sharing
21 Recognition of the value of sharing of data
Impediments To Sharing
22 Real or perceived requirement for confidentiality
23 Incompatibility in the definition, specifications, or structure of available data
Technical Capability for Sharing
24 Basis for sharing data between organizations
25 Level of planning for database or system development
26 System capacity and capability to use data
27 Data of useful technical specifications
Resources for Sharing
28 Funding source to acquire or pay for share
29 Data or source materials for shared data
30 Service area size

A similar method was previously used in a case study done on sharing information in an interorganizational GIS environment. Specifically, in this study, the mechanisms and behavioral factors that can facilitate or inhibit the willingness of organizations to share GIS databases were researched using a case study methodology (Nedović-Budić & Pinto, 2000).

3.3 Identifying What Data Gaps or Constraints Exist in the Integration of Stormwater Sewer System Maps

To provide technical recommendations for the municipalities for their MS4 mapping strategies, we used comparative data analysis to determine what data gaps exist in the CMRSWC municipalities' MS4 maps. Comparative data analysis was vital in not only ascertaining the gaps in data, but in evaluating the relationship between the municipalities and the MassDOT. All MS4 geospatial data was collected in the early stages of the project. The data was collected via email communication with key staff members of the three municipalities and the MassDOT.

3.3.1 Comparing MS4 Maps

Through comparative data analysis, the municipalities' maps and mapping strategies were compared with the MassDOT's. The available data files sent over by the three municipalities and the MassDOT via email were imported into ArcGIS Pro to analyze. In this process, we discerned what infrastructure is identified and how, and where the municipalities' systems end and the MassDOT's system begins.

3.4 Developing an Approach to Address Data Gaps and to Facilitate Interorganizational Collaboration

To develop our deliverables (a guidance document and supplementary video), we used research, thematic content analysis from previously conducted interviews, and comparative data analysis of the MS4 maps. We determined how to address data gaps and facilitate interorganizational collaboration and integration between the municipalities and the MassDOT, while factoring in the most effective ways of completing mapping projects with low-cost.

3.4.1 Determining the Best Practices for Integrating Geospatial Data

The information we acquired through research, content analysis of qualitative data acquired from previously conducted interviews, and comparative data analysis of MS4 geospatial data was synthesized to determine the best procedure or approach for addressing data gaps and facilitating interorganizational data integration. In fact, the synthesis of the different components of our findings revealed the most effective strategies for acquiring the MassDOT's geospatial data, communicating with the MassDOT, increasing the readability of municipalities' MS4 maps, and accessing easy-to-use and cost-effective training courses and educational resources.

3.5 Data Analysis

From qualitative data gathered by interviews to the geospatial data from our municipalities' and the MassDOT's MS4 maps, each component needed to be analyzed. Interviews with key staff members of the Town of Auburn, the City of Framingham, the Town of Holden, and the MassDOT were invaluable in learning about the specific condition of their geospatial data and their mapping methodologies. The interviews we conducted were transcribed and thematically analyzed. Geospatial data for MS4 maps was collected from Auburn, Framingham, Holden, and the MassDOT. Feature analysis and comparative data analysis were conducted to accurately understand what the different MS4 maps portray. Specifically, we compared the classes, symbology, and fields associated with different pieces of infrastructure. We initially overlaid the MassDOT's MS4 geospatial data onto each of the municipalities' to see how they compare visually and to determine the most effective and aesthetically pleasing way of presenting stormwater infrastructure. In a Microsoft Excel spreadsheet, fields were compared. The fields from the MassDOT and the three municipalities were sorted by major pieces of infrastructure. The municipalities' fields were then compared against the MassDOT's, imagining that the MassDOT will serve as a standardized baseline for the municipalities' fields.

3.6 Project Deliverables

As a deliverable for our project, we generated a guidance document and supplementary video. The guidance document contains all information we discovered to be crucial in helping the CMRSWC municipalities integrate the MassDOT's MS4 geospatial data with their own. Our project has addressed, identified, and displayed geospatial data differences between the municipalities and the MassDOT, while assessing the best interorganizational and technical practices for complying with the system mapping requirements of the 2016 Massachusetts Small MS4 General Permit. We also created a supplementary video for the CMRSWC municipalities. The video illustrates the importance of interorganizational collaboration for MS4 mapping, the adverse effects of contaminated stormwater runoff, and the system mapping requirements of the 2016 Massachusetts Small MS4 General Permit.

3.7 Summary

In conclusion, the lack of interorganizational connection between the CMRSWC municipalities and the MassDOT is contributing to gaps in their MS4 geospatial data - a pressing issue that the CMRSWC municipalities need help solving. Our team used a series of semi-structured interviews, comparative data analysis, and research to develop recommendations for facilitating the integration of MS4 maps' geospatial data and interorganizational collaboration.

4.0 Findings & Results

Based on the aforementioned methodology where we discussed the series of semi-structured interviews and MS4 geospatial data analyses we conducted, several findings have presented themselves. The interviews with key staff members from the Massachusetts Department of Transportation (MassDOT), the Department of Conservation and Recreation (DCR), and the three municipalities (Auburn, Holden, and Framingham) have helped us gather invaluable information in understanding the organizations' MS4 mapping methods, reasoning behind their MS4 mapping approach, and the status of their interorganizational relationships. The analyses and comparison of the MS4 geospatial data from the organizations allowed us to acquire an understanding of the complexity of integrating geospatial data from multiple organizations and sources when creating a comprehensive map. Our analyses also provided insight as to how these complexities can be alleviated to promote interorganizational collaboration and integration of geospatial data. The examination of our findings have allowed us to develop a set of recommendations for municipalities that are a part of the Central Massachusetts Regional Stormwater Coalition (CMRSWC) to consider implementing to facilitate communication and to ease the integration of data with the MassDOT and other state agencies like the DCR. In this chapter, we start by presenting our findings pertinent to the MassDOT. We then present our findings associated with each of our case study municipalities (Auburn, Framingham, and Holden), and conclude the chapter by discussing the DCR.

4.1 MassDOT Overview

Interactions between municipalities, the MassDOT, and other state agencies are essential when trying to understand the interconnections in MS4s and creating a comprehensive map. We interviewed Hung Pham, the Stormwater Program Coordinator for the organization, about the MassDOT's MS4 mapping methodology and the interorganizational relationship between the CMRSWC municipalities and the MassDOT.

4.1.1 MassDOT Interview

When asked about their relationship with the MassDOT, Auburn, Framingham, and Holden expressed that communication with MassDOT's Stormwater Program Coordinator and the agency's district personnel is and will be an essential component of a successful relationship. During our interview, Hung Pham provided information about the agency, its inner workings, and the interorganizational relationship between the MassDOT and CMRSWC municipalities.

The stormwater department consists of two people, the Stormwater Unit Supervisor and Stormwater Program Coordinator. Most municipalities have emphasized difficulty in communicating with MassDOT regarding MS4 mapping and are unsure of who they should contact for information. Proposing Hung Pham, the current Stormwater Program Coordinator, as the point person from the MassDOT for municipalities to contact will help alleviate this concern.

The MassDOT's current priority for their MS4 mapping efforts is to have a complete understanding of Massachusetts' drainage infrastructure. There is currently a general understanding, but a more complete picture is necessary to know where the stormwater flows.

The MassDOT currently uses LiDAR for data collection and ArcGIS for mapping infrastructure. LiDAR sensors emit lasers to collect data used to create maps of stormwater infrastructure. The MassDOT assets and infrastructure information were obtained through the use of LiDAR around 2015. The state agency keeps records of most of their currently mapped infrastructure internally in ArcGIS and on a website called GeoDOT - the MassDOT's public GIS database. The organization also uses the ArcGIS Collector application, which is a mobile view for field personnel to easily input inspection data or add features or assets to the existing database.

One of the MassDOT's biggest challenges is handling the size of the organization. There are six districts statewide with over 9,000 lane miles of roadways. Because the six districts range from Boston to Western Massachusetts, these districts have different needs and priorities making it difficult to coordinate mapping efforts and information.

Implementing MS4 regulations has been beneficial to the MassDOT, but time consuming. The MassDOT has implemented and constructed 1,500 stormwater basins through the Impaired Waters Program and has recorded approximately 121,000 catch basins. The construction of new infrastructure is environmentally beneficial, however, maintaining all of the infrastructure is difficult due to limited manpower as both equipment and training of personnel are two major obstacles the agency must deal with.

4.1.2 MassDOT Geospatial Data

Hung Pham sent us the MassDOT's GIS mapping data for Auburn, Framingham, and Holden via email through a Dropbox. He also provided us with a mapping guidance document developed to help hired consultants that contains a key that indicates the symbology of the different pieces of infrastructure in the geospatial data. The data provided was imported into

ArcGIS Pro to analyze.

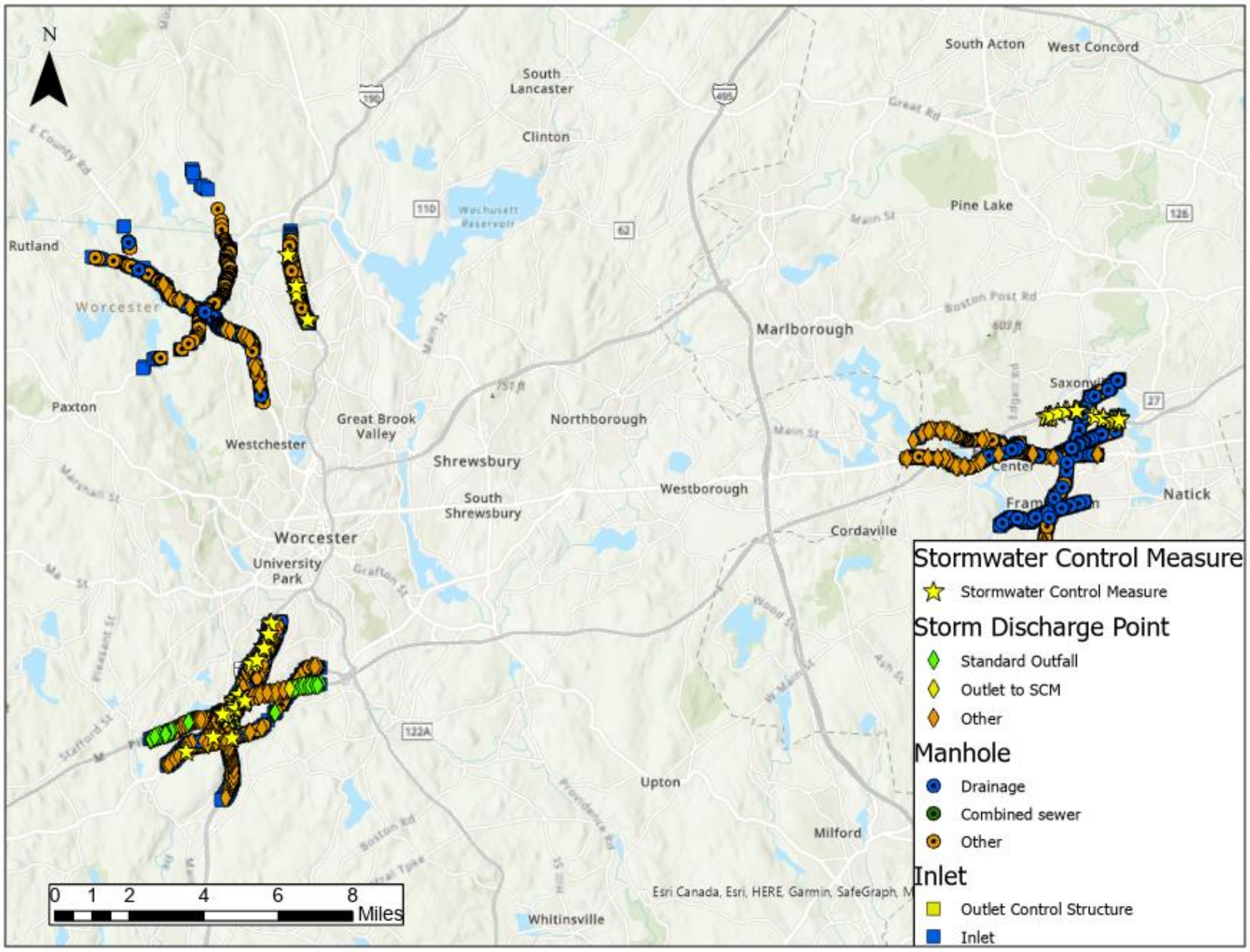

Figure 4.1 - *MassDOT Mapping Data for Auburn, Framingham, and Holden*

Note: The image above displays the MassDOT's GIS data for Auburn, Framingham, and Holden.

The symbology used in the MassDOT's maps is easily distinguishable, as shown in Figure 4.1. In Figure 4.1, the MassDOT has Stormwater Control Measures, Inlets, Manholes, and Stormwater Discharge Points mapped. A more detailed key of the organization's symbology can be seen in Figure 4.2 and a clearer view of the map for each municipality can be found in

Figures 4.3, 4.5 and 4.7.

Stormwater Discharge Points			
Abbrev. for Asset ID: SWDP **Feature Type:** Point **Inspection Form:** Stormwater Discharge Point	**Symbology:** Standard Outfall Outlet to SCM Paved Waterway Scupper Other	**Description:** This feature class identifies locations where stormwater exits a stormwater system. These points are typically found at the end of closed conveyances. Key fields include discharge type, outlet type, outlet material, and diameter.	**Notes:** This feature class includes standard outfalls, outlets to SCMs, and discharges from open conveyances. Examples may include headwalls, flared end sections, pipe ends, swale ends, and scuppers. Paved waterways are also mapped as discharge points. Headwalls and flared end sections may be inlets or outlets depending on the direction of flow.
Inlets			
Abbrev. for Asset ID: SWIN **Feature Type:** Point **Inspection Form:** Inlet	**Symbology:** Outlet Control Structure Inlet	**Description:** This feature class identifies locations where stormwater runoff enters a stormwater conveyance system. Key fields include location relative to roadway, inlet type, cover type, the material and sump depth (if present).	**Notes:** This feature class includes catch basins, drop inlets, gutter inlets, curb inlets, and yard drains. Outlet control structures are also mapped as inlets. Headwalls and flared end sections may be inlets or outlets depending on the direction of flow.
Manholes			
Abbrev. for Asset ID: SWMH **Feature Type:** Point **Inspection Form:** Manhole	**Symbology:** Drainage Combined sewer Other	**Description:** This feature class identifies locations of manhole structures, often located where closed conveyance systems come together or change direction. Key fields include location relative to roadway, cover type, manhole type, and total number of incoming pipes.	**Notes:** This feature class includes drainage manholes, although other utility manholes may be included from previous mapping efforts. Utility type should be confirmed if the manhole is not for drainage. Example cover types include standard round, large round, square, rectangular, handhole and pullbox.
Stormwater Control Measures (SCMs)			
Abbrev. for ID: SCM **Feature Type:** Point	**Symbology:**	**Description:** This feature class identifies any practice or facility that improves, retains or otherwise manages stormwater. Key	**Notes:** This feature class includes both surface and subsurface SCMs. Examples include bioretention areas, constructed stormwater wetlands, gravel

Figure 4.2 - *Key for MassDOT Mapping*

Note: The image above displays the MassDOT's mapping key.

When looking at the MassDOT's mapping key and geospatial data, the presentation is organized and consistent. The distinct and multicolored symbology for the different pieces of infrastructure increases the ease of readability.

4.2 The Town of Auburn

One of the three municipalities that were interviewed was the Town of Auburn because it was initially identified by our sponsors as one of the municipalities in the CMRSWC most willing to take part in our project. Auburn possesses a considerable GIS mapping effort for their drainage that is in need of integration with the MassDOT because of the number of state roads it possesses: I-290, I-90, I-395, RT 12, and RT 20.

4.2.1 Auburn Interview

After identifying the key staff members involved in the MS4 mapping efforts in the Town of Auburn with our sponsors, we scheduled an interview with Eilish Corey (Senior Civil Engineer) and Joanna Paquin (Assistant DPW Director/Sewer Superintendent). Both Eilish

Corey and Joanna Paquin were helpful in determining the relationship that the Town of Auburn and the MassDOT have developed in relation to MS4 mapping efforts and the methodology the Town of Auburn has used to fulfill their mapping requirements. In addition to Eilish Corey and Joanna Paquin, Bill Coyle (Public Works Director/Town Engineer) is a key staff member involved in the stormwater management efforts in the Town of Auburn.

Auburn's current goal for their MS4 mapping efforts is to have a comprehensive system map that includes interconnections with the MassDOT, private development, and bordering municipalities and to obtain more detailed information on the town's infrastructure.

Originally, Auburn had used the GIS software package and database known as PeopleGIS because the town uses it and the CMRSWC had used it in the past. PeopleGIS has been used in the town for over a decade. For consistency, PeopleGIS is where their drainage data is stored because many departments in the town hall use this program. Because it is inconvenient to make edits in PeopleGIS, the drainage data is pulled off of PeopleGIS, edits are made through Esri ArcMap, and then re-uploaded to PeopleGIS. Although this is a cumbersome process, the town is tied to PeopleGIS.

Auburn's original mapping was completed through a consultant around 2010 from record drawings to meet the year two requirements of the MS4 permit. It is possible that some of the infrastructure was field verified by the consultants. In the past, Auburn had kept a list of infrastructure that was not mapped. Five or more years ago, there was a WPI program where students came into different towns in the CMRSWC to map infrastructure. The work done through this program was very limited but there were updates made through this program. Now, as field work is done related to the MS4 permit, GIS is updated based on that as there is no global initiative to update the entire drainage map. Through field work, infrastructure that has not been mapped is being found spontaneously, which is an immediate issue and concern because it should have been already mapped in the past year.

There is a concern that verifying Auburn's interconnections with the MassDOT would require extensive field work. A major issue inhibiting data collection and updates to the MS4 mapping efforts in the Town of Auburn is the limited staff in both availability and technical knowledge. There is currently no designated GIS person employed - Eilish Corey manages the GIS work for MS4 compliance. Another issue is that there are a plethora of other priorities in the office preventing a field investigation to get the mapping to the standard desired. Other priorities include updating the MS4 bylaw in the town, the Phosphorus Control Plan, and reviewing documents for private development.

Fortunately, the MS4 permit has been seen in a positive light because it has forced a focus on stormwater. However, it is a struggle for Auburn to fund all aspects that come with the permit while recognizing the limits of being a municipality. Because taxation is needed to fund stormwater management, a lot of residents are reluctant to pay for it because they do not understand stormwater, but money is needed to implement a stormwater program to educate the public. The knowledge barrier is also present with private developers. Many private developers who just want to get their jobs out only complete the minimum requirements for stormwater management and do not understand or care about the underlying intent behind the stormwater infrastructure.

The Town of Auburn's relationship with the MassDOT is extremely limited in terms of both communication and data exchange. Auburn expressed concerns about finding where to start in building a better relationship with the MassDOT in terms of MS4 mapping. Some of this stems from not knowing who to reach out to, since the MassDOT is a massive organization. Their communication and collaboration with the MassDOT is primarily project based. For example, in 2020, Auburn received an MVP Action Grant that focused on discovering how truck rollovers were polluting a portion of Auburn's groundwater source. The MassDOT was pulled in as a stakeholder during this process. In future collaboration with the MassDOT, established state standards and a point person to contact would be beneficial.

4.2.2 Auburn Geospatial Data

After acquiring Auburn's data via an email request to Eilish Corey, the data was input into ArcGIS Pro as stated previously in the methodology. A map of Auburn's data with the MassDOT's data overlaid can be seen in Figure 4.3.

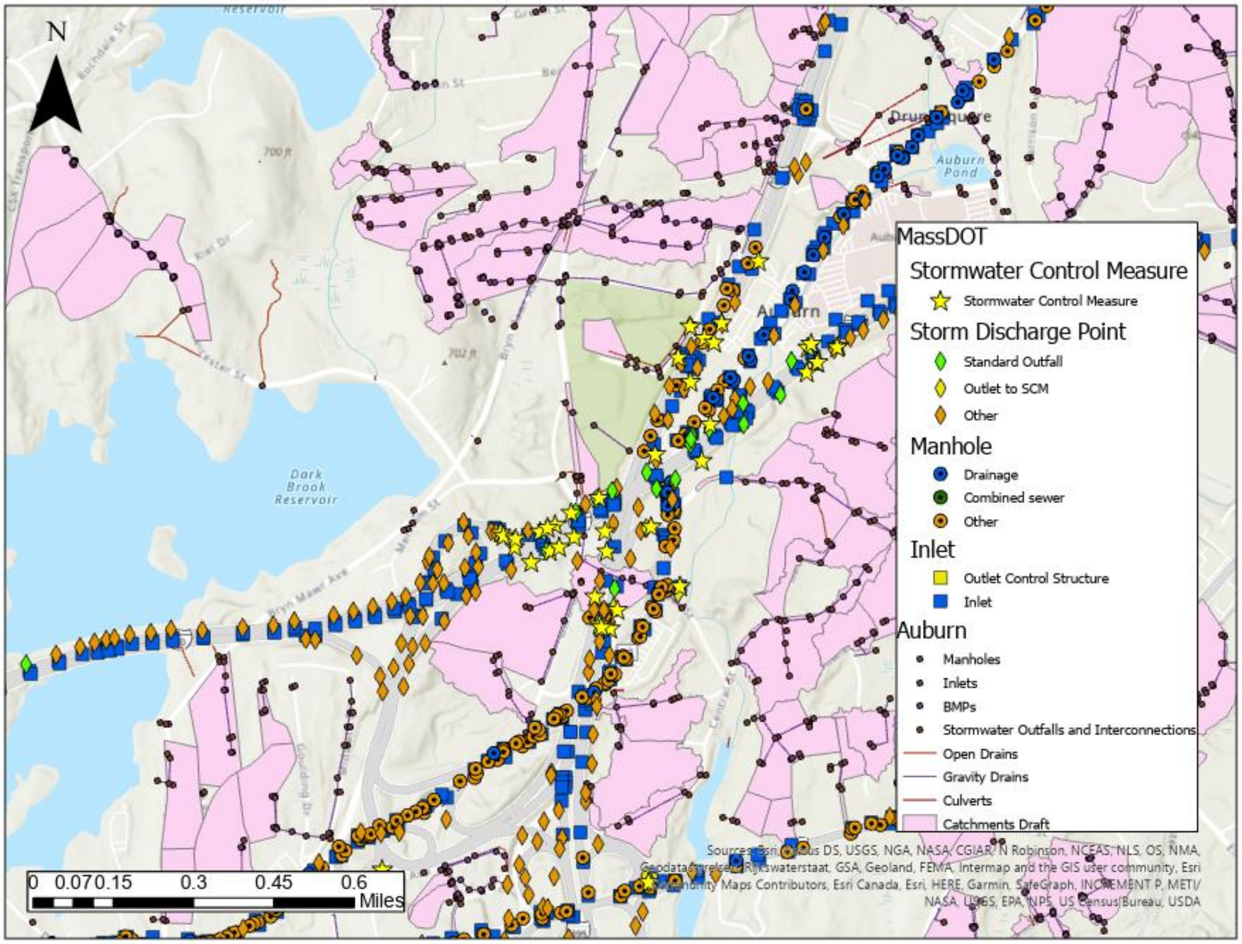

Figure 4.3 - *Auburn's and the MassDOT's MS4 Maps Overlaid*

Note: The image above depicts the MassDOT's MS4 data overlaid on Town of Auburn's.

At first glance, the map is overwhelming due to the symbology used, especially in comparison to the MassDOT's data which is easily recognizable along the state roads that run through the municipality. All of Auburn's infrastructure is either indicated by a point, line, or polygon. The choice in symbology makes it difficult to easily understand the map and to discern between the different types of infrastructure mapped. In Auburn's map, the following pieces of infrastructure are mapped: inlets, manholes, BMPs, open drains, gravity drains, culverts, and catchments.

When comparing Auburn's attribute tables to the MassDOT's, it is clear that Auburn has an excess of fields with many left completely blank. While it is rather random which fields are empty from one type of infrastructure to the next, this pattern of emptiness is consistent throughout all infrastructure. It is important to point out that fields are not a main concern because they vary drastically from one organization to the next but are important to consider.

The variation stems from different organizations using fields for different reasons, such as asset management or maintenance.

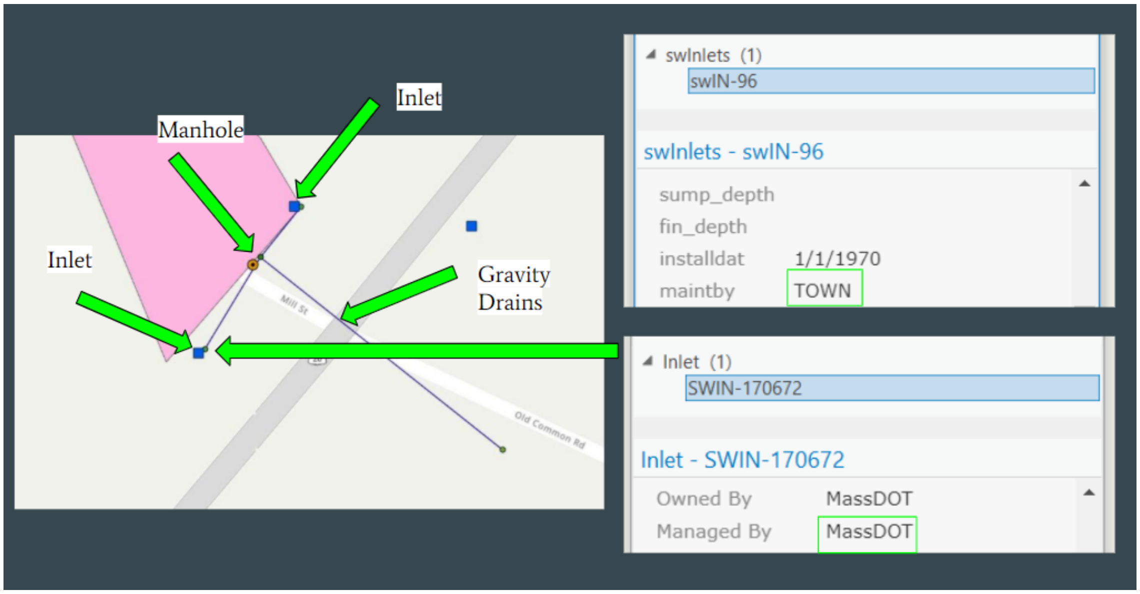

Figure 4.4 - *Auburn's Redundancies & Discrepancies with the MassDOT*

Note: The image above depicts redundancies and discrepancies in ownership seen in Auburn's data versus the MassDOT's.

Another observation made between Auburn's and the MassDOT's data was the number of redundancies and discrepancies in ownership along state roads. Because the mapping efforts are separate and have never been considered in an integrated manner or against a standard, the nomenclature from one map to the next is bound to be different. The differences in nomenclature and lack of interconnections in the MassDOT's data makes it even more difficult and time consuming to determine if a specific piece of infrastructure is a redundancy or not. Another component of this difficulty is the identification of ownership. As seen in Figure 4.4, what appears to be the same piece of infrastructure mapped by Auburn and the MassDOT is indicated by one organization that it is owned by the MassDOT and the other the town. The issue would be less critical if both the town and the MassDOT identified that the state managed infrastructure was managed by the state. While it would be impractical for municipalities to use the same naming convention for identifying infrastructure because of the amount of infrastructure in the state, one of our recommendations will help to ease the readability of MS4 maps in terms of ownership.

4.3 The City of Framingham

The City of Framingham is another municipality that we interviewed because they had expressed an interest in our project and possess one of the most detailed stormwater GIS maps in the CMRSWC. After getting in contact with the key staff members involved in MS4 mapping efforts for the City of Framingham, we scheduled an interview. We interviewed Kerry Reed (Senior Stormwater Engineer), Geoffrey Kovar (GIS Manager), and Janet Locastro (GIS Analyst). The three staff members described the extent of the Framingham's relationship with the MassDOT and private contractors in relation to their MS4 mapping efforts. We asked various questions to get a better sense of the methodology that Framingham has adopted to fulfill their mapping requirements.

4.3.1 Framingham Interview

Framingham's main objective for their MS4 mapping efforts is to develop a comprehensive mapping system that includes interconnections with the MassDOT, other state property, private development, and bordering municipalities. At the moment, Framingham is focused on delineating outfall catchments through the analysis of the catchment data that they have been actively collecting. Private detention and retention areas where drains start from or go across private properties are a concern because some are not documented properly. It is difficult to acquire information from private sources, as this is a very involved process. Aside from this, some interconnections with the MassDOT are mapped, specifically where private properties are connected to public systems. However, interconnections with private property and other structures have not been differentiated from those associated with the state. This is an issue near or on state roads such as RT 30, RT 126, RT 9, RT 135, or I-90.

The City of Framingham uses the GIS software package ArcGIS for mapping. Prior to the use of ArcGIS, a majority of their original data collected existed on paper maps. All edits to Framingham's maps are now made through this software and updated based on field work done related to MS4s and private construction. Framingham favors ArcGIS because it is the industry standard for GIS work and it is structured, minimizing transcription issues and maintaining original data "silos" or sets.

Framingham has a dedicated GIS professional who has continued to build upon the maps that they started developing in 2005. The maps are in an adequate condition as a result of the meticulous work done by Geoffrey Kovar, their GIS Manager. Through his rigorous vetting process in receiving GIS data from other organizations and departments, they have met the year two requirements of the MS4 permit and are actively meeting the year ten requirements. Framingham's main obstacle is the influx of unverified data from different sources that requires significant time and work to incorporate into their own data.

Framingham's relationship with the MassDOT is not too different from the relationship that the MassDOT has with the other municipalities that are part of our case study. There is not an abundance of communication between the two, although this has improved with the introduction of Hung Pham from the MassDOT and his current mapping efforts. Currently, Framingham is in a satisfactory position as far as meeting their mapping requirements and they are now prioritizing creating a fully encompassing map of all necessary or helpful features and attributes.

4.3.2 Framingham Geospatial Data

We acquired Framingham's MS4 maps from Geoffrey Kovar via email and began analyzing this data in ArcGIS Pro for differences with the MassDOT's. Figure 4.5 illustrates the current state of Framingham's maps, in comparison to the MassDOT's.

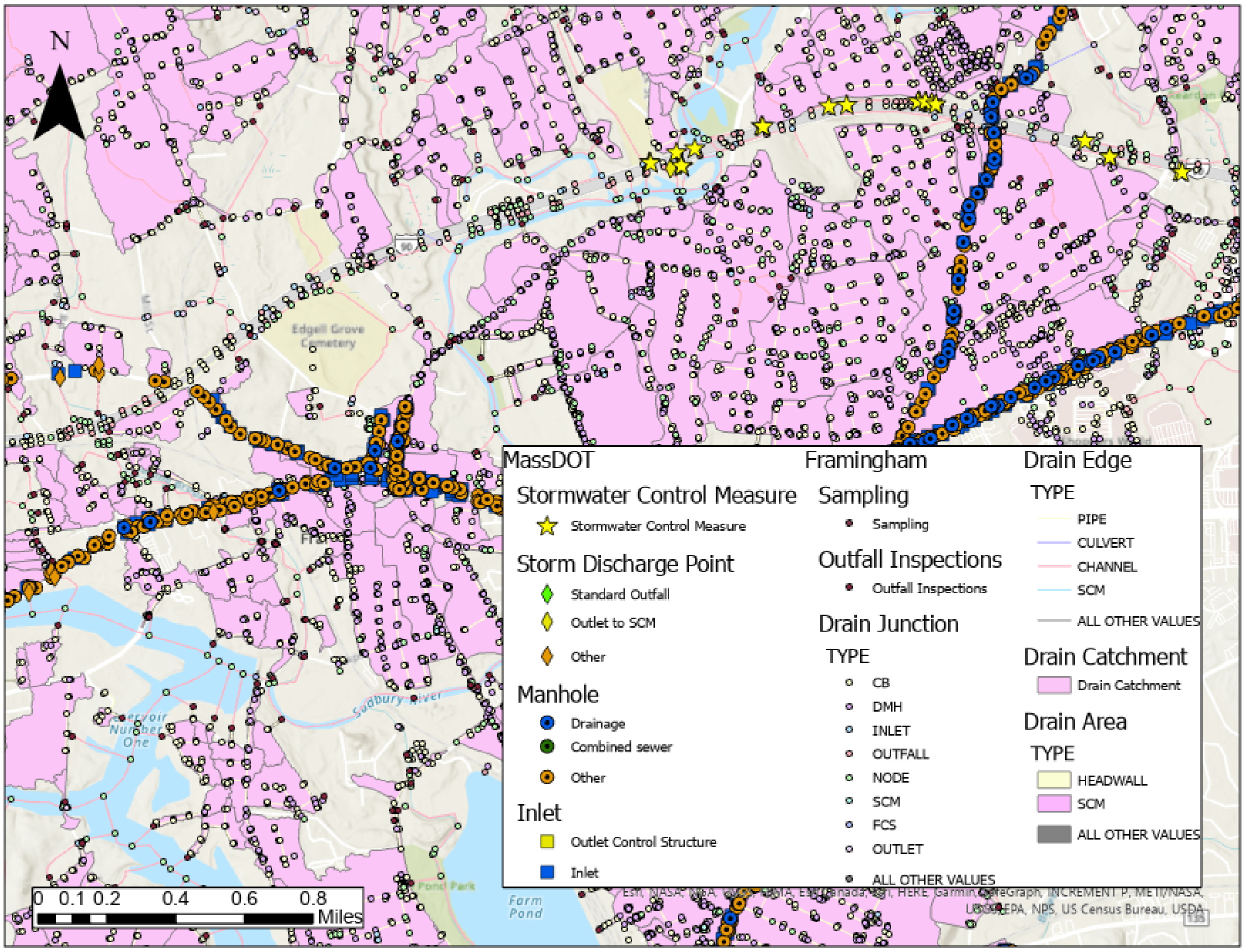

Figure 4.5 - *Framingham's and the MassDOT's MS4 Maps Overlaid*

Note: The image above shows the MassDOT's MS4 data overlaid on Framingham's MS4 data.

The map, as seen in Figure 4.5, may be overwhelming due to the overlay of symbols. However, the MassDOT's data is easily recognizable, running along state roads all across the municipality. All of Framingham's infrastructure is either indicated by a point, line, or polygon. Meanwhile, the MassDOT uses different point symbols to delineate their infrastructure. Although they both utilize different colors to further distinguish infrastructure, the differing symbology used by the MassDOT makes it easy to understand the map and discern different types of infrastructure from each other.

As shown in Figure 4.5, Framingham has specific pieces of infrastructure mapped that are also mapped by the MassDOT. Differing symbology in the two organizations' maps makes the data integration of the maps more difficult. There are certain features that are mapped by the MassDOT in certain areas, yet also mapped by Framingham. For example, Figure 4.6 displays a series of inlets mapped by the MassDOT that are not mapped by Framingham in that area.

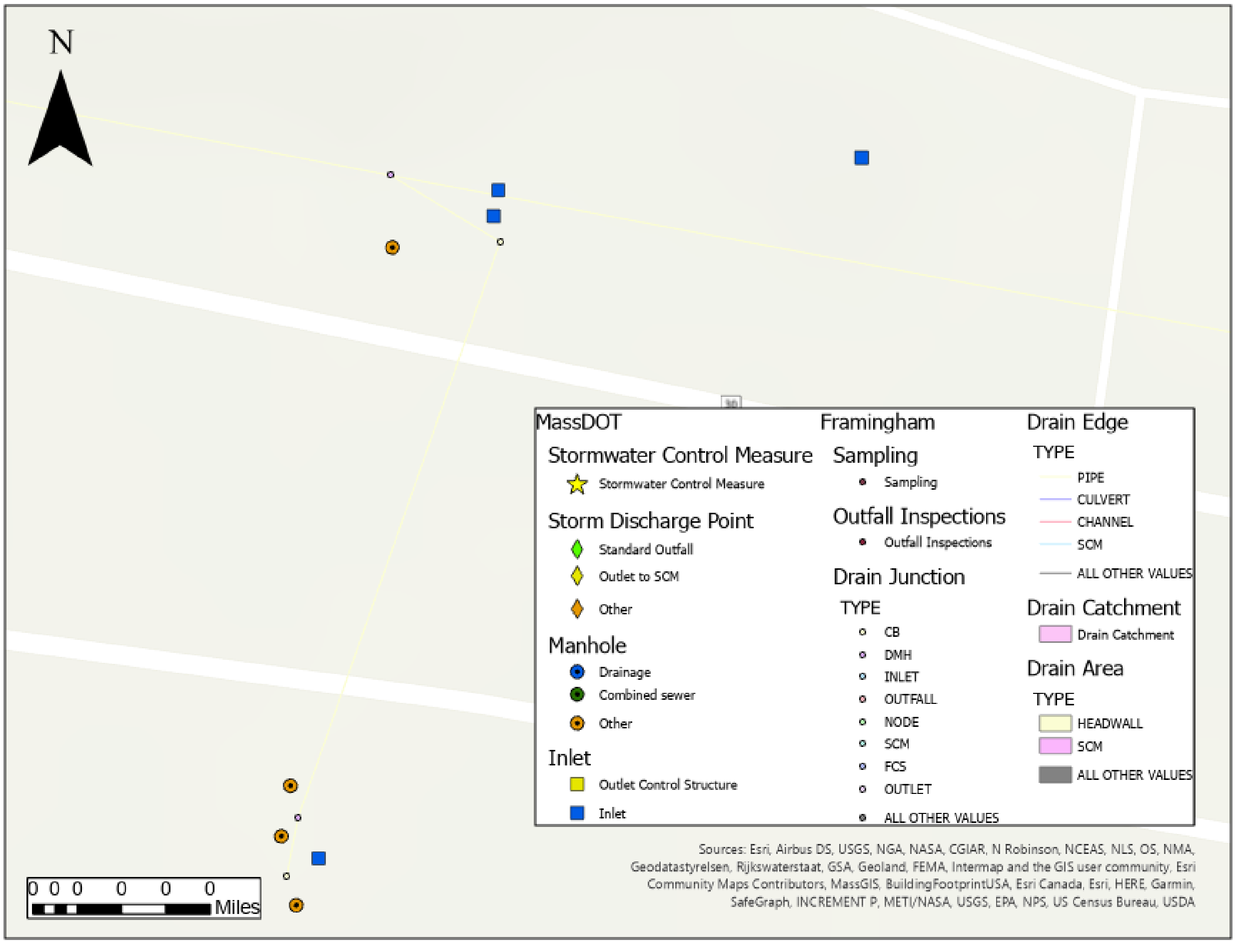

Figure 4.6 - *MassDOT Inlets*

Note: The image above shows specific inlets only mapped by the MassDOT.

4.4 The Town of Holden

The Town of Holden is the last municipality that we interviewed to gather an understanding of the unique relationship that a municipality could have with the DCR when possessing a considerable amount of DCR regulated land. After we identified the key staff members involved in MS4 mapping in the Town of Holden, we interviewed them to get a better sense of their relationship with both the MassDOT and the DCR. We interviewed Isabel McCauley (Senior Civil Engineer) and Luke Haberman (Civil Engineer II). They provided us with information on the extent of Holden's relationship with the MassDOT, DCR, and private contractors, in relation to their MS4 mapping efforts.

4.4.1 Holden Interview

We aimed to use Holden's interview as an opportunity to discuss the challenges that could come with mapping land owned by the DCR. However, in our interview with Holden, we were notified that the DCR handles the mapping of any land they own. They explained that they communicate regularly with the organization and that there has been an exchange of data between the two. Regardless, the DCR maps and manages their own land so there is no joint oversight on maps.

Holden's principal goal in their mapping efforts is to develop their maps as much as possible, given the limited staffing and GIS expertise. Holden currently does not have many mapping initiatives in progress due to limited resources and do not have a dedicated and experienced GIS team to tackle maps for drainage especially in the older areas of the town. The town uses a mapping symbology that was developed by their consultant. A significant part of their current stormwater management efforts is catch basin cleaning. The town has catch basins that need to be cleaned before they can even be mapped. As of right now, Holden has their outfalls mapped and is currently mapping drainage pipes. The town has spent nearly five to eight thousand dollars per year for the last three years on mapping. They had consultants take most of the records and as-built plans and digitize or georeference them for Holden's stormwater system. The data that was obtained in this process has become the foundation for the database they have now. Holden prioritizes adding to their geodatabase based on record drawings. They have a GIS page available to the public, utilizing the unique user-friendly sharing platform for mapping - PeopleGIS.

Aside from the missing data in their maps, Holden has had a much greater issue in terms of the limited time, funding, and resources for mapping. The interview gave insight into the struggles of being new to mapping an MS4 system as a municipality. Holden only began their efforts in 2010, so the limited data is due to a limited time to develop the data they have. Holden also expressed difficulty in obtaining MassDOT records from the north and south sides of Main Street. Holden and the MassDOT are currently working together, updating the drainage connection in parts of Main Street near Boyden Road and Bancroft Road to eliminate cross country drainage.

4.4.2 Holden Geospatial Data

We obtained Holden's MS4 data from Isabel McCauley via email and imported this data into ArcGIS Pro to analyze all the differences with the MassDOT's data.

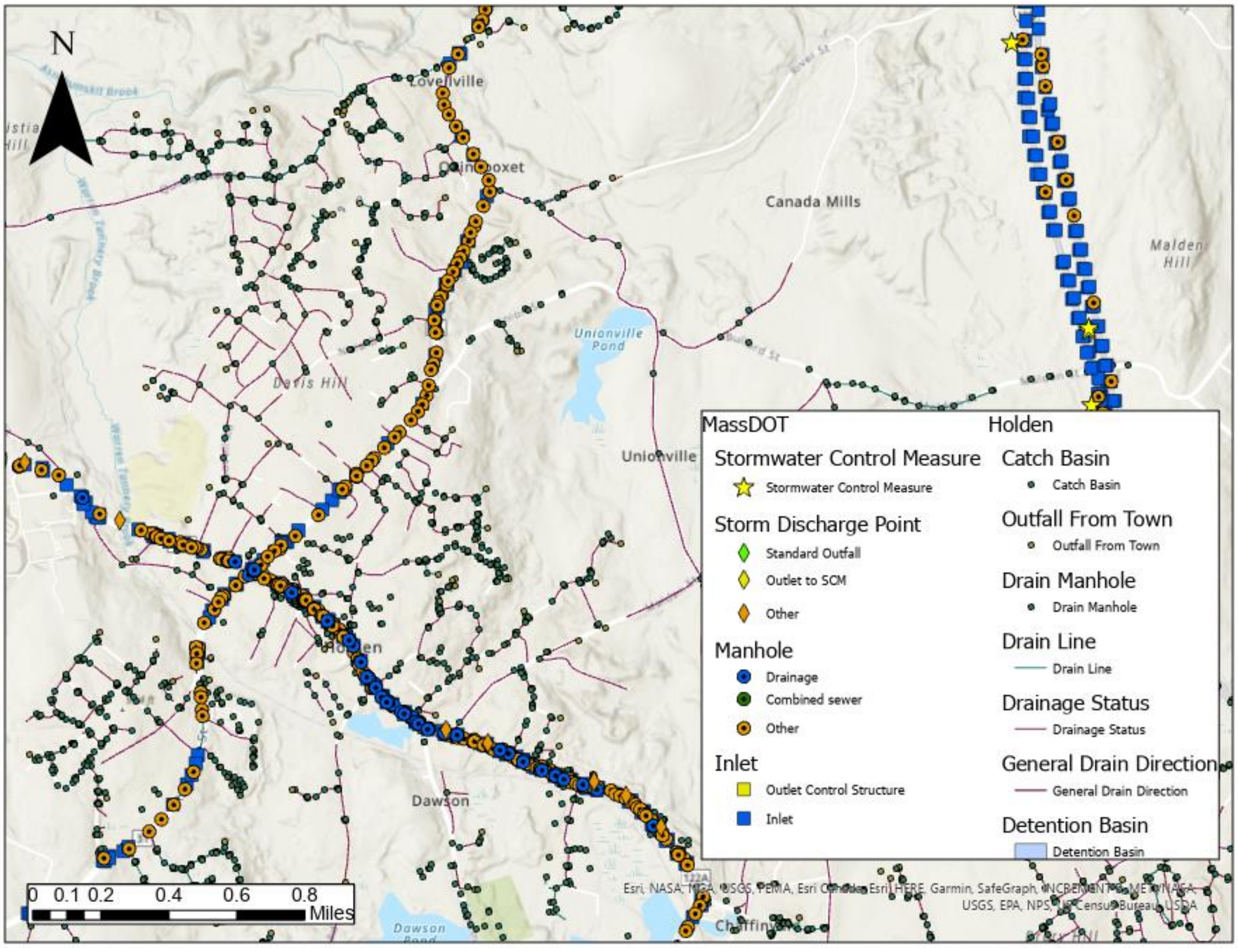

Figure 4.7 - *Holden's and the MassDOT's MS4 Maps Overlaid*

Note: The image above shows the MassDOT's MS4 data overlaid on Holden's MS4 data.

As seen in Figure 4.7, the MassDOT's data is easily recognizable in comparison to Holden's as it runs along the major state roads in the town. All of Holden's infrastructure is either indicated by a point, line, or polygon. Holden's choice in symbology makes it difficult to discern the different pieces of infrastructure in the map. In Holden's map, the following pieces of infrastructure are mapped: catch basins, outfalls from town, drain manholes, drain lines, drainage status, general drain directions, and detention basins. The figure is a clear example of why they are in need of resources and funding to develop a more comprehensive map.

4.5 DCR Overview

The Department of Conservation and Recreation (DCR) works with municipalities with whom their watersheds share land. The DCR is related to our project since the Town of Holden possesses some DCR regulated land. We interviewed Tristan Lundgren and Travis Drury, who are both Environmental Analysts and members of the mapping team for the DCR. Tristan Lundgren and Travis Drury were very helpful in providing insight to the inner workings of the DCR and describing the relationship that municipalities have with the DCR regarding MS4 mapping.

4.5.1 DCR Interview

The current goals of the DCR's mapping efforts are to assist with the MS4 regulations as a small portion of the watershed falls under MS4 regulation. Mapping the stormwater infrastructure in the watershed, however, is not primarily an MS4 effort. The DCR is interested in having information on the stormwater infrastructure in the watershed mapped to trace possible spills or anything that could impact water quality. The overarching purpose of the DCR's mapping project is to track pollution. The DCR uses the ArcGIS Collector application to collect data on each structure in the field. The data from this application is connected to ArcGIS Pro which is used on a desktop computer to refine the work done in the field. The DCR keeps their GIS data in layers. Therefore, there is no single map put together at all times. However, based on what is asked for by municipalities or other organizations, a map can be assembled using the appropriate layers and be distributed, as necessary. The data within these layers is continuously updated as development and redevelopment occur.

Data collection is a tedious process. Drainage structures are either visually verified in the field, georeferenced through plans, or interpreted. Fortunately, the DCR has powerful GPS technology to map infrastructure, using the Eos Arrow Series GNSS Receiver. GPS is extremely accurate, within inches, so the DCR is confident that their data would align with another organization's data if they were combined. The DCR has been mapping stormwater infrastructure for at least twenty years, starting with points on a paper map. Digitizing of the map began around 2005. The biggest challenge that the DCR faces in collecting data is manpower. With the COVID-19 pandemic, the DCR is entering its second year with no interns who are crucial in conducting field work.

The DCR is unique, regarding our project, because they are not entirely under MS4 regulation. It is helpful for the DCR to understand their neighboring towns MS4 data, but not required. The DCR has had minimal interaction with Holden in relation to mapping the interconnections between their land, mostly because Holden has not begun that part of their mapping process yet.

4.5.2 DCR Geospatial Data

The DCR saves their GIS mapping data in layers. Since the organization has a completely different mapping methodology than the MassDOT and the other municipalities, we thought it would be useful to include and discuss their mapping process as well.

Figure 4.8 outlines the DCR's mapping plans for their Wachusett Watershed hydrology mapping project. The five layers shown indicate the various symbology they use to discern infrastructure and other components. The organization outlines the infrastructure they will map, sets a schedule for when the mapping will be completed, and addresses what team member is responsible for each component. Our project aims to promote a similar, well-structured mapping approach for municipalities beginning to integrate the MassDOT's MS4 maps with their own.

Wachusett Watershed Hydrology Mapping Project
Task Completion

Feature Classes

Wachusett Hydro Datalayers

1. Drainage Structures: structures serving stormwater and natural hydrography (point layer)
2. Wachusett Hydrography: natural hydrography (line layer)
3. Wachusett Infrastructure: stormwater (line layer)
4. Wachusett Wetlands & Waterbodies: natural features (polygon layer
5. Wachusett Stormwater Basins: basins serving as stormwater BMPs (polygon layer)

Wachusett Hydro Supplemental Datalayers

6. Flow Direction: For use as a temporary feature, mainly in the field (line layer)
7. Research Needed: For use as a temporary feature, mainly in the field (point layer)

Schedule (tentative based on staff availability)

The project in its final form (Feb 2021) will proceed by major subbasin but likely will be unable to match the current EQA schedule and that goal may need to be abandoned.

1. Complete all tasks for Stillwater (June 2021)
2. Complete all tasks for Quinapoxet (Dec 2021)
3. Complete all tasks for Reservoir (June 2022)
4. Complete all tasks for Gates (December 2022)
5. Complete all tasks for Waushacum (June 2023)

General Tasks and Assignments

1. Drainage Structures. Complete data entry and editing: Tristan, Josh
2. Wachusett Hydrography. Complete data entry and editing: Dan, Travis, Tristan
3. Wachusett Infrastructure. Complete data entry and editing: Tristan, Josh
4. Wachusett Wetlands & Waterbodies. Complete data entry and editing: Dan, Travis, Tristan
5. Wachusett Stormwater Basins. Complete data entry and editing. Tristan, Josh
6. QA/QC: Erica
7. Run Flow Model(s): Dan

Figure 4.8 - *DCR Sample Mapping Plan*

Note: The DCR's mapping plan for the Wachusett Watershed hydrology mapping project.

4.6 Thematic Analysis of Findings

After individually analyzing the findings from each municipalities' and each organization's interview and provided MS4 geospatial data, through comparison, several themes can be drawn including limited staffing, limited funding, limited established relations with the MassDOT in terms of system mapping, and differing mapping methodologies.

4.6.1 Limited Resources

The most prominent theme across the three municipalities and the MassDOT is the limited resources available for mapping MS4s. First, there is limited funding available to these organizations because MS4 regulation is a federally unfunded mandate. Ultimately, the limited funding means that municipalities scramble within their budget to enact even the most basic efforts for stormwater management. Increased complications or updates in MS4 regulation means that more resources will be needed. Another factor playing into this funding issue is residents' reluctance to pay for stormwater management through their taxes. The reluctance stems from a fundamental misunderstanding or lack of knowledge about the adverse effects of contaminated stormwater runoff and the need for stormwater management because of it. Unfortunately, in order to educate residents, resources and time are needed to implement a substantial and effective program. With residents' pushback on taxation, there is a constant cycle of inadequacy in terms of funding that could likely only be alleviated from an outside source.

Furthermore, the three municipalities and the MassDOT expressed that there is limited staffing. The limited staffing concern is a direct result of limited funding. Most often, designated stormwater staff is not hired and, instead, the responsibilities that come with stormwater management and compliance with regulation, specifically mapping, is placed on top of the general responsibilities of an existing staff member who may or may not have GIS experience. Because of these circumstances, stormwater management efforts, including mapping, take away from the core responsibilities of the existing staff member, ultimately, leaving that member overwhelmed and overworked and stormwater runoff managed in a less effective manner because it is not receiving the attention it requires.

4.6.2 Differences in Mapping Methodologies

When considering the degree of information included in the organization's MS4 geospatial data, the three municipalities' MS4 geospatial data part of our case study is broken down into far more detail. The maps from the three municipalities had interconnections and other pieces of infrastructure like catchments that the MassDOT lacks. Because of the lack of interconnections in the MassDOT's MS4 geospatial data, it makes the situation of integrating data increasingly difficult. Field verification or georeferencing records and as-built plans would have to be performed to map these interconnections. Until then, it is questionable how useful the MassDOT's data will be to municipalities. While the municipalities' maps appear to have significantly more data, they lack the readability and comprehensibility that the MassDOT's map possesses. The MassDOT's data is not only condensed and standardized but its choice in both symbology and color scheme elicits a quick understanding in discerning the infrastructure.

In comparing the methodologies used by each organization to map their MS4s, it is apparent that all organizations we interviewed use Esri products like ArcGIS - the industry standard for GIS software packages. Between the Town of Auburn and the Town of Holden, who lack a designated GIS staff unlike the City of Framingham, the two municipalities had their original mapping done by a consultant around the year 2010. The MassDOT is subject to this commonality as well having that a consultant did the original mapping for the organization. Because consulting is generally an expensive pursuit, the organizations would like to see the MS4 maps become an internal effort entirely. However, the desire for internal mapping can be unrealistic for a lot of municipalities and organizations, again, because of the limited resources and time that they have to begin with because of the regulation being federally unfunded.

4.6.2a Attribute Analysis

As previously stated in the methodology, a Microsoft Excel spreadsheet was used to compare the fields in each piece of infrastructure's attribute table. By comparing the municipalities' fields against the MassDOT's, several conclusions were made under the notion that the MassDOT will serve as a baseline for municipalities' fields to ease the integration of infrastructure interconnections. The DCR was also factored into this comparison. Due to the nature of their data layers, the attributes from their data layers "Drainage Structures" and "Wachusett Infrastructure" were compared to the MassDOT's and the three municipalities only for the sake of discussion.

From observation, the three municipalities have several additional fields that are not included in the MassDOT's fields. Additional fields include, but are not limited to, standard GIS fields that do not have any real substance and inspection related fields. Because our project primarily focuses on the integration of data between the municipalities and the MassDOT while using the MassDOT as a baseline, the MassDOT's fields were sorted into two tiers, one with required fields and the other with optional fields. Some of the MassDOT's fields were also eliminated in this process, specifically, those that were automatically generated by ArcGIS for editor tracking and those that were designated as to likely not be used as part of the mapping effort. We were originally going to create a third tier for other suggestions for fields that would be helpful for municipalities to have that the MassDOT may not have. Recognizing the limits of our time and knowledge and the disparity in the fields from one municipality to the next, instead, we made some important considerations for municipalities, such as what other fields would be helpful in the perspective of someone who frequently uses MS4 geospatial data.

4.6.3 Coordination with the MassDOT

A major concern expressed by the three municipalities was the minimal or nonexistent relationship that they had with the MassDOT in terms of MS4 mapping efforts. In fact, the municipalities had only gained access to the MassDOT's drainage data in past projects where the MassDOT was a stakeholder. The municipalities even conveyed that they simply did not know who to even contact about such matters because of the overwhelming size of the MassDOT. The municipalities were also unaware of the existence of GeoDOT and the fact that they could easily access the MassDOT's drainage data online. When relaying this concern to Hung Pham at the MassDOT, he demonstrated an interest in being a designated point of contact for municipalities. However, he emphasized that size of the MassDOT accompanied with taking on this responsibility could be time consuming and not entirely effective.

4.7 Summary

Conclusively, there are several prominent themes within MS4 mapping efforts experienced by the three CMRSWC municipalities and the MassDOT. Considering the thematic analysis of our findings, we have been able to gather an understanding of three particular cases. We have drawn conclusions and formulated recommendations about implications of the overarching problem: municipal collaboration and integration of geospatial data with the MassDOT.

Limited funding and staffing proved to be a concern for all three of the municipalities and the MassDOT because stormwater regulation is underfunded. Indicating interconnections between municipal and MassDOT MS4s stems from differences in mapping methodology, specifically with classes of infrastructure and symbology. Limited communication and coordination with the MassDOT have also been a concern for the three municipalities. While recognizing the limits that municipalities have in implementing stormwater management efforts, the conclusions that have been drawn through analyzing our findings build the foundation for recommending a technical and organizational approach for better integrating and collaborating with the MassDOT in terms of MS4 mapping.

5.0 Recommendations

After conducting a thematic analysis on the data we gathered through interviews and GIS analysis, we have established a few recommendations for municipalities to take into consideration to facilitate the integration of their MS4 geospatial data with the MassDOT's. We derived three recommendations that are visually included in our deliverable - the guidance document for this project. The intent of the guidance document is to assist CMRSWC municipalities in improving their interorganizational relationship and data integration with the MassDOT in meeting the system mapping requirements of the 2016 Massachusetts Small MS4 General Permit. In this section, we discuss the recommendations we have curated for the CMRSWC municipalities. The recommendations apply to all CMRSWC municipalities regardless of the stage of completion of their MS4 mapping endeavors.

5.1 Increasing Readability & Integration of Maps

Municipalities' MS4 maps contain greater detail than what the MassDOT currently has mapped, regarding both infrastructure included and attribute information. The additional information that the three municipalities' maps had were primarily conveyances and catchments. While the detail and great mass of information that the municipalities have is beneficial, the way it is presented prevents a viewer from being able to acquire a quick understanding of an MS4. Although the MassDOT does not contain some of the components that the municipalities have, the MassDOT's data is condensed and standardized. The MassDOT's presentation of its stormwater infrastructure allows a viewer to easily discern, for example, a manhole versus an inlet. The comprehensibility of the MassDOT's data derives from the choice in both symbology and color choice. Distinctly different symbols and colors are used to identify the different pieces of infrastructure.

5.1.1 Condensed Symbology

Because the MassDOT has data for all municipalities, it would be beneficial for municipalities to mimic the MassDOT's symbology. Not only will this help integration with the MassDOT, but in the long run, it will also help municipalities integrate their MS4 data with bordering municipalities if they adopt the same symbology. Integration with surrounding municipalities is important as stormwater runoff is not bound by imaginary town borders.

To ease the readability and integration of MS4 maps, we first recommend that the CMRSWC municipalities follow the MassDOT standard developed for map symbology to condense the amount of infrastructure typically shown on municipalities' MS4 maps. All applicable infrastructure would be reassigned to the following categories to match the MassDOT's symbology: Stormwater Control Measure, Inlet, Manhole, and Stormwater Discharge Points, Interconnections, Conveyances, and Miscellaneous Structures. Should a municipality decide to adopt this recommended symbology, additional information that municipalities map (i.e., catchments) can be mapped however they prefer. Specifically, a star is used to identify a Stormwater Control Measure, a square for an Inlet, an annulus for a Manhole, a rhombus for Stormwater Discharge Points, a hollow rhombus for Interconnections, a polyline for Conveyances, and a cross for Miscellaneous Structures. While these categories may seem vague, there are subcategories for Inlets, Manholes, Stormwater Discharge Points, Conveyances, and Miscellaneous Structures. For Inlets, the subcategories are Inlets and Outlet Control Structure. For Manholes, the subcategories are Drainage, Combined Sewer, and Other. For Stormwater Discharge Points, the subcategories are Standard Outfall, Outlet to SCM, and Other. For Conveyances, the subcategories are Pipe, Swale/Ditch, Underdrain, and Other. For Miscellaneous Structures, the subcategories are Sediment Forebay, Check Dam, Auxiliary Spillway, and Other. To distinguish between the subcategories, different colors are assigned to the categories' symbol.

5.1.2 Ownership Identification

Another factor playing into increasing readability and integration of municipality and MassDOT MS4 maps is differentiating ownership of infrastructure. Ownership is typically identified in a piece of infrastructure's attribute table. Having ownership information is crucial but having it visible on the map would help municipalities immediately understand, upon sight, how their MS4 is interconnected with the MassDOT's. We recommend municipalities use different colors to distinguish ownership. For example, when identifying a Standard Outfall, we recommend that municipalities use a neon green rhombus (HTML color code: #55FF00) to represent state ownership and a light green rhombus (HTML color code: #CCFF90) to represent municipal ownership. In our guidance document, we have provided municipalities with our recommended condensed infrastructure categories, symbology, and color schemes with HTML color codes.

5.1.3 Specifying Infrastructure Definitions

To help clarify the specific subcategories of infrastructure that fall within this condensed symbology, there is a page a part of our guidance document that provides the definitions and specifics for each piece of infrastructure. Definitions will eliminate confusion where certain pieces of infrastructure fall within the symbology. Furthermore, if there is any additional infrastructure that a municipality desires to map that may not fall under any of these categories nor Miscellaneous Structures, they may adopt their own category, symbology, and color scheme. When incorporating additional infrastructure into the map, municipalities should use our category recommendations to make decisions on symbology and color scheme to set the new category apart from the others and to maintain the readability of the map.

5.1.4 Recommended Fields

Another important aspect of system mapping is fields in attribute tables. We recommend municipalities adopt aspects of the MassDOT's fields. In our guidance document, we have classified the MassDOT's fields into two tiers. Tier 1 includes fields that are highly recommended and considered required for proper integration while Tier 2 includes fields that would be helpful but are optional for proper integration. As addressed in our findings, the municipalities of our case study had a number of additional fields describing the conditions of infrastructure that may be useful for maintenance. Because of the number of additional fields, it is important to address other common fields that could be useful in identifying infrastructure. It is important for municipalities to include a unique identifier or Asset ID for each piece of infrastructure to tie back to any type of asset management database, to remove unused fields, and to keep a list of all field names and their MassDOT equivalencies if they are reluctant to adopt our field recommendations.

5.2 Improving Communication Between the MassDOT & Municipalities

Through thematic analysis of the interview results, a critical theme was that our three municipalities had a minimal or nonexistent relationship with the MassDOT regarding their MS4 mapping efforts. Any relationships that the municipalities hold with the MassDOT are primarily, if not entirely, project based. Because it is a state agency that oversees six districts in the Commonwealth, it can be overwhelming for municipalities to even figure out how to get in contact with the MassDOT. Despite the size of the MassDOT, their MS4 mapping efforts are overseen only by two people. Another prevalent issue present is the community's unawareness of the existence of GeoDOT - the MassDOT's public GIS database. Through GeoDOT, municipalities can easily access and download the MassDOT's drainage data.

5.2.1 MassDOT Point of Contact

Improving upon the current level of communication between the MassDOT and municipalities requires that municipalities first know who to contact in the organization and when it is appropriate. To improve communication between the MassDOT and municipalities, it is important to identify a point person to contact. The point person to contact would be Hung Pham who is the Stormwater Program Coordinator for the MassDOT. In our guidance document, his contact information, including his email, is provided to the municipalities. While providing this contact information will be helpful to municipalities, the responsibility that comes with being a point person to contact can be overwhelming especially when comparing the size of the MassDOT's stormwater team and the size of the CMRSWC alone, nevermind the entire Commonwealth. It is important for municipalities to understand that unnecessary communication with the MassDOT may inhibit the core responsibilities of the stormwater team. To help mitigate this concern, a list of reasons or scenarios that are appropriate to contact Pham will be provided in the guidance document.

5.2.2 GeoDOT

A way to mitigate unnecessary communication with the MassDOT is to make municipalities aware of how to use GeoDOT to access and download the MassDOT's drainage data. We have developed a five-step process on how municipalities can do this. Specifically, we instruct the viewer to visit the website, navigate to Highway Assets, apply a stormwater tag, download the files, and import the files into ArcGIS or another GIS software package.

5.3 Future Considerations for Limited Staffing & Funding

After interviewing the key staff members of the three municipalities and the MassDOT, it was clear to us that a major theme was that there is a funding and staffing issue for the stormwater departments within these organizations. The two issues systematically stem from the Phase II of the federal mandate being unfunded. Municipalities must use their existing budgets to support stormwater management efforts, to understand the complexity of the Massachusetts permit and to comply with it. Because most residents are unable to understand the potential effects of stormwater runoff due to a fundamental misunderstanding or lack of knowledge, taxation for stormwater management receives pushback. There is a constant cycle of inadequacy because funds are needed to implement stormwater education programs. Municipalities and the MassDOT alike face not having enough staff to sustain an effective stormwater program because of the limited funds.

Staffing and resources available to municipalities are in limited supply. As stormwater infrastructure accumulates with new development and impervious surfaces increase, stormwater runoff will accumulate. Alleviating the staffing and funding issues is essential to ensuring that stormwater runoff is managed in an effective manner to prevent the potential adverse effects it can have on public health, the environment, and the economy.

5.3.1 Forming New Relationships

Forming new relationships with universities, community colleges, K-12 schools, companies, organizations, and watershed associations could be helpful in lessening the load placed on municipalities. Programs could be put in place to get students involved in MS4 mapping or other miscellaneous stormwater management related tasks for relieving the daily workload for municipalities. The benefits of such a program are innumerable. Implementing volunteer programs on unpaid or paid internships are an effective way to get tasks done at a low cost. Not only will volunteers or interns acquire real world experience that will benefit their career, but the knowledge they gain about the importance of stormwater management in an urbanizing world is invaluable. Volunteers' and interns' newfound knowledge could indirectly educate more people as they share their experiences. The most efficacious approach to implementing a program would be for municipalities to target clubs related to sustainability at local universities or community colleges. Clubs at universities often contain a community service component in which they volunteer and help the community. Students in sustainability related clubs would also likely have a genuine interest in helping with an issue like the one at hand.

5.3.2 Educational Resources

While this recommendation is a potential option for many municipalities, educating volunteers or interns about stormwater infrastructure and how to use GIS can be time consuming. We recommend the use of a list of educational resources that could be beneficial in training volunteers, interns, or even used in implementing an education campaign for public awareness. We have included three categories of educational resources available to access in our guidance document: 1) Learning ArcGIS, 2) Stormwater Education, and 3) Other Helpful Links.

Specifically, under the Learning ArcGIS category, we have included a link to two Esri resources on their website. The first website provides the basics, mapping and visualization, and analysis in ArcGIS Pro, as well as using ArcGIS Pro in 3D. The second website provides more advanced lessons for ArcGIS Pro including topics on GIS for population and development studies, data analysis and visualization, public transit, and resources for teaching with ArcGIS Pro. Under the Stormwater Education category, we have provided links to three resources. The first resource is a YouTube video called "Where Does Stormwater Go?" posted on the Youtube channel called Practical Engineering. The video addresses the infrastructure that helps manage stormwater. We also have provided a link to a section of the Mass.gov website that addresses permit information, stormwater standards and policies, and resources and tools for MS4 compliance. The last resource provided as part of this second category is a link to the Massachusetts Stormwater Handbook which includes information on what stormwater is, why it needs to be managed, Massachusetts' goals for stormwater management, and the infrastructure involved in stormwater management. Finally, under the Other Helpful Links category, we have provided three resources. The first resource is a link to the GIS Field Use Information Report. The report was designed by the MassDEP to help towns navigate software possibilities for mapping infrastructure in the field. The second resource is a link to ThinkBlue Massachusetts which is a statewide educational campaign aiming to spread awareness about how stormwater pollution affects local water bodies and wetlands. The final resource as part of this third category is a link to a section of the EPA website that describes the problems with stormwater pollution and describes the purpose of the federal mandate for stormwater regulation - the NPDES stormwater program.

5.4 Summary

After synthesizing the qualitative data we acquired throughout our case studies, we have developed and presented three major recommendations for municipalities to promote the integration and collaboration of MS4 geospatial data between the CMRSWC municipalities and the MassDOT. The recommendations we presented, specifically, are 1) Increasing Readability and Integration of Maps, 2) Improving Communication Between the MassDOT and Municipalities, and 3) Future Considerations for Limited Staffing & Resources. The details of our recommendations and how they can be enacted are available in our guidance document for the CMRSWC municipalities.

6.0 Conclusion

Stormwater management is realistically a multi-faceted operation that requires a complete understanding of the stormwater infrastructure of an MS4. GIS software packages offer amazing capabilities for generating maps and managing stormwater by allowing organizations to map their infrastructure and store information for asset maintenance. However, there are different mapping methods used between municipalities within the CMRSWC and the organizations within the Commonwealth of Massachusetts. Individual municipalities also have different priorities in stormwater management based on the most urgent needs for their town's safety and functionality. A wide variety of perspectives and priorities has made the integration of maps a laborious task. The task becomes especially difficult if there are few commonalities established, limited resources or staffing, and limited communication in the integration process.

Our recommendations will be beneficial and effective in aiding the CMRSWC municipalities in their integration efforts with the MassDOT. The recommendations we developed aim to help municipalities in several ways. Through practicing our recommendations for increasing readability, the integration of municipal MS4 geospatial data with outside data from the MassDOT should become an easier process. Improving upon the level of communication and collaboration between municipalities and the MassDOT has been the main theme of our project. By providing a step-by-step process on how to use GeoDOT and contact Hung Pham, we lessen the amount of unnecessary communication while improving collaboration. Assisting municipalities with the limited staffing and resources for mapping operations has also been a major consideration throughout our project. Providing able bodies to carry out work for municipalities and the MassDOT will likely lessen the loads that they each bear, allowing more time to work towards improving stormwater management processes including system mapping. All of the recommendations, along with our guidance document, ultimately facilitate the collaboration and integration of MS4 geospatial data between CMRSWC communities and the MassDOT.

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Appendix A: Massachusetts Small MS4 General Permit System Mapping Requirements

From *General Permits for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems in Massachusetts*

2.3.4.5. System mapping

The permittee shall develop a revised and more detailed map than was required by the MS4-2003 permit. This revised map of the MS4 shall be completed in two phases as outlined below. The mapping shall include a depiction of the permittee's separate storm sewer system in the permit area. The mapping is intended to facilitate the identification of key infrastructure and factors influencing proper system operation, and the potential for illicit sanitary sewer discharges.

a. Phase I: The system map shall be updated within two (2) years of the permit effective date to include the following information:

- Outfalls and receiving waters (required by MS4-2003 permit)
- Open channel conveyances (swales, ditches, etc.)
- Interconnections with other MS4s and other storm sewer systems
- Municipally-owned stormwater treatment structures (e.g., detention and retention basins, infiltration systems , bioretention areas, water quality swales, gross particle separators, oil/water separators, or other proprietary systems)
- Waterbodies identified by name and indication of all use impairments as identified on the most recent EPA approved Massachusetts Integrated List of waters report pursuant to Clean Water Act section 303(d) and 305(b)
- Initial catchment delineations. Any available system data and topographic information may be used to produce initial catchment delineations. For the purpose of this permit, a catchment is the area that drains to an individual outfall or interconnection.

b. Phase II: The system map shall be updated annually as the following information becomes available during implementation of catchment investigation procedures in part 2.3.4.8. This information must be included in the map for all outfalls within ten (10) years of the permit effective date:

- Outfall spatial location (latitude and longitude with a minimum accuracy of +/-30 feet)
- Pipes
- Manholes
- Catch basins
- Refined catchment delineations. Catchment delineations shall be updated to reflect information collected during catchment investigations
- Municipal sanitary sewer system (if available)
- Municipal combined sewer system (if applicable).

c. Recommended elements to be included in the system map as information becomes available:

- Storm sewer material, size (pipe diameter) and age
- Sanitary sewer system material, size (pipe diameter) and age
- Privately-owned stormwater treatment structures
- Where a municipal sanitary sewer system exists, properties known or suspected to be served by a septic system, especially in high-density urban areas
- Area where the permittee's MS4 has received or could receive flow from septic system discharges (e.g., areas with poor soils, or high ground water elevations unsuitable for conventional subsurface disposal systems)
- Seasonal high water table elevations impacting sanitary alignments
- Topography
- Orthophotography
- Alignments, dates and representation of work completed (with legend) of past illicit discharge investigations (e.g., flow isolation, dye testing, CCTV)
- Locations of suspected, confirmed and corrected illicit discharges (with dates and flow estimates).

d. The mapping may be produced by hand or through computer-aided methods (e.g. GIS). The required scale and detail of the map shall be appropriate to facilitate a rapid understanding of the system by the permittee, EPA and the state. In addition, the mapping shall serve as a planning tool for the implementation and phasing of the IDDE program and demonstration of the extent of complete and planned investigations and corrections. The permittee shall update the mapping as necessary to reflect newly discovered information and required corrections or modifications.

e. The permittee shall report on the progress towards the completion of the system map in each annual report.

Appendix B: Auburn Interview Questions

1. What are the current goals of Auburn's MS4 mapping efforts?
2. What GIS software, if any, or geospatial data approach is currently used to map the MS4s in Auburn? What is the reasoning behind this approach?
    a. How often are these maps updated?
3. What is the process for your mapping efforts? Is there anything in particular to note about Auburn's approach?
4. The data set that was sent over contains manholes, interconnections etc. What are the main priorities for mapping? Is time spent equally on these components or is there emphasis placed on particular pieces of the infrastructure?
5. Are there particular types of infrastructure that Auburn has not mapped but feel is needed? Are there particular types of information that have not been collected about this infrastructure that would be helpful?
6. Is there a data dictionary or explanation of attributes for the MS4 data?
7. Do the GIS data layers fulfill all the year two requirements of the MS4 permit? What components of the year ten requirements are fulfilled, if any?
8. Besides system mapping, how does Auburn enforce/comply with the minimum control measure - Illicit Discharge Detection and Elimination?
9. When did Auburn start mapping their stormwater system?
10. What are the biggest obstacles Auburn faces in collecting data and keeping it up to date?
11. How has implementing MS4 regulations affected Auburn's ability to manage stormwater?
12. Have you or other stormwater officials expressed difficulty in communicating with the MassDOT?
13. Are there any key events to note on the history of the interorganizational relationship between Auburn and the MassDOT? If so, please describe.
14. Could you describe the current status of the interorganizational relationship?
15. What is the general organizational structure of stormwater management currently?
16. Can you describe the interorganizational flow and the intraorganizational flow of information?

17. Is there joint oversight over any stormwater management aspect between Auburn and the MassDOT?
18. Describe the extent of the relationship in terms of software, data, and services. Are any of these categories collaborated on?
19. Have there been any contractual or mutual agreements made between Auburn and the MassDOT? If so, please describe.
20. Are there any specific rules, policies, or procedures for sharing data or database sharing enacted by Auburn?
21. Are there any financial limitations on collaborating with the MassDOT? If so, please describe.
22. Since funding is an issue for most towns, are there any initiatives to get funding for the stormwater aspect?

Appendix C: Framingham Interview Questions

1. What are the current goals of Framingham's MS4 mapping efforts?
2. What GIS software, if any, or geospatial data approach is currently used to map the MS4s in Framingham? What is the reasoning behind this approach?
    a. How often are these maps updated?
3. What is the process for your mapping efforts? Is there anything in particular to note about Framingham's approach?
4. What are the main priorities for mapping? Is time spent equally on these components or is there emphasis placed on particular pieces of the infrastructure?
5. Are there particular types of infrastructure that Framingham has not mapped but feel is needed? Are there particular types of information that have not been collected about this infrastructure that would be helpful?
6. Is there a data dictionary or explanation of attributes for the MS4 data?
7. Do the GIS data layers fulfill all the year two requirements of the MS4 permit? What components of the year ten requirements are fulfilled, if any?
8. Besides system mapping, how does Framingham enforce/comply with the minimum control measure - Illicit Discharge Detection and Elimination?
9. When did Framingham start mapping their stormwater system?
10. What are the biggest obstacles Framingham faces in collecting data and keeping it up to date?
11. How has implementing MS4 regulations affected Framingham's ability to manage stormwater?
12. Have you or other stormwater officials expressed difficulty in communicating with the MassDOT?
13. Are there any key events to note on the history of the interorganizational relationship between Framingham and the MassDOT? If so, please describe.
14. Could you describe the current status of the interorganizational relationship?
15. What is the general organizational structure of stormwater management currently?
16. Can you describe the interorganizational flow and the intraorganizational flow of information?

17. Is there joint oversight over any stormwater management aspect between Framingham and the MassDOT?
18. Describe the extent of the relationship in terms of software, data, and services. Are any of these categories collaborated on?
19. Have there been any contractual or mutual agreements made between Framingham and the MassDOT? If so, please describe.
20. Are there any specific rules, policies, or procedures for sharing data or database sharing enacted by Framingham?
21. Are there any financial limitations on collaborating with the MassDOT? If so, please describe.

Appendix D: Framingham Supplemental Interview Questions

1. Has Framingham used GeoDOT at all for your maps?
2. How does Framingham plan on using the MassDOT's data to map interconnections? Will you wait until the MassDOT maps their interconnections or take the initiative to map the interconnections?
3. Has Framingham thought about condensing its symbols to integrate maps with the MassDOT better?
4. What is the reasoning behind the oblong polygon shaped areas marked as drain catchments?

Appendix E: MassDOT Interview Questions

1. What are the current goals of the MassDOT's MS4 mapping efforts?
2. What GIS software, if any, or geospatial data approach is currently used to map the MS4s at the MassDOT? What is the reasoning behind this approach?
    a. How often are these maps updated?
3. What is the process for your mapping efforts? Is there anything in particular to note about the MassDOT's approach?
4. The data set that was sent over contains manholes, inlets etc. but does not contain interconnections. What are the main priorities for mapping? Is time spent equally on these components or is there emphasis placed on particular pieces of the infrastructure?
5. Are there particular types of infrastructure that the MassDOT has not mapped but feel is needed? Are there particular types of information that have not been collected about this infrastructure that would be helpful?
6. Do the GIS data layers fulfill all the year two requirements of the MS4 permit? What components of the year ten requirements are fulfilled, if any?
7. When did the MassDOT start mapping stormwater systems?
8. What are the biggest obstacles the MassDOT faces in collecting data and keeping it up to date?
9. How has implementing MS4 regulations affected the MassDOT's ability to manage stormwater?
10. Is there an easy way for municipalities to get in contact with the MassDOT? If so, how?
11. Could you describe the current status of the interorganizational relationship between the MassDOT and the municipalities they work with?
12. What is the general organizational structure of stormwater management currently within the MassDOT?
13. Can you describe the interorganizational flow and the intraorganizational flow of information?
14. Is there joint oversight over any stormwater management aspect between municipalities and the MassDOT?
15. Have there been any contractual or mutual agreements made between municipalities and the MassDOT? If so, please describe.

16. Are there any specific rules, policies, or procedures for sharing data or database sharing enacted by the MassDOT?
17. Are there any financial limitations on collaborating with the MassDOT? If so, please describe.
18. Can you elaborate on how municipalities would use GeoDOT?
19. How do you expect municipalities to use the MassDOT's data exactly? As an overlay that aligns with the town's data or to compare the DOT's data with their own and draw it in?

Appendix F: Holden Interview Questions

1. What are the current goals of Holden's MS4 mapping efforts?
2. What GIS software, if any, or geospatial data approach is currently used to map the MS4s in Holden? What is the reasoning behind this approach?
    a. How often are these maps updated?
3. What is the process for your mapping efforts? Is there anything in particular to note about Holden's approach?
4. What are the main priorities for mapping? Is time spent equally on these components or is there emphasis placed on particular pieces of the infrastructure?
5. Are there particular types of infrastructure that Holden has not mapped but feel is needed? Are there particular types of information that have not been collected about this infrastructure that would be helpful?
6. Is there a data dictionary or explanation of attributes for the MS4 data?
7. How does Holden decide which infrastructure is owned by the state or owned by the town?
8. Do the GIS data layers fulfill all the year two requirements of the MS4 permit? What components of the year ten requirements are fulfilled, if any?
9. Besides system mapping, how does Holden enforce/comply with the minimum control measure - Illicit Discharge Detection and Elimination?
10. When did Holden start mapping their stormwater system?
11. What are the biggest obstacles Holden faces in collecting data and keeping it up to date?
12. How has implementing MS4 regulations affected Holden's ability to manage stormwater?
13. What obstacles does Holden face in mapping DCR land?
14. Have you or other stormwater officials expressed difficulty in communicating with the MassDOT?
15. What is the general organizational structure of stormwater management currently?
16. Is there joint oversight over any stormwater management aspect between Holden and the MassDOT?
17. Describe the extent of the relationship in terms of software, data, and services. Are any of these categories collaborated on?

18. Have there been any contractual or mutual agreements made between Holden and the MassDOT? If so, please describe.
19. Are there any specific rules, policies, or procedures for sharing data or database sharing enacted by Holden?
20. Since funding is an issue for most towns, are there any initiatives to get funding for stormwater management in Holden?

Appendix G: DCR Interview Questions

1. What are the current goals of the DCR's MS4 mapping efforts?
2. What GIS software, if any, or geospatial data approach is currently used to map the MS4s at the DCR? What is the reasoning behind this approach?
    a. How often are these maps updated?
3. What is the process for your mapping efforts? Is there anything in particular to note about the DCR's approach?
4. What are the main priorities for mapping? Is time spent equally on these components or is there emphasis placed on particular pieces of the infrastructure?
5. Are there particular types of infrastructure that the DCR has not mapped but feel is needed? Are there particular types of information that have not been collected about this infrastructure that would be helpful?
6. Do the GIS data layers fulfill all the year two requirements of the MS4 permit? What components of the year ten requirements are fulfilled, if any?
7. When did the DCR start mapping stormwater systems?
8. What are the biggest obstacles the DCR faces in collecting data and keeping it up to date?
9. How has implementing MS4 regulations affected the DCR's ability to manage stormwater?
10. Is there an easy way for municipalities to get in contact with the DCR? If so, how?
11. Could you describe the current status of the interorganizational relationship between the DCR and the municipalities they work with?
12. What is the general organizational structure of stormwater management currently within the DCR?
13. Is there joint oversight over any stormwater management aspect between municipalities and the DCR?
14. Describe the extent of the relationship in terms of software, data, and services. Are any of these categories collaborated on?
15. Are there any specific rules, policies, or procedures for sharing data or database sharing enacted by the DCR?
16. Are there any financial limitations on collaborating with the DCR? If so, please describe.

Appendix H: Table of Key Staff Members Interviewed

Organization	**Name**	**Occupation**
Town of Auburn	Eilish Corey	Senior Civil Engineer
Town of Auburn	Joanna Paquin	Assistant DPW Director
City of Framingham	Kerry Reed	Senior Stormwater Engineer
City of Framingham	Geoffrey Kovar	GIS Manager
City of Framingham	Janet LoCastro	GIS Analyst
Town of Holden	Isabel McCauley	Senior Civil Engineer
Town of Holden	Luke Haberman	Civil Engineer II
MassDOT	Hung Pham	Environmental Analyst III (Stormwater Program Coordinator)
DCR	Tristan Lundgren	Environmental Analyst
DCR	Travis Drury	Environmental Analyst

Appendix I: Project Gantt Chart