CHARLES RIVER WATERSHED ANALYSIS

TASK 3C TECHNICAL REPORT
CHARLES RIVER WATERSHED PROPERTY PARCEL ANALYSIS

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1 INTRODUCTION

This report supplants the Charles River Watershed parcel-level report published in 2022 as part of the preliminary determination ("Attachment 6 - Clean Water Act Residual Designation Determination for Certain Stormwater Discharges in the Charles, Mystic, and Neponset River Watersheds, in Massachusetts Charles River Watershed Stormwater Total Phosphorus Analysis"[1]) that was developed by EPA and is part of the administrative record for the preliminary determination in 2022. While the results of the analysis are slightly different than the previous report, the overall conclusions are consistent with the findings of the initial report published by EPA in 2022. The refinements of this updated analysis corrected some property misclassifications in the 2022 report and therefore results in different distributions within certain parcel classifications within the watershed. Section 1.1 describes the differences between the two reports in more detail.

The highly developed Charles River Watershed drains into Boston Harbor and faces multiple water quality impairments primarily from phosphorus and pathogens from human activity and urban development. These impairments are evidenced by algal blooms and macrophyte growth which contribute to anoxic bottom waters that do not support aquatic life, reduce water clarity, degrade the aesthetic quality of the river, and impair designated uses such as fishing and boating. Total Maximum Daily Loads (TMDLs) for the Charles River were published in 2007 and 2011 and provide an approach to manage phosphorus pollution to improve water quality and attain water quality standards in the Lower and Middle/Upper portions of the watershed, respectively (MassDEP, 2011, 2007) The TMDLs identify stormwater runoff as the main source of phosphorus loads within the watershed and calculated that a 65% reduction of stormwater total phosphorus (TP) loadings from high-intensity land uses is required. On May 9, 2019, the U.S. Environmental Protection Agency (EPA) received a residual designation petition from the Conservation Law Foundation (CLF) and the Charles River Watershed Association (CRWA) for the Charles River Watershed (CLF & CRWA, 2019). The petition requests that EPA permit stormwater from commercial, industrial, institutional, and multi-family residential (CIIM) properties of one acre or greater under the National Pollutant Discharge Elimination System (NPDES) program to meet water quality standards (WQS) in Boston Harbor.

This report presents a methodology to develop, and analyses of, parcel-level stormwater TP loading within the Charles River Watershed that may be used by EPA Region 1 to support decision making regarding the residual designation petition. Within the context of the TMDL process, this report makes use of updated stormwater runoff and pollutant loading developed for the Mystic and Neponset River Watersheds (Paradigm Environmental, 2023a, 2023b). These values are also used as supporting information in decision making on the residual designation and form the basis against which parcel-level stormwater management strategies can be evaluated. A 65% reduction in stormwater total phosphorus loads was used in this analysis to represent the estimated load reduction required under baseline conditions (MassDEP, 2011, 2007). Key information presented in this report includes an analysis of CIIM parcels, their characteristics such as the amount of impervious cover (IC), and their estimated stormwater nutrient loads. IC is the largest source of stormwater runoff within the watershed and findings from an analysis of the relationship between the number of CIIM parcels, IC area, and TP load are presented to demonstrate potential strategies for regulating the fewest number of parcels while achieving the largest possible pollutant reduction benefits. The results of this report can be further refined using other considerations, such as where and how communities facing environmental justice (EJ) concerns may be impacted, and apportioned into each municipality within the watershed where, ultimately, progress can be made towards meeting the TMDLs.

[1]https://www.epa.gov/system/files/documents/2022-09/epa-r1-rda-determination-charles-mystic-neponset-2022-combine-signed.pdf

1.1 Updated Chares River Parcel Analysis in Context

As part of its response to the petitions EPA received for designating private CII parcels for NPDES permitting, EPA Region 1 completed parcel level analyses to quantify the nutrient (and bacteria) load from each parcel in the Charles River Watershed in 2022. For the analyses in the Mystic and Neponset River Watersheds EPA received contract support in 2023. While the analyses for the Mystic and Neponset River Watersheds were initially based on the work done for the Charles River Watershed, further evaluations of the Charles River datasets revealed inconsistencies in processing steps. For this reason, EPA refined and updated the Charles River parcel level analysis.

A brief overview of the two analyses is presented below with datasets from the current (2024) analysis represented with the following caveats: 1) the current 2024 analysis includes all parcels in the watershed and does not exclude parcels within Combined Sewer Area as was the case in the 2022 analysis. This is because EPA was not able to obtain an updated Combined Sewer Area shapefile to accurately capture sewer separations that have occurred to date. According to the 2022 analysis, EPA estimated that 13,635 parcels were in the Combined Sewer Area. 2) the current (2024) analysis included all parcel types, and therefore the data comparison presented in this section (1.1) has been adjusted to show only the same property types in the 2022 analysis. In the 2022 analysis, EPA excluded agricultural properties and any publicly owned properties as well as rights-of-ways.
Given these differences, the 2022 analysis resulted in a total of 166,489 properties classified as privately owned Commercial, Industrial, Institutional, Multi -Family and Single-Family Residential homes. In contrast, the 2024 analysis resulted in a total of 207,770 properties of the same property classification type. In the tables below (Table 1.1-1 and Table 1.1-2), the parcel characteristics of all privately owned parcels between the two analyses is summarized. Aside from the total number of parcels being classified as private being higher in the 2024 analysis, more sites were identified as being commercial in nature compared to the 2022 analysis.

Table 1.1-1. Summary of privately owned parcels in the Charles River Watershed, as identified in the 2022 analysis.

Classification, 2022 Charles analysis	Count	Total Area (ac)	IC Acre	% IC of Total Area	IC TP Load (lb/yr)	Pervious TP Load (lb/yr)
Commercial	9,548	20,120	5,657	28%	10,102	1,273
Industrial	1000	5,016	1468	29%	2,609	330
Institutional Private	4,255	8,986	1,412	16%	2,446	416
Multi-Family Residential	33,412	9,870	3,987	40%	9,223	428
Single Family Residential	118,274	70,307	9,900	14%	19,407	4,504
TOTAL	**166,489**	**114,298**	**22,424**		**43,787**	**6,951**

Table 1.1-2. Summary of privately owned parcels in the Charles River Watershed, as identified in the 2024 analysis.

Use Group, 2024 Charles Analysis	Count	Total Area (ac)	IC Acre	% IC of Total Area	IC TP Load (lb/yr)	Pervious TP Load (lb/yr)
Commercial	28,114	31,962	9,685	30%.	18,079	3,106
Industrial	353	1,092	304	28%	544	109
Private Institutional	3,005	8,917	1,950	22%	3,508	877
Multi-Family Residential	48,776	12,794	4,920	39%	11,213	1,198
Single Family Residential	127,522	70,087	10,413	15%	19,760	6,968
TOTAL	**207,770**	**124,852**	**27,272**		**53,104**	**12,258**

Setting a size threshold of 1 acre or more of impervious cover and removing single family homes from the set of privately owned parcels and only focusing on Commercial, Industrial, and Institutional parcels, the

two analyses also resulted in slight differences in the number of parcels identified. The tables below (Table 1.1-3 and Table 1.1-4), summarize the parcel characteristics of all privately owned parcels with 1 acre or more of impervious cover resulting from the two analyses. Again, in the 2024 analysis the number of parcels identified as being Commercial is greater and the number of parcels classified as being industrial are lower compared to the 2022 analysis. The IC load coming from all privately owned CIIM parcels in the watershed with 1 or more acres of impervious cover was 13,028 lbs/yr in the 2022 analysis and 16,117 lbs/yr in the 2024 analysis.

Table 1.1-3. Summary of private commercial, industrial, institutional, and multifamily parcels with IC ≥ 1 ac in the Charles River Watershed from the 2022 Parcel Level analysis.

Use Group, 2022 Charles Analysis	# Properties	Acres	IC Area (Acres)	IC TP Load (lbs/yr)	Pervious TP Load (lbs/yr)
Commercial	1,176	10,500	3,903	6969	593
Industrial	335	2,957	1254	2230	156
Institutional Private	294	3,330	937	1648	175
Multi-Family Residential	315	2,934	947	2181	139
TOTAL	**2,120**	**19,721**	**7,041**	**13,028**	**1,063**

Table 1.1-4. Summary of private commercial, industrial, institutional, and multifamily parcels with IC ≥ 1 ac in the Charles River Watershed from the 2024 Parcel Level analysis.

Use Group, 2024 Charles Analysis	# Properties	Acres	IC Area (Acres)	IC TP Load (lbs/yr)	Pervious Load (lbs/yr)
Commercial	1,867	14,268	6,014	11,074	1,147
Industrial	81	570	221	397	39
Private Institutional	347	4,229	1,485	2,673	338
MultiFamily Residential	333	2,995	862	1,973	368
TOTAL	**2,628**	**22,062**	**8,582**	**16,117**	**1,892**

2 METHODOLOGY

The general methodology presented here follows the process used in the Mystic and Neponset River Watershed analyses (Paradigm Environmental, 2023a, 2023b). Key steps, refinements, and quality assurance checks are detailed in the following subsections.

2.1 Data Inventory

Readily available data necessary for parcel analysis were collected, reviewed, and assessed. Data were obtained from online repositories as well as from EPA staff. Table 2-1 provides an inventory of the GIS data collected and indicates the use of that dataset.

Table 2.1-1. Data used in the parcel analysis

Name	Use	Source	Source Link	Source Date
2016 Land use and land cover	IC calculation	MassGIS	https://www.mass.gov/info-details/massgis-data-2016-land-coverland-use	May 2019
Hydrologic Response Units (HRUs)	Loading rate and load calculations	Developed by EPA under Task 3B of this contract		
Parcel boundaries	For summary results	MassGIS	https://www.mass.gov/info-details/massgis-data-property-tax-parcels	Feb 2023
L3 Tax Assessor Table	Parcel details	MassGIS		Feb 2023
Municipal boundaries	For summary results	MassGIS	https://www.mass.gov/info-details/massgis-data-municipalities	April 2022
Charles River Watershed	For summary results	MassGIS	https://www.mass.gov/info-details/massgis-data-major-watersheds	June 2000
Municipal separate storm sewer system (MS4) boundaries	For summary results	EPA	TMDL Admin Record	
Zip Code	For summary results	MassGIS	https://www.mass.gov/info-details/massgis-data-zip-codes-5-digit-from-here-navteq#downloads-	March 2024
EJ Data	For summary results and Analysis	Developed by EPA under Task 3B of this contract; based on the Climate and Economic Justice Screening Tool (CEJST)		

2.2 Parcel Analysis

Parcel analysis includes two main components: 1) GIS-based spatial analysis and 2) summary analysis using a python-based tool. These steps are described below and were formulated to be as accurate, transparent, and reproducible as feasible. The parcel analysis workflow, required inputs, and outputs is shown in Figure 2-1. Results of the parcel analysis are summary attributes for each parcel, as shown in Table 2-2, and additional summaries aggregating the parcel data with other conditions and spatial scales as detailed in

Section 3. Details on how this analysis is carried out can be found in Paradigm Environmental (2023a, 2023b).

Table 2.2-1. Parcel-level summary attributes calculated

Attribute	Description
Loc_ID	Unique parcel ID
Parcel Type	Tax classification (e.g., TAX, FEE, ROW, WATER)
Municipality Name	City or Town name
Owner	Property owner's name
Owner Address	Property owner's address
Owner City	Property owner's city
Owner Country	Property owner's country
Owner State	Property owner's state
Owner Zip Code	Property owner's zip code
Lot Size (ac)	Deed area (converted to acres in this analysis)
Site Address	Site address
Site Zip Code	Site address zip code
Units	Number of units on the property
Year Built	Year building was built
Public/Private	Owner type (public or private) based on filtering described in Section 2.2.3
FY	Year of data
MS4 (boolean, 1 = within MS4)	Inside or outside of the MS4 area
CSA (boolean, 1 = within CSA)	Inside or outside of the Combined Sewer Area (CSA) (Not Used for Charles River Watershed but exists in output as "No Data")
Is EJ (boolean, 1 = within EJ)	Inside or outside of the EJ area
Subbasin	Subbasin name(s) and percentages if multiple (the Charles is Considered one Subbasin for the purposes of this analysis)
Area in Major Basin (%)	Percentage of parcel area with the watershed (All values 100%)
Use Code	Use code from Tax Assessor
Dept. Revenue Description	Use description from MA Dept. of Revenue (from Use Code)
Parcel Use Group	Land use classification in the current analysis (from Use Code)
MassGIS Land Use	Land use from MassGIS 2016 LULC
Total Area (ac)	Parcel area calculated in the current analysis
IC Area (ac)	The impervious cover area from the 2016 data
IC Percent	Percent impervious cover calculated from MassGIS 2016 LULC
Wetland Area (ac)	Wetland area on the parcel
Wetland Percent	Wetland percent on the parcel
Water Area (ac)	Water area on the parcel
Water Percent	Water percent on the parcel
Forest Area (ac)	Forest area on the parcel
Forest Percent	Forest percentage on the parcel
Pervious Area (ac)	Pervious area

Attribute	Description
Pervious Percent	Percent pervious
Total Pervious Load (lb/yr)	TP load from the parcel's pervious cover
IC Load (lb/yr)	TP load from the parcel's impervious cover
Total parcel load (lb/yr)	Total TP load from parcel

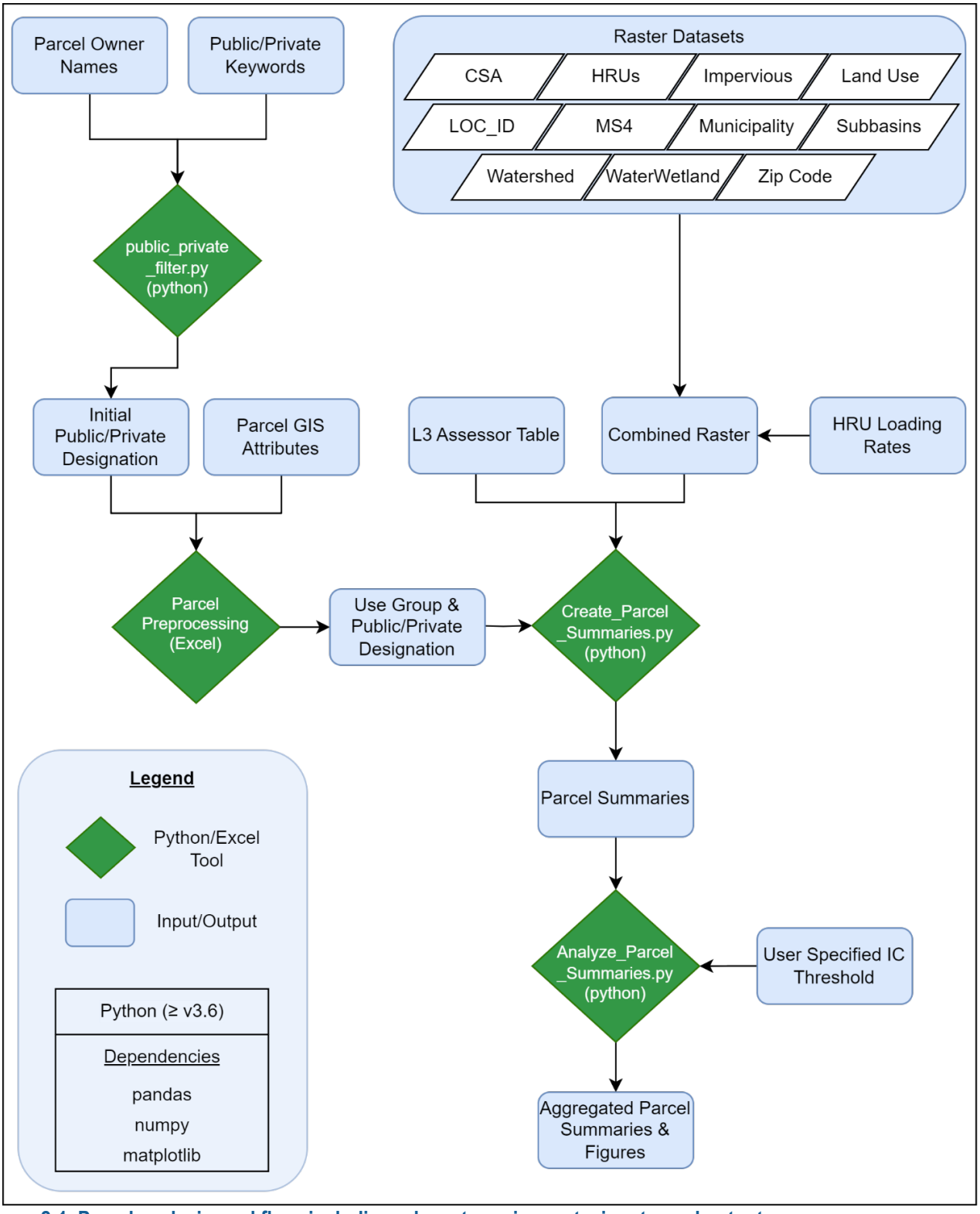

Figure 2-1. Parcel analysis workflow, including relevant requirements, inputs, and outputs.

2.2.1 *GIS-based Spatial Analysis*

The GIS-based processing is raster-based and assembles the required data for parcel-level analysis and summaries at other spatial scales. The output of this step is a combined raster layer and attribute table listing the unique combinations of all input rasters. The major GIS processing steps are:

1. Ensure all layers use the same projection (EPSG: 26986, Massachusetts State Plane Coordinate System, Mainland Zone).
2. Clip all layers to the area of interest (Charles River Watershed boundary).
3. Convert all polygon layers to rasters with 1-square meter cells (e.g., parcel layer). The raster cell values will be a unique identifier (e.g., *LOC_ID* for parcels) to allow the joining of attributes in later steps.
4. Overlay all rasters using the ESRI Combine tool. The output is a combined raster and an attribute table with a unique identifier for each unique combination of input raster values.

The combined raster attribute table is converted into a Microsoft Access table since it is too large for Excel (1,364,605 rows) and the pollutant load calculated based on the HRU by multiplying the area of each unique combination by the appropriate loading rate. The development of loading rates followed the process described for the Neponset River watershed (Paradigm Environmental, 2023c).

Parcel Preprocessing

One additional processing step was performed on the tax parcel polygon layer to create a second input to the python-based processing described below. Namely, once all the parcels were clipped to the Charles River Watershed, all the unique "Use_Codes" were mapped to a single use group (Table 2-3). This allows users to easily update parcel classifications as additional parcel details or corrections become available, without having to modify the python code. The Use Codes are generally, but not always, standardized codes set by the MA Department of Revenue and provide a greater number of categories than the 2016 LULC dataset (MA Dept. of Revenue Division of Local Services, 2016). While most municipalities followed the Department of Revenue guidance the City of Boston uses its own similar but still different codes (City of Boston, 2024).To classify all the parcels as one of the use groups, a list of all the unique codes in the Charles River watershed was generated and assigned a Use Group (Appendix A). The Department of Revenue and City of Boston code descriptions were used for classification of some land use groups where the MA Department of Revenue and the City of Boston's Use Codes were inconsistent. This applied primarily to codes starting with the number 9. For use codes that are not standard in either the Massachusetts or Boston classification systems, a decision was made based on the properties that have that use group. Additionally, to make this process as consistent as possible with the previous analyses (Paradigm Environmental, 2023a, 2023b), the same Use Code to Use Group designations were maintained where they existed and made sense. Additionally, a keyword search was used to help further identify the correct use group based on the name of the owner. This is further detailed as a public or private designation was assigned to each parcel during this preprocessing step (detailed in Section 2.2.3).

Table 2.2-2. Use Groups assigned in the Charles analyses

Charles Use Groups	Public/Private
Agriculture	Public or Private
Commercial	Public or Private
Industrial	Public or Private
Open Land	Public or Private
Private Institutional	Private
Public Institutional	Public
MultiFamily Residential	Public or Private
Single Family Residential	Public or Private
Right-of-Way	Public or Private
Water	Public or Private

The main steps in parcel Use Group classification are listed below. In general, each step reclassifies unknowns from the preceding steps.

1. Use the "Poly_Type" field to classify any kind of right-of-way as the "Right-of-Way" use group.
2. Use the Public Private Filter python script to categorize parcels into the correct use group based on the name of the owner.
3. Assign from Use Code based on existing classification.
4. Assign Based on description in MA Department of Revenue and City of Boston Guidance.
5. Use any parcel information that is known, like owner to help classify some of the remaining use codes that are not in the guidance.
6. Assign any remaining unknown Use Codes as the primary HRU for the parcel where both "Forest" and "Open Land" HRUs get classified as "Open Land" since there is no "Forest" use group.
7. Manually reclassify select parcels (Table 2-4) as needed.

Appendix A lists all the unique Use Codes and Use Groups categories within the watershed; all preprocessing steps are detailed in the accompanying excel file (AppendixA_TaxParcel_PreprocessingWorkbook.xlsx).

Table 2.2-3. Excerpt of Parcels with manually classified Use Group and Public/Private designation

LOC_ID	Owner	Use Group	Public/Private
F_740543_2922003	DEPT. OF THE ARMY CORPS OF ENG	Public Institutional	Public
F_744367_2920021	DEPT. OF ARMY CORP OF ENG.	Public Institutional	Public
F_744305_2919551	DEPT OF THE ARMY CORP OF ENG	Public Institutional	Public
F_744333_2919270	US OF AMERICA DEPT ARMY CORP	Public Institutional	Public
M_205312_874452	US OF AMERICA ARMY CORP OF ENGINEERS	Public Institutional	Public
F_708754_2880429	UNITED STATES ARMY CORPS	Public Institutional	Public
F_708928_2880392	UNITED STATES ARMY CORPS	Public Institutional	Public
F_709916_2879572	UNITED STATES ARMY CORPS OF EN	Public Institutional	Public
F_708250_2879765	U S ARMY CORPS OF ENGINEERS	Public Institutional	Public
F_712279_2880147	UNITED STATES ARMY CORPS OF EN	Public Institutional	Public
F_711743_2879979	UNITED STATES ARMY CORPS OF EN	Public Institutional	Public
F_708810_2881395	UNITED STATES ARMY CORPS OF EN	Public Institutional	Public
F_708801_2881262	UNITED STATES ARMY CORPS OF EN	Public Institutional	Public
F_702074_2882588	UNITED STATES ARMY CORPS OF EN	Public Institutional	Public
F_709672_2882744	UNITED STATES ARMY CORPS OF EN	Public Institutional	Public
F_709004_2884298	U S ARMY CORPS OF ENGINEERS	Public Institutional	Public
F_706507_2886517	UNITED STATES ARMY CORPS OF EN	Public Institutional	Public
F_707079_2885819	UNITED STATES ARMY CORPS OF EN	Public Institutional	Public
F_707638_2886098	UNITED STATES ARMY CORPS OF EN	Public Institutional	Public
F_708042_2886165	UNITED STATES ARMY CORPS OF EN	Public Institutional	Public

Results of the parcel preprocessing, in terms of total distribution within the Charles River Watershed, are shown in Figure 2-2 and mapped in Figure 2-3. This analysis shows that about one-third (33.8%) of the watershed area is made up of single-family residences and multi-family residences make up 6.2%. Public institutional groups (local, state, and federal) make up 20.1% of the watershed area with private institutional totaling just 4.3%. In total, commercial, industrial, and private institutional constitute 20.4% of the

watershed area. The distribution of public/private parcels, grouped by Use Code group, is shown in Table 2-5. In total, the current classification has 31.1% public parcels and 68.9% private; non-right-of-way public parcels account for 21.8% of parcel area.

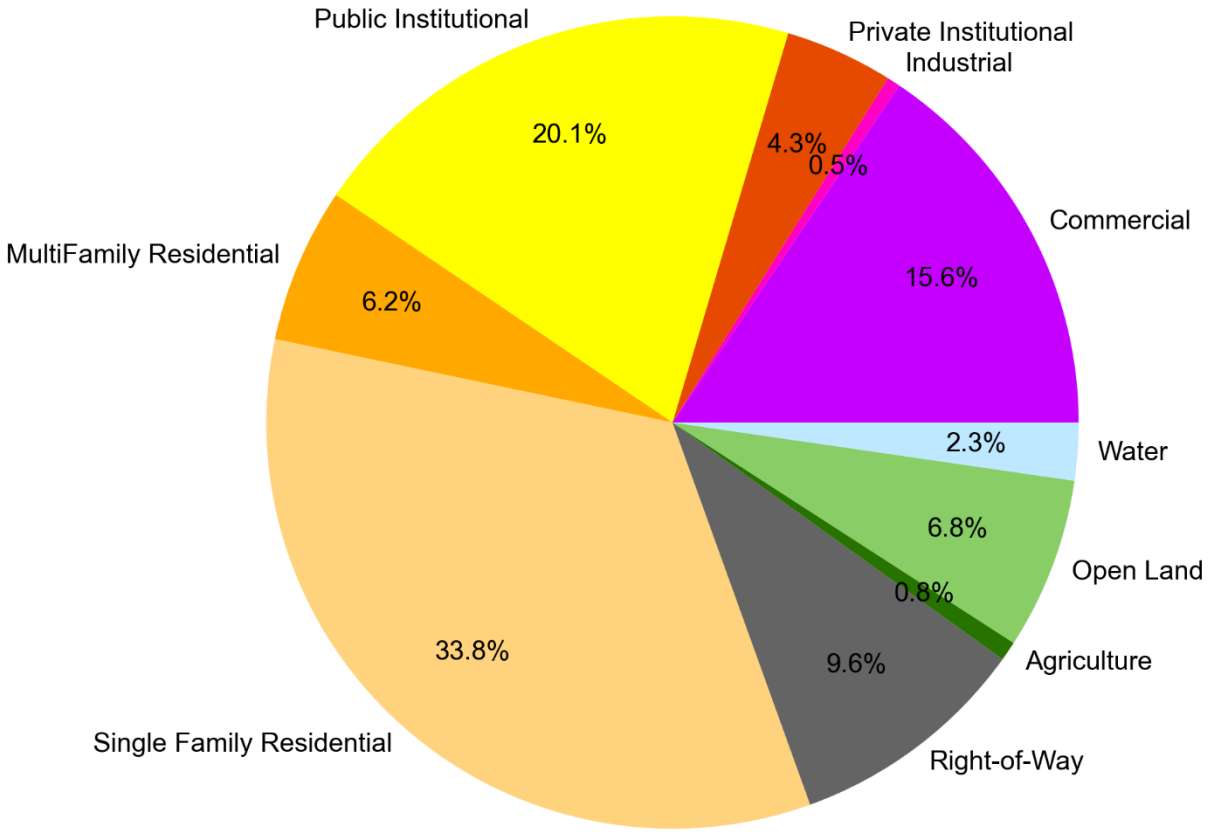

Figure 2-2. Distribution of parcel area by Use Group within the Charles River Watershed.

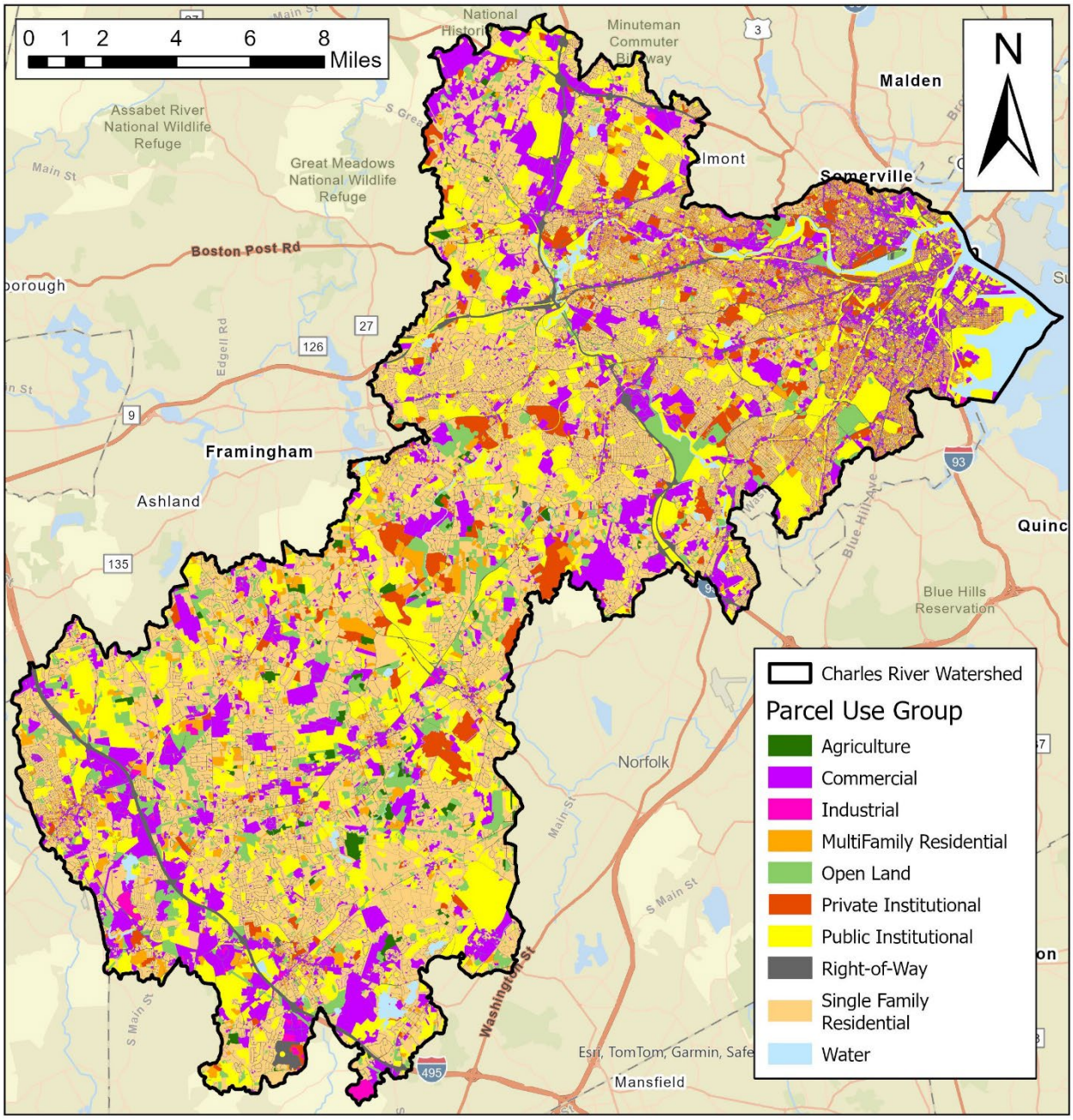

Figure 2-3. Map of parcel Use Groups within the Charles River Watershed. Note that the resolution of this map is parcel-scale; waterbodies exist within non-Water class parcels.

Table 2.2-4. Distribution of public and private parcel areas by Use Group

Public/Private	Use Group	Count	Count (%)	Total Area (ac)	Total Area (%)
Private	Agriculture	165	0.07%	1,551.8	0.75%
	Commercial	28,114	12.35%	31,962.1	15.41%
	Industrial	353	0.16%	1,091.8	0.53%
	MultiFamily Residential	48,776	21.43%	12,794.0	6.17%
	Open Land	9,658	4.24%	13,897.2	6.70%
	Private Institutional	3,005	1.32%	8,917.0	4.30%
	Right-of-Way	530	0.23%	722.4	0.35%
	Single Family Residential	127,522	56.02%	70,087.2	33.80%
	Water	-	0.00%	-	0.00%
	Subtotal	**218,123**	**95.82%**	**141,023.3**	**68.01%**
Public	Agriculture	1	0.00%	50.3	0.02%
	Commercial	32	0.01%	458.7	0.22%
	Industrial	-	0.00%	-	0.00%
	MultiFamily Residential	-	0.00%	-	0.00%
	Open Land	33	0.01%	281.5	0.14%
	Public Institutional	8,700	3.82%	41,626.8	20.07%
	Right-of-Way	622	0.27%	19,169.4	9.24%
	Single Family Residential	-	0.00%	-	0.00%
	Water	133	0.06%	4,754.0	2.29%
	Subtotal	**9,521**	**4.18%**	**66,340.7**	**31.99%**
Total		**227,644**	**100.00%**	**207,364.1**	**100.00%**

2.2.2 *Python-Based Summary Analysis*

The raster attribute table output from GIS processing was further processed using a tool developed in python (Figure 2-1). Python is a commonly used programming language for data management and analysis due to its ease of use and readability; all python software and packages used in this analysis are freely available and open source. The output of this processing is an Excel compatible spreadsheet file including every parcel and additional summaries based on aggregating the data with different conditions and spatial scales. The major python processing steps include:

1. Read the combined raster attribute table into a data frame using the pandas python package.
    - This is a powerful data structure that allows for a wide variety of data manipulation and evaluation.
    - Efficient for large-size datasets.
2. Join relevant attribute tables.
    - The parcel *LOC_ID* is used to join parcels with the preprocessed parcel data and the L3 Assessors Table, which provides parcel details such as site address, owner information, and year built.
    - Performing this step outside of a GIS environment should reduce processing time and potential data overlap errors.
3. Calculate parcel-level information.
    - The information shown in Table 2-2 is calculated for each parcel.
4. Generate parcel-level summary tables.
    - A summary spreadsheet file is generated and saved. The file includes all necessary information as shown in Table 2-2 for each property parcel.
    - The code can also optionally generate a summary table for multiple attributes (e.g., the unique intersection of parcel, municipality, and subbasin). This is useful for additional QA of area and loads.
5. Generate additional summaries.
    - Additional summaries of the calculated parcel data are created by aggregating with other conditions and spatial scales.
    - For example, TP loading from IC areas can be summarized for parcels of varying IC areas and Use Groups.

Outputs of the python-based processing are presented and evaluated in the Results and Discussion section. All input data, processing codes, and outputs will be made available to EPA; outputs can be visualized by joining with the *LOC_ID* in the parcel polygon layer.

2.2.3 *Public/Private Classification*

For the Charles River Watershed, a binary public/private classification based on similar a process that used in the Mystic and Neponset analysis was developed. The public/private designation uses keyword filters on the "OWNER1" attribute as an initial designation which is then further refined by looking at the assigned Use Group (Table 2-3). For example, any local, state, or federal institutional groups that were not classified as public in the keyword filtering were changed to public. These keywords are listed in Table 2-6 for the public keywords and Table 2-7 for the private keywords. They were selected based on previous work in other areas and by visual inspection owner names remaining after filtering out local, state, and federal institutional groups. Binary classification is important to help distinguish between parcels already subject to regulation.

The main steps in creating the public/private designation are:

1. Owner keyword filtering (performed in python script)
2. Update RoW based on parcel PolyType

3. Classify parcels with a "Water" Use Group as public
    a. These parcels are predominately water and account for only 0.1% of the total TP loads (Table 3-2)
4. Classify unknowns based on Use Group
5. Update Residential
    a. If residential, then Private
6. Manual reclassification of selected parcels

Table 2.2-5. OWNER1 keywords for initial public parcel filtering

Public Keywords searched for using python		
"CITY OF"	"MASS BAY TRANSPORTATION"	"POST OFFICE"
"COMM OF MASS"	"MASS BAY TRANSPTN AUTHOR"	"REDEVELOPMENT ASSOC"
"COMMNWLTH OF MASS"	"MASS BAY,TRANS AUTH"	"REDEVELOPMENT AUTH"
"COMMON LAND"	"MASS DOT"	"SCHOOL DIST"
"COMMONWEALTH OF"	"MASS ELECTRIC CO"	"SEWER DISTRICT"
"COMMONWLTH OF MASS"	"MASS PORT AUTHORITY"	"STATE OF"
"COMMWLTH OF MASS"	"MASS TURNPIKE AUTHORITY"	"STATE PARK"
"COMWLTH OF MASS"	"MASS WATER RESOURCE AUTH"	"THE UNIVERSITY OF NH"
"COUNTY OF"	"MASSACHUSETT PORT AUTHORITY"	"TOWN HALL"
"DCR"	"MASSACHUSETTS BAY TRANIST"	"TOWN OF"
"DEPARTMENT OF"	"MASSACHUSETTS BAY TRANS AUTH"	"TOWN OFFICE BUILDING"
"DEPT 0F CONSERVATION & REC"	"MASSACHUSETTS BAY TRANSIT AUTHORITY"	"U S POST OFFICE"
"DEPT OF"	"MASSACHUSETTS BAY TRANSPORTATI"	"U S POSTAL SERVICE"
"DEPT. OF"	"MASSACHUSETTS COMM OF METRO DIST COMM"	"U.S GOVERNMENT D.O.D"
"DEPT/CONSERVATION & RECREATION"	"MASSACHUSETTS COMM OF"	"U.S. GOVERNMENT D.O.D."
"DEVELOPMENT AUTHORITY"	"MASSACHUSETTS COMMON OF"	"UNH"
"FIRE + POLICE BUILDING"	"MASSACHUSETTS COMMONWEALTH OF"	"UNITED STATES DEPARTMENT OF AGRICULTURE"
"FIRE DEPARTMENT"	"MASSACHUSETTS COMMONWEALTH"	"UNITED STATES GOVERNMENT"
"FIRE DEPT"	"MASSACHUSETTS DEPARTMENT"	"UNITED STATES GOVT"
"HOUSING AUTH"	"MASSACHUSETTS GOVT LAND BANK"	"UNITED STATES OF AMERICA"
"LIBRARY"	"MASSACHUSETTS PORT AUTH"	"UNITED STATES OF AMERICA, FAA"
"M B T A"	"MASSACHUSETTS PORT AUTHORITY"	"UNITED STATES POST OFFICE"
"M D C"	"MASSACHUSETTS TURNPIKE AUTHORITY"	"UNITED STATES POSTAL SERVICE "
"M.D.C. RES.	"MBTA"	"UNITED STATES POSTAL SERVICE"
"M.D.C."	"MDC"	"UNITED STATES PROPERTY"

"MASACHUSETTS BAY TRANS AUTHOR"	"MWRA"	"UNIVERSITY OF NEW HAMPSHIRE"
"MASS BAY AUTHORITY"	"NATIONAL GUARD"	"UNIVERSITY OF NH"
"MASS BAY TRAN AUTHORITY"	"NEW HAMPSHIRE AIR NATIONAL GUARD"	"US DEPARTMENT OF STATE"
"MASS BAY TRANS AUTH"	"NEW HAMPSHIRE DOT"	"US GOVERNMENT FEDERAL BUILDING"
"MASS BAY TRANS AUTHORITY"	"NEW HAMPSHIRE FISH & GAME"	"US GOVERNMENT"
"MASS BAY TRANS, AUTHORITY"	"NEW HAMPSHIRE FISH + GAME DEPT"	"US POST OFFCE"
"MASS BAY TRANS. AUTH"	"NEW HAMPSHIRE HOUSING FINANCE AUTHORITY"	"US POSTAL SERVICE"
"MASS BAY TRANS. AUTHORITY"	"NEW HAMPSHIRE STATE DOT"	"US SEC OF HOUSING & URBAN DEV"
"MASS BAY TRANSIT AUTHORITY"	"NEW HAMPSHIRE, UNIVERSITY OF"	"WATER & SEWER DISTR"
"MASS BAY TRANSP AUTH"	"NH FISH & GAME DEPT"	"WATER & SEWER BOARD"
"MASS BAY TRANSPORT AUTH"	"NH FISH AND GAME DEPARTMENT"	"WATER DIST"
"MASS BAY TRANSPORTATION AUTH"	"NH WATER RESOURCES"	"WATER PRECINCT"

Table 2.2-6. OWNER1 keywords for initial private parcel filtering

Private Keywords searched for using python	Use Group
"ACADEMY"	"Private Institutional"
"AMERICAN LEGION"	"Private Institutional"
"ASSOC"	"Private Institutional"
"CEMETARY"	"Open Land"
"CHARTER SCH"	Private Institutional
"Hospital"	"Private Institutional"
"Hosp"	"Private Institutional"
"PROJECT"	"Private Institutional"
"RAILROAD"	"Commercial"
"Realty"	"Single Family Residential"
"RLTY"	"Single Family Residential"
"SOCIETY"	"Private Institutional"
"TRUSTEES OF"	"Private Institutional"
"TRUSTES OF"	"Private Institutional"
"LAND TRUST"	"Open Land"
"CONSERVATION LAND"	"Open Land"
"CONDO"	"MultiFamily Residential"
"Church"	"Private Institutional"
"CATHEDRAL"	"Private Institutional"
"mosque"	"Private Institutional"
"Parish"	"Private Institutional"
"synagogue"	"Private Institutional"
"Temple"	"Private Institutional"

"Golf Club"	"Commercial"
"Country Club"	"Commercial"
"Foundation"	"Private Institutional"
"indust"	"Industrial"
"ASSOCIATES"	"Commercial"
"Partnership"	Commercial
"Enterprise"	"Commercial"
"Business"	"Commercial"
"Commercial"	"Commercial"
"Holding"	"Commercial"
"Credit Union"	"Commercial"
"Limited"	"Commercial"
"Incorporated"	"Commercial"
"Company"	"Commercial"
"LLC"	"Commercial"
"LTD"	"Commercial"
"INC"	"Commercial"
"CORP"	"Commercial"

2.3 Quality Assurance / Quality Control (QA/QC)

Several QA/QC steps have been performed to ensure the highest level of accuracy feasible. The greatest source of uncertainty in this analysis is the parcel attributes from the L3 Tax Assessor table. As seen in Table 2-6, owner names and other details are not standardized and may have typos that make automated processing difficult.

Additional checks include:

- Ensuring parcels have a single MassGIS 2016 land use category by intersecting parcel boundaries and reclassified land use categories.
- Evaluating the fraction of public and private ownership for feasibility
- Checking the sum of all parcel areas within a municipality equals the sum of municipality area and similar checks for other boundaries such as sub-watersheds.

2.4 Limitations

One limitation of this analysis is that parcels crossing the boundary of the Charles River Watershed will only be evaluated for the portion of their area within the watershed. This is not expected to impact the calculation of load within the watershed, but will impact the calculation of area for different land uses at the parcel scale. For example, a parcel may have IC outside of the watershed boundary, but only the IC area and load within the watershed will be accounted for. The percentage of IC area will be calculated as the IC area within the watershed divided by the total parcel area within the watershed. The impact of splitting parcels on the watershed boundary should be negligible given that this is a small portion of the total number of parcels. Further, this analysis does not exclude stormwater loadings from areas served by combined sewers, even though some municipalities in the Charles River Watershed are served by combined sewers. The impact of this is only relevant to municipalities with combined sewer areas and will estimate stormwater loadings that need to be accounted for should all areas served by combined sewers be separated in the future.

3 RESULTS AND DISCUSSION

This section describes the calculated TP loads from private and public properties based on the parcel Use Group. Analyses include the proportional impact of different private property classes, the proportional impact of different property sizes based on the amount of impervious cover on each property, and a range of the optimal IC size thresholds to reduce the greatest amount of TP while potentially regulating the fewest number of properties.

Total baseline phosphorus loads used in this parcel analysis are from the same time period as in the Neponset Watershed Analysis (Paradigm Environmental, 2023a) and represent unattenuated stormwater TP loads of 100,444 lb/yr (Table 3-1). A watershed-wide 65% required reduction in TP load, as specified in the Charles River Watershed TMDLs, was calculated from the baseline load. Note that there are 2,835 ac of parcel area outside of any municipality (denoted as "No Data" in Table 3-1). TP load from these areas is 0.1% of the watershed total but was not assigned to any municipality; this corresponds to the approach for calculating municipality loading used in the loading analysis. This same approach was followed in Paradigm Environmental (2023a, 2023b).

Table 2.4-1. Stormwater annual average TP load (1992-2022) for municipalities within the Charles River Watershed

Municipality	Annual Average (1992-2022) TP Load (lb/yr)			
	Public (%)	Private (%)	Unattenuated	Municipality Area (ac)
ARLINGTON	40%	60%	208.60	263
ASHLAND	44%	56%	172.46	396
BELLINGHAM	26%	74%	1,867.48	6,289
BELMONT	28%	72%	438.14	834
BOSTON	35%	65%	23,149.24	22,122
BROOKLINE	30%	70%	3,325.33	4,367
CAMBRIDGE	29%	71%	3,551.35	2,932
DEDHAM	29%	71%	2,215.31	4,788
DOVER	13%	87%	2,076.05	8,395
FOXBOROUGH	19%	81%	6.31	14
FRANKLIN	28%	72%	5,849.05	15,682
HOLLISTON	27%	73%	3,729.06	12,134
HOPEDALE	28%	72%	207.96	679
HOPKINTON	30%	70%	790.85	2,203
LEXINGTON	39%	61%	1,514.37	3,204
LINCOLN	17%	83%	1,215.31	5,804
MEDFIELD	40%	60%	2,124.61	7,275
MEDWAY	29%	71%	2,545.72	7,467
MENDON	17%	83%	62.77	194
MILFORD	28%	72%	4,013.50	8,251
MILLIS	28%	72%	1,786.64	7,848
NATICK	21%	79%	2,662.03	6,175
NEEDHAM	33%	67%	3,925.84	8,142
NEWTON	30%	70%	8,559.54	11,619
NORFOLK	32%	68%	2,387.01	9,838
QUINCY	100%	0%	0.01	0.1
SHERBORN	23%	77%	2,007.65	8,226
SOMERVILLE	28%	72%	1,424.09	927
WALPOLE	34%	66%	409.01	1,425
WALTHAM	23%	77%	6,561.00	8,807
WATERTOWN	25%	75%	2,752.32	2,420
WAYLAND	40%	60%	128.03	365
WELLESLEY	31%	69%	3,415.16	6,738
WESTON	37%	63%	3,038.83	10,111
WESTWOOD	25%	75%	868.42	2,378
WRENTHAM	32%	68%	1,378.59	6,157
NO TOWN	80%	20%	76.81	2,897
TOTAL	**32%**	**68%**	**100,444.5**	**207,364**

[1]Note that there are 2,835 ac of parcel area within the Charles River Watershed that are not covered by a municipal boundary. These areas represent 0.1% of the total TP load.

3.1 All Parcels

A total of 227,644 parcels are in the Charles River Watershed that were included in this analysis. The parcels are predominately Multifamily and Single Family Residential, which represent 77% of all parcels by count and 40% by land area. Other major parcel types include private commercial, public institutional, and public right-of-way. Open land makes up 6.7% of the parcel area and is primarily private.

Figure 3-1 illustrates the distribution of summary attributes by Public/Private designation for all parcels in the Charles River Watershed. Private parcels account for 96% of parcels and 68% of total parcel area. Twenty-two percent of total parcel area is impervious cover, with private parcels having nearly twice as much total IC area (62% of total IC area) as public parcels (38% of total IC area). In terms of phosphorus loading, private parcels contribute 68% of the total TP. Loading from IC within private parcels amounts to 79% of the total TP load from private parcels. Private IC load represents 54% of total TP, from all parcels. These results indicate that private parcels contribute nearly three quarters of the phosphorus load and may require further stormwater controls for the watershed to meet its water quality goals. Table 3-2 provides additional details summarizing the IC area and load for all parcels by Use Group and Private/Public designation for TP.

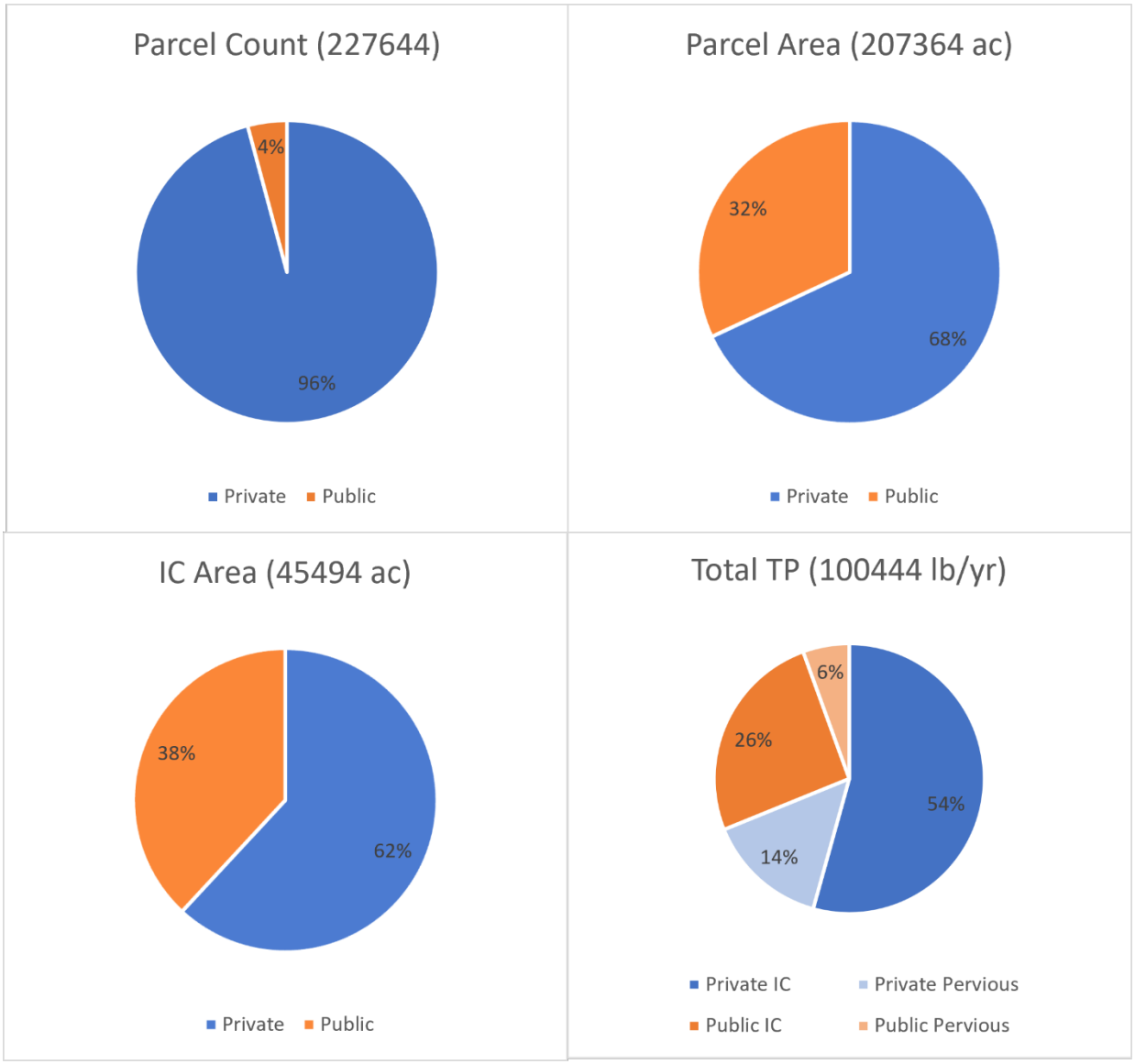

Figure 3-1. Private/Public summaries for all parcels within the Charles River Watershed.

Table 3.1-1. Summary of all parcel attributes by Use Group and Public/Private designation with TP*

Public/ Private	Use Group	Count	Count (%)	Total Area (ac)	Total Area (%)	IC Area			TP Load (lb/yr)				
						Acre	% IC of Total Area	Avg. (ac)	IC	Pervious	Total	Total (%)	Total Avg.
Private	Agriculture	165	0.1%	1,552	0.7%	33	2.1%	0.20	58	345	403	0.4%	0.26
	Commercial	28,114	12.3%	31,962	15.4%	9,685	30.3%	0.34	18,079	3,106	21,185	21.1%	0.66
	Industrial	353	0.2%	1,092	0.5%	304	27.9%	0.86	544	109	653	0.6%	0.60
	MultiFamily Residential	48,776	21.4%	12,794	6.2%	4,920	38.5%	0.10	11,213	1,198	12,411	12.4%	0.97
	Open Land	9,658	4.2%	13,897	6.7%	587	4.2%	0.06	1,014	1,949	2,963	2.9%	0.21
	Private Institutional	3,005	1.3%	8,917	4.3%	1,950	21.9%	0.65	3,508	877	4,385	4.4%	0.49
	Right-of-Way	530	0.2%	722	0.3%	272	37.6%	0.51	378	56	434	0.4%	0.60
	Single Family Residential	127,522	56.0%	70,087	33.8%	10,413	14.9%	0.08	19,760	6,968	26,729	26.6%	0.38
	Water	-	0.0%	-	0.0%	-	0.0%	-	-	-	-	0.0%	-
	Subtotal	**218,123**	**95.8%**	**141,023**	**68%**	**28,164**	**20%**	**0.13**	**54,554**	**14,607**	**69,162**	**69%**	**0.49**
Public	Agriculture	1	0.0%	50	0.0%	-	0.0%	-	-	4	4	0.0%	0.08
	Commercial	32	0.0%	459	0.2%	18	4.0%	0.57	33	16	49	0.0%	0.11
	Industrial	-	0.0%	-	0.0%	-	0.0%	-	-	-	-	0.0%	-
	MultiFamily Residential	-	0.0%	-	0.0%	-	0.0%	-	-	-	-	0.0%	-
	Open Land	33	0.0%	282	0.1%	1	0.5%	0.04	2	6	8	0.0%	0.03
	Public Institutional	8,700	3.8%	41,627	20.1%	4,143	10.0%	0.48	7,179	4,807	11,987	11.9%	0.29
	Right-of-Way	622	0.3%	19,169	9.2%	13,093	68.3%	21.05	18,402	717	19,119	19.0%	1.00
	Single Family Residential	-	0.0%	-	0.0%	-	0.0%	-	-	-	-	0.0%	-
	Water	133	0.1%	4,754	2.3%	75	1.6%	0.57	98	18	116	0.1%	0.02
	Subtotal	**9,521**	**4.2%**	**66,341**	**32%**	**17,330**	**26%**	**1.82**	**25,714**	**5,569**	**31,283**	**31%**	**0.47**
Total		**227,644**	**100.0%**	**207,364**	**100%**	**45,494**	**22%**	**0.20**	**80,268**	**20,176**	**100,444**	**100%**	**-**

* A darker color gradient represents increasing value within a column.

3.2 Commercial, Industrial, Institutional, and Multi-Family Parcels

Commercial, Industrial, Institutional, and Multi-Family parcels make up 35.3% of all parcels and 26.6% of total parcel area in the Charles River Watershed (Table 3-3). The greatest number of CIIM parcels are Multifamily Residential; however, these parcels have the lowest average IC area and TP load. Industrial parcels have the highest average IC and TP load, followed by Institutional, Commercial, and Multi Family Residential parcels. CIIM parcels make up 37.1% of total IC area and 41.6% of TP load from all IC These parcels could be candidates for additional stormwater controls while excluding the regulation of the nearly 128,000 private single family residential parcels.

If all private CIIM parcels installed stormwater controls to reduce TP loads from IC by 65%, the resulting reduction would be 21,695 lb/yr of TP. If all public parcels also reduced TP IC load by 65%, the cumulative reduction from private CIIM and all public parcels would be 73% of the required TP load reduction. If the pervious load from private CIIM and all public parcels was also treated, they would contribute an additional 4% and 5% of the required reduction, respectively. These results indicate that it may be necessary to regulate some of the Single Family parcels and/or require a higher level of treatment from CIIM and public parcels.

Table 3.2-1. Summary of private commercial, industrial, institutional, and multifamily parcel attributes in the Charles River Watershed

Use Group	Count	Total Area (ac)	IC Area			TP Load (lb/yr)		
			Acre	% IC of Total Area	Parcel Avg. (ac)	IC	Pervious	Parcel Total Avg.
Commercial	28,146	32,421	9,703	29.9%	0.34	18,112	3,121	0.75
Industrial	353	1,092	304	27.9%	0.86	544	109	1.85
Private Institutional	3,005	8,917	1,950	21.9%	0.65	3,508	877	1.46
MultiFamily Residential	48,776	12,794	4,920	38.5%	0.10	11,213	1,198	0.25
Subtotal	**80,280**	**55,224**	**16,877**	**30.6%**	**0.21**	**33,377**	**5,305**	**4.32**
Watershed Total (%)	**35.3%**	**26.6%**	**37.1%**	--	--	**41.6%**	**26.3%**	--

3.2.1 *Analysis of CIIM Parcels by IC Area*

Even though regulating all CIIM parcels may not achieve all of the required reduction to meet watershed water quality goals, it may be possible to regulate fewer CIIM properties while still getting the majority of the nutrient reduction. The relationship between the number of parcels, the amount of IC area within a parcel, and the total load was evaluated for private CIIM parcels by varying thresholds of IC area as shown in Figure 3-2 (Appendix B presents similar plots by individual parcel use group). These plots show that while the IC threshold is relatively large (e.g., ≥ 1 ac), the number of parcels regulated is relatively small, but accounts for nearly half of the private CIIM total load. As the IC threshold decreases below 1 ac, the number of parcels regulated sharply increases, but with lower increases in the total load. An IC threshold of ≥ 0.1 ac exhibits a large increase in the number of parcels regulated because more multifamily residential parcels are included (these parcels have an average IC area of 0.1 ac, as shown in Table 3-3).

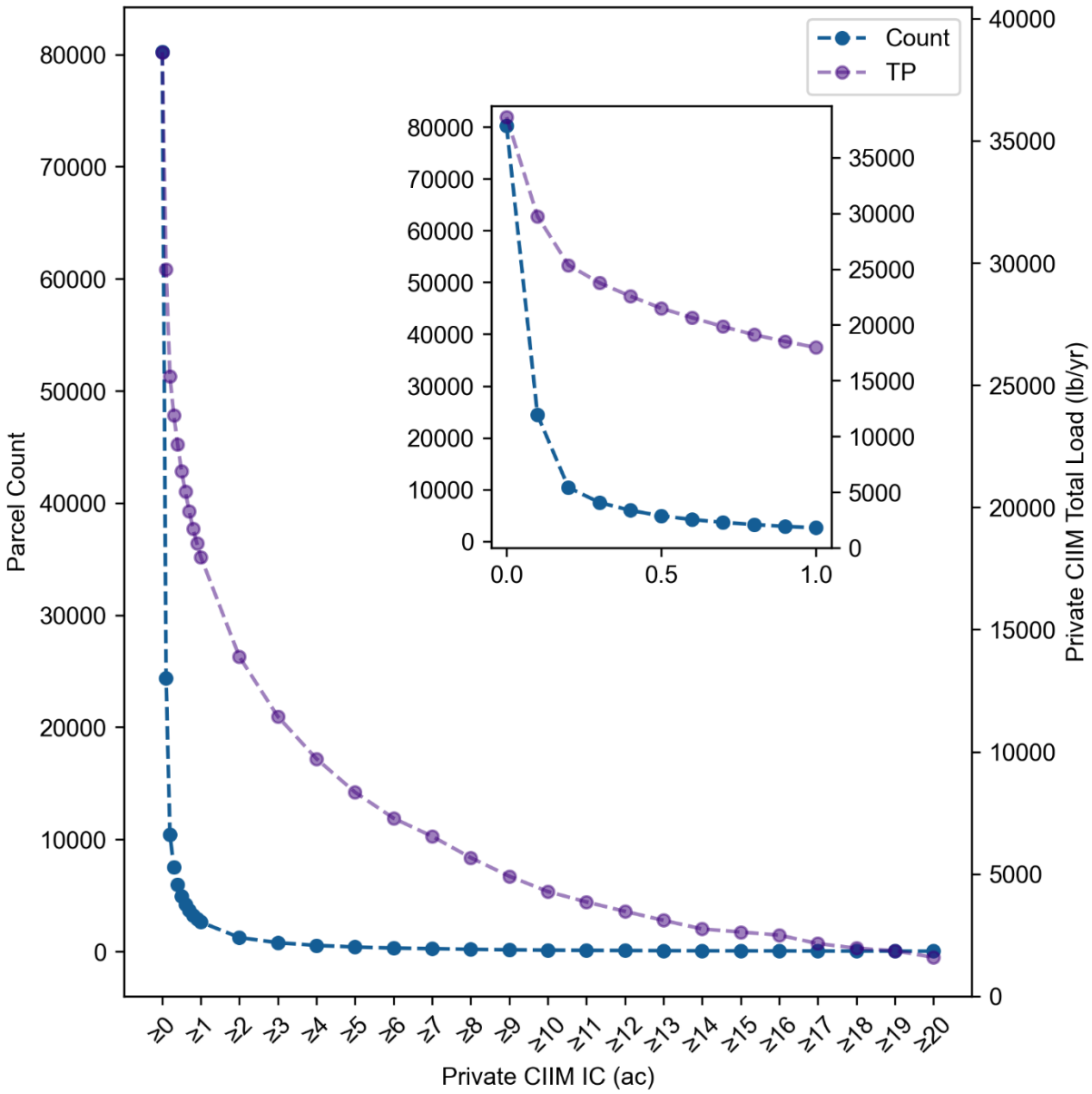

Figure 3-2. Private CIIM parcel count and total TP load by parcel IC area in the Charles River Watershed. Note that a threshold of ≥ 0ac IC includes all private CIIM parcels.

The parcel count, load, IC relationship was further analyzed for IC thresholds of 0.25 ac, 0.5 ac, 0.75 ac, 1 ac, 2 ac, and 5 ac as shown in Table 3-4 to Table 3-9. These tables show that, for a small percentage of the total number of parcels, a larger proportion of the IC phosphorus load can be controlled. For example, private CIIM parcels with ≥ 0.25 ac of IC represent 3.7% (8,631) of the total number of parcels but account for 27% of the IC TP load from all parcels. Larger IC thresholds require regulating fewer parcels, but with the potential to treat less of the phosphorus load.

Table 3.2-2. Summary of private commercial, industrial, institutional, and multifamily parcels with IC ≥ 0.25 ac in the Charles River Watershed

Use Group	Count	Total Area (ac)	IC Area		TP Load (lb/yr)		
			Acre	% IC of total Area	IC	Pervious	Total
Commercial	5,895	19,112	7,992	41.8%	14,730	1,596	16,326
Industrial	212	691	289	41.9%	518	47	565
Private Institutional	959	5,232	1,793	34.3%	3,229	425	3,653
MultiFamily Residential	1,565	5,393	1,429	26.5%	3,275	671	3,946
Subtotal	**8,631**	**30,428**	**11,504**	**37.8%**	**21,752**	**2,738**	**24,490**
Watershed Total (%)	**3.79%**	**14.67%**	**25.29%**	--	**27.10%**	**13.57%**	**24.38%**

Table 3.2-3. Summary of private commercial, industrial, institutional, and multifamily parcels with IC ≥ 0.5 ac in the Charles River Watershed

Use Group	Count	Total Area (ac)	IC Area		TP Load (lb/yr)		
			Acre	% IC of total Area	IC	Pervious	Total
Commercial	3,433	16,757	7,116	42.5%	13,099	1,388	14,487
Industrial	139	648	264	40.8%	474	44	517
Private Institutional	619	4,717	1,674	35.5%	3,015	372	3,387
MultiFamily Residential	747	4,147	1,147	27.7%	2,627	511	3,139
Subtotal	**4,938**	**26,269**	**10,201**	**38.8%**	**19,215**	**2,315**	**21,529**
Watershed Total (%)	**2.17%**	**12.67%**	**22.42%**	--	**23.94%**	**11.47%**	**21.43%**

Table 3.2-4. Summary of private commercial, industrial, institutional, and multifamily parcels with IC ≥ 0.75 ac in the Charles River Watershed

Use Group	Count	Total Area (ac)	IC Area		TP Load (lb/yr)		
			Acre	% IC of total Area	IC	Pervious	Total
Commercial	2,423	15,251	6,495	42.6%	11,953	1,212	13,165
Industrial	107	602	244	40.5%	438	40	478
Private Institutional	442	4,462	1,566	35.1%	2,820	355	3,175
MultiFamily Residential	474	3,374	983	29.1%	2,252	426	2,678
Subtotal	**3,446**	**23,690**	**9,289**	**39.2%**	**17,463**	**2,033**	**19,496**
Watershed Total (%)	**1.51%**	**11.42%**	**20.42%**	--	**21.76%**	**10.07%**	**19.41%**

Table 3.2-5. Summary of private commercial, industrial, institutional, and multifamily parcels with IC ≥ 1 ac in the Charles River Watershed

Use Group	Count	Total Area (ac)	IC Area		TP Load (lb/yr)		
			Acre	% IC of total Area	IC	Pervious	Total
Commercial	1,867	14,268	6,014	42.2%	11,074	1,147	12,221
Industrial	81	570	221	38.8%	397	39	435
Private Institutional	347	4,229	1,485	35.1%	2,673	338	3,011
MultiFamily Residential	333	2,995	862	28.8%	1,973	368	2,342
Subtotal	**2,628**	**22,062**	**8,582**	**38.9%**	**16,117**	**1,892**	**18,009**
Watershed Total (%)	**1.15%**	**10.64%**	**18.86%**	**--**	**20.08%**	**9.38%**	**17.93%**

Table 3.2-6. Summary of private commercial, industrial, institutional, and multifamily parcels with IC ≥ 2 ac in the Charles River Watershed

Use Group	Count	Total Area (ac)	IC Area		TP Load (lb/yr)		
			Acre	% IC of total Area	IC	Pervious	Total
Commercial	904	11,010	4,656	42.3%	8,578	916	9,495
Industrial	36	455	157	34.6%	283	32	315
Private Institutional	178	3,495	1,246	35.6%	2,244	281	2,525
MultiFamily Residential	134	2,096	588	28.1%	1,351	238	1,589
Subtotal	**1,252**	**17,056**	**6,647**	**39.0%**	**12,457**	**1,467**	**13,924**
Watershed Total (%)	**0.55%**	**8.23%**	**14.61%**	**--**	**15.52%**	**7.27%**	**13.86%**

Table 3.2-7. Summary of private commercial, industrial, institutional, and multifamily parcels with IC ≥ 5 ac in the Charles River Watershed

Use Group	Count	Total Area (ac)	IC Area		TP Load (lb/yr)		
			Acre	% IC of total Area	IC	Pervious	Total
Commercial	298	6,804	2,804	41.2%	5,150	565	5,715
Industrial	6	146	65	44.4%	117	9	126
Private Institutional	66	2,138	901	42.1%	1,620	161	1,781
MultiFamily Residential	33	904	280	31.0%	658	93	752
Subtotal	**403**	**9,993**	**4,050**	**40.5%**	**7,545**	**830**	**8,374**
Watershed Total (%)	**0.18%**	**4.82%**	**8.90%**	**--**	**9.40%**	**4.11%**	**8.34%**

Figure 3-3 further illustrates the tradeoff between pollutant reduction and the number of private CIIM parcels with IC area ranging from ≥20 ac to ≥0 ac (i.e., all private CIIM parcels) that would have to install SCMs. This figure assumes that runoff from IC within a parcel would be treated by SCMs sized to achieve the required load reduction target of 65%. The "knee" of the curve, where the slope begins to flatten, indicates the IC threshold where the fewest number of parcels can provide the greatest benefit in terms of TP reduction. For the Charles River Watershed, this appears to lie between parcels with ≥0.2 ac and ≥0.75 ac of IC.

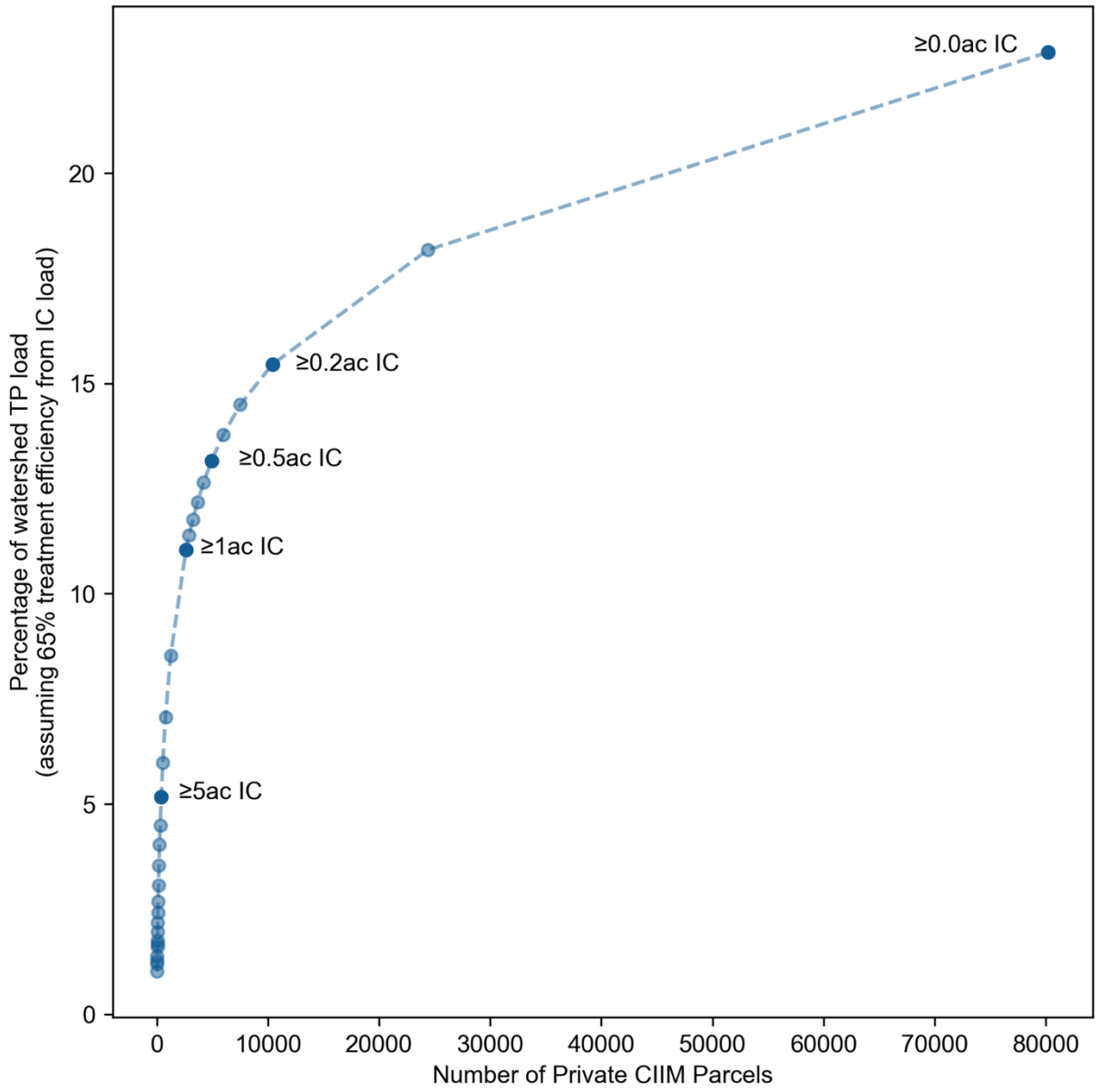

Figure 3-3. Percentage of watershed TP load that can be captured from IC runoff in the Charles River Watershed, assuming a 65% treatment efficiency, and the corresponding number of private CIIM parcels based on IC threshold. Labels for IC thresholds correspond to the dark blue dots.

4 CONCLUSIONS

This report presented a methodology for summarizing and evaluating stormwater pollutant load from parcels within the Charles River Watershed that may be used by EPA Region 1 to support decisions regarding the control of stormwater runoff from certain private properties to meet watershed TMDL goals and WQS. Findings from this analysis include:

1. Private properties contribute nearly three quarters (69%) of the watershed's total TP load.
2. The majority of TP from private properties is generated from impervious cover (79% of load from private properties and 54% of the watershed total load).
3. Private commercial, industrial, institutional, and multi-family residential (CIIM) properties make up 35.3% of all parcels, but have relatively high percentages of IC and therefore contribute a large proportion of the watershed IC TP load (42%)
4. Selecting private CIIM parcels based on their IC area (which is proportional to the amount of TP generated) can minimize the number of parcels installing stormwater controls, while providing the greatest TP reduction benefit (Table 4-1).

The findings in this report indicate that the TMDL goals for TP and other WQS in the Charles River cannot be met without additional reduction of stormwater runoff and pollutant loads from private parcels. Because the Charles River Watershed is highly developed, most stormwater runoff from private parcels is likely discharged to a local community's MS4, ultimately making that municipality responsible for the phosphorus load under their MS4 Permit. While municipalities are responsible for a large portion of the needed phosphorus reductions, placing the entire burden on municipalities will likely not result in sufficient reduction to reach the TMDL goals and WQS. Designating stormwater discharges from certain classes of private properties for NPDES permits based on the amount of IC area will help reduce the burden on the community that holds an MS4 permit by targeting properties generating the largest amount of phosphorus in stormwater on a per-property scale and makes meeting watershed-wide goals feasible. In any scenario, municipalities will still need to engage the private property owners with smaller property size or IC size to eventually meet the TMDL goals and WQS. However, requiring action on private properties with larger amounts of IC now through NPDES permitting provides greater flexibility to the communities in deciding which private properties to target to meet their own MS4 permit obligations.

Table 3.2-1. Summary of private CIIM parcels installing SCMs based on parcel IC area and the reduction achieved in watershed total TP load.

IC Threshold (ac)	Parcel Count	Total TP Load (lb/yr)	IC TP Load (lb/yr)	Total TP Treated (%)*
≥0 (All)	80,280	38,682	33,377	22%
≥0.25	8,631	30,770	25,565	17%
≥0.5	4,938	26,679	21,821	14%
≥0.75	3,446	25,008	20,295	13%
≥1	2,628	23,728	19,093	12%
≥2	1,252	20,159	15,918	10%
≥5	403	14,493	11,013	7%

* Percentage calculated as IC load times a 65% treatment efficiency divided by the watershed total TP load of 100,444 lb/yr, as calculated as part of this analysis.

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APPENDIX A

See the accompanying Excel workbook for full preprocessing steps.

Table A3.2-1. List of all unique combinations of Use Code and Use Group

Use Code	Use Code Group
010	MultiFamily Residential
011	MultiFamily Residential
013	Commercial
014	MultiFamily Residential
016	MultiFamily Residential
017	MultiFamily Residential
018	MultiFamily Residential
019	Commercial
031	Commercial
033	Commercial
034	Commercial
037	Commercial
038	Commercial
039	Commercial
041	Industrial
043	Industrial
048	Commercial
049	Commercial
061	Commercial
063	Commercial
064	Commercial
067	Commercial
071	Open Land
073	Commercial
076	Commercial
081	Commercial
091	Private Institutional
093	Private Institutional
094	Private Institutional
101	Single Family Residential
1010	Single Family Residential
1013	Single Family Residential
1014	MultiFamily Residential
1017	Single Family Residential
1018	Single Family Residential
102	MultiFamily Residential
1020	MultiFamily Residential
1021	MultiFamily Residential
103	MultiFamily Residential

104	MultiFamily Residential
1040	MultiFamily Residential
1043	MultiFamily Residential
105	MultiFamily Residential
1050	MultiFamily Residential
106	Single Family Residential
1060	Single Family Residential
1061	Single Family Residential
1062	Single Family Residential
1063	Single Family Residential
1067	Single Family Residential
107	MultiFamily Residential
108	MultiFamily Residential
109	MultiFamily Residential
1090	Single Family Residential
1091	Single Family Residential
1094	Single Family Residential
1095	Single Family Residential
1098	Single Family Residential
1099	Single Family Residential
111	MultiFamily Residential
1110	MultiFamily Residential
1111	MultiFamily Residential
112	MultiFamily Residential
1120	MultiFamily Residential
113	MultiFamily Residential
1131	MultiFamily Residential
114	MultiFamily Residential
116	MultiFamily Residential
117	MultiFamily Residential
118	MultiFamily Residential
119	MultiFamily Residential
120	MultiFamily Residential
121	MultiFamily Residential
122	MultiFamily Residential
123	MultiFamily Residential
1230	Private Institutional
124	MultiFamily Residential
125	MultiFamily Residential
1250	MultiFamily Residential
1251	MultiFamily Residential
126	MultiFamily Residential
127	MultiFamily Residential
129	MultiFamily Residential
130	Open Land
1300	Open Land

1301	Open Land
1303	Open Land
131	Open Land
1310	Open Land
1313	Open Land
132	Open Land
1320	Open Land
1322	Open Land
1323	Open Land
134	Open Land
136	Open Land
137	MultiFamily Residential
138	Single Family Residential
140	Commercial
1400	Commercial
167	Single Family Residential
170	MultiFamily Residential
172	Single Family Residential
176	Single Family Residential
181	Single Family Residential
182	Single Family Residential
183	Agriculture
187	Agriculture
199	MultiFamily Residential
201	Single Family Residential
2010	Open Land
300	Commercial
3000	Commercial
301	Commercial
3010	Commercial
302	Commercial
303	Commercial
3030	Commercial
304	Commercial
3040	Commercial
305	Commercial
3050	Commercial
306	Commercial
307	Commercial
309	Commercial
310	Commercial
3100	Commercial
311	Commercial
312	Commercial
3120	Commercial
313	Commercial

3130	Commercial
314	Commercial
3140	Commercial
315	Commercial
316	Commercial
3160	Commercial
317	Agriculture
318	Commercial
3180	Commercial
319	Commercial
320	Commercial
321	Commercial
3210	Commercial
322	Commercial
3220	Commercial
3221	Commercial
3222	Commercial
323	Commercial
3230	Commercial
324	Commercial
3240	Commercial
325	Commercial
3250	Commercial
326	Commercial
3260	Commercial
327	Commercial
3270	Commercial
328	Commercial
329	Commercial
330	Commercial
3300	Commercial
331	Commercial
3310	Commercial
332	Commercial
3320	Commercial
333	Commercial
3330	Commercial
334	Commercial
3340	Commercial
3344	Commercial
335	Commercial
3350	Commercial
336	Commercial
3360	Commercial
337	Commercial
3370	Commercial

338	Commercial
3380	Commercial
339	Commercial
340	Commercial
3400	Commercial
3401	Commercial
341	Commercial
3410	Commercial
342	Commercial
3420	Commercial
3421	Commercial
343	Commercial
3430	Commercial
344	Commercial
345	Commercial
3450	Commercial
346	Commercial
347	Commercial
348	Commercial
349	Commercial
350	Commercial
3500	Commercial
351	Commercial
3510	Commercial
352	Commercial
353	Commercial
3530	Commercial
354	Commercial
355	Commercial
3550	Commercial
356	Commercial
3560	Commercial
357	Commercial
358	Commercial
360	Commercial
361	Commercial
362	Commercial
3620	Commercial
364	Commercial
3640	Commercial
365	Commercial
369	Commercial
3690	Commercial
370	Commercial
3700	Commercial
3710	Commercial

374	Commercial
3740	Commercial
375	Commercial
3750	Commercial
376	Commercial
3760	Commercial
377	Commercial
3770	Commercial
378	Commercial
379	Commercial
380	Commercial
3800	Open Land
381	Commercial
3810	Commercial
383	Commercial
384	Commercial
3840	Commercial
3841	Public Institutional
385	Commercial
386	Commercial
387	Commercial
388	Commercial
3880	Commercial
390	Open Land
3900	Open Land
3901	Open Land
391	Open Land
3910	Open Land
392	Open Land
3920	Open Land
393	Open Land
394	Commercial
395	Commercial
399	Agriculture
400	Industrial
4000	Industrial
401	Industrial
4010	Industrial
402	Industrial
4020	Industrial
4021	Industrial
403	Industrial
4030	Industrial
404	Industrial
4040	Industrial
405	Industrial

4050	Industrial
406	Industrial
4060	Industrial
407	Industrial
4095	Industrial
410	Industrial
4100	Industrial
412	Industrial
413	Industrial
414	Industrial
415	Industrial
417	Industrial
422	Industrial
423	Open Land
4230	Open Land
424	Industrial
4240	Industrial
4241	Industrial
425	Industrial
426	Open Land
427	Industrial
428	Industrial
4280	Industrial
430	Industrial
4300	Industrial
431	Industrial
4310	Industrial
432	Industrial
4320	Industrial
433	Industrial
4330	Industrial
435	Industrial
436	Industrial
437	Industrial
438	Industrial
439	Industrial
440	Open Land
4400	Open Land
441	Open Land
4410	Open Land
442	Open Land
4420	Open Land
444	Industrial
445	Industrial
446	Industrial
450	Industrial

451	Industrial
4510	Industrial
452	Industrial
4520	Industrial
465	Industrial
601	Open Land
6010	Open Land
602	Open Land
6100	Open Land
710	Agriculture
7100	Agriculture
712	Agriculture
7120	Agriculture
713	Agriculture
7130	Agriculture
714	Agriculture
7140	Open Land
716	Agriculture
7160	Agriculture
717	Open Land
7170	Agriculture
718	Open Land
7180	Agriculture
719	Agriculture
720	Open Land
7200	Open Land
722	Open Land
801	Open Land
8010	Open Land
803	Open Land
8030	Open Land
8040	Open Land
805	Commercial
8050	Commercial
8051	Commercial
806	Open Land
8060	Open Land
8070	Open Land
8080	Open Land
811	Open Land
8110	Open Land
814	Open Land
8140	Open Land
837	Open Land
900	Public Institutional
9000	Public Institutional

9001	Public Institutional
9003	Public Institutional
901	Public Institutional
9010	Public Institutional
902	Public Institutional
9020	Public Institutional
903	Public Institutional
9030	Public Institutional
9031	Open Land
9032	Public Institutional
9033	Public Institutional
9035	Public Institutional
904	Private Institutional
905	Private Institutional
9050	Private Institutional
9051	Private Institutional
906	Private Institutional
9060	Private Institutional
907	Commercial
908	Public Institutional
9080	Public Institutional
909	Industrial
910	Public Institutional
9100	Public Institutional
9101	Public Institutional
911	Public Institutional
912	Public Institutional
9120	Public Institutional
914	Public Institutional
9140	Public Institutional
9141	Public Institutional
9142	Public Institutional
917	Public Institutional
919	Public Institutional
920	Public Institutional
9200	Public Institutional
922	Public Institutional
9220	Public Institutional
923	Public Institutional
924	Public Institutional
9240	Public Institutional
9241	Public Institutional
9242	Public Institutional
925	Open Land
9250	Public Institutional
927	Public Institutional

928	Public Institutional
929	Public Institutional
9290	Public Institutional
930	Public Institutional
9300	Public Institutional
9302	Public Institutional
931	Public Institutional
9310	Public Institutional
9311	Public Institutional
9312	Public Institutional
9313	Public Institutional
932	Public Institutional
9320	Public Institutional
933	Public Institutional
9330	Public Institutional
934	Public Institutional
9340	Public Institutional
935	Public Institutional
9350	Public Institutional
936	Public Institutional
9360	Public Institutional
937	Public Institutional
938	Public Institutional
9380	Public Institutional
939	Public Institutional
9390	Public Institutional
940	Private Institutional
9400	Private Institutional
9403	Private Institutional
941	Private Institutional
9410	Private Institutional
9413	Private Institutional
942	Private Institutional
9420	Private Institutional
9421	Private Institutional
9423	Private Institutional
943	Private Institutional
9430	Private Institutional
944	Private Institutional
9440	Private Institutional
945	MultiFamily Residential
9450	Private Institutional
946	Open Land
9460	Private Institutional
947	Private Institutional
9470	Private Institutional

9473	Private Institutional
949	Industrial
950	HRU
9500	HRU
951	Open Land
9510	Private Institutional
952	Commercial
953	Open Land
9530	Open Land
954	Private Institutional
9540	Private Institutional
955	Private Institutional
9550	Private Institutional
956	Private Institutional
9560	Public Institutional
957	Private Institutional
9570	Private Institutional
9571	Private Institutional
958	Open Land
9580	Open Land
959	MultiFamily Residential
9590	MultiFamily Residential
9591	MultiFamily Residential
960	Private Institutional
9600	Private Institutional
9601	Private Institutional
9602	Private Institutional
961	Private Institutional
9610	Private Institutional
9611	Private Institutional
962	Private Institutional
9620	Private Institutional
963	Right-of-Way
964	Commercial
965	Public Institutional
966	Commercial
968	Private Institutional
970	Private Institutional
9700	Public Institutional
9701	Private Institutional
9703	Private Institutional
971	Industrial
9710	Industrial
972	Public Institutional
9720	Public Institutional
973	HRU

9730	HRU
974	Public Institutional
9740	Public Institutional
975	Public Institutional
9750	Public Institutional
976	Private Institutional
977	Private Institutional
978	Public Institutional
979	Private Institutional
980	Public Institutional
9800	Public Institutional
981	Public Institutional
9810	Public Institutional
982	Public Institutional
983	Open Land
985	HRU
986	Public Institutional
987	Private Institutional
988	Public Institutional
989	Private Institutional
9900	Commercial
9910	Public Institutional
992	Public Institutional
9920	Public Institutional
993	Commercial
9930	Public Institutional
995	HRU
9950	Open Land
996	Open Land
997	HRU
9970	HRU
9971	Public Institutional
998	Commercial
999	Agriculture

APPENDIX B

See the accompanying Excel workbook for the data used to create these plots.

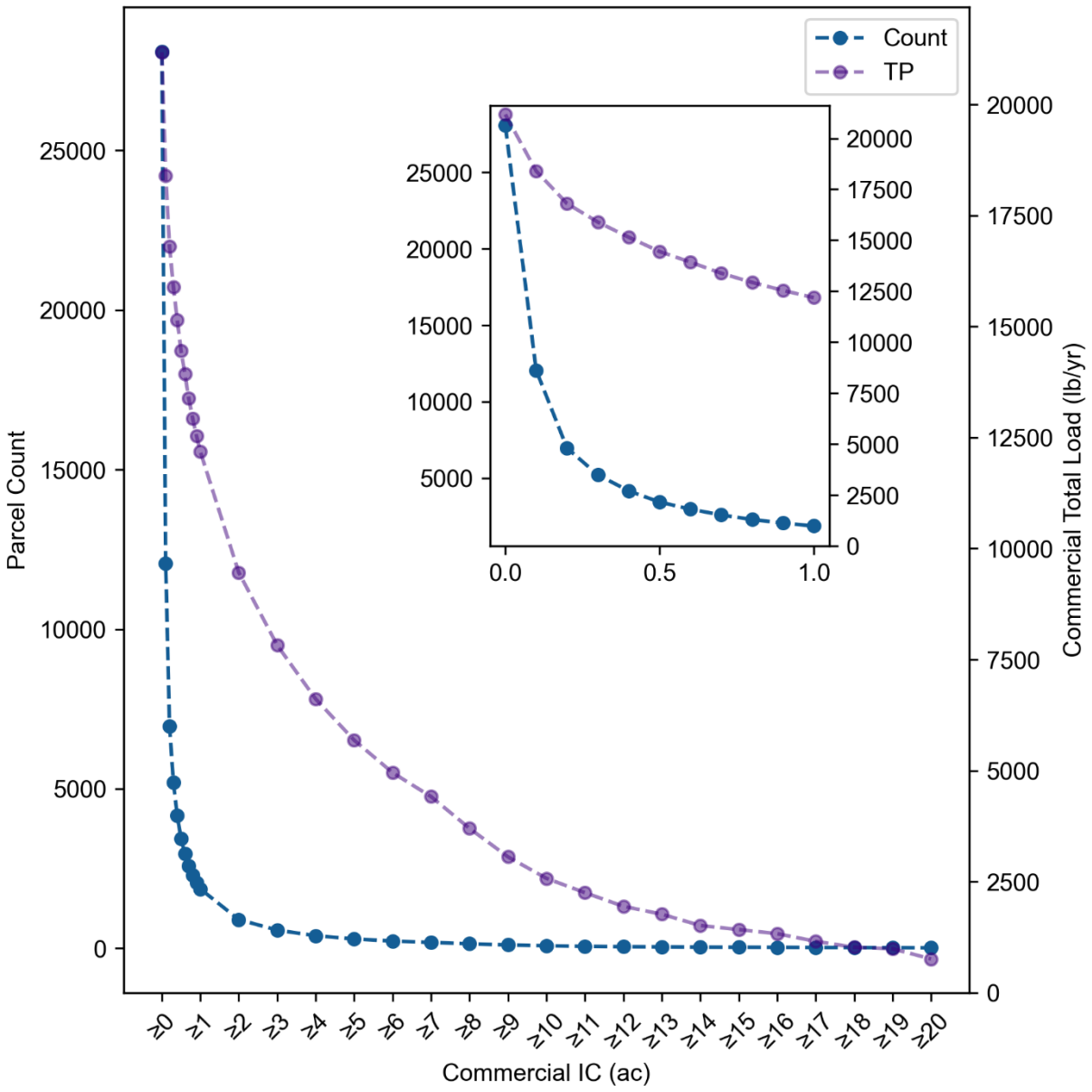

Figure B-1. Private commercial parcel count and total TP load by parcel IC area. Note that a threshold of ≥ 0ac IC includes all private commercial parcels.

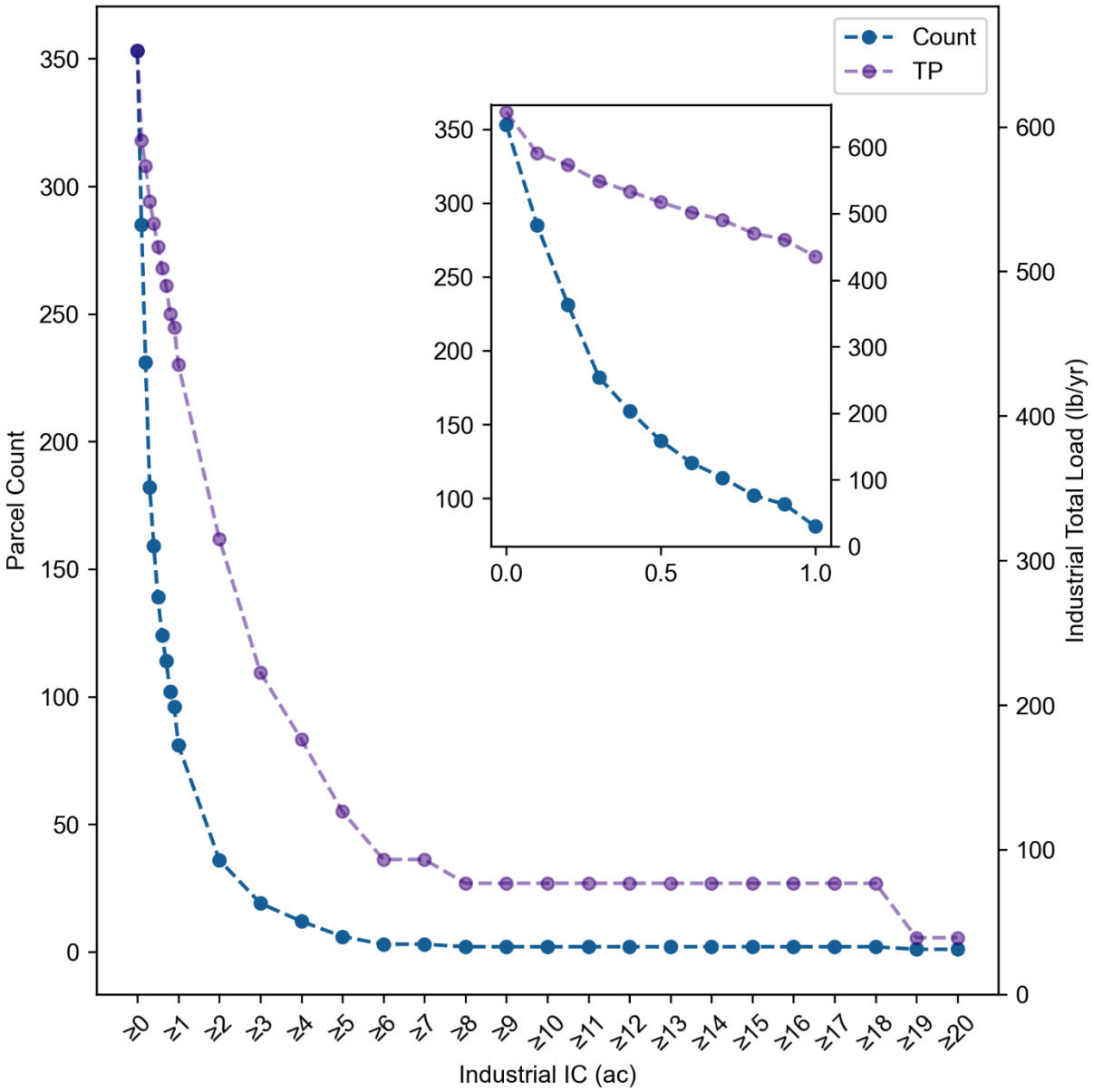

Figure B-2. Private industrial parcel count and total TP load by parcel IC area. Note that a threshold of ≥ 0ac IC includes all private industrial parcels.

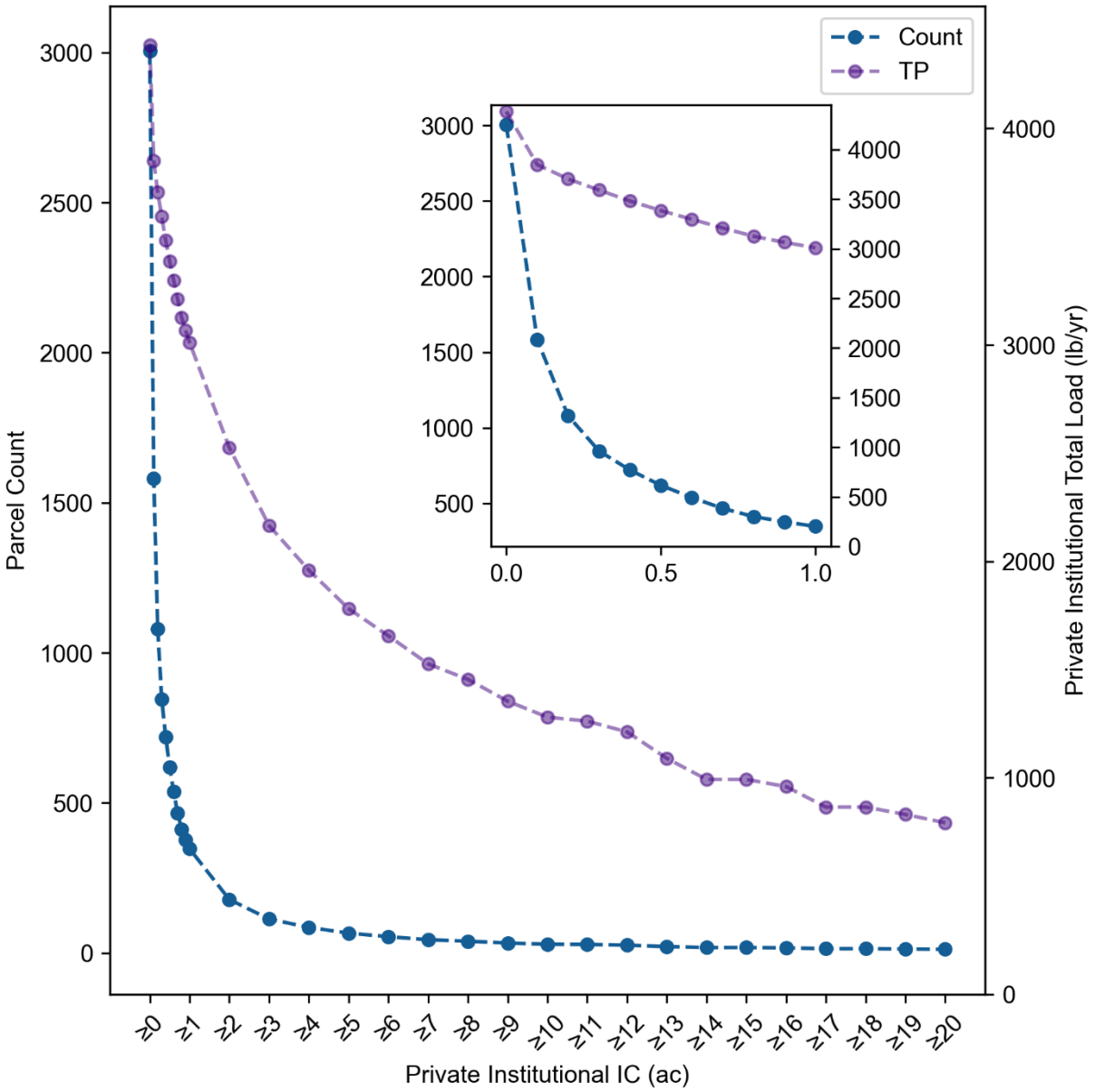

Figure B-3. Private institutional parcel count and total TP load by parcel IC area. Note that a threshold of ≥ 0ac IC includes all private institutional parcels.

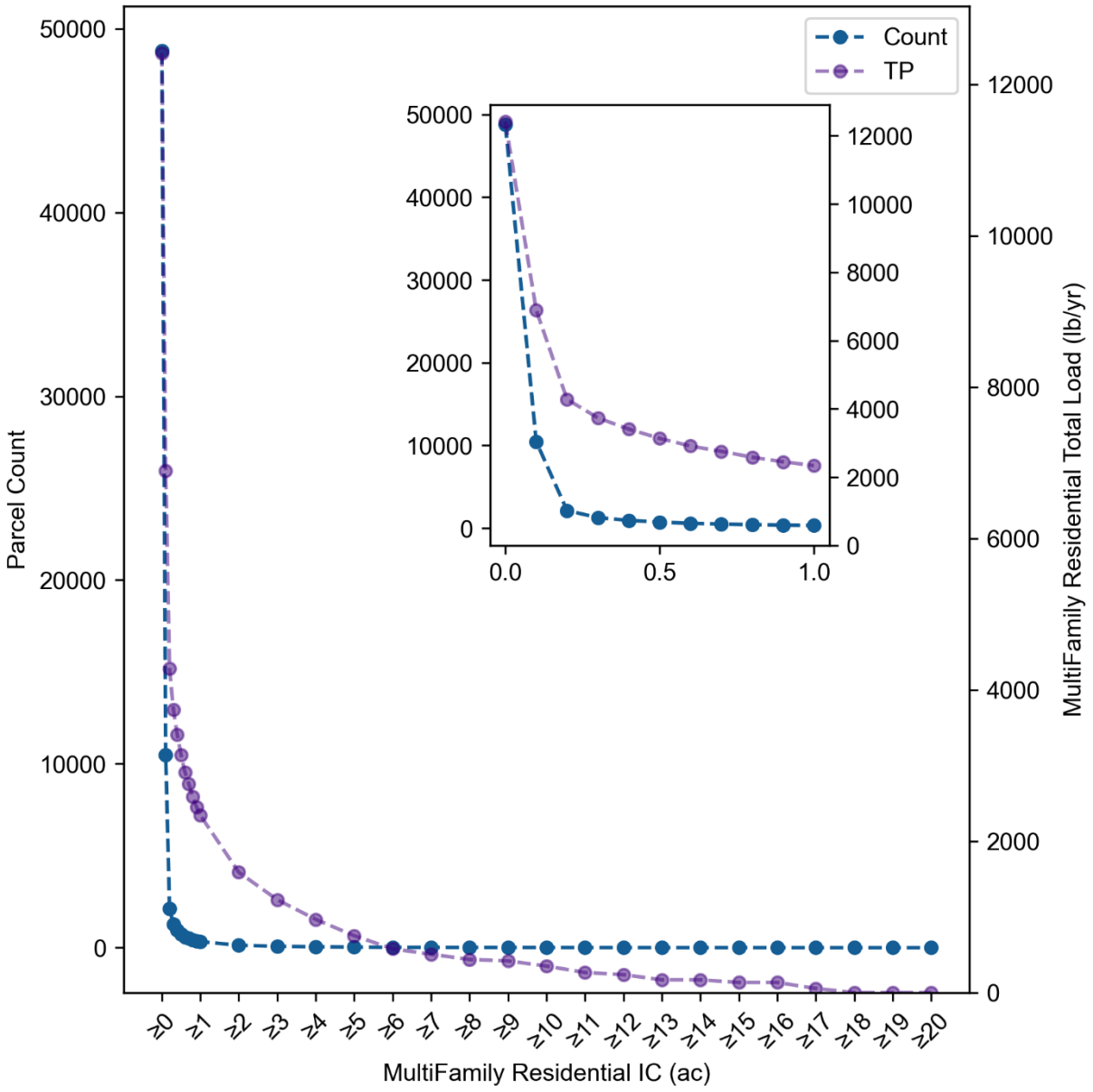

Figure B-4. Private multifamily residential parcel count and total TP load by parcel IC area. Note that a threshold of ≥ 0ac IC includes all private multifamily residential parcels.