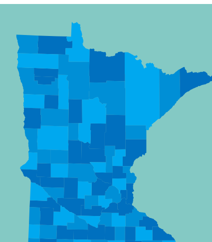
Solid waste

September 2021

Volume-to-Weight Conversions

Report detailing densities for solid waste streams and sampling methodologies.

MINNESOTA POLLUTION CONTROL AGENCY



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- Dem Com
- Eureka Recycling
- The Minnesota Department of Administration
- Ramsey County
- Specialized Environmental Technologies (SET)

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Background

This report is an update for volume-to-weight conversion factors for municipal solid waste, recyclables, organics, and a limited set of construction and demolition materials. Volume-to-weight conversion factors provide a weight for a known volume of a material (one cubic yard) and are used to determine the weight of material with a known volume. Throughout the report, these conversion factors will be discussed as densities, meaning they are represented as weight per volume (pounds per cubic yard). This information is useful in circumstances where a scale is unavailable to assess the weight of a material.

Many Minnesota state agencies and industries rely on volume-to-weight conversions and use them often. Prior to this update, the available conversion factors were not specific to Minnesota waste, and they were outdated, having been over ten years old. Additionally, the existing available data provides multiple conversions from different sources for the same material type, making it challenging to determine which conversion should be used. As the composition of waste streams changes over time (due to lightweighting of packaging, increased co-mingling of recycling streams, and organics diversion from the garbage), and as new products enter the consumer market, it is important to update volume-to-weight conversion factors to maintain an accurate picture of modern waste and recycling generation in Minnesota.

Waste conversion factors are used by many Minnesota state agencies and industries to record and report data on various waste, recycling, and reuse streams. Weighing materials preferred, because densities of materials can vary. However, in a number of situations scales are unavailable or impractical. Accurate volume-to-weight conversion factors for waste and recycling materials allow waste data from these situations to be reported as tonnage instead of volume, which in turn allows for a complete accounting of material in the waste streams.

While much of the waste generated in Minnesota is weighed, there are still many materials, facilities, and activities where measuring the volume of the waste generated is easier than obtaining a measured weight. Volume-to-weight conversion factors enable comprehensive waste generation reporting across Minnesota. This will facilitate the standardization of waste reduction efforts at local, state, and national levels, allowing for better comparison between data from multiple sites. Having a clear understanding of how much waste is being generated is also important for setting waste reduction goals across the state.

This report identifies densities for various materials and waste streams and presents field test data collected in Minnesota in addition to data requested from Minnesota-based partners. The report also details the sources, data collection methods, and condition for all of the materials as well as provides visual representations of all the data. This report prioritizes material types that are commonly reported by volume and have no recent data for conversion factors.

Methodology

Conversions listed in this report are collected through a variety of methods including field data collection, controlled scaled truckloads, and data reported from partners. Controlled scaled truckloads are semi-trailer trucks that are weighed on a truck scale when full of material, and then again after the truck is emptied. Methods for all listed materials are included in the "Protocol modification and data by material" section of this report.

Table 1. Summary of data collection methods for reported conversion factors by material.

Field data	Scaled truckload	Partner organization
Leaves	Brush – chipped	Source separated organic material – drop-site collection
Grass/garden waste	Brush – prior to chipping	Source-separated organic material – office
Mixed yard waste	Construction & demolition (C&D)	MSW – office
Source-separated organic material – commercial composting facility	C&D – General	Mixed yard waste
Single-stream recyclables – materials recovery facility	C&D – Concrete/dirt	
Single-stream recyclables – multi-unit residential property	C&D – Demolition	
Glass	C&D – Industrial	
MSW – multi-unit residential property	C&D – New home construction	

Field data was collected between November 2020 and July 2021. During this time, COVID-19 impacted the availability of locations for data. Because of the timing of data collection for various waste streams, it is unlikely that COVID-19 had a significant impact on data collection and the resulting volume-to-weight conversion factors. While SSOM, recycling, and C&D waste streams were likely impacted early into the COVID-19 pandemic when virus transmission was poorly understood, but by the time data collection began on these waste streams in March 2021, it is unlikely that the waste composition was irregular.

Equipment

Scale – Scale which records weight to tenths of a pound. The scale used in this study has a capacity of 440 lbs., but a lower or higher capacity can be used depending on the waste stream and the weight of the weigh box.

Weigh box – A box with external dimensions of 24 by 24 by 24 inches with handles and internal measurements of approximately 23 3/16 by 23 1/8 by 23 9/16 inches was used for data collection. This box measured 7.312 cubic feet or .271 cubic yards. Ideally, the interior measurements of the weigh box should measure 24 by 24 by 24 inches. The interior surface of the box must be nonabsorbent to moisture.

Small/light weigh boxes or bucket – Smaller and lighter non-absorbent boxes or bucket of known interior dimensions for weighing heavier materials. This study used a plastic 5 gallon bucket.

Shovel, pitchfork, and rake – Various tools used for placing materials into the weigh box and obtaining material from stockpiles. Depending on the waste stream different tools may be needed.

Straightedge – Rigid straightedge longer than the length and width of the weigh box, such as a nonflexible yard stick.

Tarp – Large waterproof tarp used to hold large gross samples before weighing materials. For this report, a 20' by 20' tarp was used.

Safety equipment

Safety goggles, puncture-resistant gloves, hard hats, safety boots, high visibility vests, masks (and social distancing during COVID-19 pandemic)

ASTM standards

The following ASTM standards were modified to create a sampling protocol for this report. Specific sections followed, except where modifications are noted.

- ASTM C702 standard practice for reducing samples of aggregates to testing size
  - Method B – Quartering
- ASTM D75 standard practice for sampling aggregates
  - 5.3.3.2 sampling from stockpiles without power equipment (Step 2 not followed)
- ASTM E 1109-86 standard test method for determining the bulk density of solid waste fractions
  - 6.1-3 apparatus
  - 7.1 precautions
  - 9.1-3 sample preparations
  - 10.1-5 procedure (with small exceptions)

General field testing protocol (modified ASTM E1109-86)

1. Determine the internal dimensions of the weigh box to 0.05 inches, calculate the volume to ± 0.1% accuracy.
2. Place the empty weigh box on the scale and record the weight to three significant figures.
3. Gather a gross sample, about five times the size of the weigh box, making sure to gather material representative of the material at the sampling site. This was accomplished by taking evenly from the bottom, middle, and top thirds of the material pile. Place the gross sample on the tarp.
4. Use shovels and pitchforks to evenly turn and mix the pile. Fully turn the pile 3 times.
5. Move the material into a conical pile by placing shovelfuls on top of the pile.
6. Using shovels, evenly flatten the pile to about 1 foot thick.
7. Split the gross sample into 4 even piles. Pull the piles to each corner of the tarp.
8. Randomly select a sample quarter from the gross sample. A random number generator can be used to easily select a random quarter of the gross sample.
9. Place the selected sample into the weighing box with a shovel so the box is overflowing.
10. Tamp the box 3 times by dropping the box squarely from a height of 2.5" above the ground.

11. Draw a straightedge across the top of the box, if possible for the material, to level the contents or remove excess material by hand. If the material remains below the top edge of the box, empty the contents and repeat Steps 8 through 10 with a new randomly selected sample.
12. Record the weight of the box and contents to three significant figures.
13. Repeat steps 9 through 12 for all quarters of each of 30 gross samples for each material type. When choosing the second quarter from the gross sample, the sample diagonal from the first sample should be chosen. Randomly select the third sample.

Sampling protocol considerations

For all materials sampled using the general field testing protocol, at least 30 gross samples were collected, each of which contained 4 subsamples. A minimum of thirty samples were collected to ensure a representative sampling of the material and to calculate robust estimates of the volume-to-weight conversion factors. Where feasible, gross samples were collected at multiple different sites to incorporate the locational variation of the population in the estimate.

Particles larger than 2/3 of the length, height, or width of the weigh box were not placed in the box to contribute to density measurements.

Discarding samples

Weighed samples were discarded in a pile out of the way of the sampling area, so as not to accidentally sample from the same material more than once.

Results

Table 2. Volume-to-weight conversion chart for various waste streams. Details on the data collection methods and data analysis for each material can be found following the table in the Protocol modification and data by material section of the report.

Category	Material	Data collection method	Data source	Average density (lbs/cy)	Median density (lbs/cy)	Margin of error (90% confidence) (lbs/cy)
Yard waste	Leaves	Field data	--	80.4	79.9	5.3
	Grass/garden waste	Field data	--	233.4	238.3	9.1
	Mixed yard waste	Field data	--	125.6	--	--
	Mixed yard waste	Scaled truckload	Augie's Trucking	377.5	375.5	3.5
	Brush – chipped	Scaled truckload	Rumpca Companies	349.8	352.8	18.3
	Brush – prior to chipping	Scaled truckload	Rumpca Companies	195.3	--	--
Source-separated organic material (SSOM)	SSOM – commercial composting facility	Field data	--	745.0	766.1	42.1
	SSOM - drop-site collection	Partner organization	Ramsey County/Waste Management	556.8	550.0	39.3
	SSOM – office	Partner organization	MN Department of Admin	55.9	54.0	7.5
Recyclables	Single-stream recyclables – materials recovery facility	Field data	--	113.9	114.4	5.7
	Single-stream recyclables – multi-unit residential property	Field data	--	60.9	53.6	8.3
	Glass	Field data	--	1971.1	1967.2	28.5
Municipal solid waste (MSW)	MSW – multi-unit residential property	Field data	--	167.1	155.7	26.2
	MSW – office	Partner organization.	MN Department of Admin	67.1	60.0	6.2
Construction & demolition	Mixed C&D	Scaled truckload	Dem-Con Companies	659.2	457.3	36.8

Category	Material	Data collection method	Data source	Average density (lbs/cy)	Median density (lbs/cy)	Margin of error (90% confidence) (lbs/cy)
Construction & demolition	Mixed Concrete & dirt	Scaled truckload	Dem-Con Companies	1453.2	1308.0	125.9
	Demolition	Scaled truckload	Dem-Con Companies	538.3	444.7	29.4
	Industrial	Scaled truckload	Dem-Con Companies	877.9	661.3	115.7
	New home construction	Scaled truckload	Dem-Con Companies	318.2	308.0	18.4

Category definitions

Material category definitions for yard waste, source-separated organic material, and recyclables can be found in Minnesota Statute 115A.03 DEFINITIONS at https://www.revisor.mn.gov/statutes/cite/115A.03.

Yard waste

Subd. 38. Yard waste.

Source-separated organic material (SSOM)

Subd. 32a. Source-separated compostable materials.

Recyclables

Subd. 25a. Recyclable materials.

Subd. 32b. Source-separated recyclable materials.

Protocol modifications and data by material

Yard waste

Leaves

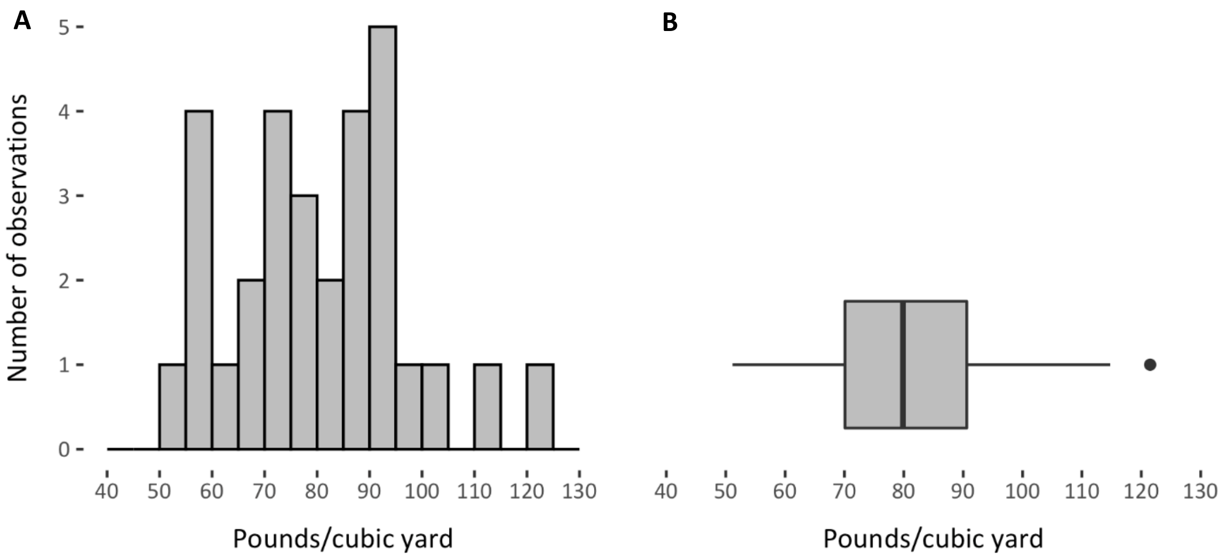
Material description. Self-hauled leaves and plant waste from residents and occasional municipal crews. Samples were gathered from various Ramsey County Yard Waste Collection Sites. Data was collected on leaves in November of 2020.

Protocol. Sampling for leaves followed the general field testing protocol. Leaves were taken from various sections within the large pile of leaves at each site in order to get as representative of a sample as possible.

Material condition. The majority of leaves sampled were dry, with some slightly damp leaves due to snow and rain. Leaves were not compacted, but were lightly tamped to settle into the box.

Figure 1. Leaves sampling process. A) Mixing a gross sample. B) Four subsamples. C) Tamped sample in the weigh box on the scale.

Figure 2. Density of leaves. A) Histogram of densities (pounds/cubic yard) from 30 samples of leaves demonstrating data variability. B) Box plot of densities from 30 samples of leaves demonstrating the first quartile (70.1), the median (79.9), and third quartile (90.6) of the data. C) Density data summary based on leaves data collection.



C

Total samples	30
Average density (lbs/cy)	80.4
Standard deviation (lbs/cy)	16.9

Grass/garden waste

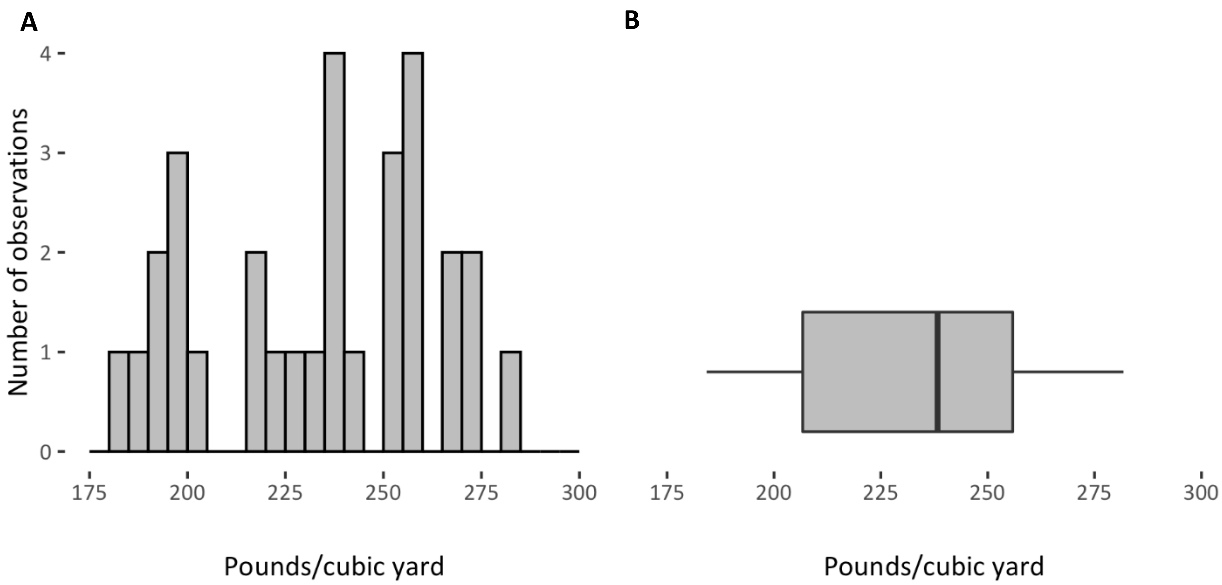
Material description. Self-hauled grass clippings and garden waste with some dry leaves and tree clippings. Samples were gathered from various Ramsey County Yard Waste Collection Sites. Data was collected on grass/garden waste in June and July of 2021.

Protocol. Sampling for grass followed the general field testing protocol. Grass/green waste was taken from various sections of the large pile of yard waste at each site to get as representative a sample as possible. Larger branches that would not fit in the weigh box and sections of dirt or mulch were not included in the samples, although these material types were present at the yard waste sites.

Material condition. The grass was a mix of fresh cut grass, grass trimmings that had already dried out, and garden trimmings. The weighed material included occasional patches of soil and dried leaves. The material was not wet from precipitation, although some material was wet from decomposition. Grass/garden waste was not compacted, but was lightly tamped to settle into the box.

Figure 3. Grass/garden waste sampling process. A) Gross sample of grass/garden waste before mixing. B) Four subsamples. C) Tamped and leveled sample in weigh box.

Figure 4. Density of grass/garden waste. A) Histogram of densities (pounds/cubic yard) from 30 samples of grass demonstrating data variability. B) Box plot of densities from 30 samples of grass demonstrating the first quartile (184.3), the median (238.3), and third quartile (255.9) of the data. C) Density data summary based on grass/garden waste data.



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Total samples	30
Average density (lbs/cy)	233.4
Standard deviation (lbs/cy)	29.4

Mixed yard waste – field data calculation

Material description. Combination of grass/garden waste and leaves representing an estimate of the annual average density of all yard waste. Calculation is based on data collected at Ramsey County Yard Waste Collection Sites in November of 2020 and June/ July of 2021.

Protocol. Mixed yard waste was calculated to represent an average density of yard waste (mix of leaves and grass) over an entire year. This value was calculated assuming that yard waste is primarily made up of leaves (i.e. materials included in measurements collected in November) from October through May and grass/garden waste (i.e. materials included in measurements collection in June/July 2021) from June through September.

Total tonnage of yard waste collected in Ramsey County was calculated for each month of 2020 based on invoices from the hauling company. In 2020, 2728.56 tons of yard waste were collected between June and September (grass), and 6532.28 tons were collected between January to May and October to December (leaves). From these tonnages, it was estimated that 29.5% of the annual yard waste by weight is grass/garden waste and 70.5% is leaves. The mixed yard waste value was then calculated by multiplying the average density of leaves by 70.5% and adding the average density of grass multiplied by 29.5%.

Using average densities from field data collection for leaves and grass/green yard waste, which were lightly placed in the weigh box and not compacted, the density of mixed yard waste is 125.6 lbs/cubic yard.

Mixed yard waste – scaled truckload

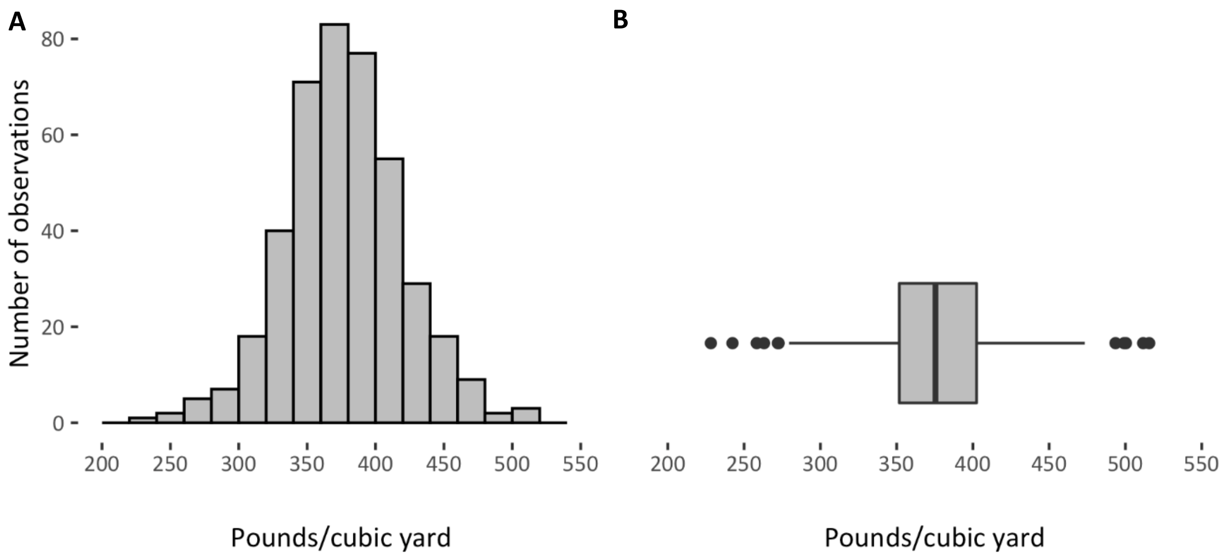
Material description. All self-hauled waste gathered at Ramsey County Yard Waste Collection Sites, including leaves, grass, garden waste, small branches and sticks, occasional mulch and dirt, and other yard waste materials. Yard waste hauling and scaling was completed by Augie's Trucking. Data was collected regularly from April 2020 through January 2021.

Protocol. Sampling for mixed yard waste – scaled truckload did not follow the general field testing protocol. Yard waste material was loaded by front loaders into trucks to haul out the material from the yard waste collection sites. Yard waste is hauled out of the yard waste sites regularly to ensure there is room for new material to come in, so the data represents a yearly average density. According to Augie's Trucking, most of the trailers used were 117 cubic yards, but a small percentage were 110 cubic yards. If all loads were in fact 110 cubic yards, the average density would be 401.5 lbs/cy, a deviation of 24 lbs from the average density assuming 117 cubic yard loads. This is well within the natural variation of the material, which has a standard deviation of 43 lbs/cy. A total of 420 trucks were filled and run over scales to determine the weight of the material. The trailers did not mechanical compact the yard waste.

Some loads may not have been completely full, especially those filled at the end of the day when there was limited material left at the yard waste collection sites.

Material condition. The exact conditions of the material is unknown, but because some material was hauled out in the winter, it is likely that some of the material was wet. Additionally, much of the material is compacted into large piles over the course of a few weeks. This allows the material to begin to decompose and generally become denser than material at the time of drop-off.

Figure 5. Density of mixed yard waste – scaled truckload. Data represents an annual average density for mixed yard waste. A) Histogram of densities (pounds/cubic yard) from 420 truckloads of mixed yard waste demonstrating data variability. B) Box plot of densities from 420 truckloads of mixed yard waste demonstrating the first quartile (351.7), the median (375.5), and third quartile (402.4) of the data. C) Density data summary based on mixed yard waste scaled truckload data collection.



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Total samples	420
Average density (lbs/cy)	377.5
Standard deviation (lbs/cy)	43.0

Brush – chipped

Material description. Self-hauled tree clippings, branches, and logs from residents and municipal crews, ground into wood chips. Generally not including stumps or tree trunks.Truckloads were taken at Ramsey County Yard Waste Collection Sites. Data was collected in April and May of 2021.

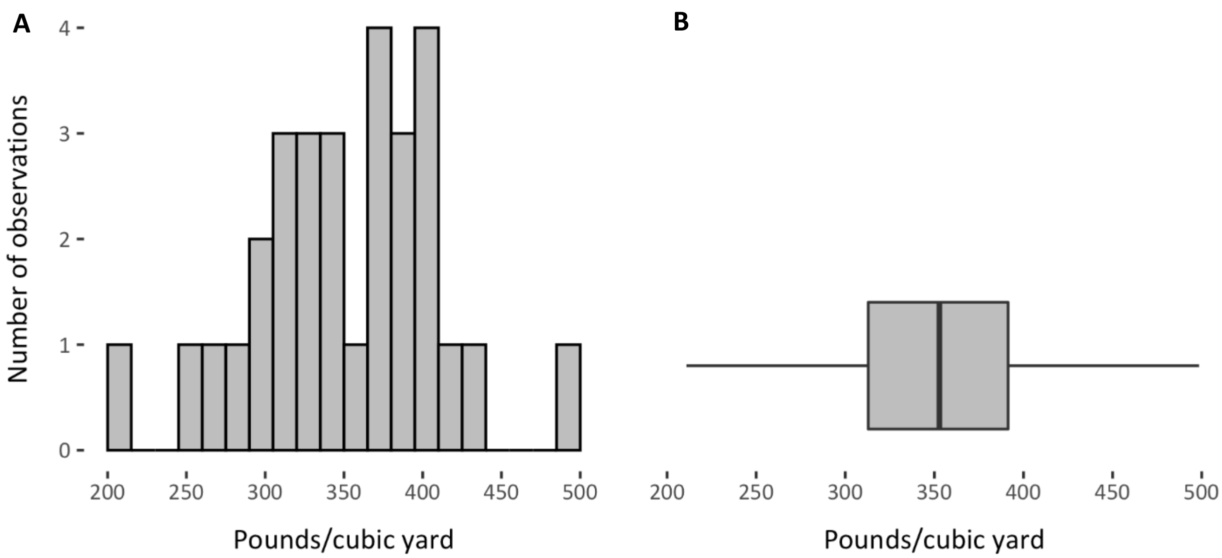
Protocol. The density of brush was calculated based on residential and landscaping. The volume of a large loose brush pile was calculated by measuring the length of each side of the pile and estimating that the pile is 14 feet tall, the maximum height of front loaders used to move and condense the piles. Some geometrical calculations were made to capture the volume of the irregularly shaped brush piles.

Loose brush piles were then put through a grinder to create wood chips for transport. Woodchips were collected in 100 cubic yard trucks, which were run over a scale to determine the density of the chipped brush material. A total of 30 trucks were filled and scaled.

Material condition. Loose brush material is very variable due to differing sizes of brush items, level of compaction of the material, and the season. The brush pile used to determine these conversions consisted of all the material collected form residents between December and April.

Figure 6. Brush sampling process. A) Large pile of loose brush before grinding. B) Brush chipping operation and filling trucks with chipped brush material.

Figure 7. Density of chipped brush. A) Histogram of densities (pounds/cubic yard) from 30 samples of chipped brush demonstrating data variability. B) Box plot of densities from 30 samples of chipped brush demonstrating the first quartile (312.9), the median (352.8), and third quartile (391.4) of the data. . C) Density data summary based on chipped brush data collection.



C

Total samples	30
Average density (lbs/cy)	349.8
Standard deviation (lbs/cy)	59.0

Brush – prior to chipping

Material description. Self-hauled tree clippings, branches, and logs before grinding. Brush – prior to chipping was determined through calculations based on truckloads of chipped brush at Ramsey County Yard Waste Collection Sites. Because of the size, weight, and irregularity of loose brush, it was not feasible to measure the loose brush material directly. Measurements of loose and chipped brush were made in April and May of 2021.

Protocol. The volume-to-weight conversion for loose brush was calculated using the estimated volume of a loose brush pile before grinding, the number of 100-cubic yard truckloads filled, and the density determined above for chipped brush at Ramsey County Yard Waste Collection Sites. Data was available from four brush grinding events between April and May of 2021, so the volumes of only four brush piles were measured.

The loose brush piles ranged from an estimated volume of 4,421 cubic yards to 9,850 cubic yards, depending on the yard waste site. The four brush piles filled 160 100-cubic yard trucks after grinding. With a total loose brush volume of 28,643 cubic yards, split between 160 truckloads, it is estimated that each truckload of chipped brush contained 179.02 cubic yards of loose brush material. The density of chipped brush was then multiplied by 100 to determine the average weight of an entire truckload of chipped brush, and divided by 179.02 cubic yards. The average density of loose brush is 195.3 lbs/cy.

Material condition. Loose brush consisted of a mix of logs and small twigs to large branches that were compressed into a large, dense pile before the volume was measured. Some of the brush was damp at the time of grinding.

Median, standard deviation, and margin of error were not calculated for loose brush because of the low sample size. Calculated conversions for loose brush ranged from 152.7 lbs./cy to 205.7 lbs./cy depending on the brush pile.

Source-separated organic material (SSOM)

Material description. Source-separated compostable materials including: wasted food, food scraps, certified compostable food packaging, and non-recyclable (unlined) paper (such as paper towels and napkins). Organics collection programs typically require compostable food packaging/products to be certified by the Biodegradable Products Institute (BPI).

Conversion factors for SSOM are broken down by the source of the material. These include conversion factors for commercial composting facilities, resident drop-site locations, and office collection.

SSOM – commercial composting facility

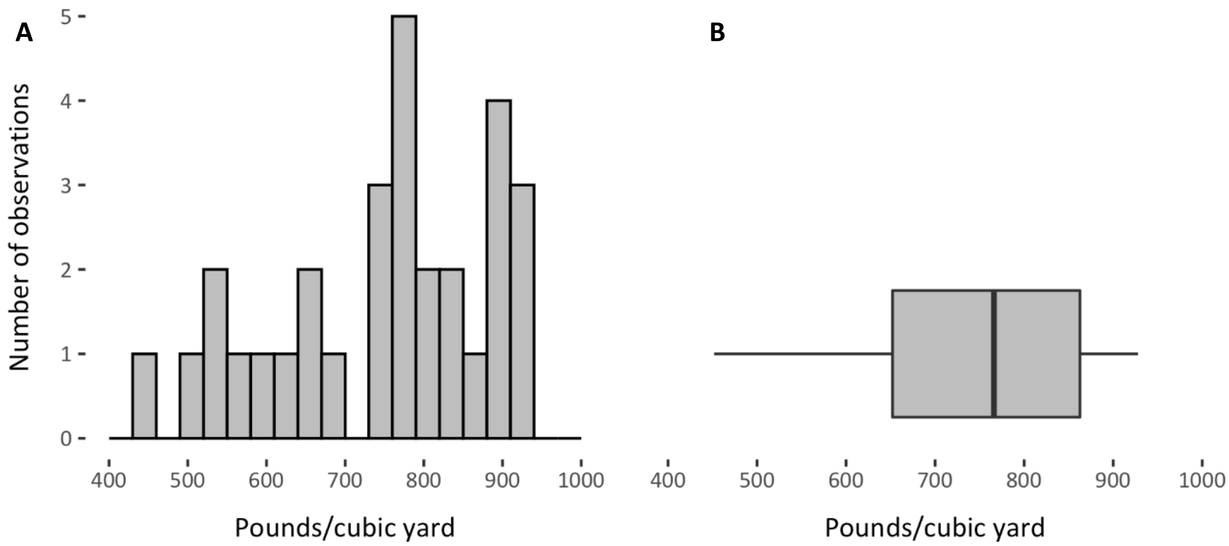
Samples were collected from the Specialized Environmental Technologies (SET) compost site in Empire, MN in April of 2021. SET accepts source-separated organics from restaurants, businesses, and homes. The SSOM includes food and compostable products.

Protocol. Sampling for SSOM at a commercial composting facility followed most of the general field testing protocol, with the following modifications. Because of the weight of source separated organics, the weigh box was only filled to half for each load. Lines were marked on the inside of the box to ensure that the half way mark was clear. Additionally, a front loader was used to create gross samples. Between 3 and 4 gross samples were created from each load of material. The front loader spread out the material as much as possible to help with mixing, and then piles were split into four sub samples each.

Material condition. The material was primarily made up of residential food waste, although some commercial material (both compostable paper goods and food) was also present. Material was in varying states of freshness, with some material already decomposing and maggots present. Material is likely to have undergone some compaction in collection trucks prior to being transported to SET.

Figure 8. SSOM – commercial composting facility sampling process. A) Three gross samples created from one front loader load. B) Four subsamples. C) Tamped sample in half-full weight box.

Figure 9. Density of SSOM – commercial composting facility. A) Histogram of densities (pounds/cubic yard) from 30 samples of SSOM demonstrating data variability. B) Box plot of densities from 30 samples of SSOM demonstrating the first quartile (652.1), median (766.1), and third quartile (862.6) of the data. C) Density data summary based on SSOM – commercial composting facility data collection.



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Total samples	30
Average density (lbs/cy)	744.9
Standard deviation (lbs/cy)	135.8

SSOM – drop-site collection

Samples were collected by Waste Management in conjunction with Ramsey County Public Health and Environmental Health in September of 2020. SSOM drop-sites are open to the public and accept compostable products and food waste.

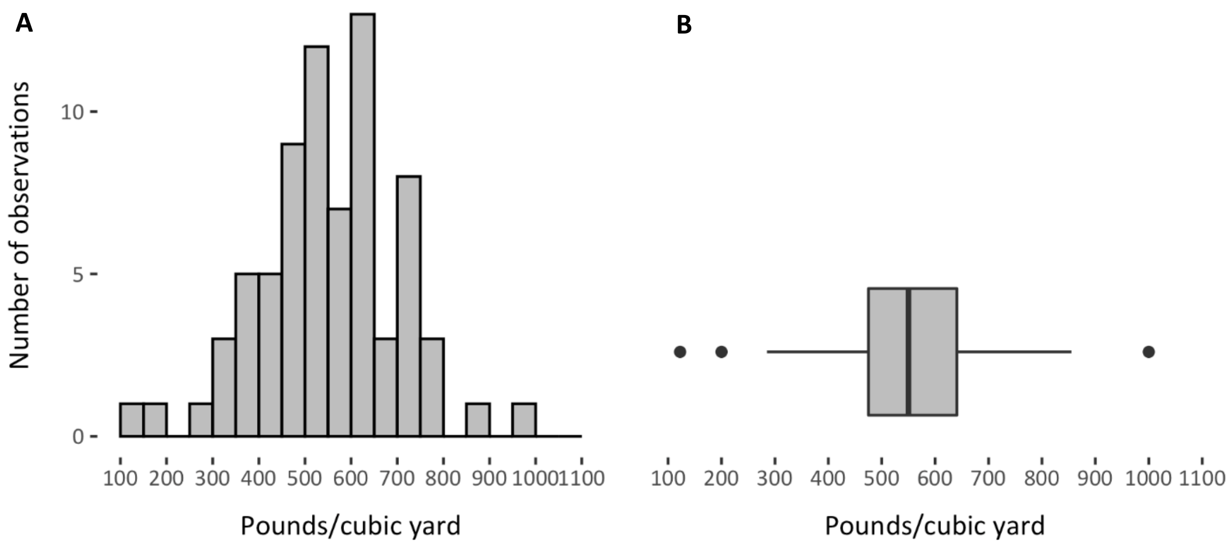
Protocol. Data was collected at all organics drop-off sites operated by Ramsey County. This included both 24/7 self-serve drop-off sites and yard waste sites that have a separate dumpster for organics during open hours.

To gather data, Waste Management haulers noted the size of each dumpster in cubic yards and made a visual estimate of how full the dumpsters were. The weight of the organic material was gathered to the 10s of pounds by weighing the dumpster and then taking a tare weight after dumping the material.

Material condition. Material consisted of residential organic material including wasted food, food scraps, and compostable products. Material at Ramsey County organics drop-off sites is bagged. Bags of SSOM were not opened or checked for contamination. Some non-recyclable papers and pizza boxes may have been present in some of the dumpsters.

Figure 10. SSOM drop-site collection at Ramsey County Yard Waste Collection Site.

Figure 11. Density of SSOM - drop-site collection. A) Histogram of densities (pounds/cubic yard) from 73 samples of SSOM at drop-sites demonstrating data variability. B) Box plot of densities from 73 samples of SSOM at drop-sites demonstrating the first quartile (475.0), median (550.0), and third quartile (640.6) of the data. C) Density data summary based on SSOM – drop-site collection.



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Total samples	73
Average density (lbs/cy)	556.8
Standard deviation (lbs/cy)	146.6

SSOM - office

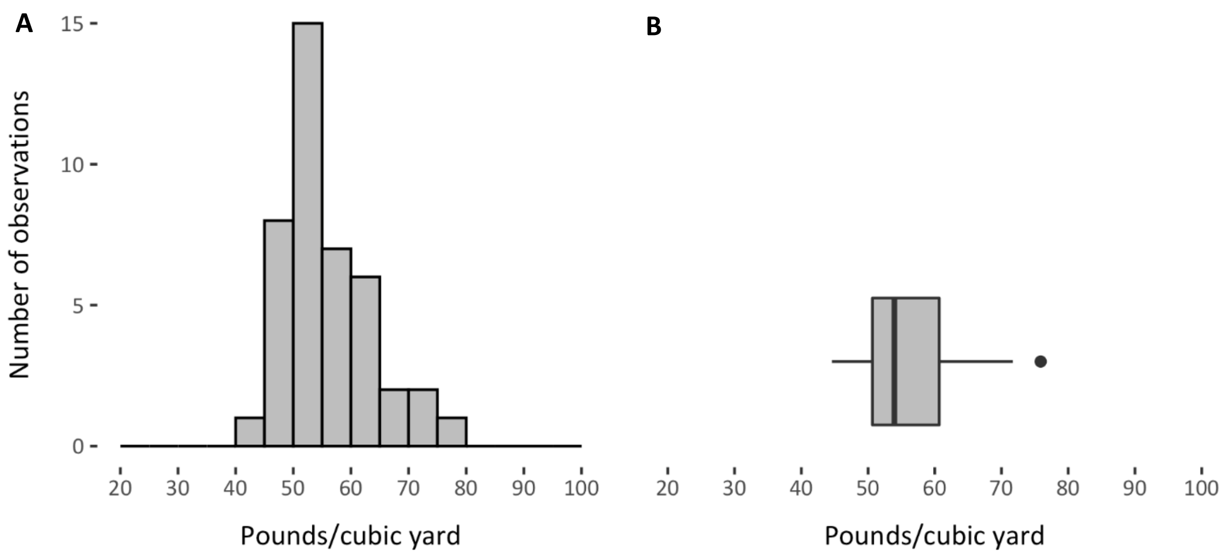
Data was collected by the Minnesota Department of Administration at state-run office properties across St. Paul from July 2016 to June 2020.

Protocol. Total pounds of organic material collected each month in organics bins at office buildings was record along with the volume of the material by month. Some of the offices include cafeterias. In some cases the cafeterias use reusable/washable dishes and in others they use certified compostable products.

Material condition. Office organic material is made up of wasted food, food scraps, and compostable products. Data collected from the first four months of organics collection at state facilities was removed from the data, as they did not appear to be correctly recorded. Additionally, data from March 2020 through June 2020 was not included in the analysis, because of employees were primarily telecommuting during the COVID-19 pandemic, affecting the organics waste stream.

Figure 12. SSOM bin at a Minnesota state-run office building.

Figure 13. Density of SSOM – office. A) Histogram of monthly densities (pounds/cubic yard) from 42 months of SSOM – office data collection demonstrating data variability. B) Box plot of densities from 42 months of SSOM – office data collection demonstrating the first quartile (50.1), median (54.0), and third quartile (62.8) of the data. C) Density data summary based on SSOM – office data collection.



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Total samples	42
Average density (lbs/cy)	55.9
Standard deviation (lbs/cy)	7.5

Recyclables

Single-stream recyclables – materials recovery facility

Material description. Single-stream recycling means that all paper, plastic, metal, and other recyclables are comingled a single recycling cart or dumpster, instead of being sorted by the generator into separate material streams. Single-stream recyclables include paper (office paper, newspaper, mail, and magazines), cardboard, glass bottles and jars, plastic bottles and some types of plastic packaging. All materials are comingled together into a single cart or dumpsters. Samples were gathered at the Eureka Recycling Materials Recovery Facility (MRF) in Minneapolis, MN in March of 2021.

Protocol. Recyclables are delivered to the MRF from residential curbside programs and some commercial sources. Materials were collected from the tipping floor. Some trucks did have some compaction of recyclables prior to delivery to the MRF.

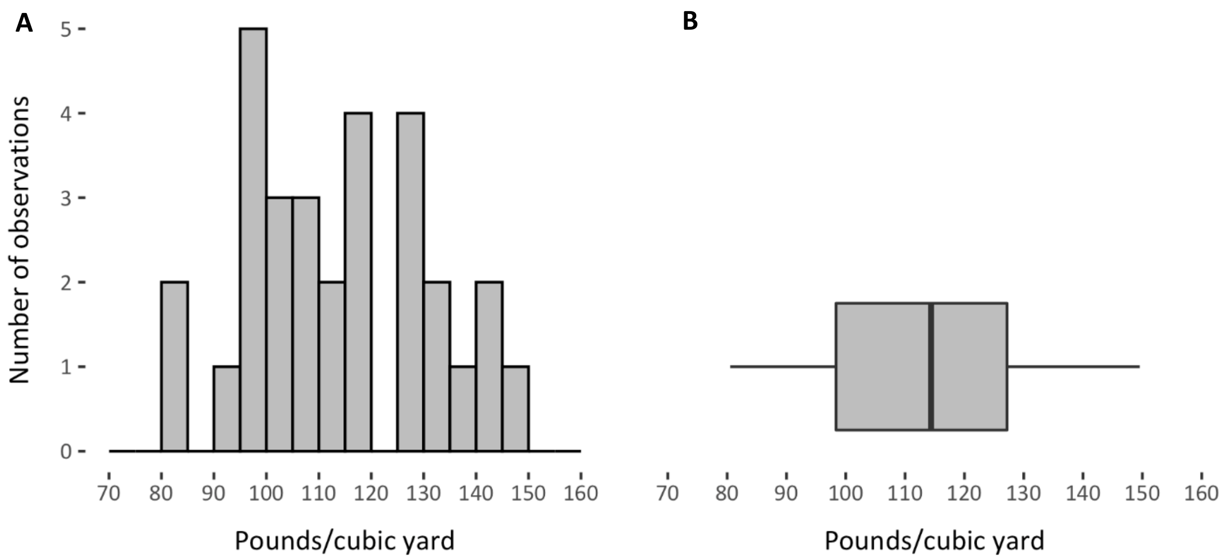
Sampling for single-stream recyclables followed most of the general field testing protocol, with the following modifications. A front loader was used to gather material from their large piles and place that material on the work area. Front loaders took material from different parts of the piles for each load, and the piles were in constant motion, as new loads came in and material was shipped out. However, for convenience of the staff at Eureka Recycling, each unit of material gathered by the front loader was split into eight subsamples instead of four. These subsamples were randomly assigned into two groups or gross samples. Subsamples of each gross sample were weighed in random order. Additionally, mixing the pile was challenge and not fully achieved by hand, so front loaders spread material out across the tarp to help spread and mix the material

All samples were tamped three times and weighed in random order, per the protocol.

Material condition. Single-stream recyclables are a very heterogeneous material, making the samples less uniform than some other materials. Large sections of cardboard and large contaminants were removed from gross samples because they were greater than 2/3 of the height, width, or length of the box. However, all small contaminants were included as part of single-stream recyclables. At the time of the report, Eureka Recycling reported an 8% contamination rate in the incoming recyclables.

Figure 14. Single-stream recyclables – materials recovery facility sampling process. A) Front loader dropping two gross sample of single-stream recyclables on the work surface. B) Gross samples split into eight subsamples (piles not fully pictured). C) Untamped sample in weigh box.

Figure 15. Density of single-stream recyclables – materials recovery facility. A) Histogram of densities (pounds/cubic yard) from 30 samples of single-stream recyclables demonstrating data variability. B) Box plot of densities from 30 samples of single-stream recyclables demonstrating the first quartile (98.4), the median (114.4), and third quartile (127.2) of the data. C) Density data summary based on single-steam recycling – materials recovery facility data collection.



C

Total samples	30
Average density (lbs/cy)	113.9
Standard deviation (lbs/cy)	18.4

Single-stream recyclables – multi-unit residential property

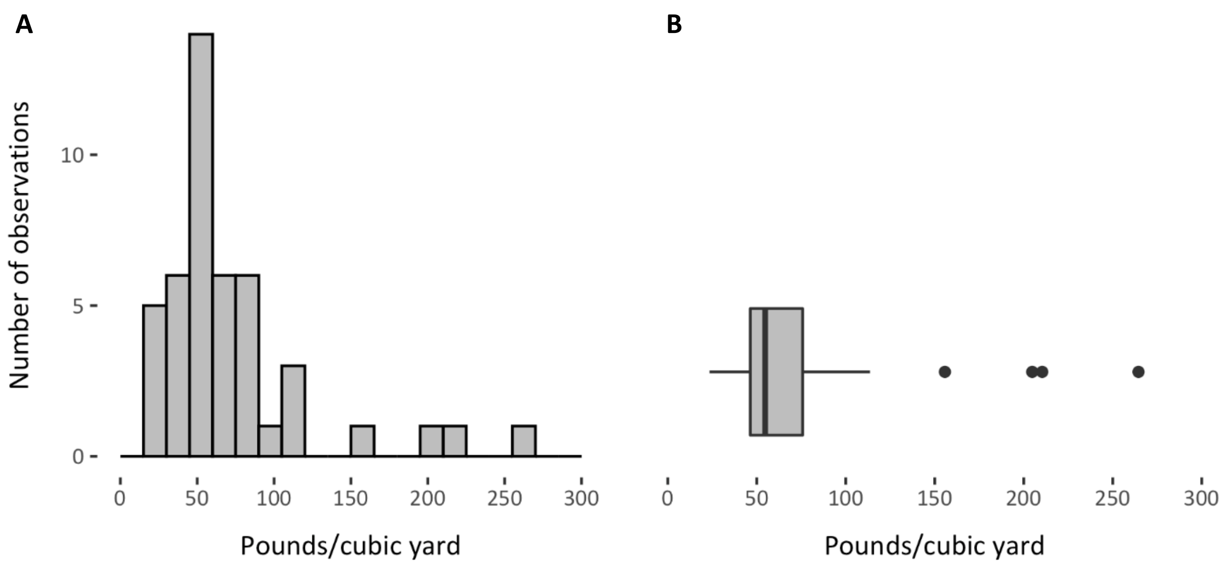
Material description. Single-stream recycling in recycling carts at multi-unit residential properties was collected from properties in St. Paul that ranged from 5 units to 222 units. Data was collected throughout June of 2021.

Protocol. Sampling for multi-unit residential property recycling did not follow the general field testing protocol. Multi-unit recycling was weighed in carts at properties varying in size around St. Paul. Carts were placed on scales, and tare weights for each cart type were subtracted from the total. Volumes for each cart were determined by using a yard stick to measure the height of the waste in the cart and by making an estimate of what percentage full each cart was. Fifty-six recycling carts were weighed.

Material condition. The single-stream recyclable material was primarily loose in carts. Some material was bundled in paper bags, making that material more compact than material that was loosely placed in carts, creating variability in the data. Material was mostly dry. Water present at the bottom of some carts was drained before weighing the material.

Figure 16. Single-stream recyclables – multi-unit residential property recycling sampling process. Measuring the height of recyclable material in carts.

Figure 17. Density of single-steam recyclables – multi-unit residential property. A) Histogram of densities (pounds/cubic yard) from 30 samples of multi-unit property recycling demonstrating data variability. B) Box plot of densities from 56 samples of recycling demonstrating the first quartile (46.3), median (54.7), and third quartile (75.7) of the data. C) Density data summary based on multi-unit residential property recycling data collection.



C

Total samples	56
Average density (lbs/cy)	70.8
Standard deviation (lbs/cy)	50.2

Glass

Material description. Broken glass from bottles and jars collected through single stream recycling was sorted into three sizes, but all sorting fed into one large pile at the facility. This meant that some samples may have had larger pieces of glass than others depending on which part of the pile it was taken from. Samples were taken from piles of the aggregate. Samples were gathered at the Eureka Recycling Materials Recovery Facility (MRF) in March of 2021.

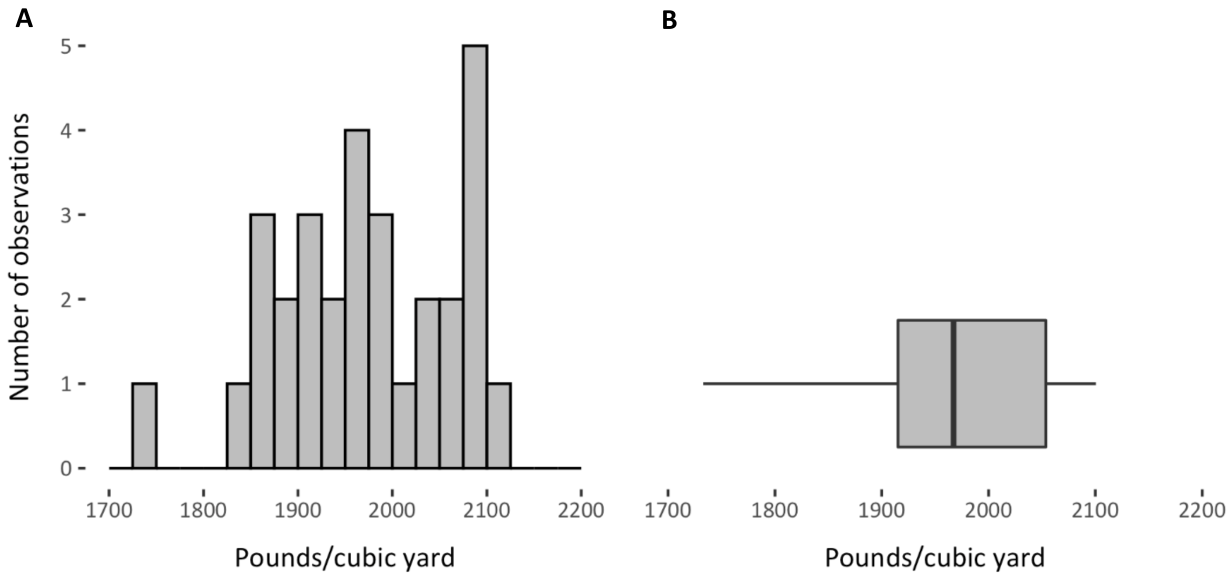
Protocol. Sampling for glass followed most of the general field testing protocol, with the following modifications. Front loaders were used to place material in the work area. From each load of material, four to five gross samples were created on the work area, depending on the size of the load of material. Glass is heavy and challenging to mix effectively, so front loaders spread out and mixed the material when placing it in the work area. Additionally, because glass is a heavy material, a measured 5 gallon bucket was used for each subsample instead of the 2x2x2 foot box.

All samples were tamped three times and weighed in random order, per the protocol.

Material condition. The glass material included small contaminants including bottle caps, food scraps, paper, and other small items. Some insignificant amounts of sand and dirt were included in a few of the samples, because the broken glass material is piled outside on soft ground. Pieces were generally less than 1 inch in size.

Figure 18. Glass sampling process. A) Four gross samples of glass on the work surface. B) Four subsamples from one gross sample. C) Tamped sample in 5-gallon bucket.

Figure 19. Density of shattered glass. A) Histogram of densities (pounds/cubic yard) from 30 samples of glass demonstrating data variability. B) Box plot of densities from 30 samples of glass demonstrating the first quartile (1915.2), median (1967.2), and third quartile (2053.6) of the data. C) Density data summary based on shattered glass data collection.



C

Total samples	30
Average density (lbs/cy)	1971.1
Standard deviation (lbs/cy)	91.9

Municipal solid waste (MSW)

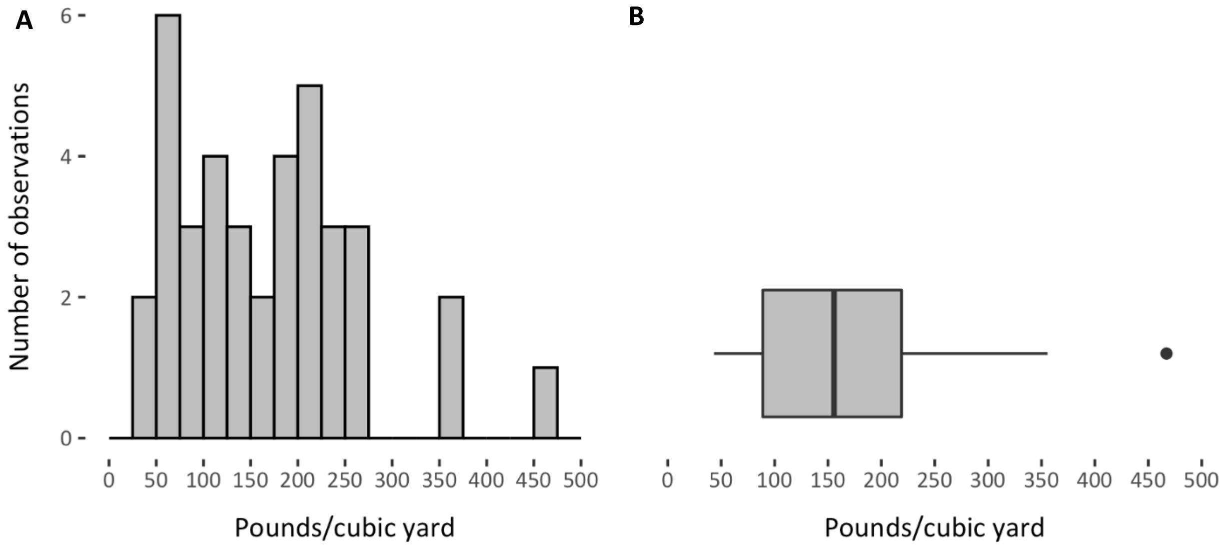
MSW – multi-unit residential property

Material description. Household MSW from multi-unit residential properties around St. Paul. Properties ranged from 5 to 21 units. Data was collected throughout June of 2021.

Protocol. Sampling for multi-unit residential property MSW did not follow the general field testing protocol. Multi-unit property MSW was weighed in carts at properties varying in size around St. Paul. Carts were placed on scales, and tare weights for each cart type were subtracted from the total. Volumes for each cart were determined by using a yard stick to measure the height of the waste in the cart and by making an estimate of what percentage full each cart was. Sampling followed the same process as single-stream recycling – multi-unit residential property data collection.

Material condition. The MSW material was primarily bagged in kitchen size plastic bags and was often very compact in the trash carts. Some trash was placed in smaller plastic grocery bags. Material was mostly dry.

Figure 20. Density of MSW – multi-unit residential property. A) Histogram of densities (pounds/cubic yard) from 38 samples of multi-unit property MSW demonstrating data variability. B) Box plot of densities from 38 samples of multi-unit MSW demonstrating the first quartile (88.9), median (155.7), and third quartile (218.8) of the data. C) Density data summary based on multi-unit residential property MSW data collection.



C

Total samples	38
Average density (lbs/cy)	167.1
Standard deviation (lbs/cy)	95.7

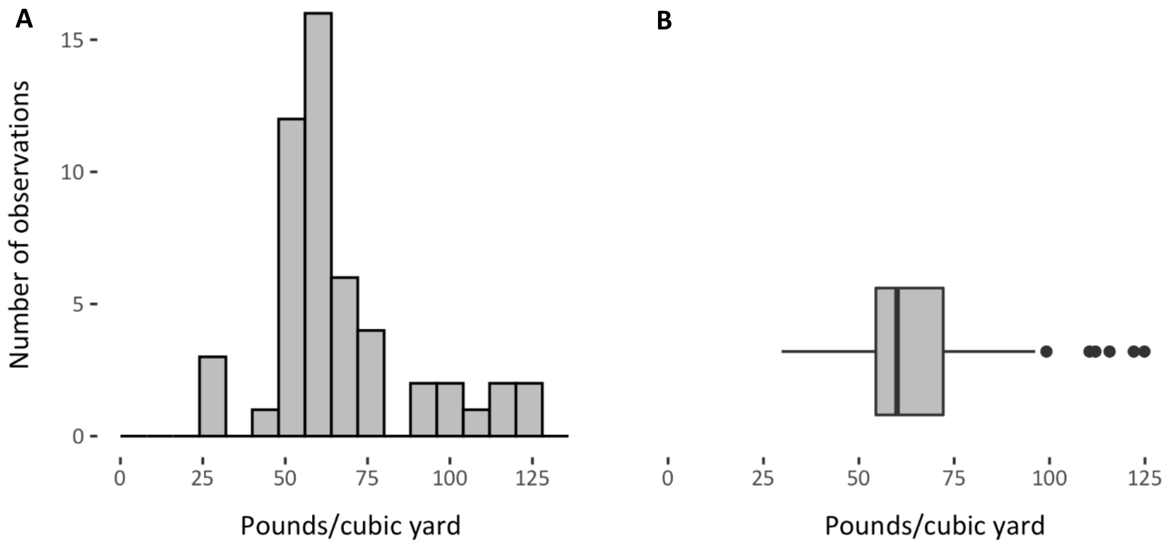
MSW – office

Material description. MSW collected in office buildings with recycling and organics collection. Data was collected at state-owned office buildings across St. Paul from January 2016 through June 2020 by the Minnesota Department of Administration.

Protocol. Total pounds of MSW material collected each month across all state-run office properties was record along with the volume of the material.

Material condition. Organics collection was implemented in June 2016, which may have impacted the amount of organic material in the MSW stream, impacting the weight of the trash. Additionally, data from March 2020 through June 2020 was not included in the analysis, because employees were primarily telecommuting during the COVID-19 pandemic, affecting the MSW waste stream.

Figure 21. Density of office MSW. A) Histogram of densities (pounds/cubic yard) from 51 samples of office MSW demonstrating data variability. B) Box plot of densities from 51 samples of office MSW demonstrating the first quartile (54.5), median (60.0), and third quartile (72.1) of the data. C) Density data summary based on office MSW.



C

Total samples	51
Average density (lbs/cy)	67.1
Standard deviation (lbs/cy)	22.0

Construction and demolition

Material description. This includes waste generated through construction and demolition (C&D) processes. A wide variety of material is included in this category, as a wide variety of material may end up in C&D dumpsters. The most common materials included in this category are concrete, roofing shingles, dirt/sand/gravel, treated wood, gypsum board, brick, and clean wood. Data was collected by Dem-Con Companies in Shakopee, MN throughout the spring of 2021.

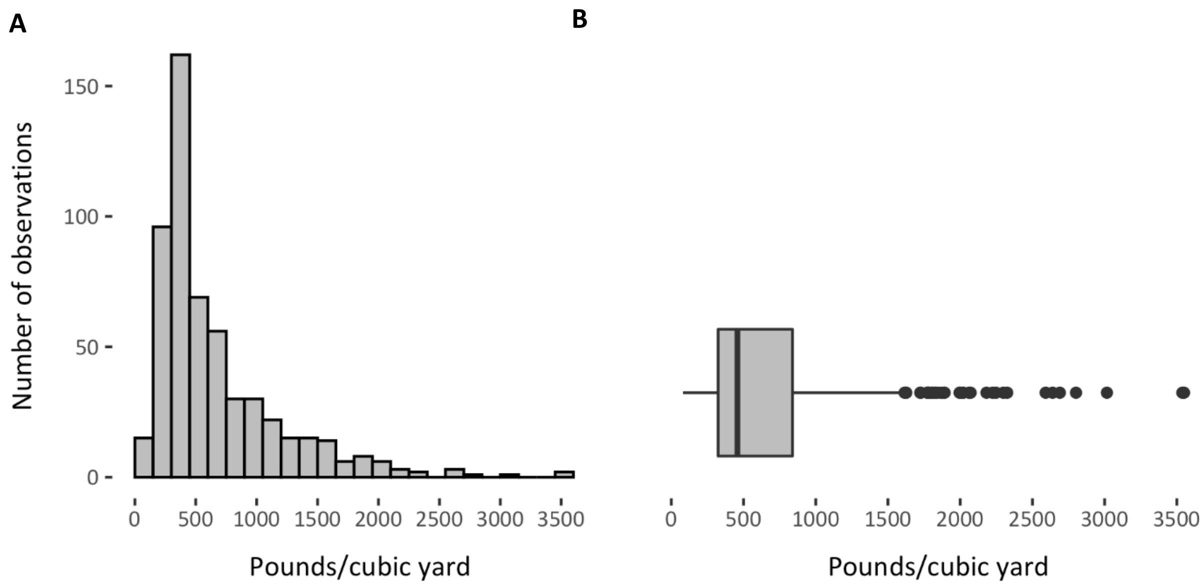
Protocol. Sampling for construction and demolition material did not follow the general field testing protocol. Construction and demolition waste was weighed in truckloads as trucks entered the Dem-Con facility to drop off material. Scale operators at Dem-Con recorded the net weight of the material in each truckload, the volume of the truck in cubic yards, and the approximate percent full of each truckload in increments of 25%. Scale operators also categorized each load into one of four categories based on the primary material present: Mixed concrete & dirt, demolition, industrial, and new home construction. Industrial waste includes residual waste from manufacturing and byproducts of the production of various types of materials, this may include some food byproducts. The number of samples per category vary depending on how many loads arrived at the Dem-Con facility. Data was recorded from February through May 2021.

Material condition. Material is quite variable, with some truckloads being filled with a single material, like concrete or some industrial wastes, and other loads were filled with a mix of different material types. Additionally, this data was gathered in early spring, but the composition of construction and demolition material varies seasonally, as certain projects are more common during the summer or fall than winter months.

Figure 22. Construction and demolition material.

Mixed construction and demolition

Figure 23. Density of mixed construction and demolition material. A) Histogram of densities (pounds/cubic yard) from 556 samples of mixed C&D demonstrating data variability. B) Box plot of densities from 556 samples of mixed C&D demonstrating the first quartile (323.0), median (457.3), and third quartile (838.2) of the data. C) Density data summary based on mixed construction and demolition data.

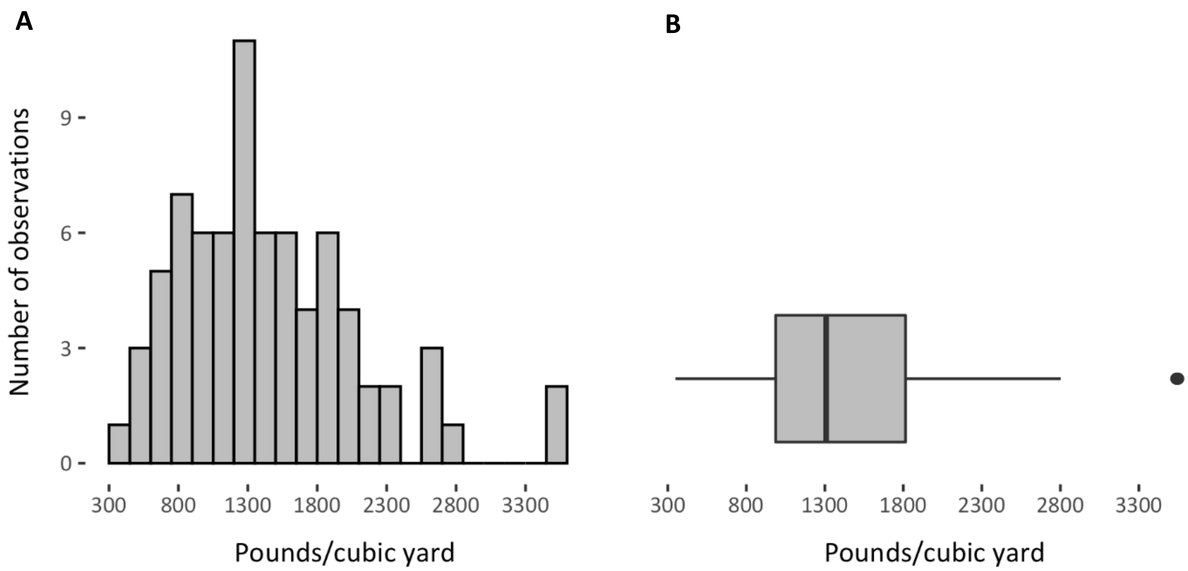


C

Total samples	556
Average density (lbs/cy)	59.2
Standard deviation (lbs/cy)	526.8

Mixed concrete and dirt

Figure 24. Density of mixed concrete and dirt. A) Histogram of densities (pounds/cubic yard) from 75 samples of mixed concrete and dirt demonstrating data variability. B) Box plot of densities from 75 samples of concrete and dirt demonstrating the first quartile (987.3), median (1308.0), and third quartile (1814.0) of the data. C) Density data summary based on mixed concrete and dirt data.

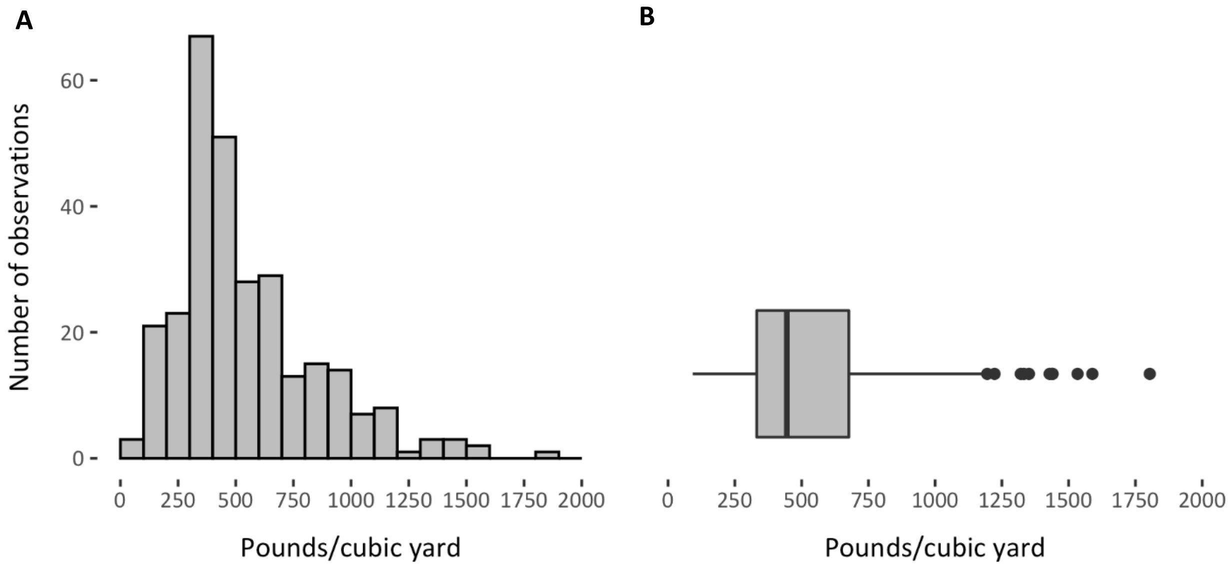


C

Total samples	75
Average density (lbs/cy)	1453.2
Standard deviation (lbs/cy)	654.5

Demolition

Figure 25. Density of demolition waste. A) Histogram of densities (pounds/cubic yard) from289 samples of demolition waste demonstrating data variability. B) Box plot of densities from 289 samples of demolition waste demonstrating the first quartile (332.0), median (444.7), and third quartile (676.8) of the data. C) Density data summary based on demolition waste data.

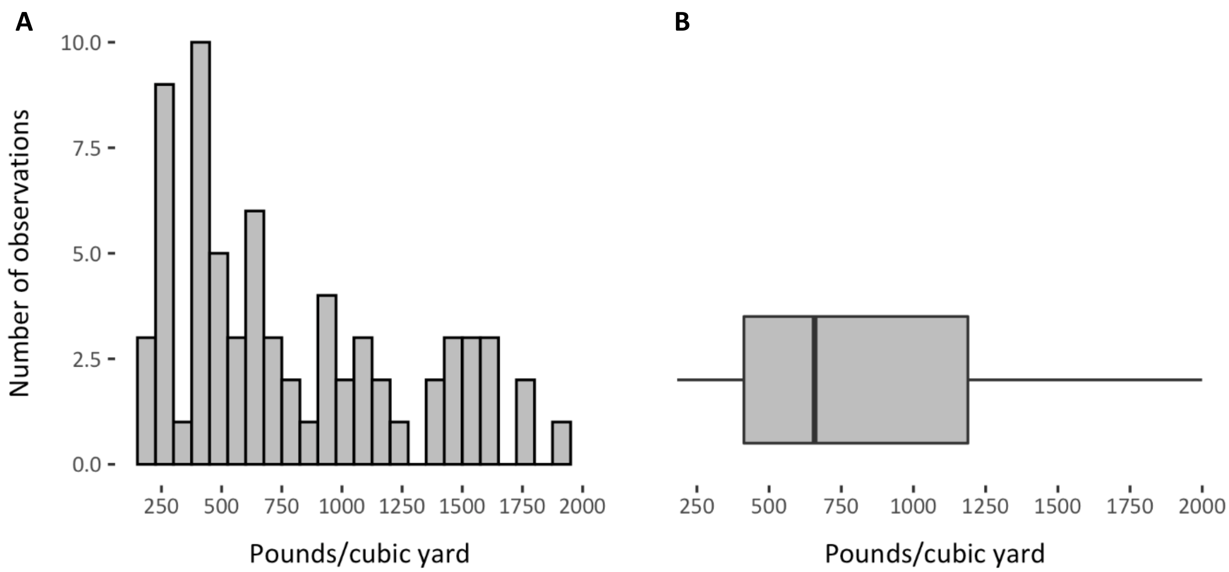


C

Total samples	289
Average density (lbs/cy)	538.3
Standard deviation (lbs/cy)	302.7

Industrial

Figure 26. Density of industrial waste. A) Histogram of densities (pounds/cubic yard) from 73 samples of industrial waste demonstrating data variability. B) Box plot of densities from 73 samples of industrial waste demonstrating the first quartile (413.3), median (661.3), and third quartile (1272.0) of the data. C) Density data summary based on industrial waste data collection.

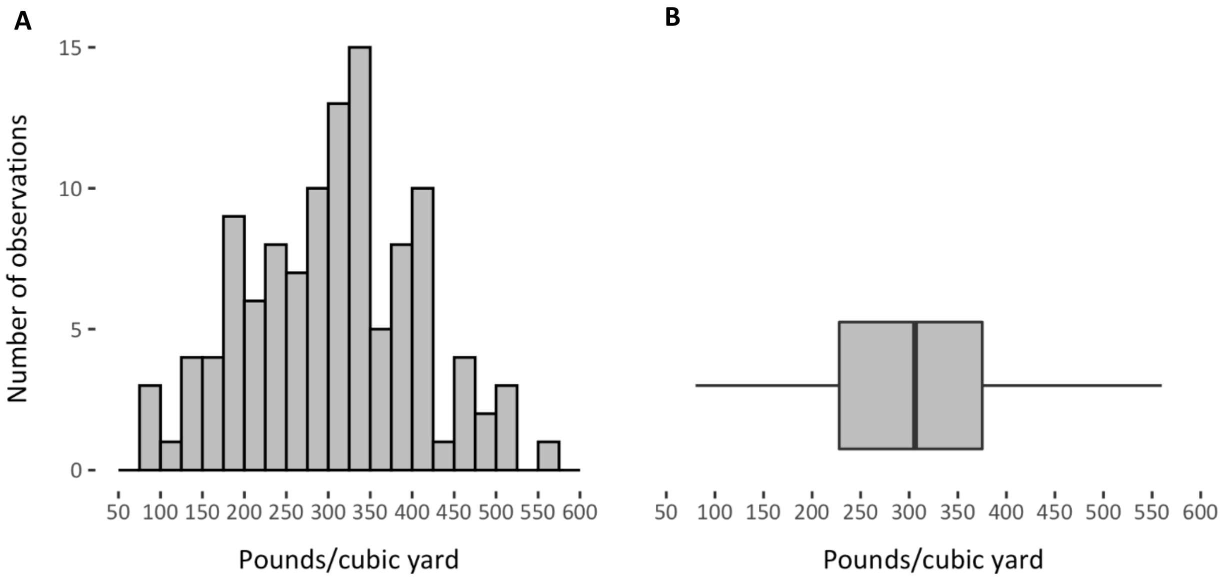


C

Total samples	73
Average density (lbs/cy)	877.9
Standard deviation (lbs/cy)	593.2

New home construction

Figure 27. Density of new home construction waste. A) Histogram of densities (pounds/cubic yard) from 119 samples of new home construction waste demonstrating data variability. B) Box plot of densities from 119 samples of new home construction waste demonstrating the first quartile (231.8), median (308.0), and third quartile (318.2) of the data. C) Density data summary based on new home construction waste data.



C

Total samples	119
Average density (lbs/cy)	318.2
Standard deviation (lbs/cy)	121.4

Recommendations

Given that many of the conversion factors in use are several years or even decades old, the MPCA encourages our partners to use these new factors where possible. The use of these new factors will reflect the current waste streams and practices for the materials in this study. Conversion factors are always going to be less accurate than using a scale to physically weigh the material and should not be used if scaling is available. Using these volume-to-weight conversion factors, where applicable, will provide comprehensive reporting of waste production. It is recommended that these conversion factors are used only when it is necessary to when report unweighted material as tonnages. In doing so, it is important to carefully determine which conversion factor to use for each material, since the conversion factor changes with waste composition, compaction, and sector.

While these volume-to-weight conversion factors provide valuable information for a few common waste streams, we recommend that states, cities, communities, and organizations undertake their own density data collection to determine volume-to-weight conversions specific to their waste streams whenever practical. Because waste stream composition varies by situation, so will the volume-to-weight conversion factors. Additionally, having more data available on volume-to-weight conversion factors will lead to a more consistent general value for each waste stream. This will provide even more confidence in accuracy to those unable to undertake their own data collection processes. Being able to use volume-to-weight conversion factors with confidence allows for more accurate calculations of waste streams and can lead to more efficiently targeted waste reduction and recycling efforts.

It is also recommended that scaled truckloads be used to determine conversion factors where possible and relevant. In waste streams with large volumes of waste, material is likely to be compressed and heavier than the weigh box might determine. Additionally, because waste streams vary, it is important to determine the best methods for gathering volume-to-weight conversion factors for each individual material type, waste stream or waste generator.

Appendix A: R code for summary statistics and plots

Below is an example of the code that was used to generate all the summary statistics, margins of error, and plots shown in this report.

```
library(ggplot2)
library(ggeasy)
library(extrafont)
library(gridExtra)

font_import(paths = "C/WINDOWS/FONTS")
loadfonts(device = 'win')

Grass<-read.csv("Data/Grass-Table 1.csv")

#5 number summary
summary(Grass$Density..lbs.cy.)
sd(Grass$Density..lbs.cy.)

#90% CI
n <- length(Grass$Density..lbs.cy.)
x_bar <- mean(Grass$Density..lbs.cy.)
std_dev <- sd(Grass$Density..lbs.cy.)
error <- qt(0.95,df=n-1)*std_dev/sqrt(n)
error

#Histogram
grass_hist <- ggplot(data=Grass, aes(Density..lbs.cy.)) +
 geom_histogram(breaks=seq(175, 300, by=5),
         color="black", fill="grey") +
 labs(x="Pounds/cubic yard", y="Number of observations") +
 scale_x_continuous(breaks=seq(175, 300, by=25),limits=c(175,300))+
 theme_bw() +
 theme(panel.border = element_blank(),
    panel.grid.major = element_blank(),
    axis.title.x = element_text(margin = margin(t = 20, r = 0,
                         b = 0, l = 0))) +
 theme(panel.grid.minor=element_blank(),
    plot.background = element_blank(),
    text = element_text(size = 11, family = 'Calibri'))+
 ggeasy::easy_center_title()

#BoxPlot
grass_box <- ggplot(data=Grass, aes(x=Density..lbs.cy.)) +
 geom_boxplot(fill = 'grey') +
 scale_y_continuous(limits=c(-.5,2))+
 scale_x_continuous(breaks=seq(175, 300, by=25),
          limits=c(175,300))+
 labs(x="Pounds/cubic yard") +
 theme_bw() +
 theme(panel.grid.minor=element_blank(),
```

```
   plot.background = element_blank())+
theme(panel.border = element_blank(),
   panel.grid.major = element_blank(),
   axis.title.x = element_text(margin = margin(t = 20, r = 0,
                         b = 0, l = 0))) +
theme(axis.title.y = element_blank(), axis.ticks.y=element_blank(),
   axis.text.y = element_blank(),
   text = element_text(size = 11, family = 'Calibri'))+
ggeasy::easy_center_title()
```

References

ASTM Standard E 1109 – 86 (2004), “Standard Test Method for Determining the Bulk Density of Solid Waste Fractions,” ASTM International, West Conshohocken, PA, 2004.

ASTM Standard C702/C702M – 18, “Standard Practice for Reducing Samples of Aggregate to Testing Size,” ASTM International, West Conshohocken, PA.

ASTM Standard D75/D75M – 19, “Standard Practice for Sampling Aggregates,” ASTM International, West Conshohocken, PA.