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Differences in Waste Generation, Waste Composition, and Source Separation across Three Waste Districts in a New York Suburb

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1 **Differences in Waste Generation, Waste Composition, and Source Separation across Three**
2 **Waste Districts in a New York Suburb**

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21 **Abstract**

22 Six tonnes of discards and recyclables from three waste districts in a New York suburb
23 were sorted in 2012. The districts were chosen because one had a higher recycling percentage,
24 one had median performance, and one was a low performing district. ASTM standards were
25 followed for the waste composition sorting. The results showed, as expected, that the waste
26 district with the highest recycling rate appeared to have the highest separation efficiencies,
27 leading to greater amounts of recyclable materials being source separated. The waste districts
28 also had different overall waste generation, both in terms of the amounts of wastes generated,
29 and their composition. The better recycling district generated less waste, but had a higher
30 percentage of recyclables in the waste stream. Therefore, in some sense, its waste stream was
31 enriched in recyclables. Thus, although the residents of that district recovered materials at a
32 higher rate, they also left large amounts of recyclables in their discards – as did the residents of
33 the other districts. In fact, the districts only recycled between one quarter and less than half of all
34 available recyclables, so that their discards were comprised of up to one third recyclable
35 materials. This level of performance does not appear to be unique to this Town; therefore, we
36 believe that additional recovery efforts through post-collection sorting for recyclables may be
37 warranted.

38

39 Key words: curbside collection, waste sorts, paper, containers, household recycling rates,
40 recycling percents, non-parametric statistics

41

42 **1.0 Introduction**

43 US national recycling rates have been relatively flat since the turn of the century (28.5%
44 recycling in 2000, 34.7% recycling in 2011) (USEPA 2013). Recycling as used here is defined
45 as the collection of material with the intention of using it to create new products; whether or not
46 true recovery of the collected materials is achieved is not part of the measurement.

47 Recycling performance has been found to relate to three classes of recycling attributes:
48 program characteristics; target population socio-demographic characteristics; and target
49 population psychological characteristics. So, Pay-As-You-Throw (PAYT) programs have higher
50 recycling rates to minimize participant disposal costs (Dahlen and Lagerkvist 2010; Skumatz
51 2008; Folz and Giles 2002; Linderhof et al. 2001; Salkie et al. 2001; Callen and Thomas 1999;
52 Miranda and Aldy 1999), mandatory recycling programs have greater participation rates than
53 voluntary programs (Viscusi et al. 2012; Nixon and Saphores 2009; Ferrara and Missios 2005),
54 curbside collection has better performance than drop-off programs (Best 2009; Ebreo and Vining
55 2000) and public outreach increases recycling (Sidique et al. 2010; Nixon and Saphores 2009;
56 Callen and Thomas 1999; Fransson and Garling 1999; Read 1999; Scott 1999; Daneshvary et al.
57 1998). Factors such as differences in age (Sidique et al. 2010; Diamantopoulos et al. 2003; Scott
58 1999), income (Jones et al. 2010; Ferrara and Missios 2005; Berger 1997), education (Nixon and
59 Saphores 2009; Jenkins et al. 2003), socio-economic status (Mukherjee and Onel 2012), home-
60 ownership (Oskamp 1995), political ideology (Fransson and Gärling 1999), race (Johnson et al.
61 2004), household size (Lebersorger and Beigl 2011), and employment (Bach et al. 2004) have
62 been shown to affect recycling rates, although the strength or direction of the trends may not be
63 consistent (for instance, opposite findings regarding age as a predictor by Stern and Dietz 1994
64 and Scott 1999). Also, note that most of those papers tracked participation rates not separation

65 rates. Attitudes that have been related to environmentally conscious activity and behaviors, and
66 recycling participation, include: concern for the community (Vincente and Reis 2008; Tonglet et
67 al. 2004); convenience and effort (Barr and Gilg 2005; Peretz et al. 2005; Sterner and Bartlings
68 1999); positions regarding morality (Berglund 2006), the environment generally (Best and Kneip
69 2011), and government (Guerin et al. 2001); social norms (Halvorsen 2008) and social
70 interactions (Shaw 2008); and, personality and past experience (Ajzen and Fishbein 1977). One
71 explanation for psychological linkages to recycling participation is that highly visible curbside
72 recyclables collection programs increase social pressure (Vining and Ebreo 1992).

73 Recycling performance is commonly measured in one of two ways. In survey-based
74 studies, one common measure is based on self-reports of the recycling frequency (i.e., the
75 number of events utilized by the participants for recycling as a function of the number of
76 recycling events available to them). These "participation rates" can also be measured by counting
77 the number of households setting out recyclables. Other studies measure the material or percent
78 of material recycled. It is assumed that increased participation rates result in greater diversion
79 rates, but there are no studies that document this. Therefore, most general recycling assessments
80 (USEPA 2013; Greene et al. 2011; NYSDEC 2010; Johnstone and Labonne 2004) focus on
81 recycling rates as reasonable means to compare recycling performance.

82 The composition of solid waste is different from nation to nation (Hoornweg and Bhada-
83 Tata 2013), has been said to vary across the US as a whole (USEPA 2013; OTA 1989), and has
84 been documented to be different from state-to-state (Staley and Barlaz 2009) and for
85 communities across the rural-suburban-urban spectrum in one state (DSM Environmental
86 Services Inc. and MSW Consultants 2013; NYSDEC 2010). Because waste streams vary, ability
87 and success at recycling may be at least partially dependent on the amount of recyclables that are

88 available to recycle -- the composition of the generated waste stream. Comparisons of recycling
89 performance across varying programmatic, demographic, and psychological groupings appear to
90 assume there is similar waste stream composition, and that differences in effort at recycling will
91 therefore equate to differences in recycling performance. This assumption appears to be shared
92 by those who link participation rates directly to recycling performance. Although recycling rates
93 may very well vary due to programmatic, demographic, and psychological differences, the
94 effects could be masked or accentuated by differences in the availability of materials to recycle.

95 Determining the composition of pre-source separation solid waste turns out to be more
96 difficult, and undertaken fewer times, than might be supposed. USEPA uses its Franklin
97 Associates model to determine waste composition for the nation as a whole before any
98 management of those wastes is accomplished (USEPA 2013). The accuracy of this methodology
99 has been questioned (Tonjes and Greene 2012). There are many site, locality, and state level
100 waste composition studies, made by sorting collected wastes in a formalized fashion. ASTM
101 (2006) has issued widely followed guidance for this. We have collected 107 examples of local
102 and state waste composition studies. All begin with discarded wastes. We are not aware of any
103 studies, save one (RW Beck 2005), that also included collected recyclables, and attempted to
104 relate recycling and waste discard rates to subsets of the studied region. The sprawling RW Beck
105 report to New York City Department of Sanitation never directly linked particular subset area
106 waste generation with recycling, partly because there were mismatches between routes for waste
107 collection and routes for recycling.

108 We report here on a waste composition study for the Town of Brookhaven, conducted
109 with an eye on multiple objectives. We sought to quantify the capture rate for particular
110 recyclable materials, and to relate those capture rates to three different levels of recycling

111 performance in the Town. We sought to determine the composition of discards and recyclables
112 for the three districts. We also sought to create a composite waste composition for each district,
113 and to determine if there were meaningful differences in the overall waste compositions in the
114 three districts, and if those differences related to any differences in recycling.

115 **2.0 Materials and Methods**

116 **2.1 Study Location**

117 The Town of Brookhaven (Long Island, New York) is located approximately 75 km east
118 of Manhattan Island, New York City (Figure 1). The Town created a residential waste collection
119 program in 1988. Mandatory curbside recycling was added in 1989. Separate collection of leaves
120 and brush and a ban on grass clippings collection was instituted in 2002. Recycling switched
121 from alternate week dual stream collection to single stream collection in 2014. Residents pay a
122 fixed fee per household serviced, which is collected through property tax bills. Approximately
123 115,000 single, two, and three family housing are provided service. Multi-family, condominiums
124 and cooperatives and other areas with private streets, and the nine incorporated villages in the
125 Town are not included in the collection program.

126 Town government administers the program, but the physical collection of wastes is
127 accomplished by contracted private companies. There are 35 geographically distinct districts in
128 the Town waste collection program.

129 **2.1.1 Waste Districts**

130 We selected three districts that delivered discarded wastes to the Town Transfer Station
131 on the Monday/Thursday collection cycle: District 1, District 18, and District 31. District 1 had
132 the greatest curbside separation percentage of all 35 districts in 2011, District 18 ranked 15 (of
133 35), and District 31 ranked 33. Curbside separation rates were defined as the sum of paper and

134 container recyclables divided by the sum of the collected recyclables plus collected discards.
135 District 1 is smaller than the other two districts, contains a smaller percentage of minority
136 residents, and its residents tend to be wealthier, and better educated (Table 1). Town waste
137 administrators believed that the three carting companies for these districts have better than usual
138 compliance with various collection rules, such as avoiding using the same truck to collect from
139 two districts on the same day (doing this would confuse our analysis).

140 **2.2 Waste Sorts**

141 **2.2.1 General Procedures**

142 We assumed that the waste composition data would be normally distributed, and used
143 ASTM (2006) assumptions regarding waste composition, selecting "mixed paper" as our key
144 component, as it required many fewer samples than all other components under the guidelines.
145 The ASTM algorithm for samples, with an allowable error of 10%, produced a value of 17
146 samples needed per district. We collected 18 discard samples per district, and five container
147 samples from each district.

148 All discard samples were processed on Mondays and Thursdays in a paved, open area
149 near the transfer station at the Town Waste management Facility. The first truck generally
150 arrived by 10 am. All waste from the three samples was processed by 4 pm. No rain occurred on
151 any of the 18 sampling days. Some materials were lost to wind and scavenging gulls, but the
152 impact was minimal.

153 All recyclable samples were processed within the on-site Materials Recycling Facility
154 (MRF) on Wednesdays. Only container loads were sampled, so at most two samples were
155 processed each day. The first sample generally arrived after 10 am, and all materials were
156 processed by 3 pm.

157 Although Districts 18 and 31 deliver wastes to the transfer station on the
158 Monday/Thursday cycle, due to their large size they also deliver wastes on the Tuesday/Friday
159 cycle as well. The second collection cycle on Tuesday/Friday was not sampled, although the
160 delivery data were used to generate waste profiles. Sampling began August 20, 2012, and
161 continued until November 15, 2012. Samples were not taken on Labor Day (September 3) and
162 Columbus Day (October 8) as the Town does not offer service on these holidays. Because of the
163 disruption of sampling associated with Superstorm Sandy (we did not sample October 25, the
164 week of October 29, and the week of November 5) and the potential that storm debris would
165 change the waste composition, the samples collected on November 15 were not included in the
166 analysis. Therefore, the analyses that follow will report on 17 samples from each district (eight
167 Monday samples, nine Thursday samples).

168 Recyclables sampling began August 22 and ended October 24. District 1 container
169 recyclables were delivered August 22 and every two weeks thereafter. Districts 18 and 31
170 container recyclables were sampled August 29 and every two weeks thereafter, so that a total of
171 five container samples from each district were sampled over 10 weeks.

172 Source separated paper recyclables were not sorted, as visual inspection and the history
173 of sorting recyclables at the MRF created confidence that close to 100% of delivered paper loads
174 would be sorted for resale. Thus, information regarding the composition of the paper recyclables
175 was not gathered. Logistical difficulties prevented sorting of yard wastes; inappropriate material
176 in yard waste collections has been noted but were assumed to be unimportant for this study,
177 which focused on other materials.

178 Wastes were sorted into 14 categories (Table 2), including all general categories of
179 recyclable materials managed by the Town. Materials were not disaggregated, except that

180 garbage bags and other waste holders were emptied, and aggregations that were formed due to
181 compaction in the truck were separated as was possible. Thus, containers and other packaging
182 were counted in with food at times, and other packaging was contaminated by food. Containers
183 were not drained of liquids. Multi-material pieces were sorted according to judgements of
184 predominant material, although the broad categories of "organic" and "inorganic" removed some
185 particular uncertainties associated with multi-materials. Bulk wastes were excluded because they
186 did not fit into the bucket loader well, and very large objects were not encountered (such as
187 garbage cans). Uncontainerized liquids were not included. Dirt and fines often coated materials,
188 but these were ignored in terms of classifications.

189 **2.2.1 Further specific sampling procedures**

190 For discards, the delivered wastes were mixed by the transfer station front-end loader for
191 several minutes. A partial bucket was taken from the discard pile and spread on a level asphalt
192 surface. Sorting continued until the entire pile had been sorted or it was estimated that
193 considerably more than 90 kg had been sorted. Materials were stored in 110 L containers, and
194 weighed by electronic scale (data given in 0.2 lbs [0.1 kg] increments). Tare weights were used
195 for each container.

196 With container recyclables, a truck load was mixed by loader for several minutes. A
197 partial bucket load was selected from the pile and brought into the MRF to an open area where
198 the materials were sorted into the same 14 categories as the discards. The segregated recyclables
199 were entirely sorted each time.

200 These procedures are generally in compliance with ASTM guidance (ASTM 2006).
201 However, ASTM specifications suggest slicing along the waste slug to gather materials, and
202 would cone and quarter this selection to achieve the sample material. ASTM also suggests

203 proportionate distribution among categories for multimedia or mixed materials. ASTM would
204 not like sampling to extend for as long as we conducted it.

205 **2.3 Data Analysis**

206 The weights in the 14 sorted categories were converted into percentages. Rate measures
207 were generated using the total amount of wastes delivered in each district each day (collected at
208 the scale house), the percentages in each category, and the time from the last waste collection.
209 For paper deliveries, 100% of the delivery was assumed to be recyclable paper (per above).

210 The most commonly used waste rate in the US is per capita computations (e.g., Greene
211 and Tonjes 2014; USEPA 2013; van Haaren et al. 2010). However, the waste districts do not
212 conform with census tracts, and certain housing types (multi-family housing, condominiums, and
213 co-ops) are not included in the waste district. Therefore, the number of people served by each
214 waste district was thought to be very difficult to determine accurately. Household rates are
215 commonly used in European waste studies (e.g., Beigl et al. 2008; Johnstone and LaBonne
216 2004). The prejudice against "household" as the base unit in solid waste analyses in the US relies
217 on the accurate perception that all households do not have the same number of members.
218 However, households are a self-defined unit for waste collection for curbside programs, and they
219 are the billing unit for the waste districts (and so are carefully tracked by both the Town and the
220 contract carters), and so we selected "per household" values for this report. We chose "week" as
221 our unit of time to prevent presentations with many values <1 (sometimes considerably <1).

222 There was an obvious mismatch between the frequency of waste analyses (17 over 10
223 weeks) and recyclables analyses (five container analyses, five paper data points over 10 weeks).
224 We combined the waste data into two week increments. The estimates of container separation,
225 derived from scale data and the sort data, were added to the paper tonnage from the two week

226 interval to create an estimate of district wide source separation. These two values could be
227 summed to estimate the district wide amount and composition of curbside set out wastes over
228 each two week interval. This process therefore created five estimates of composition (by percent
229 and weight) and total amounts of discards, recyclables, and total curbside waste generation over
230 the study period.

231 Town carters also collect source separated yard wastes. However, the period of August to
232 October is not a peak generation time for yard wastes on Long Island, so yard waste was thus
233 collected irregularly during our sampling period. We collated records for yard waste collections
234 for each of the three months and used that as a measure of yard waste diversion over the
235 sampling period.

236 The waste data were not normal, and were not generally transformable to normal
237 distributions. This resulted from the heterogeneity of solid waste generally, and from the “batch”
238 nature of discards. In a 100 kg sample, a single 10 kg bag of yard waste could skew the entire
239 distribution of the sampling results. One closet clean-out could also bias a sample. Because
240 wastes adhere naturally, were almost always disposed in plastic bags, and then were compacted
241 in the truck, the loader mixing did not separate householder wastes much. We inferred (from
242 similarities in the garbage, and direct evidence such as mail) that each sample was derived from
243 a few households: perhaps as few as six or eight, but seemingly never more than 20 distinct
244 households. This may have also enhanced the inherent heterogeneity of wastes compared across
245 samples. The estimates of district wide waste composition for each collection day were based on
246 tonnages recorded at the scale house. This had a good deal of variability within each district.
247 Compared to the greatest delivery tonnage, the mean delivery tonnages were about half, and
248 varied from a low of 31.9% of the maximum to 91.7% (container recyclable deliveries were

249 much more consistent, averaging 90% of the maximum delivery with a range of 77.6% of the
250 maximum to 97.5%). Thus, particular heterogeneities in the sampled waste may have been
251 suppressed or made greater, depending on the amount of waste delivered that day. For some of
252 our data, increasing the number of samples considered in the analyses (from five to 17, for
253 instance) increased overall variance measures.

254 Because the data were not normal, we analyzed the data using PERMANOVA (Anderson
255 2005), a multi-variate, non-parametric approach, using rank ordering of permutations of the
256 groups being tested (the null hypothesis is that substitution from one group into another should
257 not affect the ordering). Therefore, references to mean values with associated standard deviations
258 do not imply the statistical significance measures were actually made on these values.

259 Differences in mean values can only be inferred from differences in the ordering of the results
260 across districts. The statistical analyses were made across all three samples; we will not report
261 any pair-wise tests. We used a sample size of 17 for the discards analysis only; all other analyses
262 were based on five samples. The significance level used for all analyses was $p < 0.05$.

263 **3.0 Results**

264 Scale house records and raw sorting data are available in the Supplementary materials
265 (Tables S1-S8). Source separated yard waste collection data are included in Table 4.

266 **3.1 Capture Rates for Recyclables**

267 Previously we identified recycling percent and per capita recovery rates as two of the
268 better measures of recycling program performance (Greene and Tonjes 2014). Therefore, we
269 focus here on the per household recovery weights (for total recyclables, and the constituent
270 materials of the recycling program) and the percentage of the total waste stream of these

271 materials to determine differences across the districts, a largely pro forma exercise, given the
272 districts had been selected based on prior differences in overall recycling percents.

273 The rate of curbside recyclables separation across the three districts, in kg/HH/wk (Figure
274 2), was significantly different when measured in terms of all 13 constituent materials (mixed
275 paper and corrugated cardboard had been collapsed into one material category, recyclable paper),
276 five materials (the primary recyclable categories of paper, plastic containers, glass containers,
277 and recyclable ferrous and aluminum), two general categories (paper and containers), or one
278 lumped sum. The same was true for the sum of the five recyclable materials only (excluding non-
279 recyclable materials) (significant differences for five constituent categories, two categories of
280 paper and containers, or one category only). The rate of paper separation (in kg/HH/wk) was
281 significantly different across all three districts, as was the rate of total container separation (as
282 four constituent materials and as a single summed term). The rate of glass separation as a single
283 constituent was also statistically significant. The rate of separation of the other containers was
284 not found to be significantly different (only recyclable plastics is illustrated in Figure 2,
285 however).

286 The percentage separated from the whole waste stream (here considered to be only
287 discards and recyclables) (Figure S1) was significantly different across all three districts, as was
288 the percent of the five target recyclables (as five constituent variables, as two variables of paper
289 and containers, and as a single summed variable). The percentage of paper, total containers (as
290 four constituent variables and a single summed variable), and glass separated across the three
291 districts were also significantly different. Other recycling separation percents were not
292 significant (again, only recyclable plastics are shown in Figure S1).

293 **3.2 Discards and Recyclables Composition**

294 The amount of discards were significantly different across the three districts, considered
295 by each constituent material (a 14 variable set), the two major divisions of recyclable and non-
296 recyclable materials, or the single sum of materials. Plastic bags, yard waste, and other organics
297 were specific materials where the discard rates were found to be significantly different. Non-
298 recyclables (as an eight material set or as a sum) and recyclables plus yard waste (as a three
299 constituent set of paper, containers, and yard waste, or as a single sum) were also significantly
300 discarded differently across the three districts. Recyclables (as a sum, as individual constituents,
301 and as the grouped sets of recyclable paper and containers) and other individual constituents not
302 specified above were not discarded significantly differently (Figures S2 and S3). When the
303 percentage of these constituents were considered, the 14 variable sets as a whole were
304 significantly different across the three data sets, although the only individual constituent that was
305 significantly different was yard waste (Figure S4). The only aggregated data sets that were
306 significantly different across the three districts were non-recyclables (as an eight variable set, but
307 not as a single value) and recyclables plus yard waste (as a seven variable set or as the grouping
308 of paper-containers-yard waste, but not as a single value) (Figure S5).

309 The composition of the curbside recyclables has been partially presented above (Section
310 3.1). There it was shown that the total composition of the collected curbside recyclables,
311 measured as 13 constituent materials, the five primary recyclable categories, or as the two
312 general recyclable categories of paper and containers, were all significantly different when
313 measured by weight. The composition of the recyclables was significantly different by weight
314 considering the total paper category alone, and for total containers (as four constituent materials
315 and as a single summed term). However, the only container type with a significantly different
316 composition amount across the three districts was glass.

317 In terms of percentages of the source separated curbside recyclables, the only statistically
318 significant differences were for a bivariate comparison of total recyclable paper and containers as
319 a summed category, and for total paper as a single category. All other percentage composition
320 comparisons were not significantly different (Figure S6).

321 **3.3 Overall Waste Composition**

322 We constructed an overall waste composition for each district by summing the discards
323 and recyclables for each two week collection period. We lost the distinction between mixed
324 paper and corrugated cardboard in doing so, because we did not sort the collected paper
325 recyclables.

326 The total waste stream, as a rate (kg/HH/wk), was statistically significantly different
327 across all three districts, measured for 13 categories, a bivariate division into recyclables and
328 non-recyclables, and as a single value. Non-recyclables, as an eight variable measure or as a
329 single value, were also significantly different across all three districts. Recyclable containers, as
330 a four constituent variables measure but not as a single value, were statistically significantly
331 different across the three districts, as was the constituent category, glass. Other organics were
332 also statistically significantly different. All other measures were not found to be statistically
333 significantly different (Figures 3 and 4).

334 The composition of the waste stream was also determined in terms of percentages. There
335 were more statistically significant differences determined for this measure. Significant
336 differences were found for the composition of the total waste stream, using 13 variables and the
337 two variables of recyclables and non-recyclables, recyclables considered by itself (with five
338 variables of paper and the four container types, two variables of paper and containers, and as a
339 single value), recyclables and yard waste as a combined category (using six variables, and the

340 three variable measure of paper, containers, and yard waste, but not as a single variable), for
341 recyclable paper, and for containers (but only as four constituent variables; the single variable
342 measure of containers was not found to be significantly different). All other measures were not
343 found to be statistically significantly different across the three districts (Figures 5 and 6).

344 **3.4 Separation Efficiency**

345 The Town collects seven different types of recyclables; because we constructed an
346 overall waste generation composition for the three districts, it was possible to compute the
347 separation efficiency for paper recyclables and containers (as a whole and as the four constituent
348 materials). We also estimated yard waste separation efficiency, although it was not statistically
349 analyzed, being a single data point for each district.

350 There were significant differences across the three districts for separation efficiencies for
351 curbside recyclables as a whole (considered as two variables of paper and containers, and as a
352 single variable, but not as the five constituent variables of paper and the four constituent
353 container materials), for recyclable paper, and for containers as a whole (as a single variable, not
354 as the four constituent variable test). Separation efficiencies for the four individual container
355 types were not found to be statistically significant across the three districts (Figure 7). Yard
356 waste separation rates and estimates of separation efficiency are shown in Table 3.

357 **4.0 Discussion**

358 We were able to reconstruct the initial composition of wastes generated in our three waste
359 districts. We measured the amount and composition of the waste streams set out for management
360 in the districts, and so we can determine the differential effects of the recycling actions taken by
361 the residents.

362 Residents are asked to separate out paper and container recyclables for collection on
363 alternate Wednesdays. District 1 appears to set out more paper (mean of 3.47 kg/HH/wk)
364 compared to District 18 (mean of 2.51 kg/HH/wk) and District 31 (mean of 1.58 kg/HH/wk).
365 District 1 sets out more containers (mean of 1.71 kg/HH/wk) compared to District 18 (mean of
366 1.21 kg/HH/wk]) and District 31 (mean of 0.96 kg/HH/wk). This results in a higher mean
367 recovery percentage (measured as the sum of recyclables set out curbside against the sum of
368 discards and recyclables set out curbside) of 20.3% for District 1 compared to 11.8% for District
369 18 and 8.4% for District 31. This unsurprising result mirrors and closely matches the basis for
370 our selection of the districts (see Table 1).

371 Not only do the residents follow the Town requirements to recycle differently (as
372 measured by separation amounts and efficiencies) but the composition of their wastes prior to
373 recyclables set out are different (in some ways). So, our data suggest that District 1 generates less
374 waste overall (mean of 26.66 kg/HH/wk) than District 31 (mean of 30.21 kg/HH/wk), which
375 appears to be less than is generated in District 18 (mean of 33.64 kg/HH/wk). But because
376 District 1 seems to have a higher proportion of recyclable materials in its wastes (mean of 46.0%
377 recyclable materials compared to District 18 which has a mean of 35.3% and District 31, with a
378 mean of 34.3%), there seems to be not too much difference in the overall amount of recyclables
379 generated by each household in the three districts. The total of recyclables in the waste stream
380 for District 1 is a mean of 12.29 kg/HH/wk compared to District 18 which has a mean of 11.84
381 kg/HH/wk, although District 31 is notably lower at 10.38 kg/HH/wk, with the latter difference
382 stemming entirely from a deficit in paper waste generation (paper mean waste generation values
383 are 8.48 kg/HH/wk for District 1, 8.17 kg/HH/wk for District 18, and 6.73 kg/HH/wk for District
384 31; the difference appears negligible for containers, with mean values of 3.83 kg/HH/wk for

385 District 1, 3.68 kg/HH/wk for District 18, and 3.66 kg/HH/wk for District 31). So this
386 interpretation suggests that the difference in recycling rates is directly related to the efficiency
387 that residents separate out their recyclable materials – their degree of compliance with Town
388 recycling regulations – because they have approximately the same amounts of recyclable
389 materials for sorting.

390 It is interesting, however, that District 1 is relatively enriched in recyclables, considered
391 as a percentage of its wastes. When residents of District 1 examine their wastes, there are
392 relatively more recyclables available for selection, on a per item basis. That may allow for easier
393 selection of recyclable items out of all wastes; since the District 1 waste stream proportionately
394 contains more recyclables, if those residents separated them at the same rate as residents of the
395 other districts, they would separate out a greater percentage of their wastes. But apparently they
396 tend to separate out a higher percentage of recyclables, and this increases the difference in
397 recycling rates.

398 Another perspective is to say that the amount of non-recyclable materials appears to be
399 much less in the District 1 waste stream: a mean value of 14.38 kg/HH/wk for District 1,
400 compared to a mean of 19.83 kg/HH/wk for District 31 and a mean of 21.80 kg/HH/wk for
401 District 18. District 1 also seems to discard much less than District 18 and District 31 (a mean of
402 21.27 kg/HH/wk compared to a mean of 27.19 kg/HH/wk for District 31 compared to a mean of
403 29.41 kg/HH/wk for District 18). However, because the District 1 overall waste stream appears
404 to contain proportionately more recyclables than the other two districts, the amount of recyclable
405 material discarded across the three districts appears to be very similar: a mean of 7.04 kg/HH/wk
406 in District 1, 7.86 kg/HH/wk in District 18, and 7.90 kg/HH/wk in District 31. Thus, in a sense
407 the residents of District 1 are as wasteful as the residents in the other two districts, because their

408 increased recovery efficiency is not enough to account for the proportionately enriched waste
409 stream with which they begin.

410 Details become a little more complicated. For instance, residents in all three districts
411 appear to be more faithful in recycling glass than any other material. District 1 residents appear
412 to do better (a separation efficiency of 58.7%) than District 18 residents (separation efficiency of
413 49.3%) and the residents of District 31 (separation efficiency of 40.7%). However, because of
414 waste generation differences, the residents of District 1 separate nearly twice as much glass on
415 average (1.09 kg/HH/wk) than District 18 (a mean value of 0.58 kg/HH/wk) and nearly three
416 times as much as District 31 (mean value of 0.38 kg/HH/wk). Still, District 1 residents appear to
417 discard a little more glass than the residents of the other two districts: a mean of 0.73 kg/HH/wk
418 compared to 0.60 kg/HH/wk in District 18 and 0.61 kg/HH/wk in District 31.

419 Sometimes the combination of different waste stream percentages, waste generation rates,
420 and separation efficiencies combine in ways that hide very large differences in processes. Figure
421 8 illustrates how all three districts appear to have very similar mean recovery rates (in
422 kg/HH/wk) for plastic containers, ferrous metals, and aluminum. However, presenting discard
423 data for these same categories (Figure 9) shows that recovery performances, as measured by their
424 opposite (the discards of recyclables) appear to be quite different across the districts. Even the
425 small absolute difference in mean values for aluminum discards between Districts 1 and 18 (0.05
426 kg/HH/wk) is a 20% relative difference.

427 Recyclable paper was computed to be the largest single category of generated waste,
428 based on discard and recycling sorts (although “other organics” was nearly as large in Districts
429 18 and 31). The mean overall waste composition percentages ranged from 22.3% (District 31) to
430 32.3% (District 1). Although District 1 residents separated out a mean of 3.47 kg/HH/wk, nearly

431 43% of what was available, this effort still left a mean of 4.95 kg/HH/wk in the disposed waste.
432 So, after recovery efforts, recyclable paper was the second largest component in the discards
433 (behind other organic) for District 1, which was also the case in the other two districts. In the
434 Town's best recycling district, the discard waste stream after recycling was nearly 25%
435 recyclable paper by weight (a mean value of 23.8%) (because District 18 and 31 began with
436 more wastes per HH, and a smaller proportion of paper, after recycling the mean recyclable
437 composition was less at 18.1% and 19.4%, respectively).

438 The Town has operated its recycling program for over 20 years. The last major change
439 (prior to the 2014 modification to single stream recycling) was over 10 years before this
440 sampling program. This is a mature recycling program, in a fairly affluent, fairly well-educated,
441 and still relatively ethnically homogenous suburb. The Town has conducted continuous outreach
442 programs, through presentations at public events, Town-wide mailings, public service
443 announcements, school outreach and education programs, and the like. Still, compliance rates (as
444 measured by separation efficiencies) are not robust. The best overall separation efficiency was
445 less than 50% for the curbside recyclables (District 1); separation efficiency was less than a third
446 for District 18 and less than one-quarter for District 31. Curbside recycling is the easiest and
447 most convenient form of recyclables collection program, and is generally thought to have the
448 best participation rates (Best 2009; Ebreo and Vining 2000) (compared to drop-off or buy-back
449 programs, for instance). The poor performance by the residents means that approximately one-
450 third of District 1 discards are recyclable, and a little more than one-quarter of District 18 and 31
451 discards are recyclable, too. If yard wastes are included in the tally, the percentages of discarded
452 recoverable materials increases to 40% or so for all three districts (please note that yard waste
453 collections over the August-October period were sporadic, and when generation rates of yard

454 wastes increase, collection frequency increases; so we think the amount of discarded yard wastes
455 would be found to be less on an annual accounting).

456 The Town's discards are transferred to a Long Island waste-to-energy plant (in another
457 municipality). The Town pays approximately \$110/tonne for this disposal (\$88/tonne for the
458 tipping fee, and approximately \$20/tonne for operations of the transfer station and the hauling of
459 the wastes). In 2012 the Town disposed of 173,044 tons (~155,000 tonnes) this way. Using a
460 conservative estimate of 25% recyclables content, this suggests that the Town spent \$4 million -
461 \$5 million to dispose of potentially recyclable materials.

462 Another perspective to consider is lost revenue. District 1 households discard a mean
463 value of 1.00 kg/wk of PET and HDPE containers and aluminum. The similar mean value for
464 District 18 is 1.20 kg/HH/wk and for District 31 it is 1.36 kg/HH/wk. This means that between
465 50 and 75 kg of these valuable recyclables are discarded by each household each year. The value
466 of the materials on the secondary market has been well in excess of \$500/tonne for several years.
467 This suggests each household discards more than \$50 worth of plastics and aluminum each year,
468 conservatively. The district waste fee charged by the Town is approximately \$375/HH/yr;
469 therefore, if these revenues were realized instead of being lost in the discards, residents might
470 receive as much as a 15% reduction in direct waste costs.

471 The irony is that valuable plastics and aluminum are recovered at much lower rates than
472 glass is. Glass was recovered at higher rates than all other materials except for yard waste. Glass
473 has no real reuse market in the New York metropolitan area. The management of recovered glass
474 represents an ongoing problem for all local waste systems. The most common reuses for glass
475 are as structural materials in landfill cell management (berms and roadways). Another common
476 management technique has been to stockpile the glass and wait for offers. Yard waste, on Long

477 Island, has substantial fees associated with its management at compost sites (\$60/tonne and
478 higher, often with extra transportation costs). Thus, the two materials source separated with the
479 greatest efficiencies by Town residents either have no or negative market value.

480 Poor performance by recycling programs is not limited to the Town of Brookhaven.
481 USEPA data (2013) suggest 11.5% of the total residential, commercial, and institutional discards
482 waste stream is newspaper, corrugated cardboard, and PET (#1) and HDPE (#2) plastic, ferrous,
483 and aluminum containers. The New York City waste sort (RW Beck 2005) found that about 23%
484 of New York City residential refuse consists of materials designated by the City as curbside
485 recyclables. The study also found that 47% of street basket waste could have been recycled under
486 the City's curbside recycling program. The last time San Francisco published its waste
487 composition, the discards from the residential and small business sector (the Fantastic Three
488 program) were determined to be approximately 50% recyclable (although San Francisco has an
489 expansive definition of recyclable materials) (ESA Assoc. 2006).

490 **5.0 Conclusions**

491 We sorted approximately 6 tonnes of waste and recyclables from three waste districts in
492 the Town of Brookhaven. One district was a good recycling district, the other was a median
493 recycling district, and the third had poor recycling performance (relative to performances in the
494 other 32 waste districts in the Town).

495 We made some unsurprising findings. Paper constituted most of the curbside recyclables,
496 which agrees with 20 year data sets from the Town MRF, and echoes USEPA reports. The
497 recycling district with the highest recovery rate recovered a higher percentage of its available
498 recyclable materials, and the district with the lowest recycling rate had much lower recovery

499 efficiencies. Glass was the largest constituent of the container recyclables, again in agreement
500 with Town and national data compilations.

501 We made some unexpected discoveries. Our data suggest that containers are recovered at
502 a higher rate than recyclable paper, overall. But separation efficiencies vary for different
503 materials, and some container recyclables (such as aluminum) were recovered at fairly low rates
504 (a mean separation efficiency of 14.7% for aluminum in the poorest performing district).
505 Generally, less than half of recoverable materials was separated in the best recycling district; that
506 value was closer to one-quarter of the available material in the poorest performing district. This
507 also meant that the discards stream was relatively rich in recyclables: at least one quarter and as
508 much as one third of the discards were curbside recyclables.

509 The composition of the total waste stream, pre-recycling, was different in many aspects
510 for the three districts. In terms of percentage composition, the better recycling district had an
511 enriched environment for recycling, which coupled with its higher efficiency rates led to
512 appreciably more recovered materials.

513 Although the better recycling district had a smaller overall waste stream and then
514 recycled available material with a higher efficiency, the difference in waste composition meant
515 that its discard stream appeared to hold more recyclables of some kinds (such as glass) than the
516 other districts. So although the overt compliance with Town recycling rules, as measured by
517 separation efficiencies, was much higher in the best recycling district, those residents still left a
518 great deal of recyclable materials in their waste, sometimes more (by some measures) than the
519 poorer performing districts.

520 We have not investigated the causes of the differences in waste composition. We noted
521 that there are some demographic differences across the districts, but our sample size of three is

522 too small to seriously investigate that complicated issue. Our subjective, qualitative collective
523 observation is that the wastes from the three districts are different in kind, and that some
524 differences appear to be linked to socio-economic factors, such as more expensive wine bottles
525 and more newspapers in District 1. But our slice of these areas is somewhat limited: we estimate
526 we sorted discards from some 60 to 150 households in each district over the 10 weeks. That is a
527 large sample, but our formal waste categorizations are a little too gross, and our observations too
528 subjective to parse disposal habits that closely. New York State is also a “bottle bill” state, with a
529 \$0.05 deposit required at the purchase of many container drinks. Differential returns of deposit
530 containers could also affect the measured waste stream differences (again, subjective, qualitative
531 observations were that all three districts disposed of many deposit containers).

532 It is clear that this long-standing, fairly typical suburban recycling program is not
533 succeeding at recovering most recyclables in the waste stream. There are many who believe that
534 reuse of materials (“closing the loop”) is essential if we are to be more sustainable in our use of
535 the Earth’s resources. The Town’s program is legally mandatory, but admittedly the Town is
536 loathe to fine its residents for non-compliance with recycling regulations. A local, but Long
537 Island-wide political consensus was reached in the 1980s and 1990s that an active enforcement
538 program with recycling would not help re-elect current office holders, and so there has been little
539 enthusiasm to increase rates that way. Pay-As-You-Throw (either weight or volume based fee
540 systems) has faced opposition, as well, despite some compelling evidence that it leads to higher
541 recycling rates (Skumatz 2008), as managers believe capital costs for provided container systems
542 or difficulties in distributing bags in decentralized suburbia outweigh perceived benefits. The
543 Town of Brookhaven has instituted single-stream recycling. The increased convenience of one
544 set out a week of all recyclables (no one needs to remember the alternation of materials and

545 weeks) is expected to increase performance of the program. We sorted wastes for the three
546 districts in the fall of 2014 and hope to report our findings soon.

547 If higher recovery rates are required, we believe that post-collection sorting should be
548 considered. The Town of Brookhaven is a good example of the large amounts of materials left
549 behind by traditional curbside recycling programs. A recent report on post-collection waste
550 processing in San Jose (CA) found that the combination of continued residential source
551 separation and additional post-collection recovery efforts appeared to work well (SWANA
552 Applied Research Foundation 2013). Our analysis of recycling economics (Tonjes and
553 Mallikarjun 2013) found that the economics of source separation appear to be positive at almost
554 all levels, even the lowest recovery percentages, as long as truck allocations are optimized and
555 there is at least a \$20 difference between tipping fees at the disposal point and the recyclables
556 collection point. For the Town of Brookhaven, disposal fees are approximately \$110/tonne, and
557 recyclables earn money. Disparities such as these are found throughout the northeast US. So we
558 believe curbside collection, which produces higher quality recovered materials, will continue to
559 make economic sense, but needs to be augmented by post-collection recovery systems. We
560 believe it is time to clean up after the residents, after they have done their best.

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581

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729

730 **Tables**

731

	District 1	District 18	District 31
Carter	Jody	T&D Doherty	European
Households (2012)	2,316	4,059	6,234
Population estimate*	6,173	16,365	26,163
2011 Separation Percentage	20.5%	12.2%	8.5%
2011 Discards (kg/HH/wk)	26.7	33.8	31.6
2011 Paper Recyclables (kg/HH/wk)	3.5	2.7	1.6
2011 Container Recyclables (kg/HH/wk)	2.0	1.4	1.1
2011 Yard Waste (kg/HH/wk)	6.4	7.9	5.6
2011 Separation Percentage (including Yard Waste)	35.9%	28.8%	22.3%
Median per capita Income**	\$51,796	\$34,207	\$36,963
Some College Education***	86.7%	62.7%	40.2%
Black Population*	1.1%	1.1%	5.3%
Hispanic Population*	7.0%	11.4%	19.1%

732 * estimated based on interpolations from 2011 ACS (American Community Survey) data from
 733 census tracts that show partial or complete overlap with the geographic extents of waste districts;
 734 the following census tracts were used – CT 158002 for District 1; CT 158512, 158511, 58508 for
 735 District 18; and CT 159511, 159506, 159408, 159404 for District 31

736 ** Derived from the selected census tracts (see above)

737 *** Derived from the selected census tracts; 25 years old and older

738

739 Table 1. Selected characteristics of the sampled waste districts

740

741

Category	Materials included
Mixed paper*	Newspaper, office paper, magazines, mail, boxboard (non-corrugated boxes)
Corrugated*	Corrugated boxes and brown/kraft paper bags
Plastic Bags	Included sheet plastic and garbage bags (included some retained food and other organic matter)
#1/#2 Plastic*	PET (#1) and HDPE (#2) rigid plastic containers
Rigid Plastic	Plastic containers and materials not #1 and #2 plastic containers
Yard waste	Branches, twigs, leaves, grass, flowers
Food waste	(included some packaging materials)
Wood	Manufactured wood: lumber, pallets, furniture
Other organics/ combustibles	Textiles, rubber, leather, and other primarily burnable materials not included in the above component categories, especially soiled paper, diapers, food cartons
Ferrous*	Magnetic metal containers, aerosol cans, small appliances
Aluminum*	Fabricated aluminum, aluminum cans, and aluminum foil
Glass*	Glass containers (broken or intact)
Other inorganics	Non-combustibles, such as rock, sand, dirt, concrete, ceramics, plaster, non-ferrous metals not containers, aerosol cans, or foil, metal chunks, sheet glass and other glass, bones
Electronics	Electrical/electronic equipment

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743 Table 2. Sorting categories (* = recyclables)

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District	Tonnes Collected, Source Separation	kg/HH/wk, Source Separation	Mean kg/HH/wk in Discards	Separation Efficiency
1	84.41	2.77	1.28	70.3%
18	97.98	1.84	3.88	29.9%
31	137.58	1.68	2.05	44.0%

747 Table 3. Yard waste separation amounts, rates, and separation efficiencies, August-October 2012

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750 **Figure Captions**

751 Figure 1. Town location map

752 Figure 2. Mean recyclables separation rates (kg/HH/wk) (with std. dev.) (black = District 1,
753 white = District 18, gray = District 31) (COL = amount collected curbside; REC = recyclables;
754 ALL RP = mixed paper + corrugated; CONT = #1/#2 plastics + ferrous + aluminum + glass;
755 GLS = glass; TRP = #1/#2 plastics)

756 Figure 3. Mean total waste stream composition (total waste stream = discards + curbside
757 recyclables) (kg/HH/wk) (with std. dev.) (black = District 1, white = District 18, gray = District
758 31) (TOT = total; REC = recyclables; NONREC = non-recyclables; CONT = #1/#2 plastics +
759 ferrous + aluminum + glass; REC-YRD = recyclables + yard waste)

760 Figure 4. Mean total waste stream composition (total waste stream = discards + curbside
761 recyclables) (kg/HH/wk) (with std. dev.) (black = District 1, white = District 18, gray = District
762 31) (ALL RP = mixed paper + corrugated; BGS = plastic bags; TRP = #1/#2 plastics; RGD =
763 rigid plastic; YRD = yard wastes; FD = food wastes; WD = wood; ORG = other
764 organics/combustibles; FE = ferrous; AL = aluminum; GLS = glass; INORG = other inorganics;
765 ELC = electronics)

766 Figure 5. Mean total waste stream percentages (amount of discarded and curbside recycled
767 materials/[total discards + all curbside recyclables]) (with std. dev.) (black = District 1, white =
768 District 18, gray = District 31) (REC = recyclables; NONREC = non-recyclables; ALL RP =
769 mixed paper + corrugated; CONT = #1/#2 plastics + ferrous + aluminum + glass; REC-YRD =
770 recyclables + yard waste)

771 Figure 6. Mean total waste stream percentages (amount of discarded and curbside recycled
772 materials/[total discards + all curbside recyclables]) (with std. dev.) (black = District 1, white =
773 District 18, gray = District 31) (ALL RP = mixed paper + corrugated; BGS = plastic bags; TRP =
774 #1/#2 plastics; RGD = rigid plastic; YRD = yard wastes; FD = food wastes; WD = wood; ORG =
775 other organics/combustibles; FE = ferrous; AL = aluminum; GLS = glass; INORG = other
776 inorganics; ELC = electronics)

777 Figure 7. Separation efficiency percentages (amount of curbside recyclables/amount of curbside
778 recyclables in total waste stream) (with std. dev.) (black = District 1, white = District 18, gray =
779 District 31) (REC = recyclables; ALL RP = mixed paper + corrugated; CONT = #1/#2 plastics +
780 ferrous + aluminum + glass; TRP = #1/#2 plastics; FE = ferrous; AL = aluminum; GLS = glass)

781 Figure 8. Mean recyclables separation rates (kg/HH/wk) (with std. dev.) (black = District 1,
782 white = District 18, gray = District 31) (TRP = #1/#2 plastics; FE = ferrous; AL = aluminum)

783 Figure 9. Mean discards rates (kg/HH/wk) (with std. dev.) (black = District 1, white = District
784 18, gray = District 31) (TRP = #1/#2 plastics; FE = ferrous; AL = aluminum)