Trash In Creeks: A field survey of trash intensity and source types in Austin, Texas

RR-22-01, August 2022

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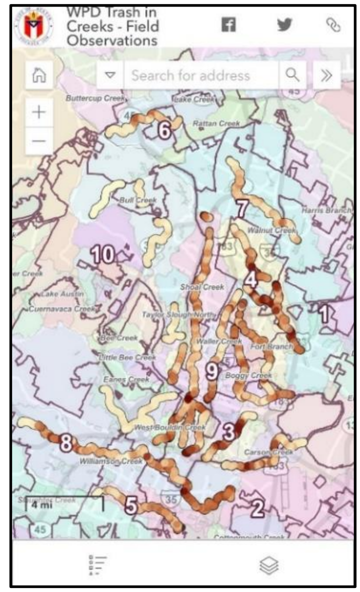

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Abstract

The Watershed Protection Department conducted a field survey to understand distribution and sources of trash in creeks to inform solutions. Data points were collected every 30ft for a total of 19,467 observations in 110 miles along 20 creeks from November 2021 to April 2022. Results show that trash intensity does not correlate well with stream position (upstream-to-downstream) which implies that trash does not move evenly through the system, complicating efforts to quantify the relative impact of different sources. Presence of trash is more strongly influenced by stream roughness (primarily riparian vegetation) than by source inputs which presents an opportunity to use these natural "strainers" as locations to periodically remove trash from the system. ArcGIS attributes and linear regression, at the raw data level and aggregated, were used to evaluate relationships between trash intensity and observed point sources such as overflowing dumpsters, illegal dumping, historic dumping, encampments, as well as land attributes such as population, transportation, and land use (e.g., single family residential, multifamily, commercial, parks, etc.). Surprisingly, there were no strong relationships with any of the sources or watershed attributes. This indicates that culpability of trash in creeks should not be directed specifically at any one source, but rather it is the cumulative influence of the Austin community. Spatial analysis indicates that 76% of the total volume of trash was located at only 10% of the observation points. The most encountered items were single use plastic beverage and food containers resonating a global appeal for reduction. A companion report "Trash in Creeks: Benchmarking Solution Space" (RR-22-02) provides recommendations synthesizing the data from this field survey in the context of international strategies to prevent and abate trash in waterways.

Introduction

Purpose

Due in part to public comment asserting an increase of trash in creeks over time, prevalence of scooters thrown in waterbodies and concerns with encampments, the City Council passed Resolution No. 20200123-108 (CIUR 2234) directing the City Manager "to prepare a study with recommendations to improve the ecological health and safety of Austin's rivers, lakes, and creeks by addressing litter problems, prevention, and abatement in our watershed." The resolution further specified a list of deliverables to address litter problems and illegal dumping of electric micro-mobility devices (i.e., "scooters") in waterways. Responsive to one of these deliverables, the Watershed Protection Department (WPD) Environmental

Monitoring and Compliance (EMC) Division completed a review of available data and comparable studies and subsequently implemented a field study quantifying the extent of trash in creeks as well as correlating predetermined sources to trash accumulation in representative locations around Austin.

Available Data

Existing in-house data on trash in waterways was determined to be inadequate to provide an immediate response to CIUR 2234. From 1999 – 2022 the City's primary baseline water quality monitoring project called the Environmental Integrity Index program (EII), included the collection of limited qualitative data related to litter in creeks through the sub-index "Non-Contact Recreation" assessment. The most relevant information in this assessment is parameter 316 "litter", for which the data is recorded as a 0-20 score based on an overall condition as defined by a qualitative rubric. Unfortunately, the data cannot be reliably correlated to sources or provide spatial or temporal comparisons because the method does not specify the physical boundaries of the area represented in the score and has therefore inherently been implemented differently through the years. In addition, the method was developed to describe recreational considerations and presence of any amount of glass disproportionately affected the score. For these reasons, the Non-Contact Recreation data is not useful for characterizing litter intensity for the purpose of spatial analysis or other related objectives in this study.

Cognizant of the benefits of citizen science and other volunteer-led initiatives, in 2011 WPD initiated a study called the "Litter Intensity and Sources Index" ("LISI" Project 552 SR-21-06) to determine if volunteer-collected data could effectively and consistently identify composition and sources of litter in creeks based on visual observations using staff-designed field sheets. Data was collected at 15 sites with duplicates and controls. Results of the study (Jackson and Richter 2020) indicate that while visual litter assessment forms may be useful for identifying some sources, volunteer-based data collection based on perception is not recommended due to poor precision and accuracy. Recommendations from the project included use of a limited number of trained personnel rather than an unlimited number of volunteers. This implies that a study focusing on trash in creeks should be implemented by a small number of trained staff recording data using a well-defined method that limits differences in visual perception.

The lake crew of WPD Field Operations Division removes trash from Lady Bird Lake weekly. Until recently, the crew removed both anthropogenic trash and organic matter and conflated the estimates of volume removed. Trend analysis of the data over time is impossible due to the shift in method. Organic matter is estimated to have been the bulk of material removed. Debris removal from Waller Creek Tunnel facilities has been anecdotally described as primarily (as much as ~80%) organic matter.

WPD EMC designed a rapid visual litter assessment method to evaluate success of litter management efforts in the lower Waller Creek watershed over time (Jackson, 2015). The study concluded that:

- there was a significant presence of litter in lower Waller Creek,
- beverage containers were identified to be the most prevalent type of litter, and
- additional data points at each site were needed to better describe baseline conditions.

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Although each of these efforts to characterize trash intensity served a specific purpose, due to their unique limitations they could not be used to characterize trash in creeks/riparian corridors for the purpose of correlating sources and/or spatial trends. A reproducible method with defined observation area boundaries, a less subjective visual method, and a large area and density of data points would be necessary for a city-wide survey.

Literature Review for Trash Survey Methods

Municipal, regional, state, national and international efforts to understand, quantify, and reduce trash in waterways are diverse and appear to be increasing over time. However, most available data appears to be from studies that focus on marine litter which typically use volunteer-driven beach clean-ups as a vehicle for data collection (Carpenter & Wolverton 2017, Carson et al. 2013, Hidalgo-Ruz and Theil 2013, Hong et al. 2014, Koelmans et al. 2015, Ryan 2015, van der Velde et al. 2017, Vincent et al. 2017, Xanthos and Walker 2017). Often, beach collection efforts are centered around hot spots and are typically not representative of the baseline litter accumulation in a watershed (EPA TFW 2018). Freshwater litter studies tend to focus on large river/lake systems and/or non-point source production and illegal dumping (Allison et al. 1997, Armitage 2007, Armitage & Rooseboom 2000, BASMAA 2014, Cowger et al. 2019, Jakiel et al. 2019, Kim et al. 2008, Liu et al. 2017, Marais & Armitage 2004, McCormick 2015, McCormick & Hoellein 2016, Santos et al. 2019, Vincent et al. 2017, Weaver 2015). Many studies provided insights for experimental design including:

- Land use: Various land uses such as recreation (Moore et al. 2007, Weaver 2015) can influence litter in aquatic systems (BASMAA 2014, Cowger et al. 2019). Monitoring sites in BASMAA (2014) represented seven different land use types, with a focus on retail and residential trash generation rates. BASMAA (2011) found that retail and residential areas generally had higher litter rates than other land use types. These rates can be explained by higher population density in residential and retail zones (BASMAA 2014).
- Seasons: Seasonality can affect litter trends (BASMAA 2014, City of Los Angeles 2016, Moore et al. 2007) and therefore, repeated site visits are required for studies that seek to address temporal trends, such as accumulation rates (Moore et al. 2007), which can be critical in determining litter sources, and for evaluating management actions.
- Vegetation density: Some studies report a relationship between dense riparian buffers and less trash accumulation in stream beds (Cowger et al 2019, EPA TFW 2018, McCormick 2015). McCormick (2015) found a higher density of litter in riparian zones compared with instream zones due to the buoyancy of the materials found in each zone. High velocity streams are more likely to transport heavy materials, while riparian zones tend to accumulate lighter materials through lower energy transportation methods such as wind or rain events (McCormick 2015).
- Stream width, stream order, catchment area: Stream size is likely to influence transport and retention of different types and categories of litter. Incorporating a variety of stream sizes, for example, can assist in evaluating longitudinal (Moore et al. 2007) and regional trends (Moore et al. 2007, Kiessling et al. 2019). In a study looking at major rivers, tributaries and small streams, Kiessling et al. (2019) speculated that larger rivers, possibly due to better accessibility and recreational areas, may lead to aggregation of both visitors and litter. Moore et al. (2007) included numerous sites per watershed in the San Francisco Bay Area, which allowed for specific longitudinal analyses of watersheds with unique sources of litter.
- Impervious cover (IC): IC is positively correlated to litter accumulation and urban runoff. The storm drain system is a primary source for floatable debris entering a watershed (Armitage 2007, Conley et al. 2019, Cowger et al. 2019, Moore et al. 2007).
- Proximity to major roadways: Trash dispersal can be increased from incidental littering from passengers and unsecured items (Cowger et al. 2019, Jakiel et al. 2019). Cowger et al. (2019) found significant positive correlation between road density and trash accumulation rates.

Two recent methodologies that can be applied to a wide variety of freshwater systems and riparian corridors are: the Rapid Trash Assessment Method (RTAM) applied to waters of the San Francisco Bay region, and the Escaped Trash Assessment Protocol (ETAP) developed by the Environmental Protection Agency Trash Free Waters Program. The RTAM was the first published account of a methodology which met the objectives of quantifying trends and identifying sources of litter in municipal freshwater streams (Moore et.al 2007). The ETAP (EPA TFW 2018) represents the most recently updated version of litter assessments conducted in California intended for development into a national standard for documenting and assessing anthropogenic litter in stream habitats, making it a primary source of guidance for City of Austin litter assessment. The protocols employed by the ETAP were not used in the City of Austin assessment because they were designed for estimating the trash of a large area such as a park, river basin, or large parcel through a detailed assessment of a subsampled area; they were not designed for thin, long, linear systems like Austin's first- and second-order creeks.

WPD water quality monitoring staff have not noted, anecdotally, a significant increase in trash at the ~120 routine water quality monitoring sites over time, however, these monitoring sites may not represent the conditions at other locations within the city. With the unprecedented and sustained accelerated growth that the Austin metropolitan region has experienced it is certainly plausible that trash in creeks is an increasing problem as reported anecdotally by citizens. WPD Field Operation crews dedicated to routinely clearing obstructions in creek culverts and removing trash from Lady Bird Lake cannot document a trend of increasing trash due to the variability in their efforts and methods, however, there is a chronic trash problem in these areas. Just in the first three quarters of FY 2022, the lake crew has removed 22.5 tons of trash from Lady Bird Lake from booms on creek deltas and from the shoreline.

As Austin's population continues to grow and dependence on single use plastics and disposable items increase, so too will the problem of trash in creeks. The City of Austin supports organizations such as Keep Austin Beautiful and The Other Ones Foundation that remove tons of trash from the landscape in addition to facilitating cleanup events such as Its My Park Day (Austin Parks Foundation), Clean Lady Bird Lake and Keep Austin Beautiful Day. In addition, a newly created team of City staff within the Austin Resource Recovery Department (ARR) has begun to focus on removing trash in creeks this year. Sustaining and increasing the effort to remove the trash can be improved by a comprehensive look at the location and sources of trash in our creeks.

Methods

After an extensive literature review of trash survey methods, existing data and preliminary field reconnaissance, the following methods were developed for Austin-area streams to maximize the potential for identifying source types and understanding spatial patterns of trash intensity.

Timing of survey

Inputs of trash into a creek is unlikely to be steady or uniform due to changes in weather, social patterns, and economic changes. The Trash in Creeks study was originally initiated in 2020, however the radical changes in social patterns due to the COVID-19 pandemic, in addition to resulting safety precautions delayed the study until late 2021. The literature review revealed that seasonality is known to affect trash patterns due to changes in storm events and human activity, therefore the field survey was concentrated within a single season to the extent practical. Due to Austin's bimodal rain patterns (increased risk of storms in late spring and early fall) the preferred season for a field survey was either winter or summer to avoid stormflow disturbance and redistribution of trash. Anecdotal observations by WPD Field Operations indicate that the intensity of trash in creeks is more noticeable after drought-breaking storm events.

Staff determined that winter would also be the optimal time frame due to "leaf-off" conditions, when the normally densely vegetated riparian areas would be dormant, providing maximum visibility of the litter items accumulated on the ground. This period was also optimal for safety considerations due to dormant poison ivy and lower water levels. Following preparations, the survey was conducted from 23 Nov 2021 to 12 April 2022 during which time few rain events occurred.

Survey location selection

Within the City Limits, there are approximately 217 miles of creek mainstems in the COA regulatory watersheds and thousands of miles of tributaries. These creek lengths almost double when including the

Extra Territorial Jurisdiction. Preliminary surveys in East Bouldin Creek indicated a high amount of variability in trash intensity that did not appear to be related to source locations, so a high number of data points, 30-foot length reaches, was proposed by the study team. More than a hundred miles of creeks were selected to represent the general spatial extent within the city limits (Figure 1) as well as to ensure representation of creeks within all ten council districts (Figure 2). Sample areas included a mix of residential, multifamily, commercial, park, urban, suburban and undeveloped space within twenty watersheds. Sixteen creeks were sampled in their entirety from the headwater to their confluence with the receiving waterway, however, four creeks were only partially sampled because of their large size, access problems, and extent beyond the City of Austin jurisdiction.

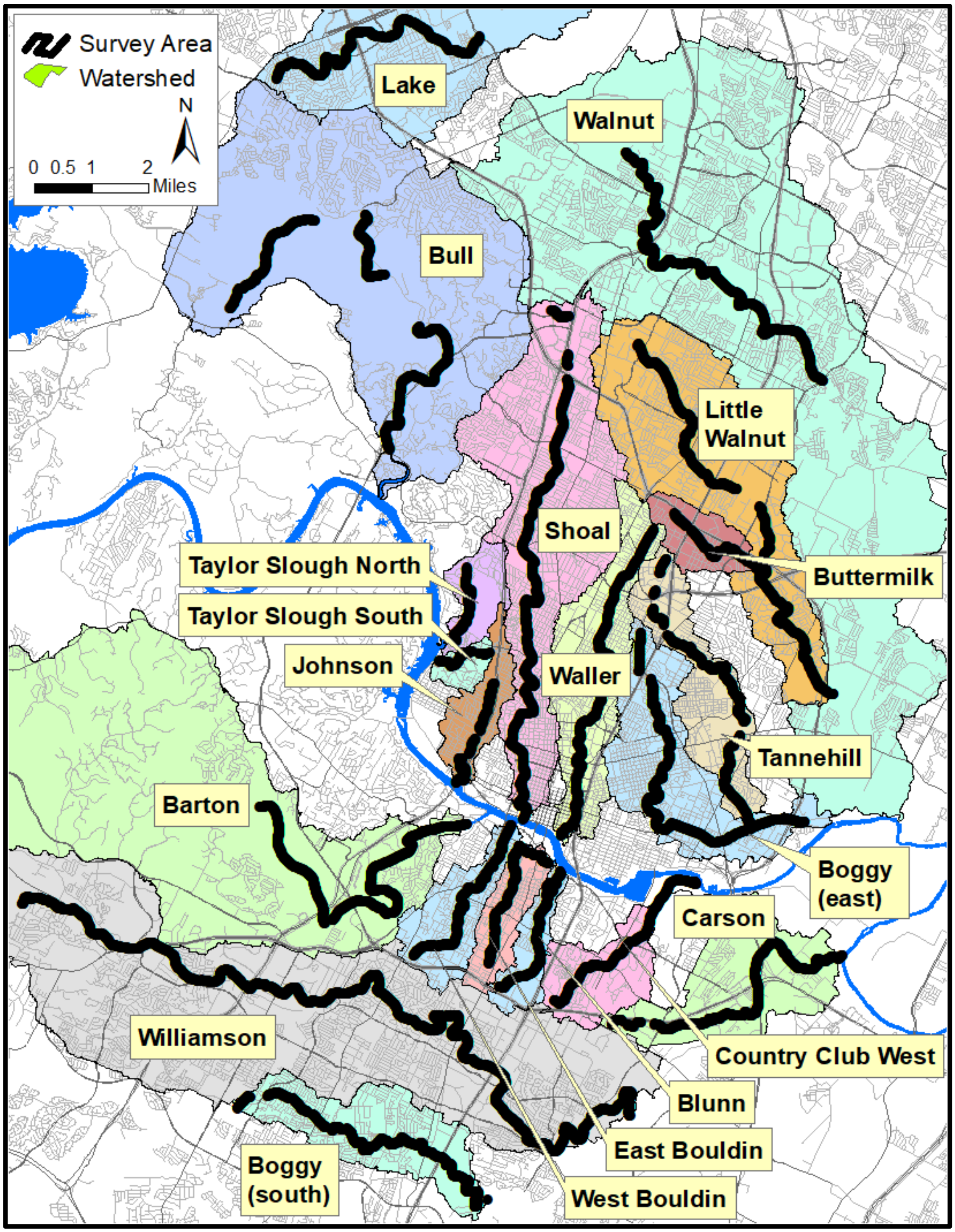


Figure 1. Survey location within the 20 selected watersheds

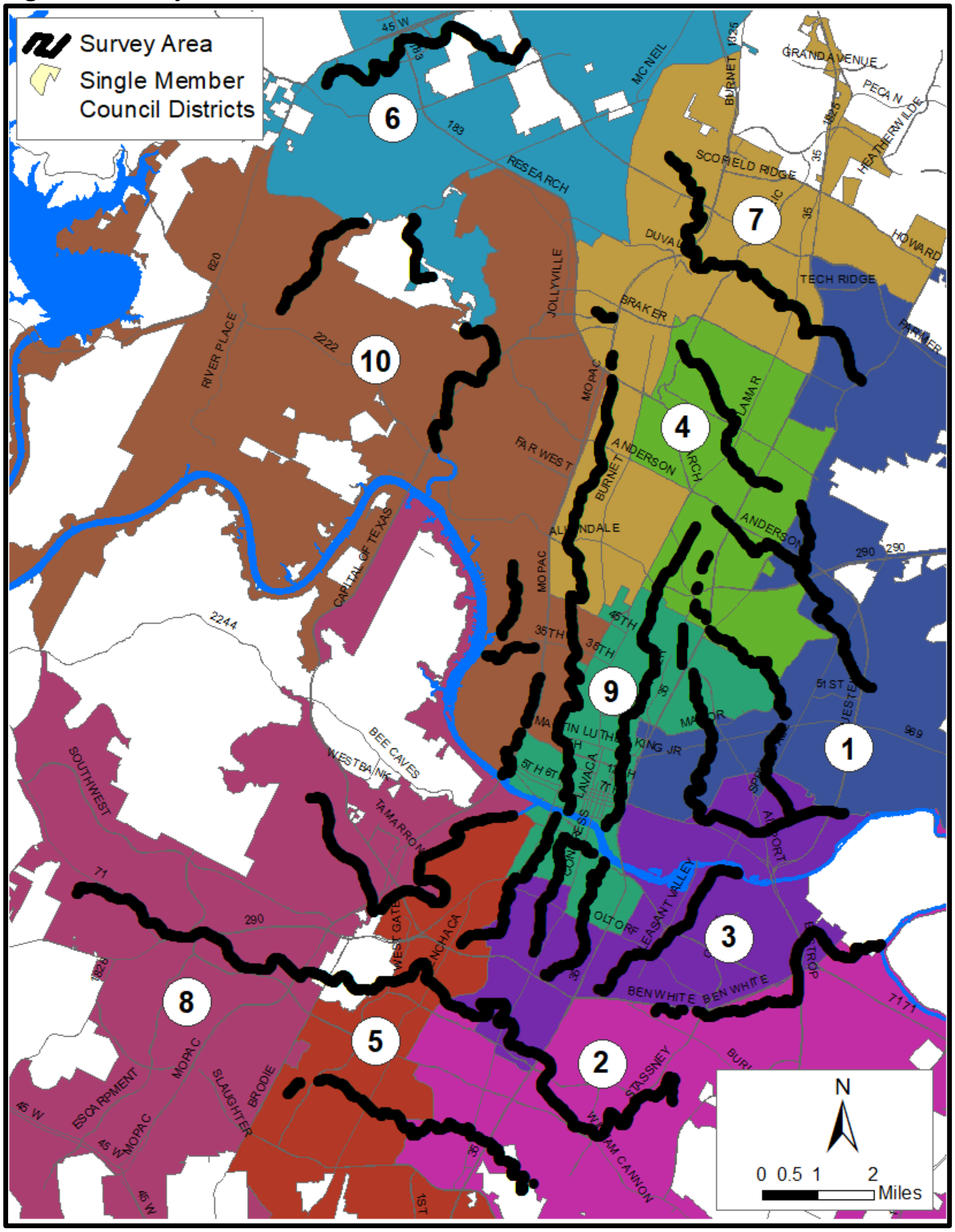


Figure 2. Survey location within the 10 Single Member Council Districts

Assessment Unit

A standardized unit of 30 ft long stream reaches was selected, as measured along the centerline of the creek. The assessment area extends laterally from the centerline through the stream bed, to beyond the lower banks (bank full) to include the first floodplain bench. This floodplain bench can be assumed to be inundated with less frequency than the channel-forming events (~2yr), but more frequently than a 100-yr event. This area will be characterized by riparian vegetation, notable drift lines from larger storms and floodplain areas where trash and other items are likely to be deposited in or mobilized from. Staff shall use these cues and topographic changes to assess the area that appears to be flooded with frequency between approximately a two-year and ten-year event (Figure 3).

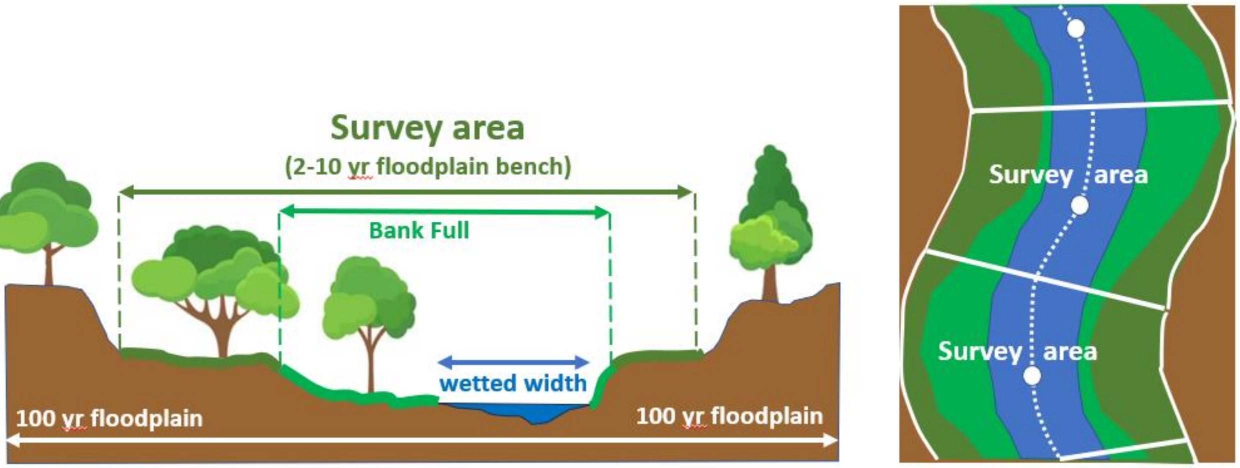


Figure 3. Survey area cross section and top view. The survey area is 30ft long (15ft on either side of the center point) and extends outward past the bank full into the riparian zone of the low floodplain bench. The 100-year floodplain typically extends beyond the survey area.

Within each assessment unit the intensity or volume of the trash is evaluated. Although the term “trash” may seem intuitive, certain limitations were drawn to maintain consistency. For this assessment:

“Trash” includes (Figure 4):

- Anthropogenic garbage and/or human possessions that are out of place
- Abandoned shopping carts, scooters, vehicles
- Erosion and stabilization materials (silt fence, matting, etc.) if completely detached from the application area
- Bricks, asphalt chunk, cinder blocks, concrete chunks, rebar, etc. that is has mobilized, and/or is otherwise no longer in its intended place.
- A bag or sack that contains sand/organics (but “trash” does not include the organics)
- Loose possessions or trash on the outside/around an actively used tent or temporary living space
- All items within a tent/camp that is no longer in use

“Trash” *does not* include: (Figure 5):

- Vegetation (e.g., leaf litter, branches, sticks, etc.) whether naturally distributed or dumped
- Failing structures that are still attached (e.g., fence wire, in-place bricks, pipe segments, etc)
- Slumping or failing bank stabilization still in place but vulnerable to mobilization for which removal would compromise integrity of the bank
- Large pieces of concrete or pipe that are no longer in place but could not be removed without heavy equipment
- Sand/organics (leaves, mulch) that are contained within bags/sacks
- An actively used tent or temporary living space

Figure 4. Objects were considered trash if they were mobilized beyond their intended place

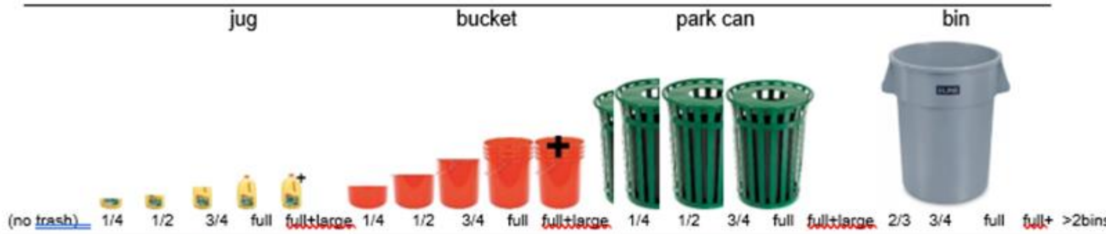
Figure 5. Objects were not considered trash if they were in process of failing (e.g., fences, utilities, revetments, pipes, etc.), were still attached, were stabilizing a bank, or were too large to be removed by hand.

Trash Intensity Method (Rubric)

A rubric, or matrix, to visually characterize trash intensity for a one-time snapshot of trash in creeks was developed for the purpose of estimating aesthetic intensity, cumulative volume and time necessary to collect. Variability in rubric interpretation, or error, was limited by utilizing a small number of trained and calibrated staff throughout the survey period. The rubric, visual aids and narrative guidance is contained in a creek walk field sheet that was laminated and carried by each team (Figure 6).

Visual Trash Intensity Rubric for Creek Walk

1) Score is recorded at the center of a 30ft creek segment (15ft upstream and 15ft downstream of point)
2) Survey area extends outward to the high bank (perceived floodplain) visible from the channel banks, to include areas that trash will imminently reach the stream in a storm event even if above high bank
3) Accumulations of dead vegetation will not be considered trash, however if contained in bags, the bags will be considered trash (presume the bag is separated from leaves). Same with sandbags.
4) Immobile abandoned infrastructure (e.g., pipelines in channel, large blocks of concrete) will not be considered trash if infeasible (without heavy equipment) to remove/cleanup by hand), however, portions that could be easily cut off with hand tools (exposed rebar, cables, etc.) and removed will be considered trash. Small construction debris (bricks, cinderblocks, asphalt etc.) that can mobilize during storm events are considered trash. Materials that are in-place but failing are not considered trash (fence sagging, erosion matting dangling, etc.), but can be considered trash if no longer in-place and mobile



	Minimal	Apparent	Abundant	Dense
0	1 2 3 4 5	6 7 8 9 10	11 12 13 14 15	16 17 18 19 20
No litter observed within survey area	**Description:** "good" Few items here or there but not very noticeable. If noticeable, few **Volume**: The cumulative amount could easily fit within a 1-gallon milk jug, however, a single item that is larger than a milk jug (but still fits in a 5-gal bucket) can still be in this category **Effort:** Site could be easily and quickly cleaned by one person (<5 minutes)	**Description:** "not bad" Trash is noticeable but doesn't define the site **Volume**: The cumulative amount could easily fit within a 5-gallon bucket, however, a single item that is larger than a bucket (but still fits in a 25-gallon can) can still be in this category **Effort:** Site could easily be cleaned by one person but not quickly (~5-15 minutes)	**Description:** "bad" Site has obvious and salient accumulation. "Trashy" is forefront **Volume**: The cumulative amount could easily fit within a 25-gallon park trash can, however, a single item that is larger can still be in this category **Effort:** Site looks like a two-person job but could be cleaned by one person (~15-30 minutes)	**Description:** "horrible" Trash defines the site and offends the visitor. Desire for cleanup is overwhelming **Volume**: The cumulative amount requires the big 55-gallon bin(s) **Effort:** Site would take a long time for one person, (~30+ minutes) but site is better suited for a team

Figure 6. Field Sheet for evaluating Litter Intensity at each 30ft assessment reach

The rubric for scoring trash intensity was designed such that the observing team would consider three facets of trash located within the assessment unit area. The first facet was one of four general adjectives for which the area could be described as: Minimal, Apparent, Abundant, Dense. These descriptors represent four "bins" under which the observing team determines the 0-20 score. The "Minimal" category is characterized by a small volume of trash that would fit within a 1-gallon jug and take a single person less than 5 minutes to fully pick up. Apparent, Abundant and Dense categories have increasing volume and time thresholds as described in Figure 6. In the field, the observer team discusses and agrees on the value that best fits the assessment area. The estimated volume of the trash is the primary driver determining the score, and the estimated time to collect can influence the score for better or worse. This method was devised due to the variability of types (size, weight, etc.) and character (distribution, difficulty, etc,) of trash observed during pilot assessments.

Field Method

Trash study field crews typically consisted of a team leader and one or two supporting staff from a small pool of individuals that had been trained/calibrated to reduce variability in method application. At each site, the team utilized the following equipment and protocol:

Field equipment:

- iPad for georeferenced data input, Fulcrum mapping application, charger cable, external battery
- waders, first aid, phone, water
- 2 vehicles (one staged upstream, begin survey at downstream site)

Field Protocol:

- Team identifies stream reach that has not already been surveyed
- Team navigates to the first observation point in Fulcrum app
- Team lead stands 15ft upstream of first point, partner stands 15ft downstream of first point
- Team observes the survey area (Figure 3) and determines the trash intensity value (Figure 6) for the 30ft reach and enters the value in Fulcrum app plus any observations of scooters, specific sources, and other comments. If a scooter is observed, company name is recorded in comment field.

At each observation point, additional site attributes were recorded and georeferenced. If a source of trash was obvious and without-question, it was logged within the 30ft reach. Multiple sources were allowed at each observation point, but at no point were speculative "guesses" recorded. For a source to be identified as "present" within the app, trash had to be observed emanating from the source and could not have been deposited by any other method (i.e., stormflow, etc.). The following six trash sources and one stand-alone attribute (scooter) were options for presence/absence in each 30 ft study reach:

- Dumping – known point source
- Dumping – historic dump site
- Dumping – unknown source
- Overflowing dumpster
- Encampment
- Outfall/Tributary
- Property Management
- Scooter

Descriptions of each of the parameters is provided in the Results section. A comment field was also provided to record such information as the name of the scooter company and any other salient information the team deemed important.

Geospatial Analysis

Segmented buffers generated along surveyed creeks were used as the spatial unit to relate trash observation with potential drivers of trash presence (e.g., land use, roads, impervious cover). ESRI ArcGIS Pro 2.9.2 and Safe Software Feature Manipulation Engine 2021 were used to generate segmented buffers. The process was to first buffer creek centerlines to widths of 300 feet and 3000 feet and then cut the buffers into segments every 300 linear feet and 3000 linear feet, respectively (Figures 7 and 8). Segmented buffers generated by software were manually inspected and modified so that segment breaks were roughly perpendicular to creek lines and consistently applied around bends and meanders.

Trash observation points and spatial data representing potential drivers were then associated with the intersecting 300-foot and 3000-foot segments. Trash observation points were each assigned the unique ID values of the intersecting segments. Nine types of drivers were associated with each segment (Table 1).

Table 1. Potential drivers associated with trash observations via creek buffer segments

Driver	Data source	Spatial association, per segment
Land use	Land Use Inventory Detailed, COA Planning and Zoning Dept.	Overlapping area and percentage cover of parcels intersecting segments, by land use class.
Impervious cover	Impervious Cover 2019, COA Watershed Protection Dept.*	Overlapping area and percentage cover of impervious features intersecting segments, by feature type.
Street centerlines	Street Segments, COA Transportation Dept.	Linear feet and segment count of street centerlines intersecting segments, by road class.
Encampments	Observed by field staff	Attributes of homeless activity points within segments.
Points of interest	Open Street Map	Count of ways and nodes intersecting segments, by type.
Population	2020 Decennial Census blocks, US Census Bureau	Population within segment estimated via areal weighted interpolation.
Stormwater inlets and headers	Drainage Infrastructure GIS, COA Watershed Protection Dept.	Count of inlet and header points intersecting segments, by type.
Water quality pond drainage areas	Drainage Infrastructure GIS, COA Watershed Protection Dept.	Count, overlapping area, and percentage cover of drainage areas intersecting segments.

* With definition query applied: *FEATURE NOT IN ('Above Ground Pool', 'Compacted Soil', 'Courtyard', 'Golf Course', 'Gravel/Sandpit', 'In Ground Pool', 'Open Space', 'Quarry', 'Unpaved Athletic Field', 'Paved Ditch')*

In addition to analyzing trends by summarizing the area around creeks, several attempts were made to build regressions with spatial associations of adjacency and concentration of land uses and encampments at various drainage area scales (e.g., storm sewer drainage areas, watershed subbasins), that could explain the trash severity scores. Spatial analysis tools in ArcGIS Pro 2.9.1, such as Exploratory Regression and Colocation, did not yield any insights. Dividing land use categories into more specific values (e.g., “fast food” or “convenience store” instead of “commercial”) was considered in hopes that insight could be gained regarding specific sources of trash (such as stores that generate single use items) however, since land use did not end up being a good predictor of trash (i.e., not a significant correlation with increasing trash), further specificity was not thought to offer better resolution.

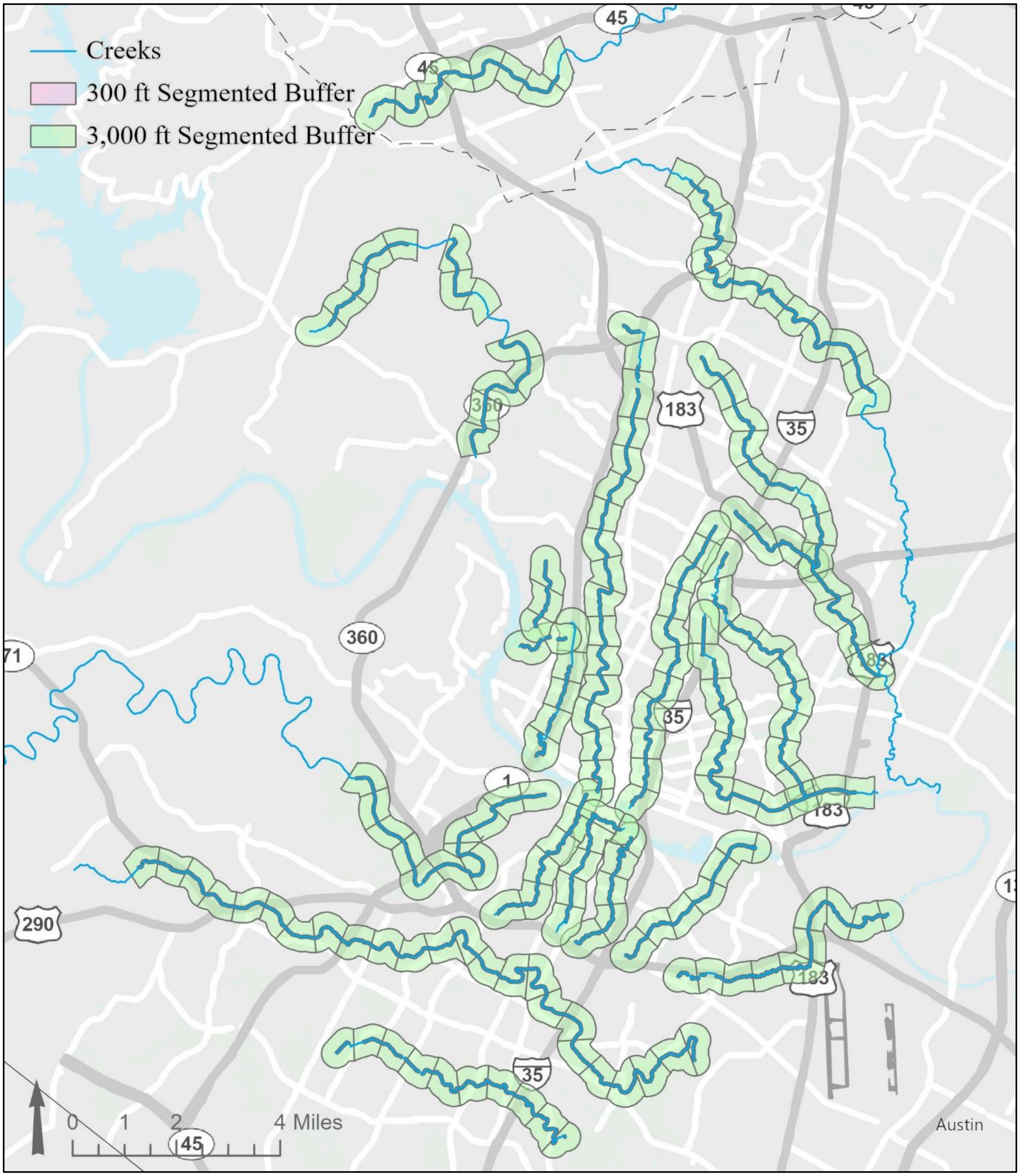


Figure 7. Geospatial analysis units. Data were aggregated into small (300ft, the thinner blue lines) and large (3,000ft, the larger green buffers) linear segments with polygons created with similar widths to characterize the area surrounding and potentially influencing the creeks (e.g., land use, population, etc.).

Figure 8. Within each 300ft (pink) and 3,000ft (green) segment (A), attributes such as population by census block (B), transportation (C), and land use (D) were calculated and correlated to the median value of trash intensity within each respective segment.

Regression Analysis

Surrounding land use types were evaluated for correlations to trash intensity. Median values for trash scores were used instead of mean values because the data were not normally distributed. Medians were compared to the land use characteristics at two different scales. First, the median of trash volume estimates was calculated for 300 ft and 3,000 ft square segments. Second, the land use percentages for each segment were extracted from City land use GIS layers. Standard land use categories were aggregated to a smaller number that more simply represented potential trash sources. Transportation infrastructure was also represented by using the roadway and right of way areas. Median impervious cover in each unit was also calculated using the 2019 City of Austin data.

It was hypothesized that correlation between land use and trash volume would be an indicator of a possible causal relationship. A simple univariate linear regression analysis was performed using the land use percentages for each category as single independent variables and the estimated trash volume as the dependent variable. Impervious cover was also used as an independent variable.

Results

Spatial patterns

The field investigation included 19,467 observation points in over 110 miles of creek within 20 watersheds. Some anomalies in antecedent conditions at a few sites were apparent due to recent trash collection. Individuals performing creek clean ups such as The Other Ones Foundations (TOOF), Keep Austin Beautiful (KAB), Austin Resource Recovery's Clean Creek Crew, creek-adjacent landowners, other contractors and volunteers may have affected surveyed areas in the preceding days/weeks/months. However, effects of these anomalies on the results are thought to be insignificant due to the large total number of observation points. Over half of the observations were in the "minimal category" (volume ≤ 1gallon) and approximately a quarter were in the "apparent category" (volume that fits in a 5gallon bucket). A surprising 25% of the surveyed area (~28 miles of creek) were characterized to be in the worst two categories "abundant" (requires a 25gallon trash can) and "dense" (requires one or more 55gallon trash bins) (Figure 9). Although the "dense" category was only observed at 10% of all the sites, it accounted for 76% of all the trash by volume.

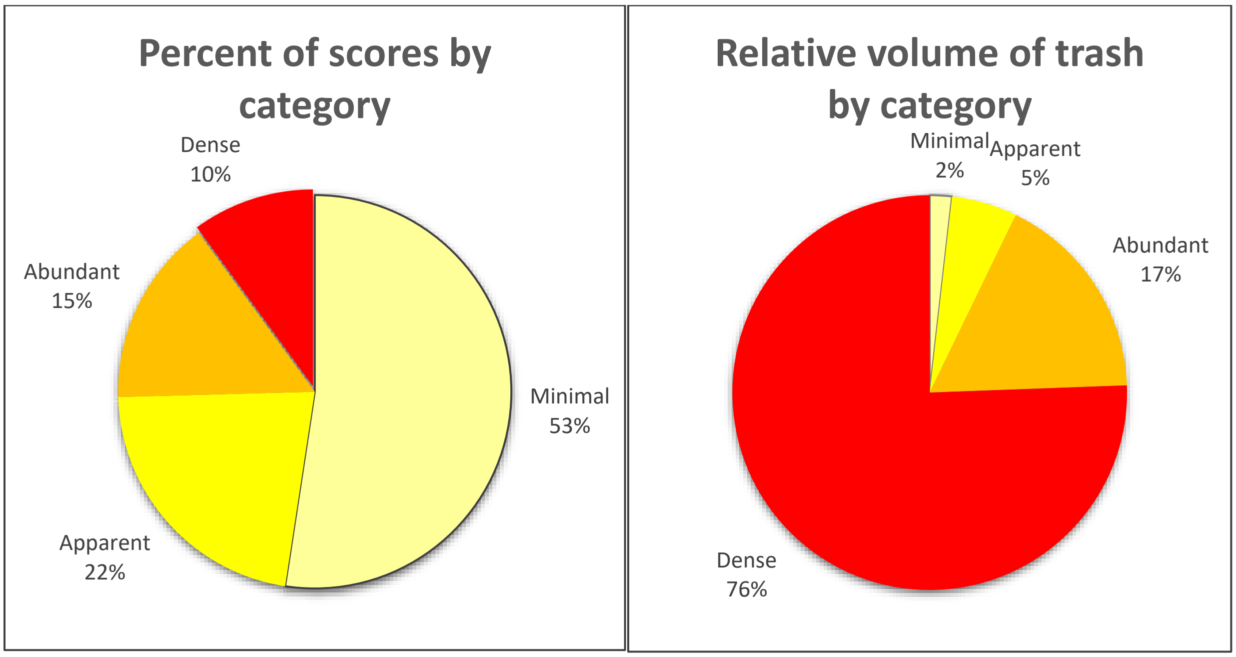


Figure 9. Trash intensity scores (left) and relative amount (right) of trash by category. Most scores were in the "minimal" category, while roughly a quarter were in the two worst categories "abundant" and "dense". The dense category, 10% of the observations, accounted for 76% of the total trash volume and the combination of these worst two categories accounted for 93% of all the trash by volume.

Trash intensity scores within the Council Single Member District varied greatly (Figure 10).

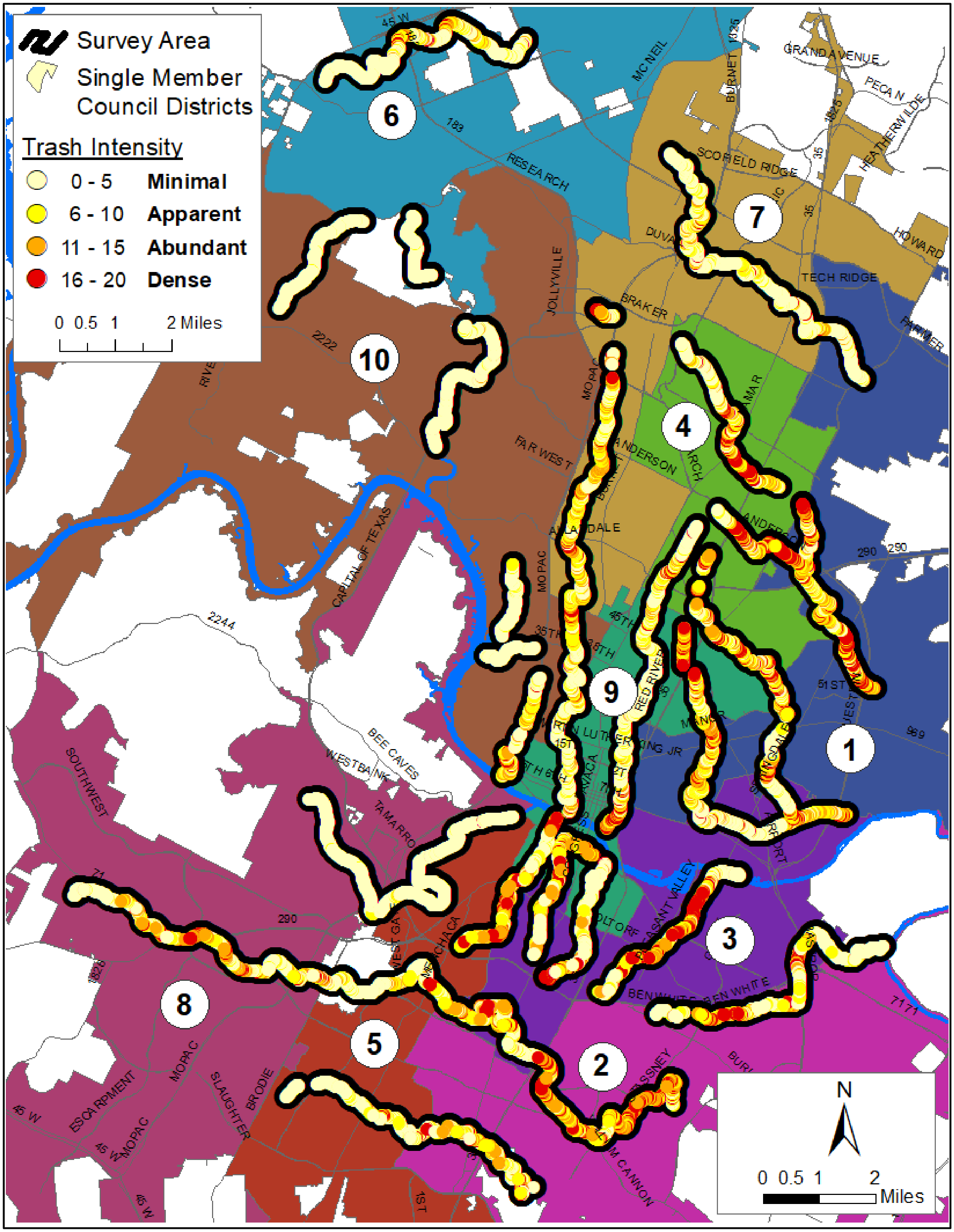


Figure 10. Overview of trash intensity scores for survey area within Single Member Districts

Determining the relative contribution of trash from a specific source depends greatly on the conveyance of trash through the stream network system. An experiment that assesses the contribution of a localized trash source could be designed to sample upstream and downstream of the source input to assess relative increase at one point in time, or throughout time. That experiment would require the assumption that all trash travels downstream and travels at a similar rate, otherwise the design will not work. Anecdotal observations by staff senior environmental scientists indicated that trash did not appear to simply move downstream as evenly as one might assume. To test the relationship of trash moving from upstream to downstream, the data points from the survey were normalized by their position in the creek and plotted against the trash intensity score. Normalizing stream position (ordering all observations incrementally from upstream to downstream) enables trend analysis for intensity within a creek as well as comparison to other creeks. If it were true that most trash flows through the creek from upstream to downstream, then as the watershed grows bigger (more land, more tributaries, more outlets), then trash intensity should grow larger downstream.

The rate at which trash is conveyed downstream varies greatly. Mobility is generally dependent on 1) the item (buoyancy, shape, size, weight, etc.), 2) the water (velocity, depth, frequency of storms) and 3) the roughness, or complexity of the stream and riparian corridor. Floatables like beverage bottles may quickly transport down the stream, however, large, irregularly shaped and/or flexible items (fabrics, foam rubber, erosion matting, etc.), can easily become entrained in stream vegetation. Woody vegetation in the stream and riparian corridor provides stability and integrity to the stream system, but with this advantage comes entrainment of trash. This "straining" effect can be seen as a benefit because it keeps some trash from entering the stream and also provides a natural detaining focal area for staff, contractor, or volunteer efforts to extract trash from the system.

This is an important facet of an evaluation of the various source relationships because sources found in the lower watershed may inherently appear to contribute disproportionate amounts of trash as well as the converse. Creeks in which trash intensity increases in a downstream trend should show a trendline upward to the right (increasing score downstream). Creeks in which the inverse is true (trash intensity decreases downstream) will show a trendline down to the right. A flat (or virtually flat) trendline indicates that trash intensity is effectively the same regardless of stream position.

Fortunately, there were no major storms during the survey period for any creek that would have otherwise redistributed trash from upstream to downstream. Although the trend lines may appear to show some relationships, none were very strong. R^2 values provide an indication of the strength of the relationship between the driver (stream position) and the response variable (trash score), an R^2 of 1.0 is a perfect predictor, >0.7 would be considered strong predictor and <0.4 would be considered weak at best. However, even with some significant relationships in some watersheds, the overall trends were inconsistent, with the same number of creeks showing increasing trends downstream as those showing increasing trends upstream and at least a quarter of the creeks showing no trend at all (Figure 11).

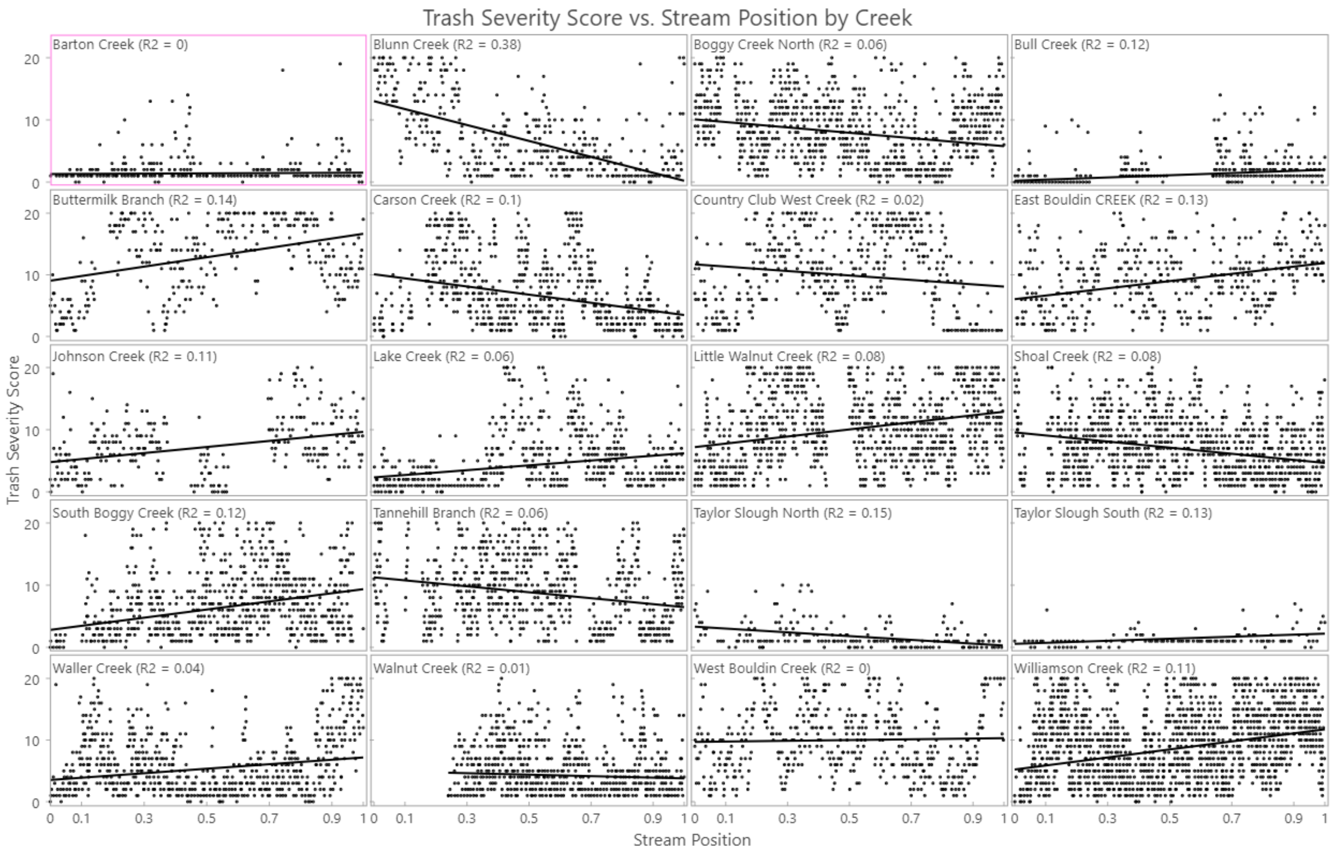


Figure 11. Trash score is poorly predicted by stream position (R^2 0 - 0.4) in all surveyed watersheds. Scores plotted against creek position (normalized from 0=farthest upstream to 1=farthest downstream) show that 40% of the creeks have a weak trend for increasing trash downstream, 35% of the creeks have a weak trend for increasing trash upstream and 25% of the creeks show no discernable trend. However, none of the relationships were very strong (all R^2 <0.40)

Our results show that stream position does not predict trash intensity. This finding is important because it implies that trash does not flow in such a uniform manner that a particular point source could be evaluated for its effect on a stream by comparing trash upstream and downstream of that point. Further, it implies that trash intensity in a creek is either a result of diffuse or combined local inputs that are typically not mobile and/or that stream roughness might predict trash scores (i.e., trash detained in areas of thick vegetation or rough stream beds).

Spatial Distribution of Trash Sources

Seven types of trash sources were pre-selected for field identification and location including:

- encampments,
- property management,
- overflowing dumpsters,
- outfall/tributary,
- historic dumping,
- recent point source/known dumping, and
- recent unknown dumping

These sources were observed 869 times in the 110 miles of creek that were surveyed. Frequency of occurrence (Figure 12) for each source indicates that encampments (352 observations) were by far the most common source in the survey area. Volume of trash doesn’t necessarily correlate with these sources because of the different physical and anthropogenic characteristics of each source. For example, illegal dumping is a focal point that typically creates a high score in one observation point, but property management may be diffuse and extend for several linear observation points but with lower scores. Regardless, some sources (such as encampments) were very common while other (such as overflowing dumpsters) were not.

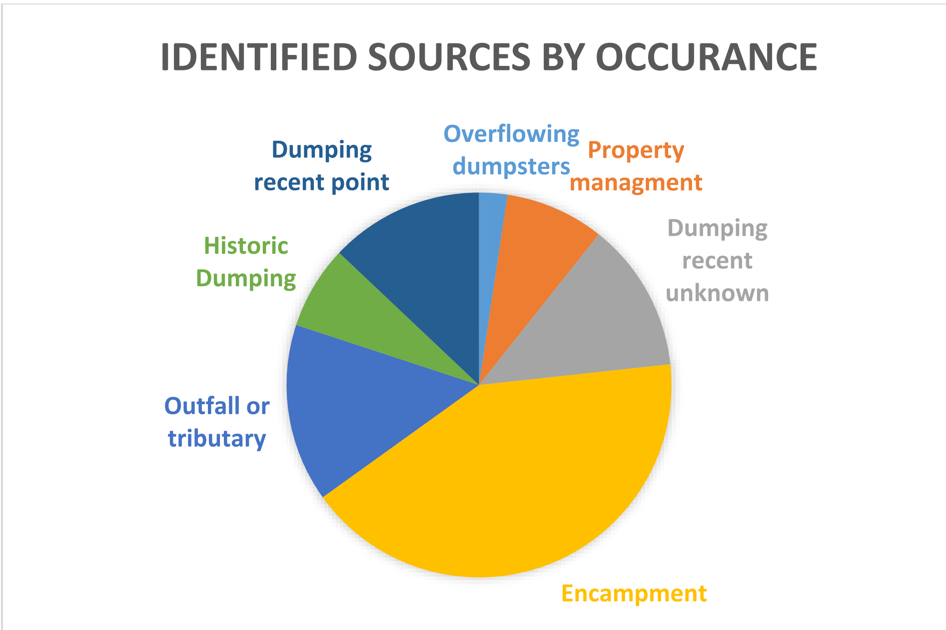


Figure 12. The seven potential trash sources selected a-priori and logged during field surveys, and their relative frequency of observation.

The following sections provide a narrative and spatial description of each of the observed seven sources in addition to observations of micromobility devices (i.e. “scooters”).

Scooters

Dumping/abandonment of micromobility devices (herein “scooters”) was a concern expressed in CIUR 2234. Scooters provide an inexpensive and low-pollution alternative to traditional transportation, however, when they are dumped in creeks, the scooters effectively become large trash items, obstructing flow and potentially contributing to ancillary pollution through degradation of the various components (e.g., battery, plastics, electronics, etc.). The field survey observed a total of 21 abandoned/dumped scooters in the 110 miles of stream channel (Figure 13). Although this is an average of 1 scooter for every 5 miles of creek, most scooters were in the downtown area. The vendor is responsible to collect abandoned scooters. The location and description (photograph suggested) of an abandoned scooter should be communicated through 311 to the Austin Transportation Department (ATD), or directly to ATD. ATD then contacts the respective vendor who has 24hrs to retrieve the device. A provider’s failure or refusal to recover devices from waterways could result in action directed by ATD, such as suspension of operations or permit revocation. To date, ATD indicates that providers have demonstrated cooperation in retrieving reported devices in waterways and ATD has not encountered issues where licensed providers were unable to retrieve a device. Devices that do not belong to a currently licensed provider are retrieved with City assistance.

Figure 13. Observations of micromobility devices (“scooters”) abandoned/dumped in the survey area

Active/Observed Encampment

Presence of "encampment" was recorded for any site with an active camp site with peripheral trash if they constituted a living space such as sleeping areas, food preparation, storage of possessions, etc. Loitering was not considered "encampment." 352 active encampments were observed in 17 of the 20 watersheds (Figure 14). Bull Creek, Taylor Slough North and Taylor Slough South were the only creeks in which encampments were not observed. Size ranged from single campsites to comingled aggregates of tents/temporary structures. Most encampments were concentrated in urban watersheds, but some extended to the farthest reaches of the survey area indicating that there are no boundaries to the activity. Some encampments were associated with large amounts of floatables, containers, fabrics, possessions, etc. resulting in "Dense" or "Abundant" scores, however, other encampments were virtually clear of trash resulting in "Minimal" or "Apparent" scores. Similarly, survey staff observed people in the encampments actively littering, but also observed people cleaning up trash as well which is indicative of the wide diversity of people experiencing homelessness. Some encampments had been supplied with trash receptacles, and others were in locations inaccessible to these services.

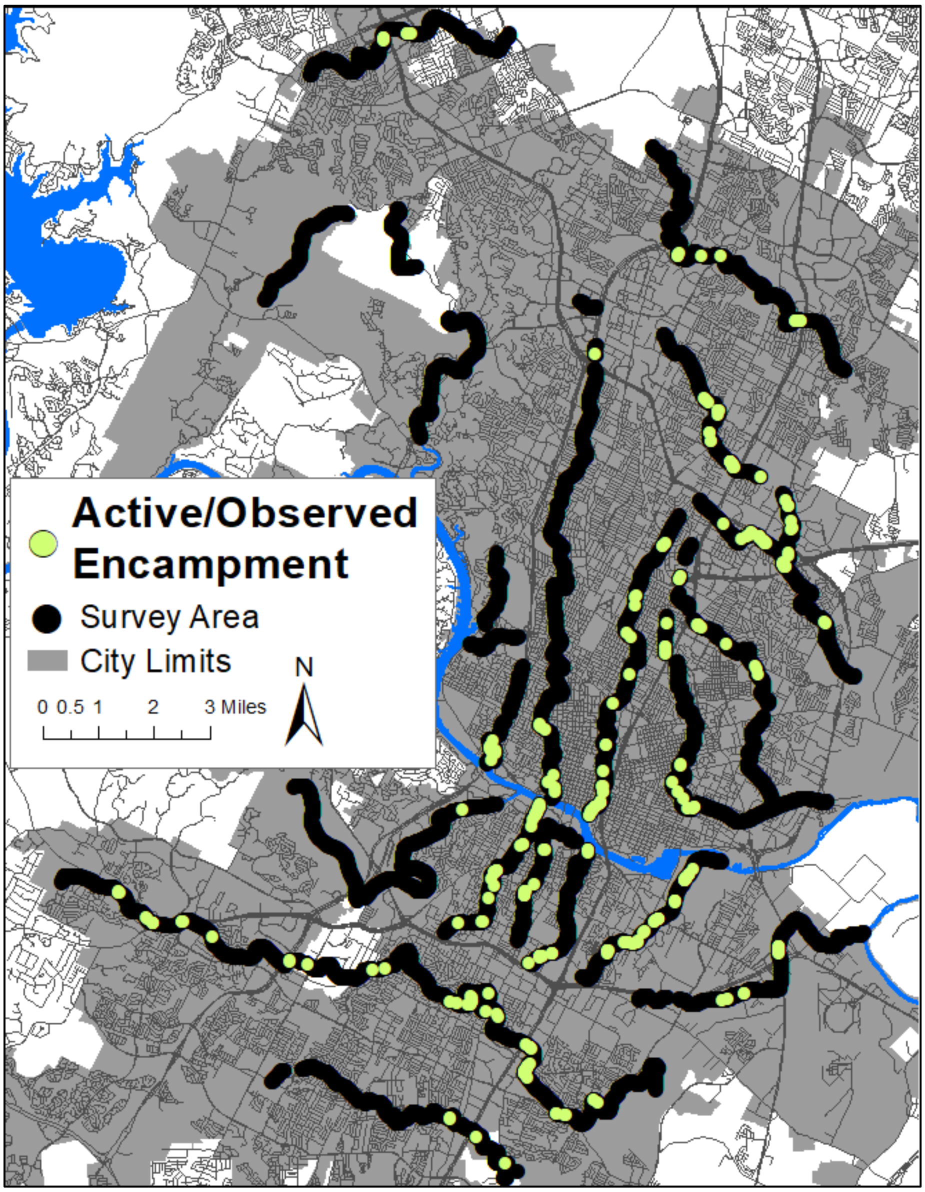


Figure 14. Observations of encampments with clear and present trash inputs in the survey area

Overflowing Dumpsters

Only 20 overflowing dumpsters near creeks were observed (Figure 15). They were often associated with high concentrations of trash but present a seemingly easily preventable problem compared to other sources because they indicate either an undersized capacity or deficient frequency of emptying rather than human disregard for misplaced trash. Overflowing dumpsters that do not have barriers surrounding them are even more likely to contribute to trash in creeks.

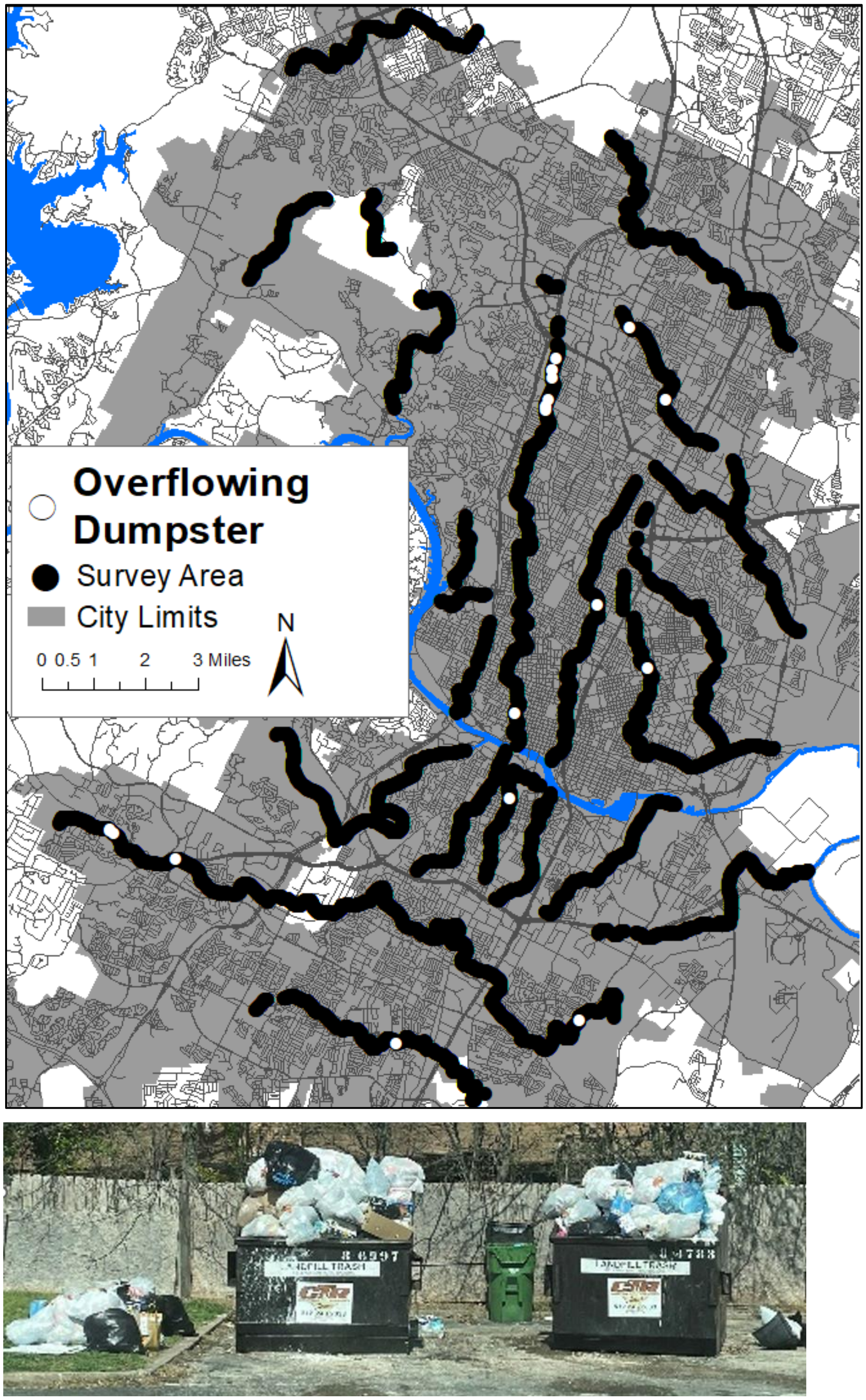


Figure 15. Observations of overflowing dumpsters in the survey area

Outfall or Tributary

Storm drains and tributaries effectively do the same thing: they collect/concentrate stormwater that has washed over the landscape and deliver contents to the creek mainstem. Although all outfalls and tributaries can be sources of trash, there were 126 observations (Figure 16) in which accumulations of trash were notable. Significant amounts of trash emanating from outfalls/tributaries reveal information about the catchment area, such as a lack of stormwater controls, an anomalously large source and/or an opportunity to isolate and address a trash problem.

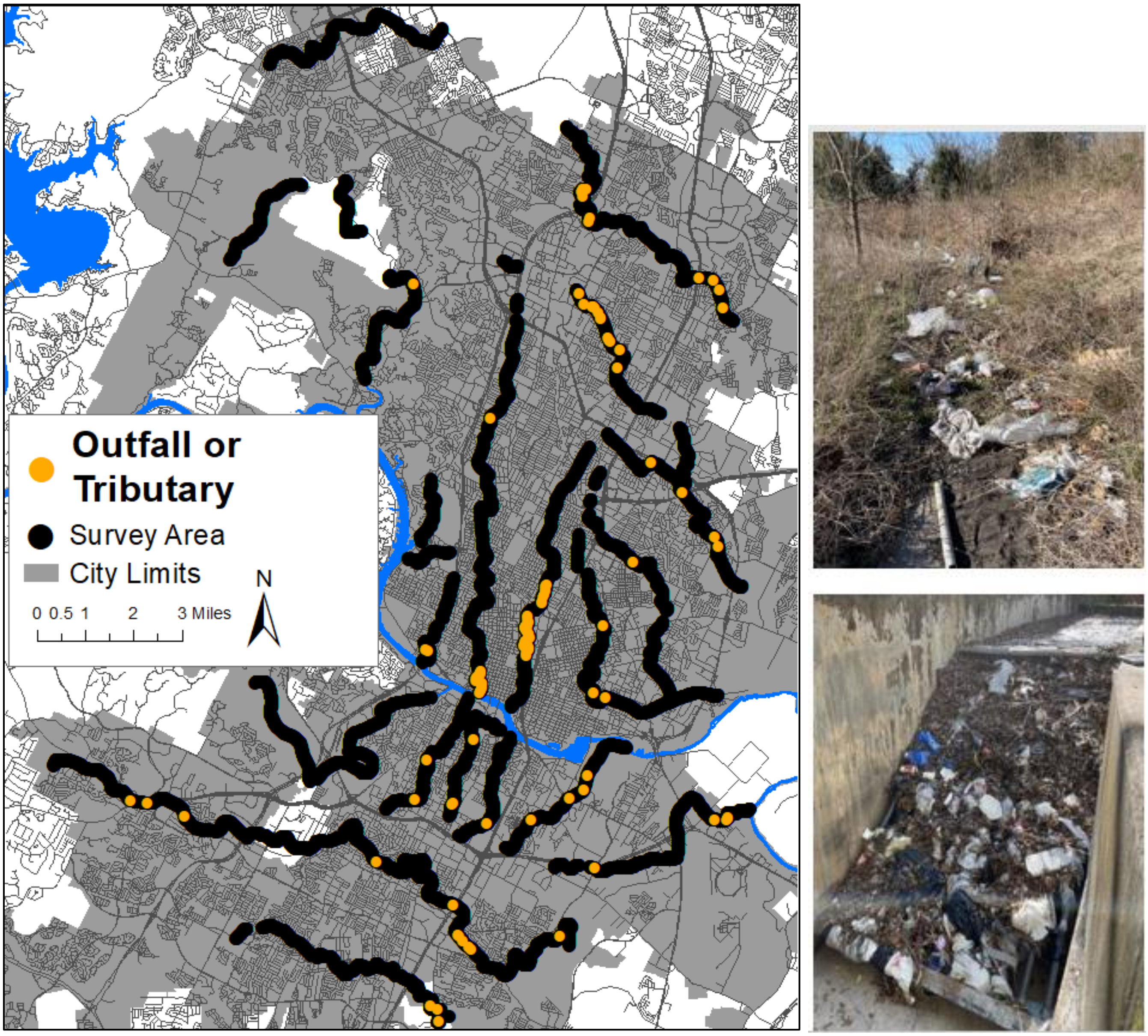


Figure 16. Observations of outfalls/tributaries with notable trash inputs in the survey area

Recent Dumping - Unknown Source

There were 106 observations (Figure 17) of recent illicit disposal for which the responsible party is not apparent. This meets the State definition of "Illegal Dumping" reserved for items that have been knowingly transported from a non-adjacent location. Illegal dumping violations can carry misdemeanor or felony charges (Texas Health and Safety Code and/or the Texas Water Code), however, identifying and convicting a perpetrator is extremely difficult. The ease at which an offender can quickly dump bags of trash or large items over a bridge or slope facilitates this activity. Although it is sometimes possible to sift through the trash for clues to identify the perpetrator, the task is daunting. Sites with illegal dumping may encourage additional dumping, so expeditious removal is important. This type of dumping was absent in 6 watersheds (Figure 17) but was common in others.

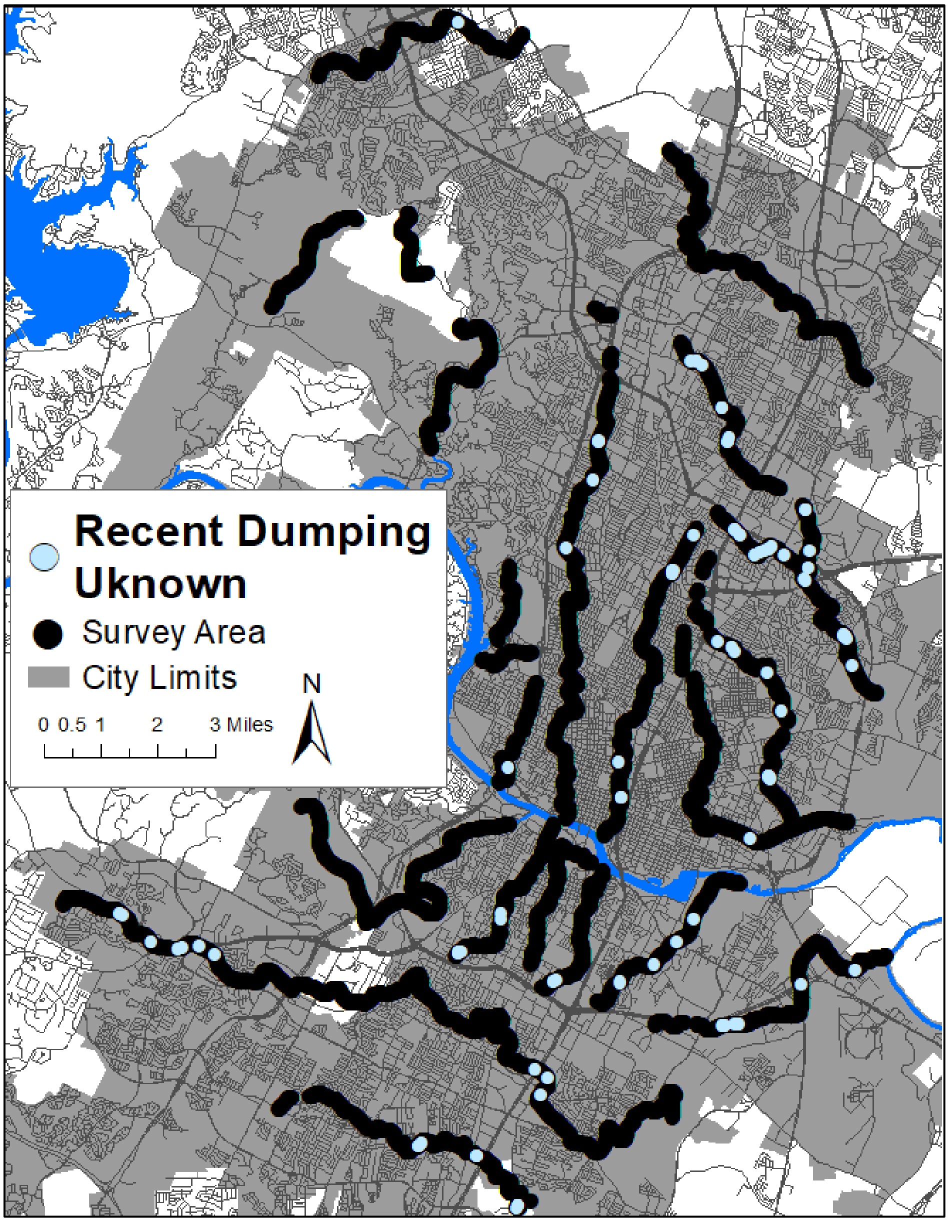


Figure 17. Observations of recent dumping with unknown sources

Recent Dumping – Known or Point Source

Observations of dumping (Figure 18) in which the source of the trash is obvious was as common (109) as unknown sources (106). Recent point sources were intentional disposal of trash by an identifiable residence, commercial entity, or other responsible party. They frequently included construction materials, landscaping/gardening, household waste, fencing, home renovation materials, and industrial refuse. Enforcement action should be feasible. Most locations were in low visibility areas (fence abutting creek). Violations can carry misdemeanor or felony charges (Texas Health and Safety Code or the Texas Water Code) which should be a deterrent, but the threat of potential referral for enforcement may be more effectively used as an incentive for the landowner to clean up the trash even if the responsible party denies culpability.

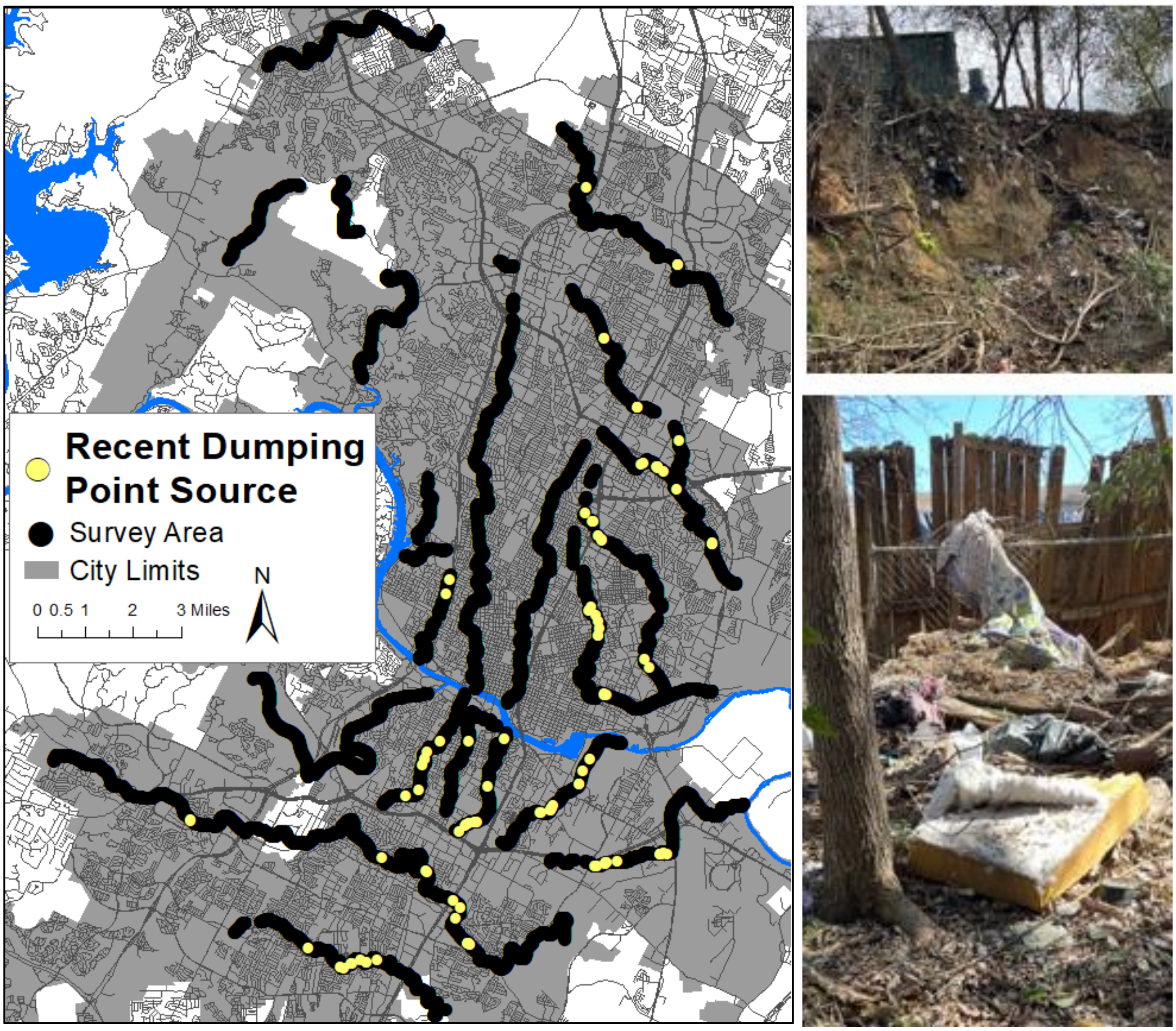


Figure 18. Observations of recent dumping with identifiable sources

Property Management

"Property management" sources are similar to "Recent Dumping- Point Source" but refers specifically to activities that property managers or their contractors do or don't do with respect to trash on their property. Examples include neglected or intentional disposal of items like mattresses, carpet, building materials, maintenance materials, and the inappropriate use of leaf blowers. Improperly disposed of items from apartments and commercial lots were observed 70 times and occurred in half of the creeks of the survey area (Figure 19). Although large items such as furniture, office items and building materials dumped over fences into creeks or on the banks may have been deposited by tenants, it is still the responsibility of the property owner to address. Similarly, the actions of landscaping and maintenance workers that routinely sweep or blow leaves/grass/trash from parking areas into storm-drains and riparian areas are responsible to property owners. Individually, the littering tenant or worker could be responsible for the action and enforced upon (if caught in the act), but ultimately the property owner should monitor/address these issues and implement corrective actions to prohibit or limit the improperly disposed of trash. Physical barriers such as a chain link fence between parking areas and riparian corridors were observed to intercept and retain trash while properties with no physical barriers were observed to have years of blown leaf litter mixed with trash onto the banks of creeks.

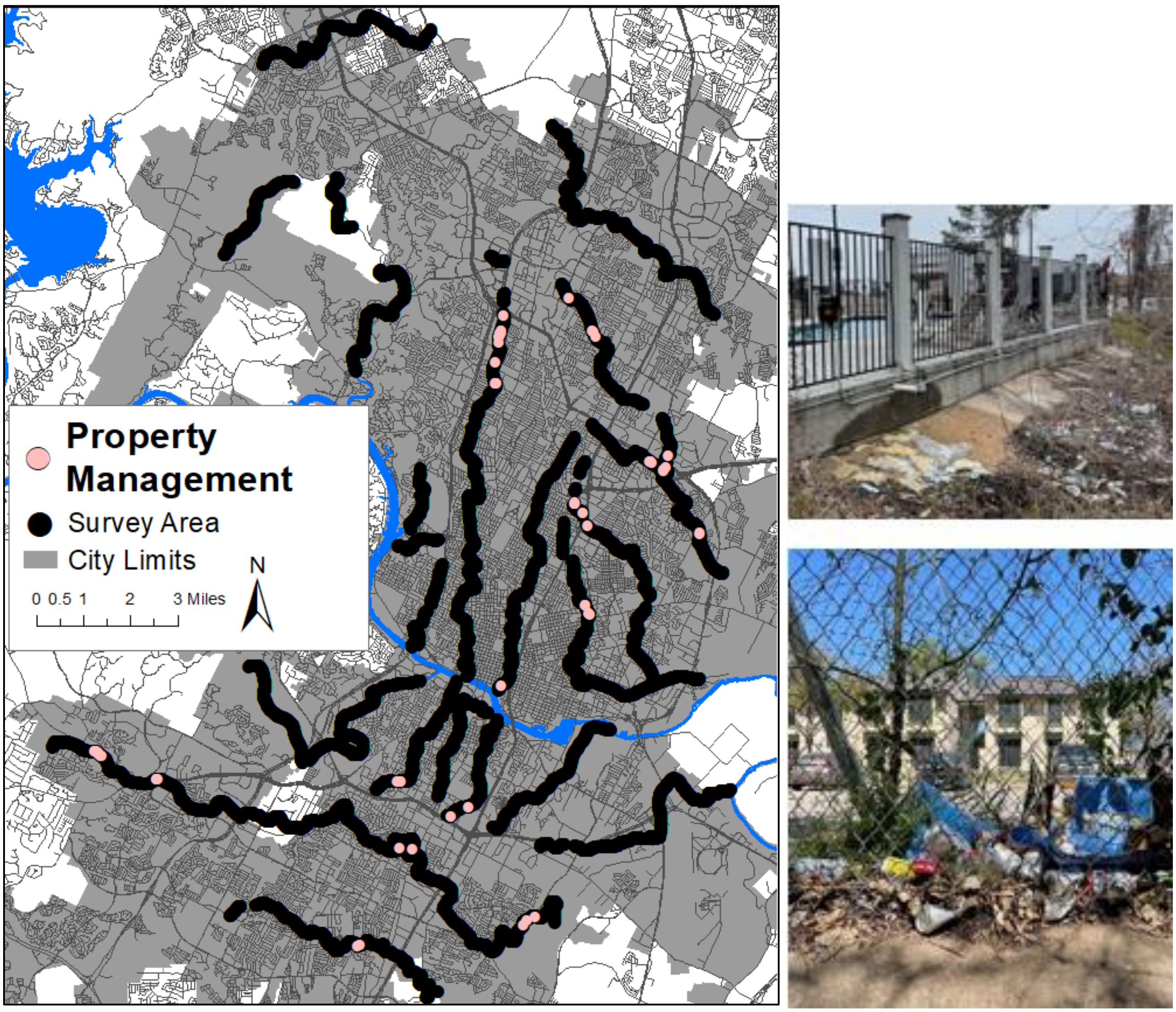


Figure 19. Observations of property management that resulted in obvious trash inputs

Historic Dumping

These location sources were generally items dumped in piles or partially buried in the past, but have more recently been exposed due to erosion or storm events. Age is evident from material degradation, weathering, lichens, moss, etc. Dumping may be small or substantial but does not appear to be currently taking place. Observations of trash that had been improperly disposed of decades ago (either by burial or dumping on slopes/floodplains) were relatively few (Figure 20) compared to other sources. 59 instances of varying degree were either identified by antiquated items degraded by time or revealed by erosion exposing a cross section of buried garbage. Historic dump sites near creeks did not appear to be a significant source of trash relative to the other identified sources but can present a persistent and chronic contribution of trash of all sizes in creeks. In contrast to the current dominant types of trash in creeks (plastics and fabrics), historic dumping is primarily composed of metal and hard building materials (brick/tile/cinderblocks) that have degraded slowly.

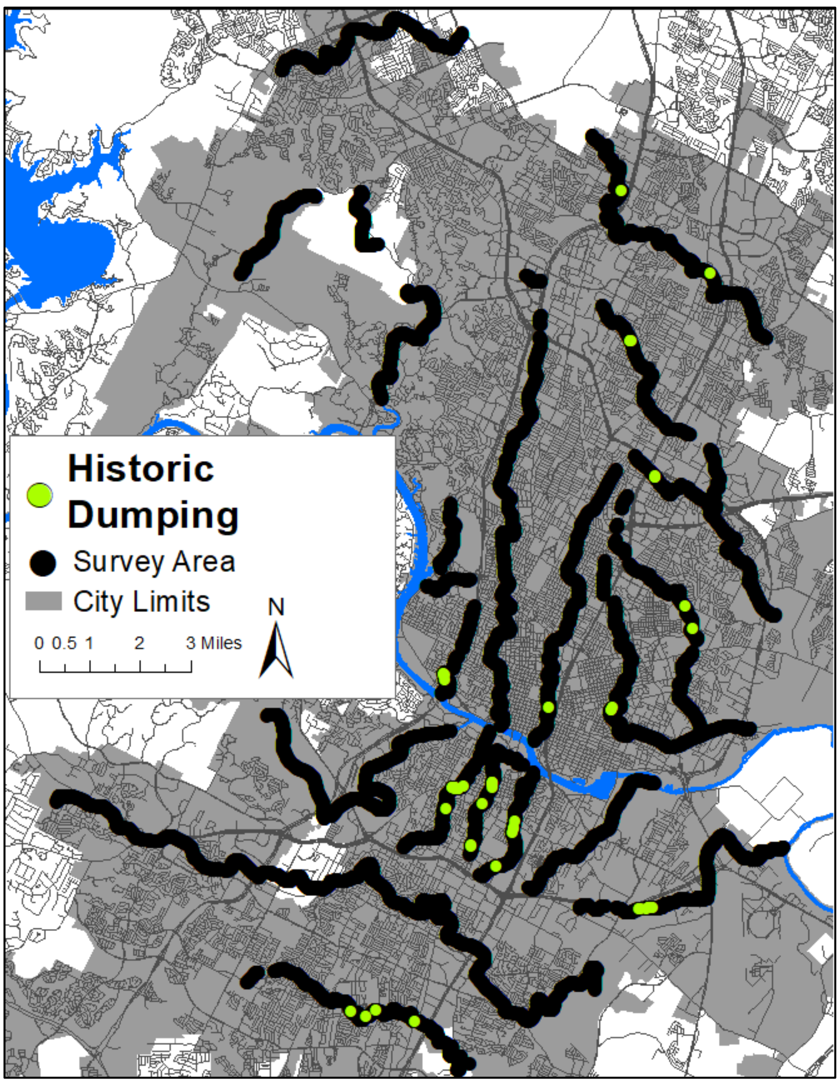


Figure 20. Observations of historic dumping locations.

Districts 1, 2 and 4 all shared the highest median score of 9 (out of 20) and higher total volumes of trash, while sources of trash per mile of creek indicated that these high values are due to a combination of different sources, including different dumping types and encampments (Table 2).

Table 2. Number of surveyed creek miles, median scores, gallons of trash, and average number per mile of trash sources in the ten Council Districts.

			Average Numbers per unit mile							
District	survey miles	median score	gallons of trash	dumping historic	dumping recent - point source	dumping recent - unknown	overflowing dumpster	encampment	property management	outfall/ tributary
1	10.3	9	4237	0.4	1.5	2.0	0.0	2.8	1.3	0.9
2	12.4	9	3633	1.1	2.6	1.2	0.2	3.3	0.4	1.0
3	15.7	7	3858	0.7	2.1	0.8	0.0	6.4	0.5	0.7
4	8.6	9	4845	0.7	1.5	3.5	0.2	6.3	1.4	1.7
5	7.2	2	945	0.0	0.1	0.7	0.0	0.7	0.0	0.1
6	5.3	1	947	0.0	0.0	0.0	0.0	1.7	0.0	0.0
7	11.5	5	1139	0.2	0.3	0.4	0.7	1.0	1.3	0.6
8	9.8	1	1518	0.0	0.2	0.8	0.4	1.6	1.4	0.3
9	14.2	6	2584	1.3	0.5	0.3	0.3	5.2	0.2	4.4
10	11.7	1	611	0.3	0.2	0.1	0.0	0.9	0.0	0.3

Multiplying the estimate of trash volume and clean-up time (provided in the scoring rubric, Figure 6) by each of the 19,467 scores yields an estimate for the total volume and clean-up time for the entire survey area. Assuming the non-surveyed creeks (117 miles of mainstem creeks) within the City of Austin full purpose jurisdiction (city limits) are generally similar to the surveyd creeks, then the total volume and clean-up time can be estimated for the city limits the and extra territorial jurisdiction (Table 3). These estimates would need to be scaled up further if all creeks with CWQZ are desired. There are approximately 628 miles of CWQZ creek in the city limits and an additional 650 miles in the ETJ.

Table 3. Estimated volume of trash and time to pick-up* trash by each trash score extrapolated to total miles of mainstem creeks in the City Limits and the Extra Territorial Jurisdiction.**

			Volume (gallons)			Time (hours)		
	Trash intensity score	Total number of observations	volume of trash in survey area (110mi)	volume of trash in mainstems of city limits (227mi)	volume of trash in mainstems of ETJ (161mi)	Time to pick up trash in the area (110mi)	Time to pick up trash in mainstems of city limits (227mi)	Time to pick up trash in mainstems of ETJ (161mi)
Minimal	0	782	0	0	0	0	0	0
	1	4260	1065	2198	1559	71	147	104
	2	2007	1004	2071	1469	67	138	98
	3	1225	919	1896	1345	61	126	90
	4	1044	1044	2154	1528	70	144	102
	5	885	996	2055	1457	74	152	108
Apparent	6	1011	1106	2283	1619	118	243	173
	7	1020	2528	5216	3699	153	316	224
	8	646	3825	7893	5598	118	244	173
	9	745	3230	6666	4728	161	333	236
	10	892	4191	8648	6134	223	460	326
Abundant	11	901	4656	9609	6815	451	930	659
	12	773	11150	23010	16320	387	798	566
	13	460	16894	34863	24726	230	475	337
	14	453	19325	39880	28285	227	467	332
	15	408	14260	29427	20871	204	421	299
Dense	16	354	27379	56500	40073	207	426	302
	17	243	36795	75932	53855	182	376	267
	18	371	49555	102264	72531	371	766	543
	19	458	85030	175471	124453	687	1418	1006
	20	529	101200	208840	148120	1058	2183	1549
	total	19467	386150	796873	565183	5119	10563	7492

* time estimates only include the approximate time to collect trash one time and do not count time for mobilization, access, delivery to landfill/recycle, sorting, etc. Or repe

**mainstem creeks do not include the thousands of miles of tributaries.

Statistical Analysis of Trash Sources

Box-and-whisker graphs are often used to show summary statistics for large datasets in a distilled and easily comparable way. In the graphs below, the median of the dataset is expressed as a thick horizontal line within a "box" that represents the boundaries of the 25th and 75th percentile for the data (i.e., the "middle half" of the data). The lines extending vertically from the box are an expression of the "range" of the data, but it does not show the full extent, rather it extends 1.5 times the difference between the 25th and 75th percentile and the median. Median was used (rather than mean) because the data was not normally distributed (i.e., the scale for scoring was not linear).

The source type "Dumping Unknown" had both the highest median and highest 25/75 percentile range (Figure 21). The median value for "Encampment" was the second highest, however there was a much wider range of values, which matched the anecdotal observation that there was a wide variety of ancillary trash at encampments, and also the variability of "size" of encampments (e.g., number of residents, intensity of use, etc.). "Outfall/tributary" had the lowest median and range and was the only source for which the bulk of the scores were low. This data summary implies that "Dumping Unknown" is a focal point characterized by the highest intensity of trash compared to the other sources. The other forms of dumping (historic and point source), overflowing dumpster, encampment and property management were all comparable in median scores and 25th/75th range.

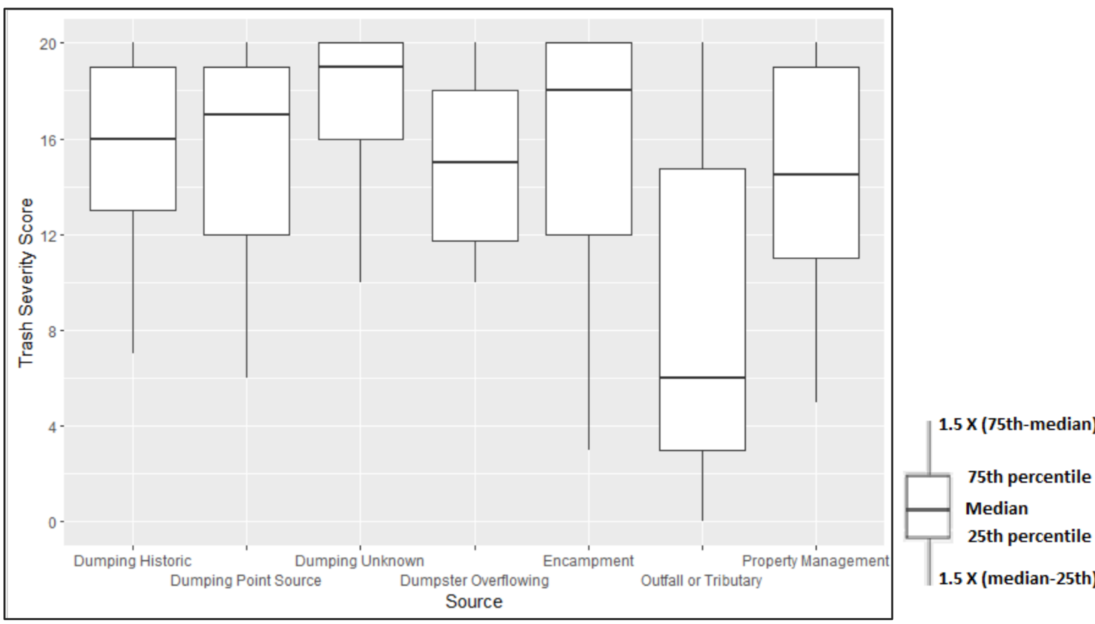


Figure 21. Trash score medians and 25th/75th percentile by source type. With the exception of "Outfall/Tributary" sources had similar medians with the majority of data points in the Abundant (11-15) and Dense (16-20) score categories.

Regression analysis can estimate the relationship between a dependent variable (trash intensity) and various independent variables. For example, a hypothesis that a land use is correlated with trash intensity could be assessed by the slope, variance (R^2) and "fit" (p-value) of land use vs. trash score plots. A threshold of significance is typically considered to be $p<0.05$. Regression analysis of different land characteristics (land use, population, roads, impervious cover, etc) at different spatial scales (300' and 3000' reaches) yielded no significant relationships (Figure 22 and Table 4).

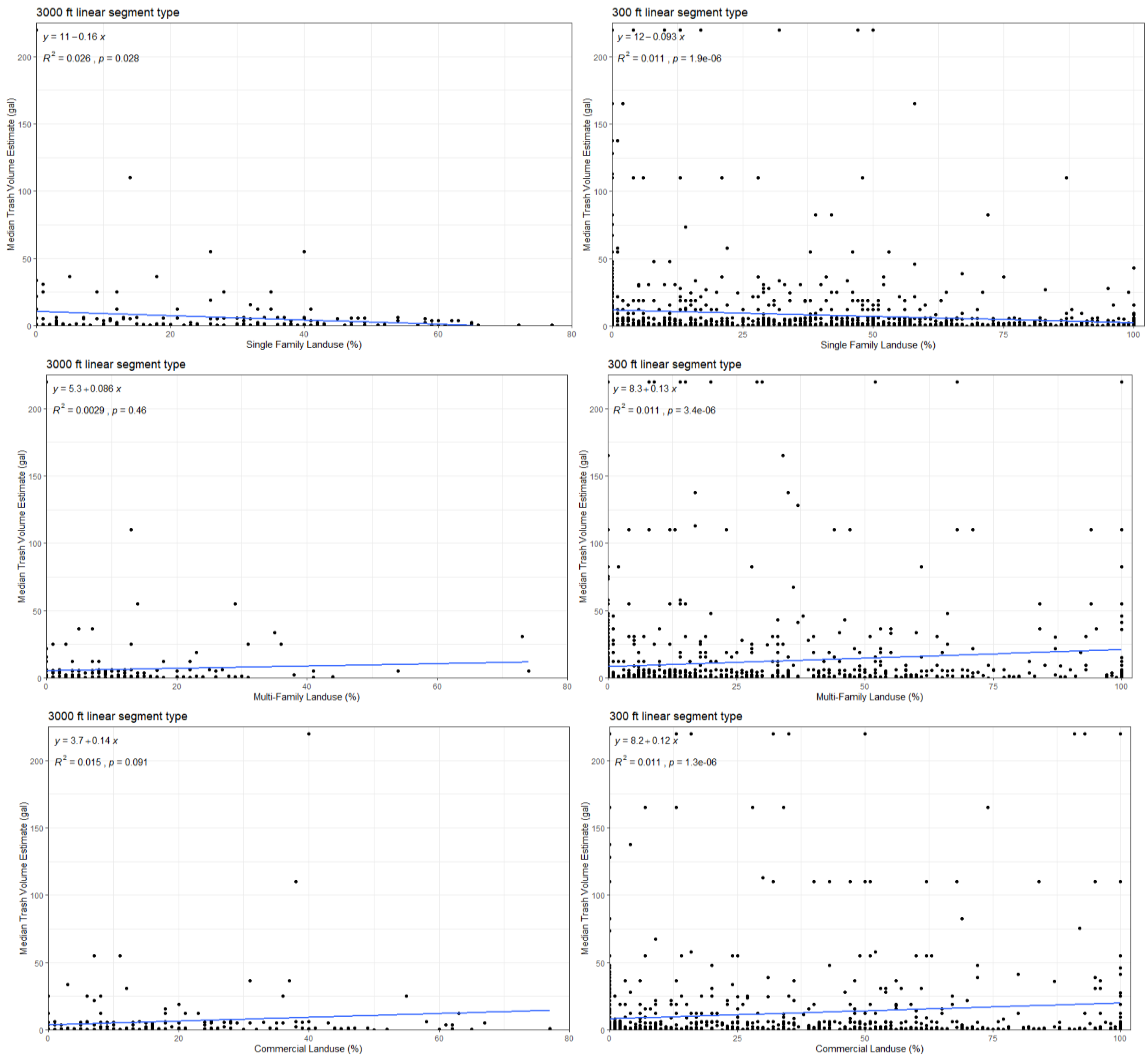


Figure 22. Examples of regression analysis of 3,000 ft and 300 ft reach lengths for the land use categories of Single Family, Multifamily and Commercial against the total estimated volume of trash (converted from trash score using the scoring rubric, Fig 6)

Of the seven land characteristics evaluated (Table 4), even the strongest relationships (% Single Family, % Multifamily, and % Commercial) were not good predictors of trash scores explaining less than 3% of the variability in the data ($R^2<0.03$). Some had significant relationships because of the large number of data points ($p<0.05$), but none of these independent land use variables had meaningful relationships with trash volumes

Table 4. R^2 and p-values for regression analysis of surrounding land characteristics vs. trash intensity

Independent Variable	3,000 ft reach length		300 ft reach length	
	R^2	p-value	R^2	p-value
Single Family Landuse	0.026	0.03	0.011	0.0000015
Multifamily Landuse	0.029	0.46	0.011	0.0000034
Commercial Landuse	0.015	0.09	0.011	0.0000013
Parks Landuse	0.007	0.25	0.002	0.029
Undeveloped Landuse	0.008	0.23	0.004	0.0031
Impervious Cover	0.006	0.29	0.003	0.022
2020 Population	0.012	0.13	0.008	0.000061
Road area (%)	0.0003	0.94	0.002	0.065

Trash Characterization by Watershed

The watershed with the highest median trash score (14) was Buttermilk Creek which includes high (but not the highest) concentration of encampments per mile in addition to high concentration of dumping and property management issues (Table 5). For a detailed presentation of watershed-specific maps and narratives that provide greater context for the variety of trash related issues in Austin's creeks see Appendix.

Table 5. Trash score summaries, by watershed, from highest (worst) median score to lowest.

Watershed	survey miles	median score	Average amounts per unit mile							
			gallons of trash	dumping historic	dumping recent point source	dumping recent unknown	overflowing dumpster	encamp ment	property manage ment	outfall/ tributary
Buttermilk	2.1	14	10284	1.5	3.4	5.4	0.0	9.3	2.9	0.5
Country Club W	3.7	10	6170	0.0	3.5	1.3	0.0	11.3	0.0	1.1
Little Walnut	7.9	10	5710	0.4	1.3	2.8	0.3	5.7	1.1	2.0
West Bouldin	3.5	10	5788	3.7	2.0	2.0	0.0	9.7	1.1	0.6
East Bouldin	2.9	9	2554	3.1	0.3	0.0	0.3	3.4	0.0	1.0
Tannehill	5.2	8	3055	0.4	1.5	2.1	0.0	2.7	1.3	0.2
Williamson	16.9	8	3360	0.0	0.8	0.7	0.3	4.1	1.1	0.7
Boggy (east)	6.9	7	2324	0.4	1.6	0.1	0.1	2.0	0.7	0.4
Johnson	1.9	7	1573	2.1	1.0	0.5	0.0	5.2	0.0	1.0
Shoal	9.8	6	1538	0.0	0.0	1.0	1.6	0.2	3.0	0.2
Blunn	3.1	5	3275	1.6	2.6	0.7	0.0	4.2	0.7	0.3
Carson	5.5	5	2416	1.8	2.7	1.6	0.0	3.3	0.0	0.9
South Boggy	5.7	5	1899	0.7	1.6	1.6	0.2	0.7	0.3	0.5
Waller	6.1	4	1556	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Walnut	7.6	3	520	0.3	0.5	0.0	0.0	1.4	0.0	1.3
Lake	5.0	2	1146	0.0	0.0	0.2	0.0	1.8	0.0	0.0
Barton	7.1	1	96	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bull	7.6	1	62	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Taylor Slough N	1.4	1	94	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Taylor Slough S	1.8	1	62	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Trash scores for the 2022 survey area can be viewed through an interactive online map (**https://arcg.is/0z48bj0**). This map shows trash intensity with a color ramp from light yellow to dark red in the context of Council Districts and other informative options (Figure 23). The map can be used to identify areas that are the highest priority for staff, contractors or volunteer groups. Storms and future cleanups may change the trash scores over time, however, because trash location appears to be largely driven by stream roughness or a highly localized source (like overflowing dumpster or point source) it is likely that "hot spots" will remain locations of high trash intensity. This means that the map may be relevant for years to come.

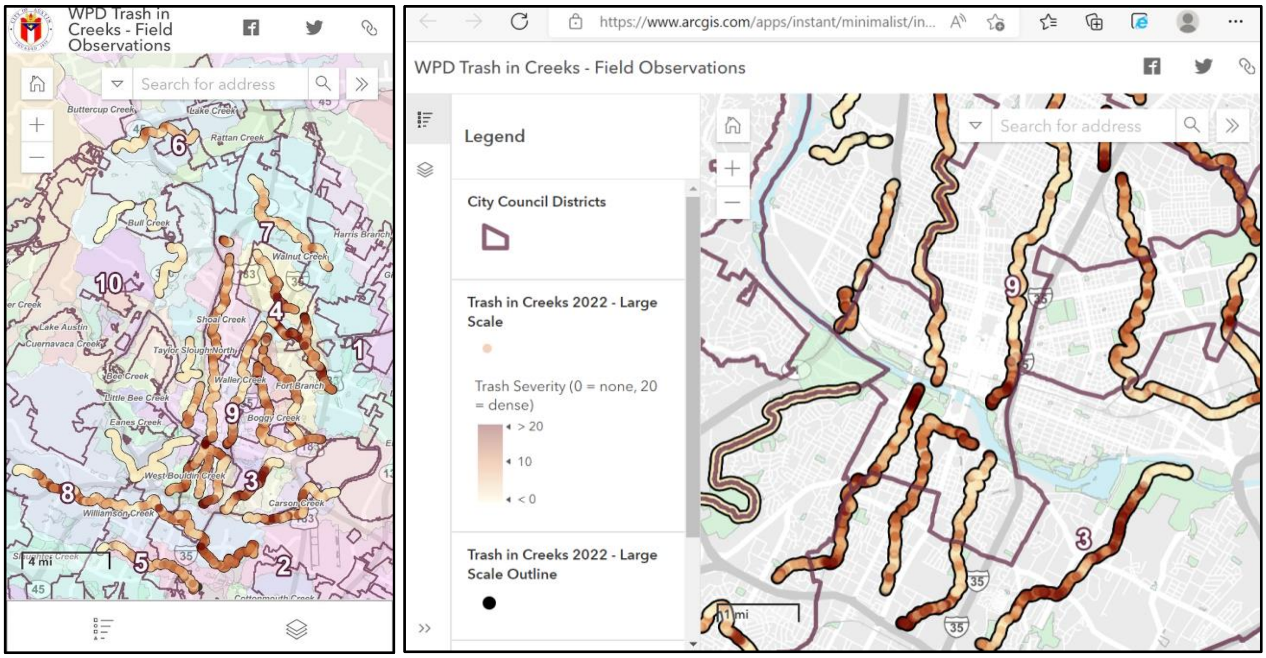


Figure 23. AGOL online website showing results of the field survey in the context of watersheds and council districts. Access the interactive map here: https://arcg.is/0z48bj0

Discussion

Trash in creeks in Austin is a deceptively complex issue. The vision is ugly, the sources are many, the pathways are obscured, and the solutions appear either fleeting or overwhelming. Certainly, increased quantity and number of sources leads to increased trash in creeks, but the dominant factor determining the specific location of trash in a creek is likely stream roughness. Although this factor obscures detection of source and renders it virtually impossible to assign relative contributions to various sources, it does provide a path forward: control the outputs of various sources to the extent practical and implement physical intervention at strategic locations of trash accumulation.

More area does not necessarily mean more trash. Regression analysis indicates that drainage area does not have a strong correlation with trash intensity. The rate at which trash is conveyed downstream varies greatly. Mobility is dependent on 1) the item (buoyancy, shape, size, weight, etc.), 2) the water (velocity, depth, frequency of storms) and 3) the roughness of the stream and riparian corridor. Floatables like beverage bottles may quickly transport down the stream, however, large, irregularly shaped and/or flexible items (fabrics/foam rubber/erosion matting/etc.), can easily become entrained in stream roughness like vegetation. Woody vegetation in the stream and riparian corridor provides stability and integrity to the stream system, but with this advantage comes entrainment of trash. The survey indicates that 76% of all the trash in creeks is located at only 10% of the area, with most intense accumulations occurring at locations which physically strain the trash from storm flow downstream of either high, acute inputs or low, chronic inputs.

By far, the most abundant type of trash encountered in all creeks was single-use plastic beverage and food containers (Figure 24). Even though these items are conveyed quickly through the system by storms, they persist in all parts of all streams as the most common item.

Figure 24. Single-use plastics are (by far) the most numerous trash type in all watersheds

Although single use plastics were the most common item, there were several types of trash that warrant mention as they illustrate that the source of the problem is at the community level. No one single source is to blame for the current problem, rather it is a result of homeowners, business owners, customers, children, recreation, accidents, poor property management, people experiencing homelessness, flash flooding, utility work, and a myriad of other daily life activities. Often noted in trash cleanup reports, cigarette butts and "vape" devices were uncommon (~1 every 5 miles) as were observations of hypodermic needles (~1 every

10 miles). These items may be more common to upland areas. Shopping carts were common. Over 500 shopping carts (~5 every mile) in creeks and riparian areas. Although many were clustered in riparian areas near encampments, most were in streambeds, and many were partially buried in the bed. Shopping carts in creeks highlight a financial loss to retail businesses and present a significant amount of trash mass and difficulty in removal. Camping equipment (tents, sleeping bags, pillows, etc.) were common near areas of encampments. However, items used primarily by homeowners (hoses, lawn equipment, appliances, etc) were common across the entire survey area, demonstrating that the problem of trash in creeks is a communal issue. The following photographs and anecdotal observations by field staff help characterize the scope and scale of trash in creeks in Austin (Figures 25-30).

Figure 25. Transportation construction accoutrements (cones, barriers, signs, etc) were frequently encountered. It is unclear if the pathway for these items were due to roadway flooding, vandalism, dumping, etc. but they represent a municipal loss and expense

Figure 26. Toys, specifically foam rubber "nerf" projectiles, balls, and stuffed animals

Figure 27. Telecommunication cables were a common, preventable, and significant issue in some stream reaches. Thousands of feet of internet cables were observed in discarded in creeks, some still partially attached, likely disconnected on one end by service contractor during a change in service.

Figure 28. Fabrics (primarily clothing and bedding, etc) and foam rubber padding were common and tend to become wrapped around vegetation persisting for as long as the fibers take to completely degrade which may take a very long time such as the carpet in the righthand photo.

Figure 29. Erosion and stabilization controls (e.g. silt fence, mulch socks, netting/matting, etc) are vulnerable to becoming trash in creeks when improperly secured or neglected. All were observed as significant large items in creeks.

Figure 30. Trash detained by the rack (left) of the stormwater bypass on Johnson Creek indicating how much trash is contributed from the roadway system (headwaters of Johnson) and delivered to the lower part of the creek (right). These two areas (inlet and outlet) present an opportunity for strategic interception/removal of trash.

Conclusions

The 110-mile field survey of 20 creeks that collected 19,467 data points resulted in the following conclusions regarding the character, source, and pathways of trash in Austin's creeks:

- Stream position and drainage area do not correlate with trash intensity. This identifies the difficulty in quantifying impacts from source type by invalidating upstream/downstream comparisons and implies that transport of trash through a stream is more strongly controlled by factors such as stream roughness. Areas with high roughness (dense woody vegetation) are natural trash detention "strainers" that keep much trash from entering our lake/river and are opportunities for focal areas of trash removal.
- Of the seven sources identified in this study, trash intensity was highest at locations of illegal dumping. Outfalls/Tributaries was the lowest intensity, and all other sources (overflowing dumpsters, property management, encampments, historic dumping and point source dumping) have similar trash intensity and range of scores.
- Single-use plastic/polystyrene beverage and food containers were the most encountered item.
- Although encampments were the most common of the seven source of trash in waterways, based on the spatial analysis, high trash intensity is also common in areas without an encampment source, indicating that the source of trash in our waterways is a complex, community-generated dynamic.
- Regression analysis indicates that there were no statistically significant correlations between trash intensity and census population, roadways, impervious cover, and land use categories (single family, multifamily, commercial, parks, undeveloped), supporting the hypothesis that location of trash is primarily driven by a physical factor such as stream roughness.
- 76% of the trash is found at 10% of the sites. The map created from the survey can be used to focus/prioritize creek cleanup efforts to extract the most amount of trash in the smallest areas.
- Micromobility devices (e.g. "scooters") in creeks does not appear to be a signification problem in 2022, only 21 scooters were discovered (avg 1 scooter every 5 miles) and there is an active 311 process to have them removed by the vendor.

Recommendations

(For a comprehensive review of trash program, projects and practices from around the world please see the companion to this study, Trash in Creeks: Benchmarking Solution Space and Resources, Gosselink et al. 2022. In addition, City of Austin staff prepared a Program Inventory of trash related efforts in June of 2020 and can be found here: https://www.austintexas.gov/edims/document.cfm?id=348493)

Recommendations for future trash surveys

- Future surveys for trash in creeks should perform fieldwork during the winter leaf-off season, Nov-Apr, for large assessments. Small site assessments can be conducted at any time of year.
- Add the following object observation options to the field sheet: shopping cart, partial shopping cart, pallets, erosion/sedimentation controls, telecommunication lines, as well as a comment field for "top 3 materials".
- Verify/substantiate volume estimates by collecting trash in containers at select sites that represent low to high trash intensity.
- Add the remaining 107 miles of creek to a future assessment rotation where 10% of full rotation gets surveyed every 10 years, to allow for assessment of temporal and spatial trends.
- Conduct a repeat-visit survey at locations representing different parts of the city that looks at accumulations rates after an area has been completely cleared of trash by clean-up crews. This will help understand movement rates and volumes and types of trash that are mobilized vs static.
- Collaborate directly with all City Departments that work in the realm of litter and trash in survey purpose, methods, locations and data interpretation.

Recommended Strategies to address trash in the creeks (Extraction)

- Continue creek cleanups with staff, subcontractors and volunteer organizations.
- Target creek cleanups at the locations of highest intensity (Online map: **https://arcg.is/0z48bj0,** Figure 23), especially those of high stream roughness (woody vegetation) that serve as existing natural strainers.
- Target large diameter storm outlets with increased maintenance and potentially novel extraction solutions. For example, the Johnson Creek bypass channel outlet collects a lot of trash after every large storm event. This would be an effective method to collect trash where it is concentrated before it gets to our receiving water body and distributes widely.
- Follow up with enforcement action for each location identified as "Point Source Dumping"
- Increase incentives for Adopt-a-Creek and other programs that encourage citizens to collect trash throughout our stream network using the data and tools generated from this report.

Recommend Strategies to keep trash from getting into the creeks (Interception and Enforcement)

- Continue to support and increase waste services to encampments. Develop programs to incentivize proper disposal of trash and recyclables for people experiencing homelessness.
- Review and improve ordinances and enforcement to reduce incidence of overflowing dumpsters. Increase requirements for minimum dumpster size for commercial and multifamily and require secondary containment around the dumpsters (fences, walls, etc).
- All picnic tables (in parks and commercial/multifamily) near creeks should have a waste receptacle near them
- Strengthen City ordinances on telecommunication providers, assess fines for abandoned lines
- Review/study Street Sweeping efficiency/effectiveness in geographically targeted areas
- Improve and promote enforcement programs that report dumping, and other source of trash getting to creeks.
- Evaluate appropriate trash controls within drainage conveyance system. E.g. Trash racks or modification of stormwater controls at outlets to creeks and/or detention facilities.
- Strategies for retail businesses to retain shopping carts onsite are recommended. Some retail businesses in Pennsylvania use bollards to prohibit carts from entering the parking lot, keeping them close to the store. Other retail businesses use shopping carts with sensors that lock wheels at a designated distance from the store. These and other strategies to keep shopping carts on the premises should be considered for promotion and possible support by the City.

Recommend Strategies to keep trash from reaching the landscape (Source Reduction)

- Campaigns or strategies to reduce use of single use plastics and polystyrene including, but not limited to continued/increased education/outreach, regulations/bans, and political solutions.
- Expand and improve education and outreach efforts that target the complex path from communities and individuals to trash in creeks.
- Collaborate, strategize, and share data with other departments that are working on litter and trash issues in our watersheds, with the goal of a citywide, integrated trash management effort.

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Appendix
Watershed-specific trash scores and sources

Barton Creek (Figure A)
Similar to Bull Creek, the Barton watershed is characterized by large preserves, open space, greenbelts and accordingly has less trash. During the survey only one observation of an active encampment was observed near the creek and no other sources or attributes were recorded. Similarly infrequent, there were only two observations of "Dense" trash accumulations, and only eight observations of "Abundant", most of which associated near the crossing of Loop 360. Although there were some "Apparent" trash observations, the overwhelming majority of the survey area was in the "Minimal" category.

Bull Creek (Figure B)
Similar to Barton, the Bull Creek watershed is characterized by large preserves/openspace/greenbelts and accordingly has less trash. The apparent dominant type of trash were small single-use plastics, styrenes and other floatables. Within the survey area, no scooters were observed, no encampments, and no dumping. The only source-attribute was observed was an outfall/tributary located near Spicewood Springs and Loop 360. No instances of "Dense" trash accumulations (score 16+) were recorded in the survey area, and only a few instances of "Abundant" trash accumulation (score 10-15) were observed.

Buttermilk Creek and Little Walnut Creek (C)
Buttermilk Creek was the worst creek for trash intensity as measured by the highest median value. A variety of sources were noted including and dumping (recent point source and unknown), property management, tributary/outfalls and several encampments. Although the streambed is primarily scoured Austin Chalk limestone, the stream is prone to very high flows or "flash flooding" in which the riparian edges are inundated causing trash to be entrained high up the banks. Numerically single use plastic was by far the most commonly encountered item, however, the most salient trash item in Buttermilk was likely fabrics (clothing, bedding, etc.). Encampments do not explain all of the trash in this creek as dumping appears to be a chronic issue, compounded by the lack of stormwater controls and high impervious cover characteristics of the age it was developed. Little Walnut upstream of the confluence with Buttermilk is similar in trash intensity and source composition, however, downstream of the confluence few sources are apparent, yet trash remains very high.

Carson Creek and Country Club West Creek (D)
Carson Creek is a small watershed that is high in impervious cover and dominated by commercial, industrial and transportation (e.g., roads/highway/parking lots). An area of encampments just north of Highway 71 contributes to localized dense accumulations of trash between Highway 71 and Highway 183. An area of similar trash intensity is located in the upper watershed, yet no encampments are associated, rather various forms of dumping are apparent. Country Club West Creek had the second highest median score and is punctuated by apartment complexes with several encampments, however, almost all source types are present, including an inordinate amount of point source dumping. The lower watershed downstream of Krieg Field Complex is heavily influenced by encampments.

Lake Creek (Figure E)
The upstream portion of Lake Creek watershed is primarily single family residential, while the downstream portion is largely commercial, but both include a prevalence of manicured (mowed) trapezoid/engineered channels for improved conveyance. Areas of high trash density were typically associated with naturally vegetated (high roughness) corridors just downstream of mowed trapezoid channels. The woody vegetation in these areas act as strainers detaining trash from the upper watershed. There were few encampments in the survey area, but each was associated with uncommonly high concentration of shopping carts, which increase the trash score disproportionately due to their size/weight and difficulty in removal.

Shoal Creek and Waller (F)

Although single use plastics were clearly numerically dominant in all watersheds (including Shoal), the most salient aspect of litter in this creek were fabrics (clothing, bedding, etc.). Fabrics along with foam rubber appeared to visually dominate the total mass of trash in Shoal Creek. This prevalence of fabrics was most noticeable in the downstream half of Shoal (south of Beverly Sheffield Park) including primarily clothing and bedding, etc. A reasonable assumption would be the conclusion that these fabrics result from the influence of encampments, however there was only one active encampment observed in the upper half of Shoal (located far in the upper watershed). Several other sources were present in the upper watershed. Overflowing dumpsters and property management issues in upper Shoal Creek may be the source of dense/abundant trash in the upper half of the watershed since no other significant sources (only 1 encampment, no point source dumping, no historic dumping, etc.) were observed. It should be noted that fabrics become entrained in woody vegetation and do not easily migrate downstream, therefore, these items may have simply been accumulating over time through a densely populated part of town with few stormwater controls due to old development. Waller Creek is similar in character to Shoal Creek except for dense encampments in the downtown area and a much higher instance of outfall/tributary sources, likely the result from old development without many stormwater controls.

Taylor Slough North, Taylor Slough South and Johnson Creek (G)

No instances of "Dense" or "Abundant" trash scores were recorded in either Taylor Slough North or South, and no sources (dumping, outfalls, encampments) or scooters were observed. Trash in Taylor Sloughs were primarily associated with single use plastics and home construction/renovation. Long strands of detached or partially attached telecommunication cables were common. Construction materials such as lumber, tile, metal, bricks were all common in addition to evidence of labor crews such as ice bags and fast-food containers. Land use is overwhelmingly single family residential in all three watersheds, for which the areas adjacent to the creek were developed long before Critical Water Quality Zones provided a buffer to creeks. Salient trash items indicated refuse from landscaping and home renovation such as an abundance of empty icebags, mulch bags, water bottles, fast food containers/wrappers, building materials, telecommunication cable, etc. The Johnson watershed presents a unique difference compared to other watersheds in that the uppermost portion of the watershed (~275 acres) above the terminus of the natural channel is dominated by roadway (primarily Loop1) and is conveyed to the creek through a large network of underground storm drains and culverts. This drainage system conveys any trash on the roadways directly to the channel and thence to a large stormflow bypass that diverts stormwater (and trash therein) from the upper watershed through a ~1.5-mile tunnel extending all the way to the to the lowest 1/4 of the channel.

Tannehill Branch and Boggy Creek (H)

Much like other urban creeks, single use plastic and styrene floatables dominated trash composition. Several of the focal points of trash intensity were associated with clusters of point source dumping. This may be a result of the positive feedback loop dumping tends to cause. Both watersheds have long stretches of historic Corps of Engineers trapezoid concrete channels. These concrete channels have a tendency to show less trash due to the low roughness, however the transition to natural channel and wooded riparian corridors are high in trash concentration.

Walnut Creek (Figure I)

Compared to most other watersheds of its size, Walnut had relatively little trash and few sources. Walnut Metro Park stands out as a clean reach with no observed sources. Outfalls/Tributaries were the primary source in Walnut. Most of the watershed is beyond the city limits.

South Boggy Creek and Williamson Creek (Figure J)

South Boggy Creek is an example of a watershed that has few encampments, yet many dense trash sites. The intensity of trash in South Boggy is due to a number of other sources underscoring the finding that encampments are not singly to blame for much of the trash in creeks. Williamson Creek was the longest watershed of the survey and included pristine headwaters and horrific sections of dense trash far exceeding other watersheds. Some areas of encampment were not identified in the survey as they had been recently cleared by the authorities and were no longer active. An interesting and unexplained observation is the prevalence of tin cans between Oak Hill and IH35. Tin cans (both historic and recent) were a common item and were described as occurring in most of the survey observation points. No other creek in the survey shared this characteristic.

East Bouldin Creek, West Bouldin Creek and Blunn (Figure K)
West Boulding and East Bouldin had the fourth and fifth highest median values of the survey. Although the trash composition was diverse in West Bouldin Creek, the total mass was greatly influenced by heavy building materials from construction and renovation. Bricks, broken concrete, cinderblocks, lumber, tiles, metal and other structure components were prevalent. The East Bouldin watershed is dominated by single family land use, but the corridor around the creek is largely commercial. Subdivided largely before the1980's there are few stormwater controls and pervasive encroachment into the areas that is now the Critical Water Quality Zone. An encampment in Gillis Park was associated with some high scores on East Bouldin. All three watersheds included a higher number of historic dump sites exposed by eroding banks which opens a window to the historic development of south Austin. Property management in the upper watershed is similar in West Bouldin and Blunn.

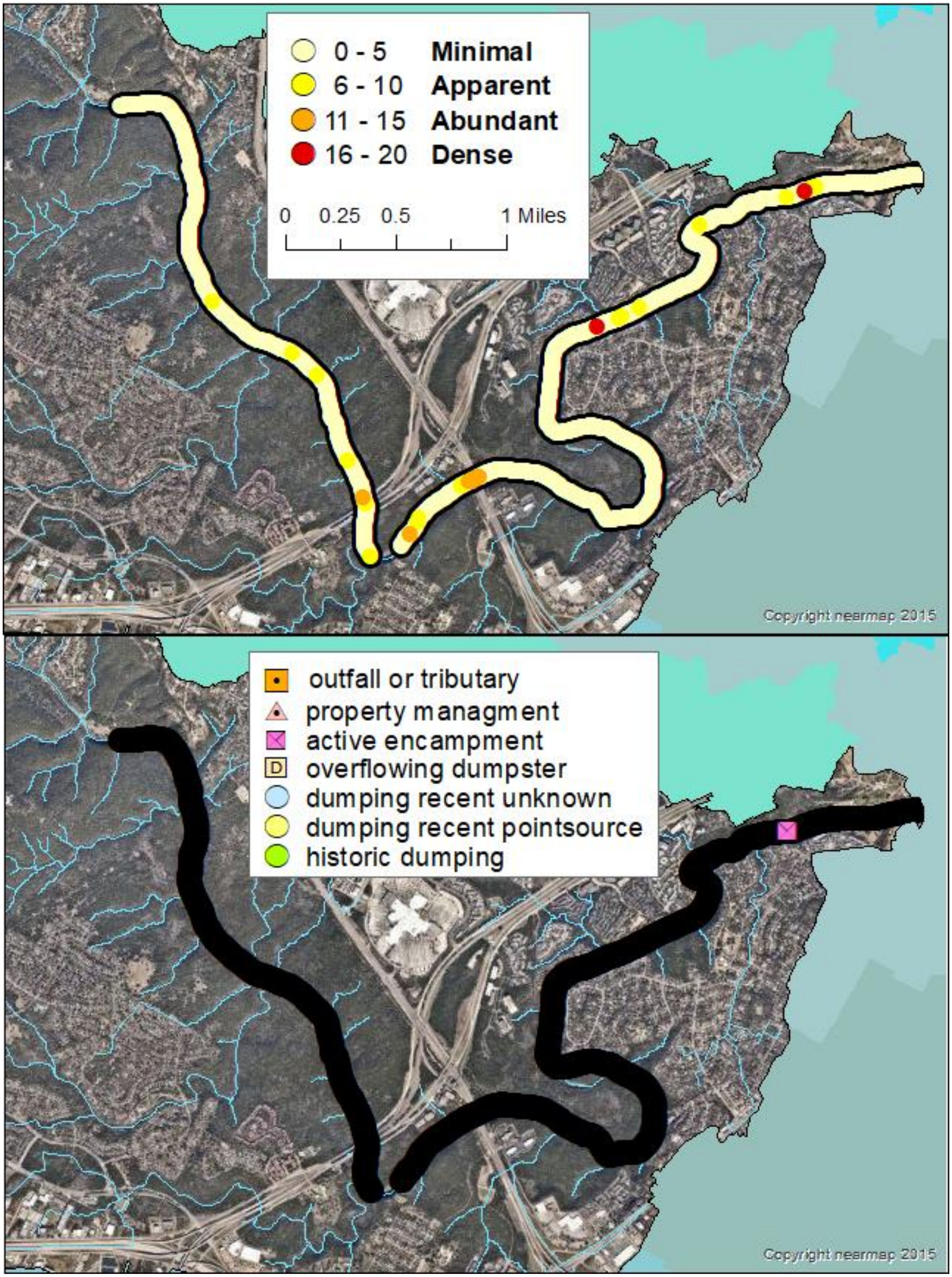

Figure A. Barton Creek scores and observed source types

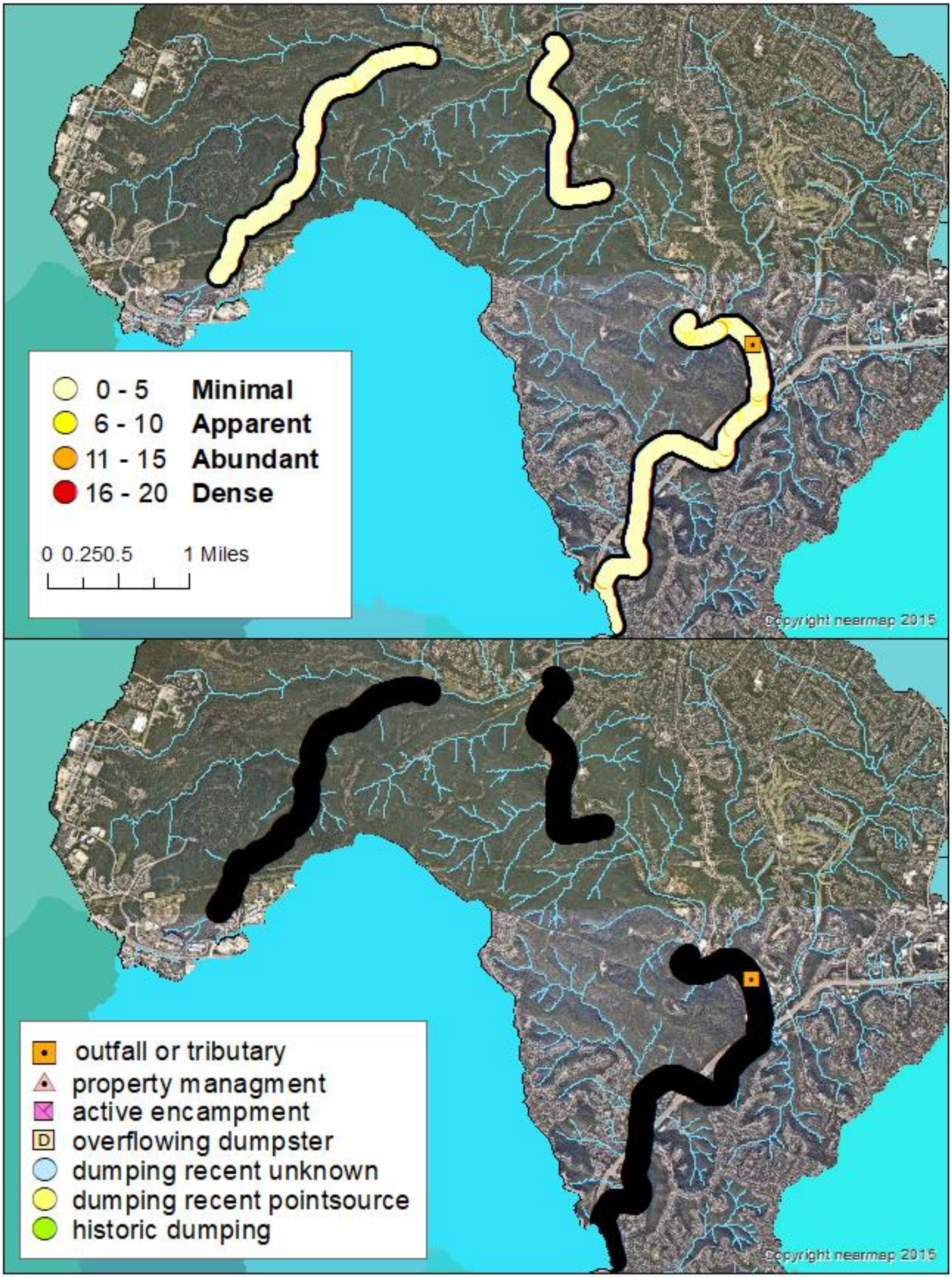

Figure B. Bull Creek scores and observed source types

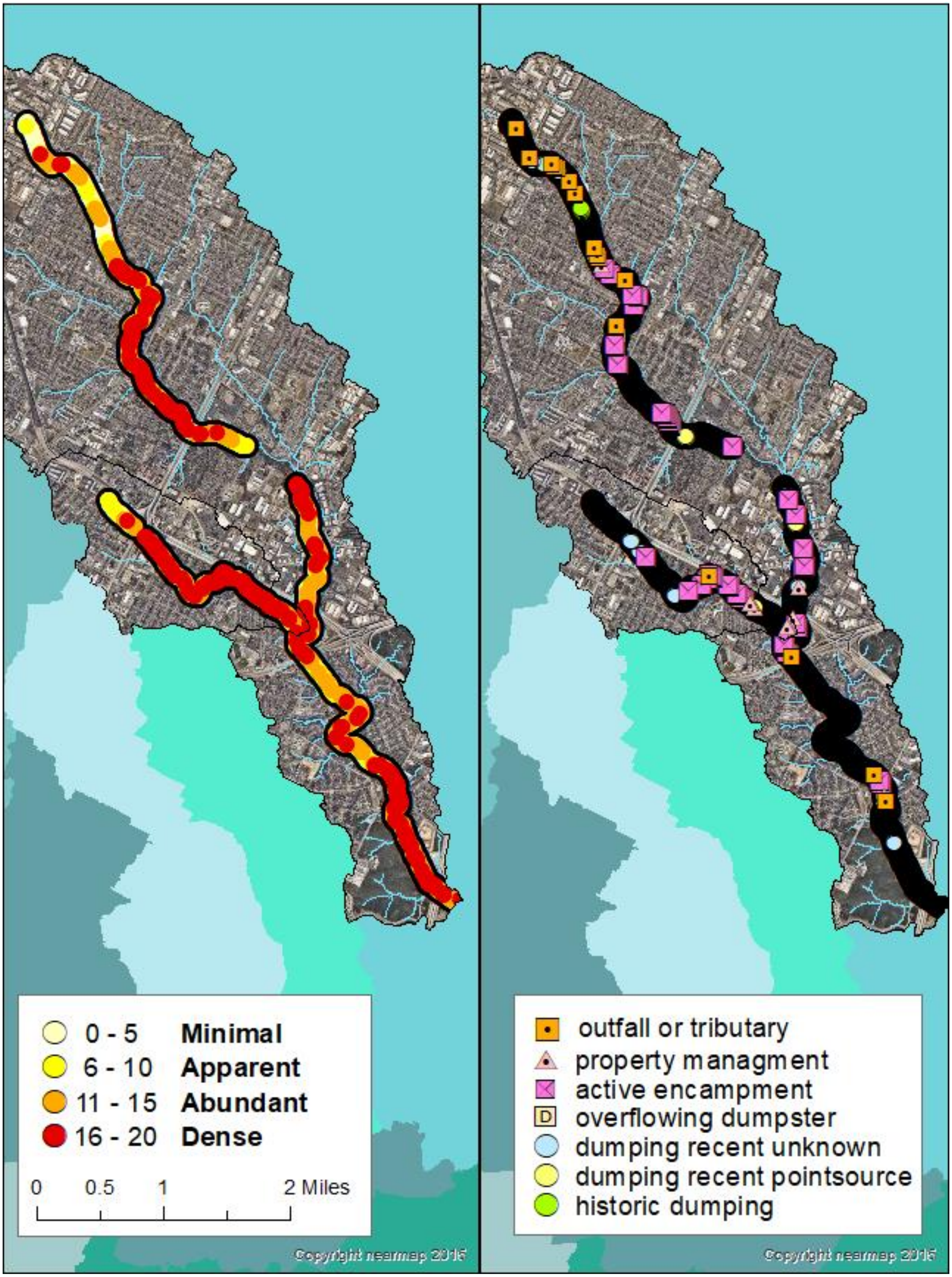

Figure C. Little Walnut and Buttermilk scores and observed source types

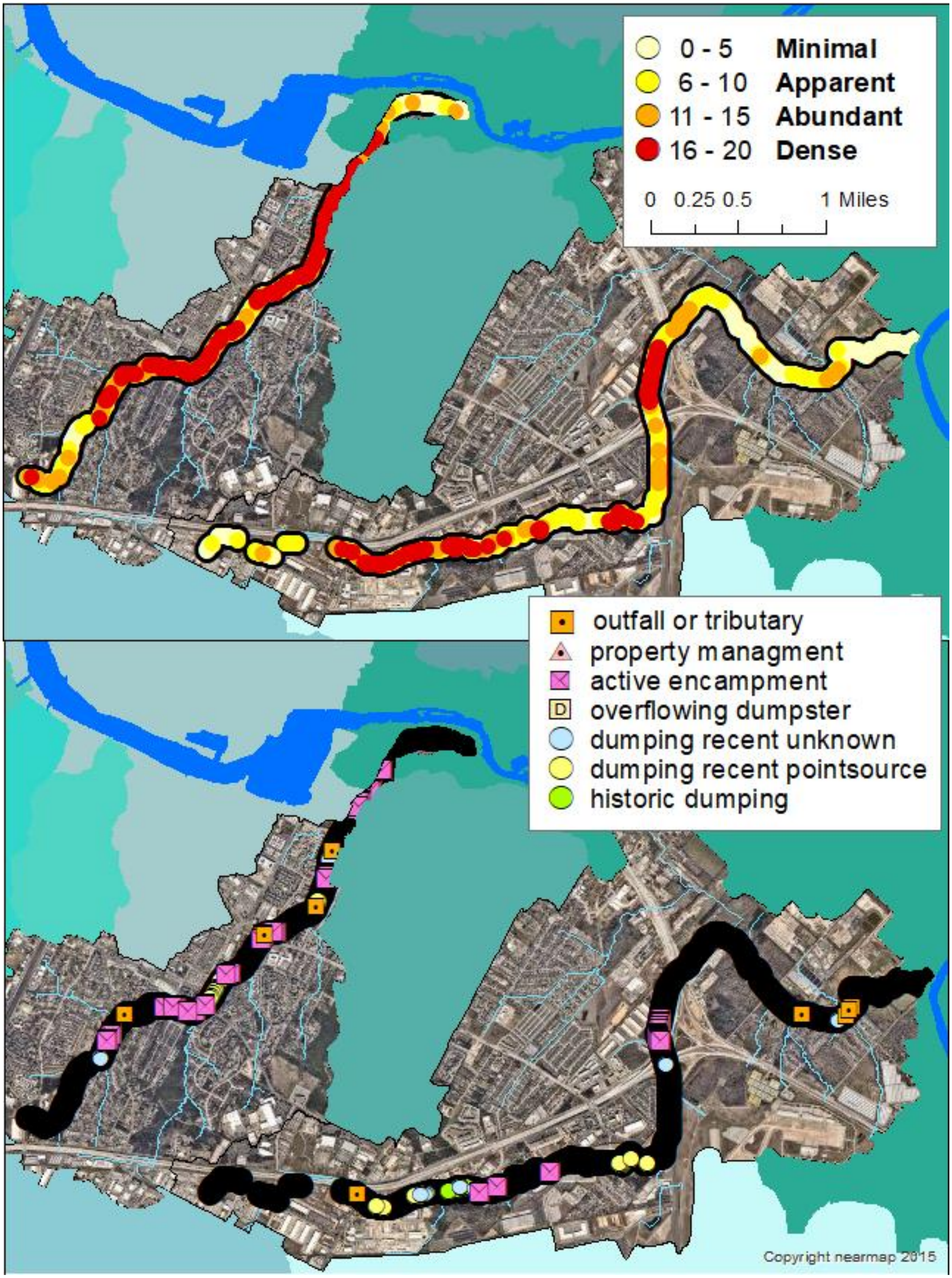

Figure D. Country Club West and Carson scores and observed source types

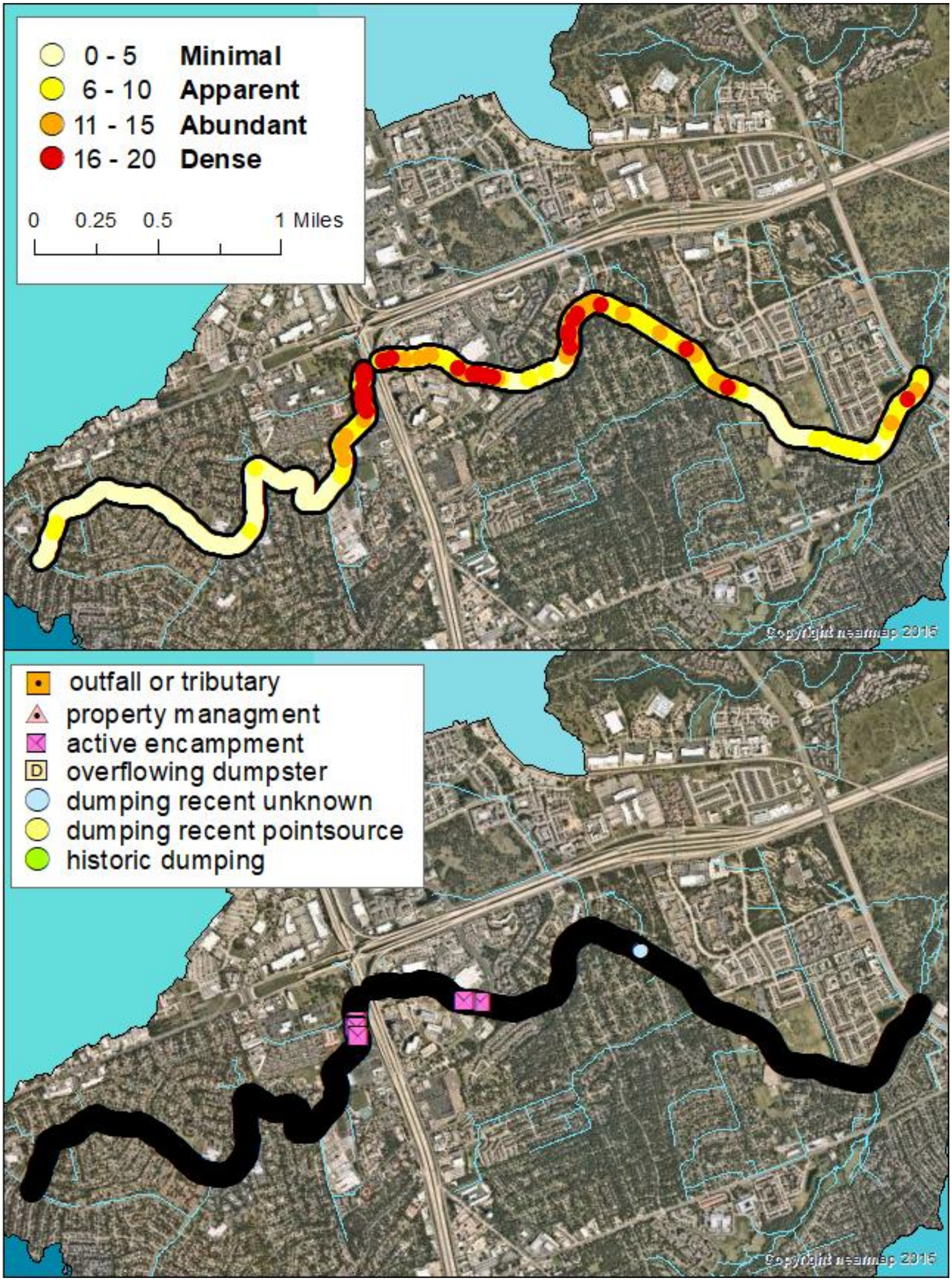

Figure E. Lake Creek scores and observed source types

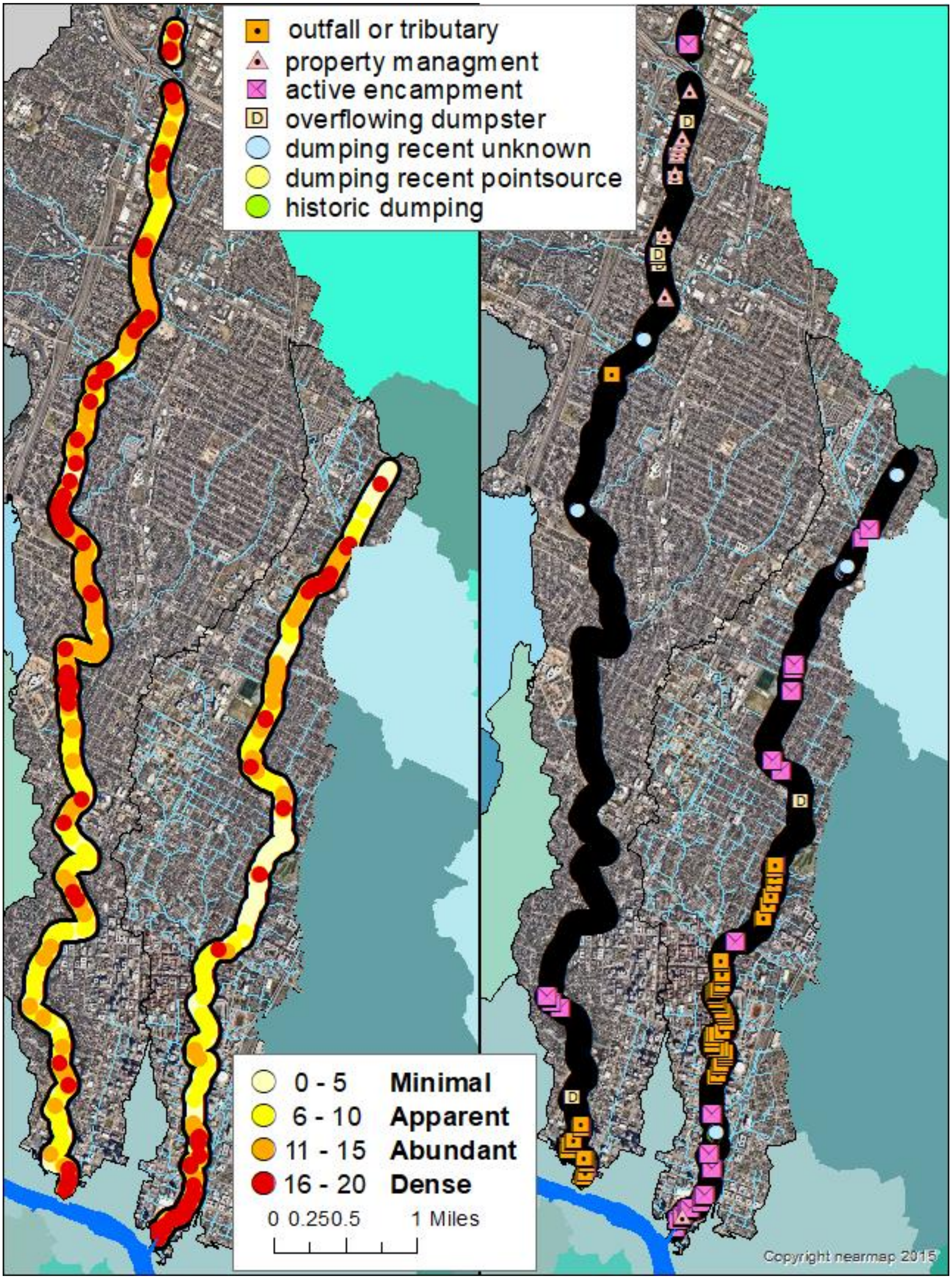

Figure F. Shoal and Waller Creek scores and observed source types

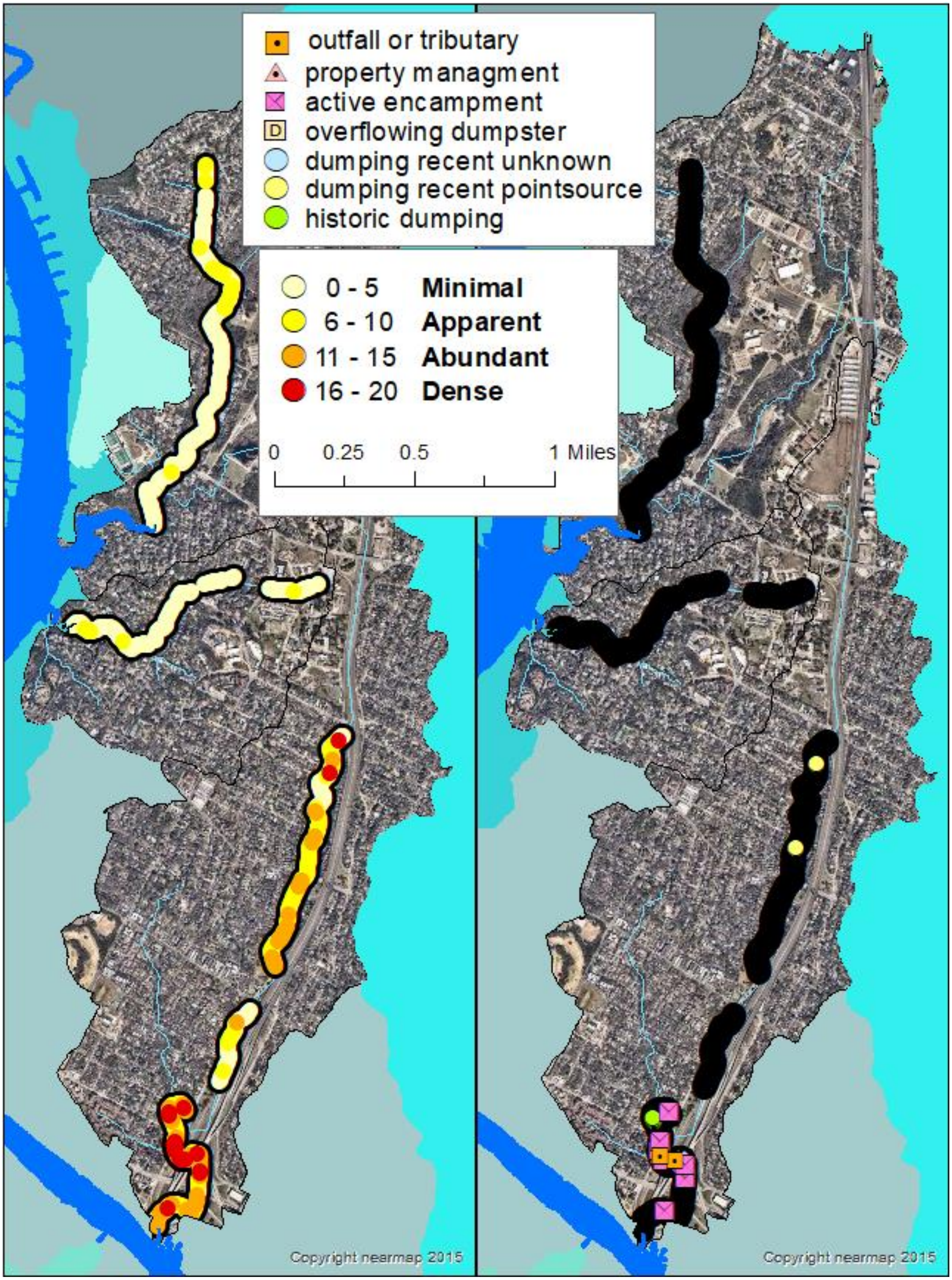

Figure G. Taylor Slough South, Taylor Slough North, and Johnson Creek scores and source types

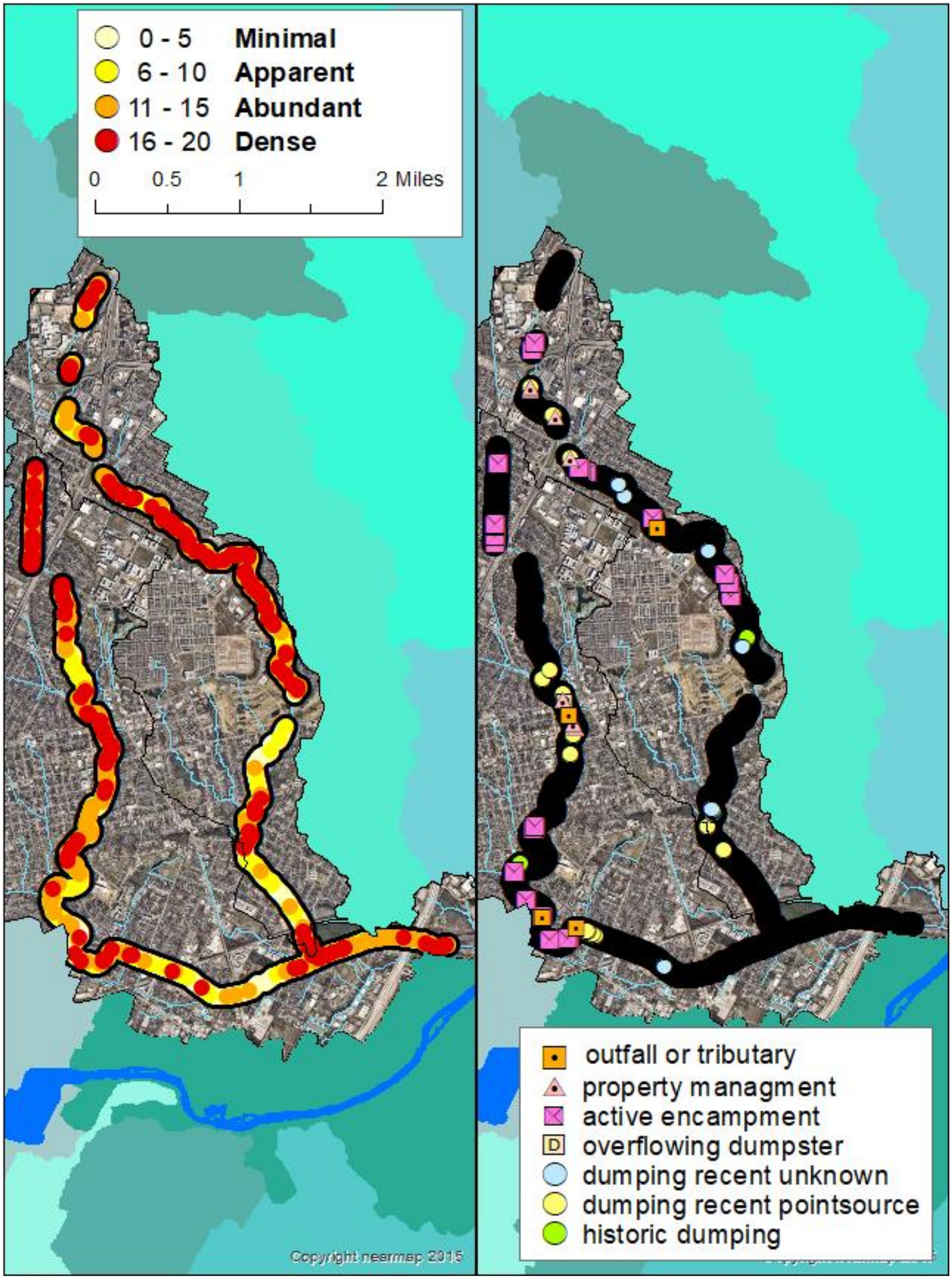

Figure H. Tannehill and Boggy (East) scores and observed source types

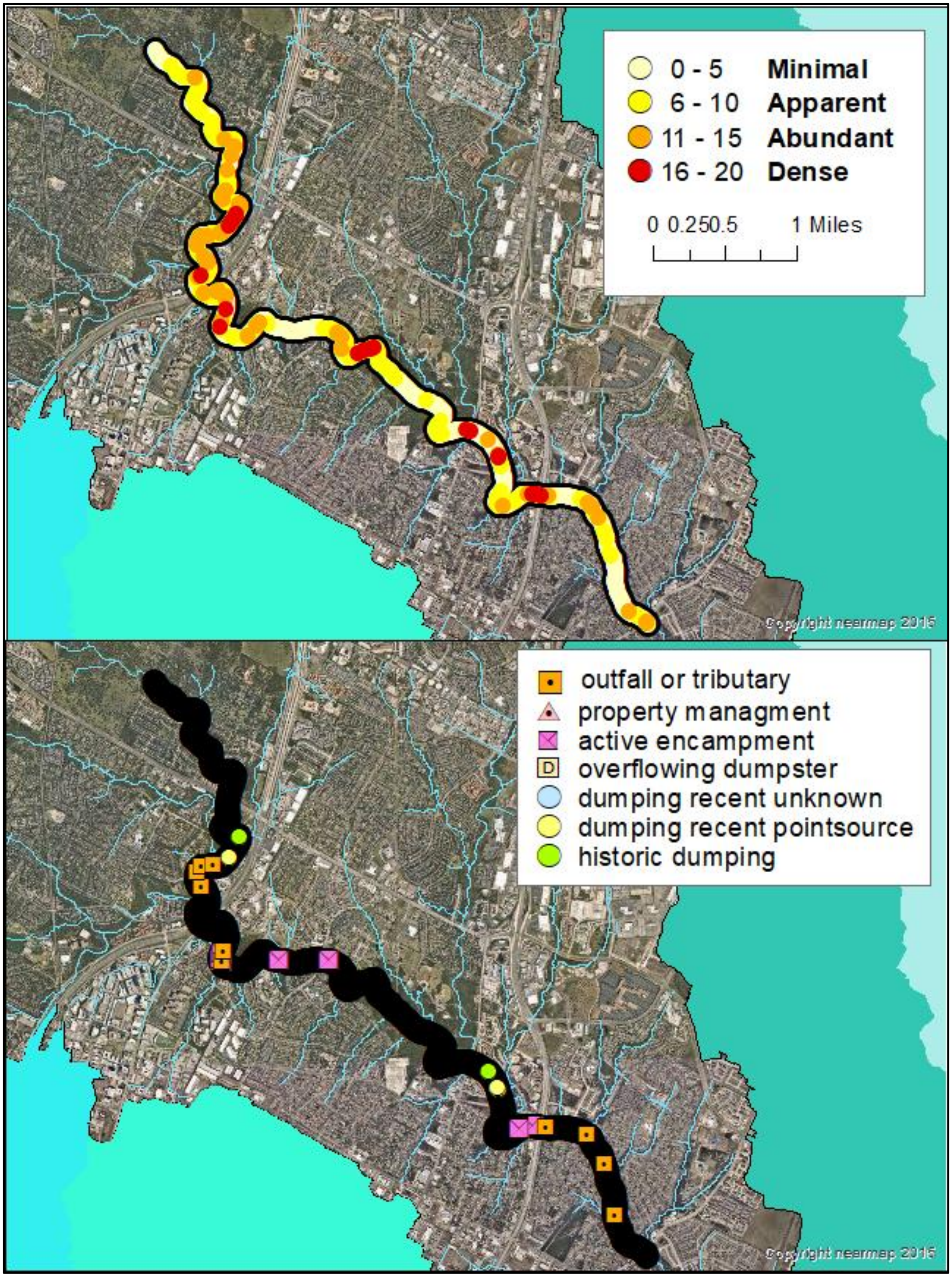

Figure I. Walnut Creek scores and observed source types

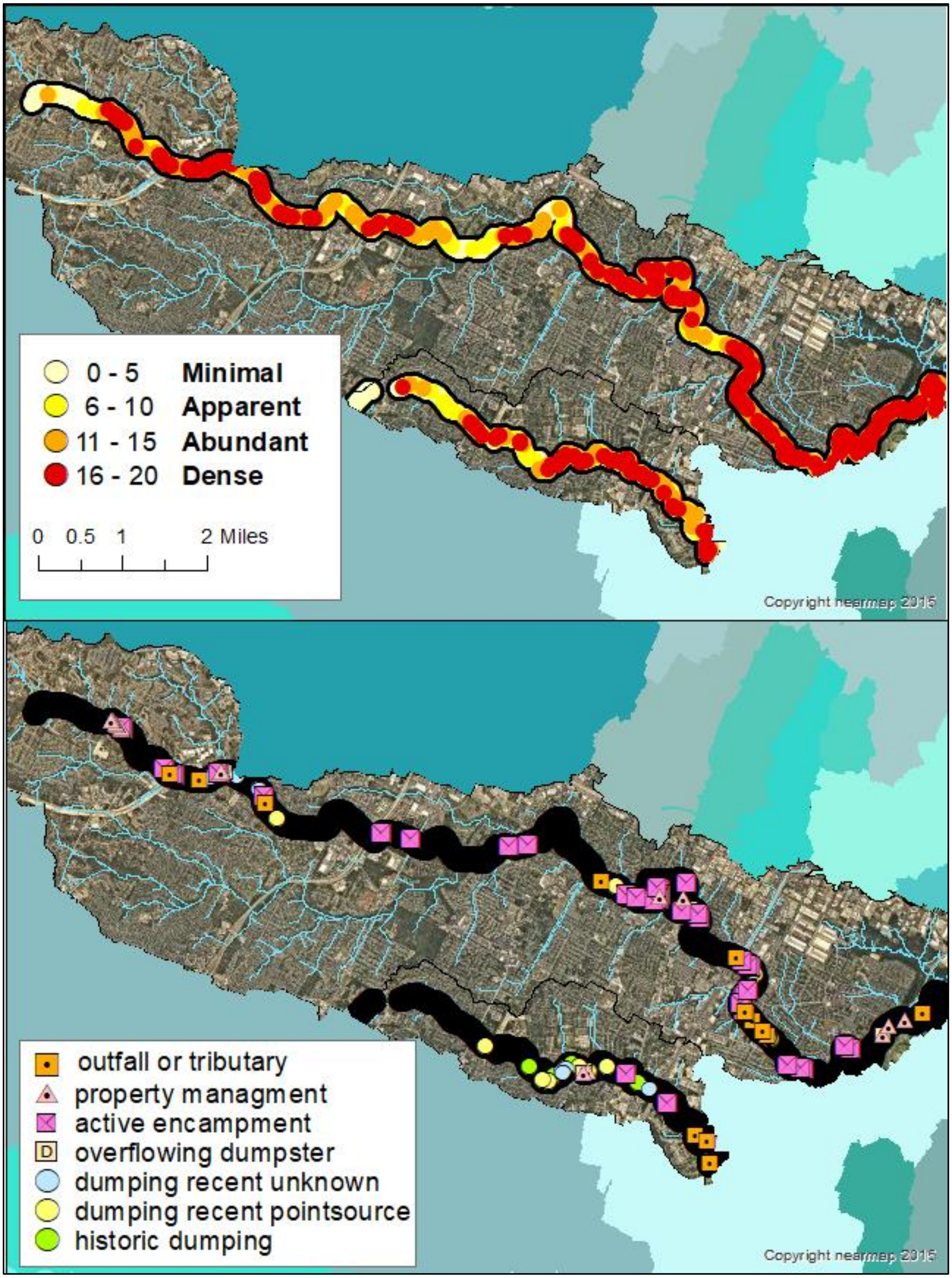

Figure J. Williamson and Boggy (South) scores and observed source types

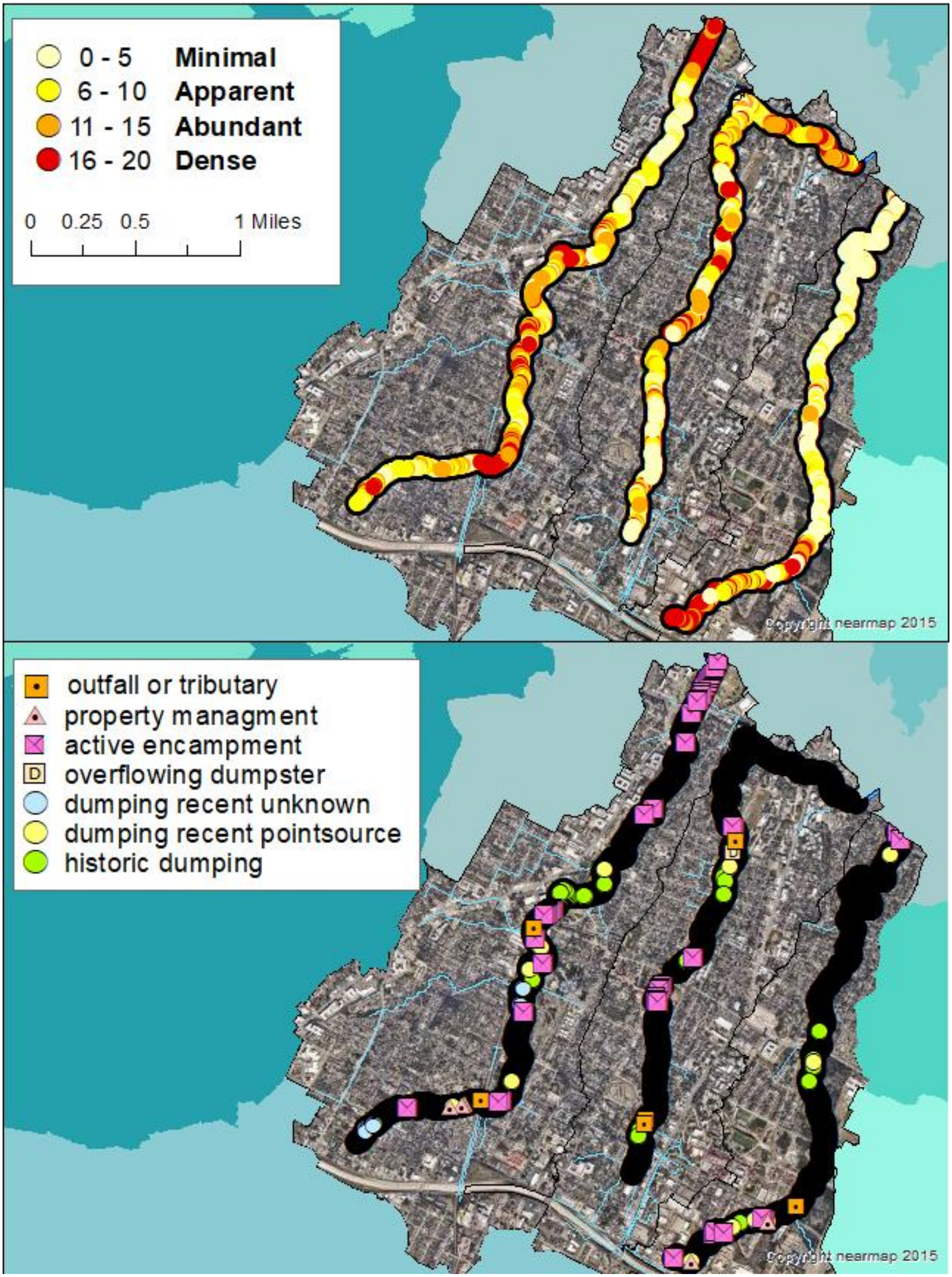

Figure K. West Bouldin, East Bouldin, and Blunn scores and observed source types