Analysis of Solid Waste Disposal and Diversion Trends in Chittenden Solid Waste District, Chittenden County, Vermont

FINAL REPORT – 11/25/20

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Organization of the Report

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1. Background: CSWD's Responsibilities and Needs

1.1 CSWD's Responsibilities and Needs

The Chittenden Solid Waste District (CSWD) is responsible for planning and managing solid waste within the District. It has developed a system that includes mandatory recycling (since 1993) and mandatory diversion of food scraps (residential and commercial) in 2020. The District's responsibilities include overseeing a system that includes:

- non-exclusive licensed franchises for residential and commercial solid waste collection (most using competitive subscription systems),
- contracted residential recycling and/or trash collection in some jurisdictions in the District, and
- self-haul delivery of materials by other residents and businesses.

Furthermore, the District owns and operates several facilities vital to managing the District's waste streams, including:

- Commercial composting facility,
- Materials recovery facility,
- Household hazardous waste processing facility, and
- Seven drop-off centers throughout Chittenden County.

The District also maintains and monitors three closed landfills and brokers biosolids.

Effective and efficient solid waste management requires accurate estimates of the amount of solid waste generated, diverted, and disposed now and into the future so the District can: 1) plan effective programs, 2) predict facility needs, and 3) estimate associated management costs.

For the last few years, the District has found that solid waste tonnages have been less predictable. After the decreases seen by all jurisdictions during the recession, the District's tonnages have increased more rapidly than the increase in population. The District needs the ability to more accurately project future tonnages.

The District requested assistance in improving their tonnage forecasting capabilities, with a focus in several key areas:

- Examine the economic, demographic, or other drivers of solid waste stream tonnages (MSW and C&D) and use the information to develop improved predictions of the levels and changes in waste stream tonnages in the District.
- Use the information to be able to understand how the regional economy impacts tonnages and the associated planning, program, policy, and facility implications.
- Drill down on the C&D sector to develop suitable characterization of the material that is sent for disposal in the County.
- Improve the ability to understand disposal and how to affect and better monitor it.
- Provide a model to meet these objectives.

2. Summary of Methods

2.1 Project Objectives

This project is designed to provide defensible estimates of tonnages generated, reduced, and disposed to support future:

- Planning for effective programs,
- Predictions of facility needs, and
- Estimations of solid waste management costs.

The project is needed because tonnages have become less predictable and appear to be growing more rapidly than simple population increases can explain.

The project team, SERA[1], was responsible for developing:

- Reliable forecasting methods, material compositions, and forecasts, and
- A model that allows CSWD to project MSW and C&D tonnages generated, diverted and disposed into the future.

One point of note is that the key tonnages tracked by CSWD are not available for residential vs. commercial sector due to mixed hauler collection routes. The District only gathers total tons destined for facilities or sites. The model uses CSWD-provided estimates to apportion the material to the residential vs. commercial sector.

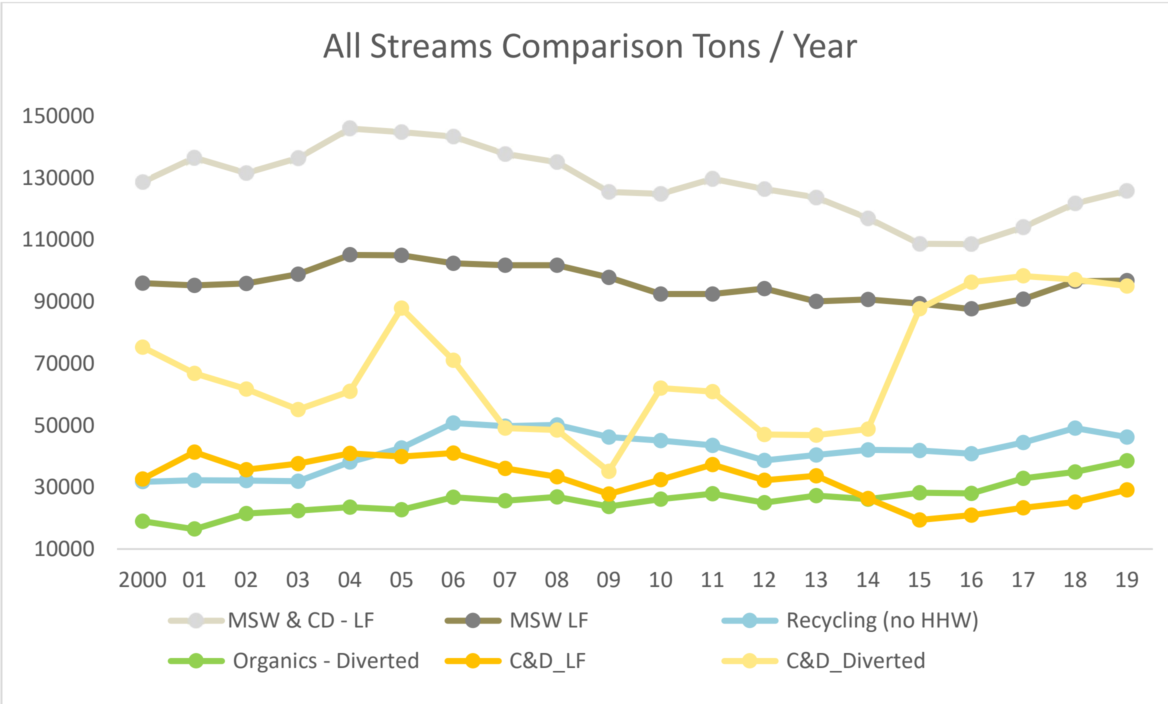
2.2 Development of the Tonnage Estimates

Understanding Variations in District Tonnages – Trends and Directions

Figure 2.1 displays the 2000-2019 tonnage amounts provided by the District for use in this study. The data show numerous fluctuations, with variations in growth or decline year to year depending on the material stream.

[1] Project Lead Skumatz Economic Research Associates / SERA, was assisted on specific issues by RRS (evolving ton publication), and William Turley (C&D expertise).

Figure 2.1: All Streams Historical Tonnage



Multiple factors influence the streams such as economic, regulatory, and demographic.

- **MSW- LF:** During more affluent economic times this stream tends to grow as more materials are purchased and disposed. There is a decline following the 2008 housing crisis and the 2012 economic dip and a slow return following both. The 2015 / 2016 tonnage drop may be due to adjustments (reductions) made beginning in 2015 to account for out-of-District materials. Regulations that required additional diversion of organics reduced tonnages. In 2015, the District strengthened its requirement for haulers to implement unit-based pricing.
- **Recycling:** In addition to the above economic factors, which result in a tonnage decrease for recycling, and unit-based pricing (tonnage increase), increased reporting on direct to market business recycling began in 2016.
- **Organics:** This stream remains fairly consistent but does show the effects of economic downturns. It is also affected by precipitation amounts each year. Tonnage increased following the beginning of the phased-in state-wide food scraps ban in mid-2014 and the requirement for separation of clean wood enacted in mid-2015.
- **C&D – LF:** The C&D streams tend to lag slightly behind material flows from other streams but are very susceptible to economic conditions as seen by the tonnage decline in 2009. The landfill tip fee also increased around this time potentially encouraging more diversion of materials. Between 2009 and 2011 there was a larger increase in population, a surge in new housing units (~35%), and construction employment, resulting in a significant increase in generation of C&D materials. Starting in 2015, the out-of-District portion of non-recyclable C&D was subtracted from this waste stream tonnage. There were also regulatory changes and a decrease in C&D LF tonnage and a corresponding increase in C&D Recycling tonnage the same year.

- **C&D Recycling:** This stream had the greatest fluctuations throughout this time period. It shows the same decline following the 2008 housing crisis, with a recovery reflecting the housing, tip fee, and population increase, and then a decline again beginning in 2012. In 2014 and 2015, two new C&D recycling facilities came on line. In 2015 there were regulatory changes to separation and commingling of C&D materials and in 2016 additional C&D material bans became effective. There is a significant increase in the C&D recycling stream between those two years and the previous year.

Figure 2.2 provides additional detail on the pattern of deviations in the particularly volatile C&D streams.

Figure 2.2: Variations in C&D Tonnages in CSWD

Tons C&D Reported Recycled / Reused	Tons C&D Landfilled / Incinerated	Total Tons Generated	C&D Diversion Rate	Year	Event / Policy	Details
75,333	32,639	107,972	70%	2000		
66,825	41,349	108,174	62%	2001		
61,738	35,644	97,382	63%	2002		
55,089	37,608	92,697	59%	2003		
61,065	40,939	102,004	60%	2004	Good Economy, Landfill Disposal Increased	
87,940	39,886	127,826	69%	2005	Good Economy, Landfill Disposal Increased	
71,104	40,992	112,096	63%	2006	Good Economy, Landfill Disposal Increased	
49,092	36,037	85,129	58%	2007	Landfill Disposal Began Decreasing	
48,541	33,418	81,959	59%	2008	Housing Crash / Recession	
35,134	27,740	62,875	56%	2009	Landfill Disposal Significant Decrease; Landfill & C&D Tip fees increase	
62,038	32,444	94,483	66%	2010	Landfill Disposal Continued Decrease	
60,875	37,307	98,182	62%	2011	Increase in Population, Construction Employment and Number New HH (35% New HH)	
47,012	32,268	79,281	59%	2012	Slight Decrease Construction Employment; Election Year; European Debt Crisis; GDP dropped by end of year.	
46,833	33,639	80,472	58%	2013		
48,786	26,299	75,085	65%	2014	Economic improvement; mixed C&D recycling facility opens	
87,799	19,397	107,196	82%	2015	Continued economic improvement; Separation & Comingling Changes July; DOC Scrap Metal up 29%; 2nd mixed C&D recycling facility opens	Requires the separation of clean wood from solid waste; Amend separation requirement for scrap metal to reduce the minimum size required to be recycled; new C&D

Tons C&D Reported Recycled / Reused	Tons C&D Landfilled / Incinerated	Total Tons Generated	C&D Diversion Rate	Year	Event / Policy	Details
						recycling facilities operating
96,354	20,956	117,310	82%	2016	Material Bans (effective July)	Adds asphalt shingles, OSB, and plywood to definition of special wastes (list of banned items)
98,404	23,330	121,734	81%			
97,181	25,179	122,360	79%	2018	C&D Facility Closure	

Identifying Causes and Relationships

The overall project steps included first, identifying potential explanatory factors to use to account for the variation in each MSW and C&D stream. Then, using statistical regression analyses (ordinary least squares), we fitted equations to model past relationships between "driver" variables and tonnage. Then, the resulting equations (along with forecasts of the driver variables) were used to calculate the projected tonnages to estimate total tons annually by stream for the period out to 2045.[2] As a last step, we applied the appropriate waste compositions for each stream to estimate the tonnages of specific materials available for diversion for the forecast period.

SERA worked with CSWD's data (Figure 2.1) to understand the waste generation and material composition history within the District. We identified likely causes and drivers underlying changes in tonnages: e.g., greater rain increases organics, greater (population and) income tends to lead to greater consumption, and therefore, increases in material available to recycle and dispose. Increases in construction employment correlate with increases in C&D material generated and available to recycle and dispose. We also worked with the District to identify when various programs or mandates or unusual tonnage events occurred.

Figure 2.3 presents the types of economic, demographic, and other "drivers" that were considered as possible explanatory variables in the models for CSWD. To set up successful efficient modeling work, we organized the variables into a matrix and identified their logical relationships (positive / negative) for explaining variations in tonnage streams.[3]

- A plus sign means a positive relationship – higher values of the explanatory variable increases the resulting tonnage
- A negative sign means a negative relationship - higher values of the explanatory variable decreases the resulting tonnage
- An "X" indicates that the factor could have an effect, but whether it is positive or negative is not known *a priori* (beforehand).

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[2] With, of course, decreasing reliability for outer years. In addition, the 2018/19 figure was calibrated to actual values

[3] Note it is not possible to easily display the "strength" of each of the explanatory factors by displaying the resulting coefficient, because each has different units.

Figure 2.3: Causal Factors and Logical Direction Relationships for Stream Forecasts

Explanatory Variables	MSW Generation	MSW Recycling	MSW Compost	MSW Disposal	C&D Generation	C&D Recycling	C&D Disposal
Population, Households (HH)	+	+	X	+	+	+	+
Income indicators	+	+	X	+	+	+	+
Firms, businesses	+	+		+	+	+	+
Age distributions, age head of HH	X	X		X	X	X	X
Housing starts	+			+	+	+	+
Employment all	+	+		+	+	+	+
Employment, construction	+		X	+	+	+	+
Employment, tourism	+	-		+	+	+	+
Meals & rooms tax (tourism) indicators	+	-		+	+	+	+
MSW landfill tip fee		+	+	-			
C&D landfill tip fee						+	-
MRF tip fee		-		+		-	-
MRF / recycling material revenues	X	+		-		+	-
Organics tipping fee			-	+			
Rainfall	+		+				
Program / policies / bans / mandates		X	X	X		X	X
Other	TBD	TBD	TBD	TBD	TBD	TBD	TBD

Specific Explanatory Variables Used in the Modeling Work: Definitions, Abbreviations, and Sources

Many of the conceptual economic, demographic, and other explanatory variables can be represented by any of multiple variables. Income might be personal income or median income, or other specifications. The variables we assembled and tested in the modeling work are displayed below. Some were created specifically for CSWD; for instance, the District may have put in a ban in a particular year, so an indicator of that programmatic structural change was created to affect one or more tonnage streams. The variables are defined in Figure 2.4 below, along with their sources, which can be useful for updating data and forecasts in the future.

Figure 2.4: Explanatory Variable Abbreviations, Definitions, and Sources

Variable Abbreviation	CSWD Variable Description	Source
$C&Dtip	Annual tip fee including SWM Surcharge	Client provided data
TonsC&D_Div	C&D Diverted	Client provided data
TonsC&D_LF	C&D Landfilled	Client provided data
$MSWtip	Annual Tip fee including SWM Surcharge	Client provided data
TonsAll_R_O_HHW	MSW Materials Diverted (Includes All Recycling, Organics, Textiles, HHW and Tires)	Client provided data

Variable Abbreviation	CSWD Variable Description	Source
TonsRecyAll_R&C _NoHHW	Total Paper, Containers, and Packaging recycling stream tonnage. (Includes Single Stream, Bottle Bill, Commercial Economic Recycling) Excludes C&D recycling and HHW. This variable was used for Recycling Regressions and Forecasting.	Client provided data
TonsMSW_LF	Total MSW sent to LF excluding C&D	Client provided data
TonsOrgDiv	Total Organic material diverted / composted	Client provided data

Variable Abbreviation	Economic and Census Variable Description	Data Source
#NewHH	New Private Housing Structures Authorized by Building Permits for Chittenden County, VT, Units, Annual, Not Seasonally Adjusted	Federal Reserve Bank of St. Louis Economic Research Division Economic Data https://fred.stlouisfed.org
#BusEst.	Number of Private Establishments for All Industries in Chittenden County, VT, Establishments, Quarterly, Not Seasonally Adjusted	Federal Reserve Bank of St. Louis Economic Research Division Economic Data https://fred.stlouisfed.org
%over60	Annual Estimates of the Resident Population for Selected Age Groups by Sex for the United States, States, Counties and Puerto Rico. Client recommended statistic.	U.S. Census Bureau, Population Division https://www.census.gov/programs-surveys/cps/technical-documentation/complete.html
Hhsize	Data for the average person per household in the county did not go back to 2000 so used the state of Vermont data	https://www.census.gov/data/tables/time-series/demo/families/households.html
#CnstrEmpl	The number of persons employed in construction. This data is only available from the year 2010. For early years the % of construction (.79) of Mining, Logging, & construction was used for earlier years. This variable was updated with more complete data.	Federal Reserve Bank of St. Louis Economic Research Division Economic Data https://fred.stlouisfed.org
Rooms	State of Vermont Department of Taxes Meals and Rooms Statistics Report Notes: Period Summary by County/Town- per year. Data for this is only available starting in 2005	VT state tax records based on Sales receipts www.vtLmi.info https://tax.vermont.gov/sites/tax/files/documents/mr_cy_2005_prelim.pdf
AccomdFoodSvcEmploy	Employed Persons in the Accommodation and Food Service industries in Chittenden County, VT, Persons, Annual, Not Seasonally Adjusted	U.S. Bureau of Labor and Statistics https://www.bls.gov/data/#employment
NumEmpl	Total Employed Persons across industries in Chittenden County, VT, Persons, Annual, Not Seasonally Adjusted	Federal Reserve Bank of St. Louis Economic Research Division Economic Data https://fred.stlouisfed.org
ConstructionEmploy	Persons in the County Employed in the construction industry	U.S. Bureau of Labor and Statistics https://www.bls.gov/data/#employment
ArtEntertRecEmploy	Persons in the County Employed in the Arts, Entertainment, and Recreation industry	U.S. Bureau of Labor and Statistics https://www.bls.gov/data/#employment
HotelsResorts	Persons in the County Employed in the Hotels and Resorts industry	U.S. Bureau of Labor and Statistics https://www.bls.gov/data/#employment
ContractConstruction	Persons in the County Employed in Construction Contracts industry	U.S. Bureau of Labor and Statistics https://www.bls.gov/data/#employment

Variable Abbreviation	Economic and Census Variable Description	Data Source
MineLogCnstr	This variable was used to determine construction employment, since construction employment data only began in 2010. Construction employment was later updated with a more complete data set.	Federal Reserve Bank of St. Louis Economic Research Division Economic Data https://fred.stlouisfed.org
HousingUnits	Intercensal Estimates of Housing Units for Counties of Vermont: April 1, 2000 to July 1, 2010 and Annual Estimates of Housing Units for Counties in Vermont: April 1, 2010 to July 1, 2019	https://www.census.gov/data/tables/time-series/demo/popest/intercensal-2000-2010-housing-units.html and https://www.census.gov/data/tables/time-series/demo/popest/2010s-total-housing-units.html
MedHH_incm	The median household income for the county per year	https://data.ers.usda.gov/reports.aspx?ID=17828
MedAgeHoH_US	Households by Age of the Householder	https://www.census.gov/programs-surveys/cps/technical-documentation/complete.html
$PersIncm	Personal Income in Chittenden County, VT, Thousands of Dollars, Annual, Not Seasonally Adjusted	Federal Reserve Bank of St. Louis Economic Research Division Economic Data https://fred.stlouisfed.org
ResPop	Resident Population in Chittenden County, VT, Thousands of Persons, Annual, Not Seasonally Adjusted	Federal Reserve Bank of St. Louis Economic Research Division Economic Data https://fred.stlouisfed.org
SeasPop	The client used a state-provided calculation to come up with seasonal population based on seasonal housing. This calculation may provide an inflated estimate and was replaced with rooms and food service / accommodation variables.	Client provided data
Hsg_Units	Intercensal Estimates of Housing Units for Counties of Vermont: April 1, 2000 to July 1, 2010 and Annual Estimates of Housing Units for Counties in Vermont: April 1, 2010 to July 1, 2020	https://www.census.gov/data/tables/time-series/demo/popest/intercensal-2000-2010-housing-units.html and https://www.census.gov/data/tables/time-series/demo/popest/2010s-total-housing-units.html
UnmplRate	Unemployment Rate in Chittenden County, VT, Percent, Annual, Not Seasonally Adjusted	Federal Reserve Bank of St. Louis Economic Research Division Economic Data https://fred.stlouisfed.org
GDP	Gross Domestic Product: All Industries in Chittenden County, VT, Thousands of U.S. Dollars, Annual, Not Seasonally Adjusted	Federal Reserve Bank of St. Louis Economic Research Division Economic Data https://fred.stlouisfed.org
#Poverty	90% Confidence Interval Lower Bound of Estimate of People of All Ages in Poverty for Chittenden County, VT, Persons, Annual, Not Seasonally Adjusted	Federal Reserve Bank of St. Louis Economic Research Division Economic Data https://fred.stlouisfed.org/series/PECILBAAVT50007A647NCEN
PerIncmPerCap	Per Capita Personal Income in Chittenden County, VT, Dollars, Annual, Not Seasonally Adjusted	Federal Reserve Bank of St. Louis Economic Research Division Economic Data https://fred.stlouisfed.org
AnnlPrecip	The amount of precipitation received in the county per year	Burlington International Airport - https://nowdata.rcc-acis.org/btv/

Variable Abbreviation	Program Variable Description	Data Source
PrgC&D2015	2015 C&D Program Changes with Additional Materials.	Ordinance / Program Timeline provided by client
PrgC&D2016	2016 C&D Program Changes with Additional Materials.	Ordinance / Program Timeline provided by client, adjusted to see if effects had more impact in 2016
2015PrgYW_PAYT_C&D	2015 C&D Add'l Materials & Changes; Yard Waste program changes. This addressed multiple program changes that occurred in 2015.	Ordinance / Program Timeline provided by client
Prg_DOCfeePre2007	2007 DOCs-CSWD begins accepting plastics #3-7 and eliminates fees for recyclables and compostables at DOCs.	Ordinance / Program Timeline provided by client
PAYT_Prg2015	PAYT (Pay as You Throw) program changes. The county added a requirement that haulers implement a unit-based rate system for customers. This strengthened a previous weak law.	Ordinance / Program Timeline provided by client
PAYT_Prg2015&YW	PAYT (Pay as You Throw) program changes and YW/ Organics Program Changes- both in 2015.	Ordinance / Program Timeline provided by client
R_Prg_AdjMand2005 / PrgRecy_AdjMand_2005	2005 (Nov. 2004) Recycling Program adjusting the list of mandatory recyclables, changes to hauler outreach and cart labeling, requiring drop-off facilities to accept at least mandatory recyclables. *(These are the same variable; one was an earlier abbreviation)*	Ordinance / Program Timeline provided by client
PrgYW_PAYT_C&D	2015 changes to C&D, organics, and PAYT programs. All are in the same year and can't necessarily differentiate, so they have been included into one variable.	Ordinance / Program Timeline provided by client
YW_PrgLFban	2015 Bans materials such as clean wood from the landfill, beginning of food waste residuals separation requirements.	Ordinance / Program Timeline provided by client and CSWD CY 2015 Annual Report.

Variable Abbreviation	Adjustment Variable Description	Data Source
TonsRecyAll_R&C_NoHHWrooms	Total Paper, Containers, and Packaging recycling stream adjusted to 2005 for analysis with the rooms variable which has no data until 2005.	Consultant Adjusted Variable
HotelFood2yrLag2002	This "lag" variable was created to see if selected streams "lagged" 2 years after Accommodation and Food Service employment data.	Consultant Adjusted Variable
#NewHHforROOMS	Total Paper, Containers, and Packaging recycling stream adjusted to 2005 for analysis with the rooms variable which has no data until 2005.	Consultant Adjusted Variable
DummyV12_13	A created variable to explain changes that happened in 2012 and 2013	Consultant Created Variable
C&D_RecyRate	C&D Calculated Recycling Rate	Consultant Created Variable
Recession1yrlag09_10	This "lag" variable was created to see if selected streams "lagged" 1 year after other economic changes.	Consultant Created Variable

Variable Abbreviation	Adjustment Variable Description	Data Source
Recession08_09	This variable selected 2 years, 2008 and 2009 to see if the 2008 recession had a significant effect on waste streams.	Consultant Created Variable
Recession2yrlag10_11	This "lag" variable was created to see if selected streams "lagged" 2 years after other economic changes.	Consultant Created Variable
PrgC&D2015Rooms	Adjusted the 2015 C&D program variable to 2005 for analysis with the rooms variable which has no data until 2005.	Consultant Adjusted Variable
$C&DtipRooms	The C&D Tip Fee data points adjusted to 2005 for analysis with the rooms variable which has no data until 2005.	Consultant Adjusted Variable
TonsC&D_DivAjd	The C&D recycling stream data points adjusted to 2005 for analysis with the rooms variable which has no data until 2005.	Consultant Adjusted Variable
C&D_DivLag2 (2002)	This "lag" variable was created to see if the amount of C&D recycled "lagged" 2 years after other economic changes.	Consultant Created Variable
$MSWtipforROOMS	Annual Tip Fee adjusted to 2005 for analysis with the rooms variable which has no data until 2005.	Consultant Adjusted Variable
RoomsAdj	County Rooms Tax Data adjusted for analysis with other variables. Room data had limited years available- other variables were adjusted to same years. This variable was not used in the modeling.	County Rooms Statistics from ST tax records adjusted by consultant for Rooms Starting 2005
ConstructionEmployRooms	Construction Employment Variable adjusted to 2005 for analysis with the rooms variable which has no data until 2005.	Consultant Adjusted Variable
Const/totalEmply	The Ratio of Construction Employment to Total Employment	Consultant Calculated Variable
Timeline	Number variable starting from the beginning of the data series to the end.	Consultant Created Variable
DummyV2018_20	This could be the effects of the food scraps diversion requirement affecting the larger number of smaller businesses	Consultant Created Variable
Year	Annual year of data series starting from 2000 to 2019 (depending on number of data points available.	Consultant Created Variable

Fitting the Regression Equations

Regression analysis uses data from the past to identify the relationships between these explanatory factors. Multiple models are usually estimated, and the one with the "best" statistical fit is selected. These models yield equations of the form of a series of coefficients (alpha, beta) times the explanatory factor. For example:

"estimated tonnage = α times one explanatory factor plus β times a second explanatory factor, plus etc."

Then, the explanatory factors are projected into the future, and their values for each future year are substituted into the equation to calculate future values of the tonnages. This type of modeling work supports "scenario analysis" work. High and low values of explanatory factors – representing high and low growth years, etc. can be used and the resulting tonnage values give rational explanations for the values of tons in strong or weak growth years, recessions, and booms for CSWD.

Fitting Equations: Excel was used to estimate the regression models. Dozens of regression models were developed for each stream, and the "best" fit was selected based on a combination of the following criteria:

Preferred Coefficients for each Explanatory Variable:
- Correct / logical "sign" for the estimated coefficient
- t-statistic for the coefficient that shows it is significantly different from zero with 85% or greater statistical confidence

Preferred Overall Model "Fit":
- Strong adjusted R-squared that indicates the extra variable pulls its weight
- Strong F-statistic, indicating the modeled equation has strong explanatory power overall

Other criteria
- Explanatory variable relatively easily gathered into the future for projections

To select among candidate models, we looked at the statistical performance criteria noted above (strong t-statistic, and model performance statistics), but also reviewed the graph of actual vs. fitted tonnage to compare the model's ability to capture variations in the material stream over the historical period, and the reasonableness of resulting projected values into the future.

Each of the top performing candidate regressions were then used to calculate a "backcast" to use to compare to the actual tonnage for the stream for the period 2000-2018 and 2019 where available. The backcast (as well as the projected values) were calculated using the equation that is estimated by the regression[4]. For the backcast period, actual past values for the explanatory factors were used in the calculation. Then both the backcast tonnages and the actual tonnages for 2000-2019 were compared on a graph to compare the "fit" vs. actual historical tonnage data.

The Fitted Regression Models for Each Stream

The regression results (coefficients, t-statistics, etc.) for the final, selected equations for each material stream are presented in Figures 2.5-2.9 below. Recall that the landfill streams were not estimated via statistical regressions, but as residuals (generation minus diversion). In each case, the results are consistent with expected signs, and the coefficients are generally statistically significant (t-stat >1.645), or nearly so. A summary of the content of the model specifications in the Figures follows.

- MSW generation is fitted as a function of precipitation, construction employment, and housing units, reflecting some of the main drivers of overall MSW. Because generation includes the diverted materials, it makes sense that precipitation would increase generation; it increases organics to be diverted. Housing units reflect growing consumption (or consumers) and

[4] Calculated as: estimated coefficient 1 times explanatory variable 1 + explanatory coefficient 2 times explanatory variable 2, etc. using the annual values of the explanatory variables included in that equation.

construction employment, or any employment, reflects business activity and generation of business MSW.

- MSW recycling is fitted to explain recycling percent, not percent tons – and is then translated to tons for the graphs and tables. This stream is forecast with key variables housing units (reflecting program participant and tonnage growth), and a factor that reflects the policy variable that added 6 percentage points through the action of adding new materials to the mandated materials list, and other concurrent tweaks. While this model misses some peaks and valleys (See Figure 2.11), recycling's variations proved very difficult for the models to explain, and this model had the correct signs, and a credible growth rate.

- MSW organics is fitted as a function of the organics program bans, the MSW tip fee, and the annual precipitation level. The ban added 4,300 organics tons to the diversion stream, and increases in the MSW tipping fee drives tons away from the landfill and into the organics program.

- C&D generation is fitted as a function of construction employment and number of new households, both with positive signs, indicating that growth in these variables increases construction generation (some of which then is available for recycling). A variable reflecting the recession of 2010 (in a lagged form) is also included, which indicates the recession affected C&D material beyond the ability of the other explanatory variables.

- C&D recycling is explained as a function of the number of new households (adding to recycling), and a variable reflecting the enhancements to the C&D programs that occurred in 2015 (also a positive factor, adding more than 29,000 tons to recycling in that timeframe and beyond (a "permanent" shift upward in tons).

Figure 2.5: MSW Generation

Label	MultiR	AdjR	F	Sig F
MSW GEN24	0.75	0.48	6.58	0.00
	Co-effec.	t Stat	P-value	
Intercept	-11815	-0.24	0.82	
AnnlPrecip	992	3.19	0.01	
ConstructionEmploy	8.58	1.56	0.14	
HousingUnits	1.45	2.62	0.02	

Figure 2.6: MSW Recycling

Label	MultiR	AdjR	F	Sig F
RECYC RATE 22	0.93	0.84	49.21	0.00
	Co-effec.	t Stat	P-value	
Intercept	0.16	1.66	0.12	
R_Prg_AdjMand2005	0.06	5.03	0.00	
HousingUnits	0.0000016	1.04	0.31	

Figure 2.7: MSW Organics

Label	MultiR	AdjR	F	Sig F
ORG MV6	0.94	0.86	38.12	0.00
	Co-effec.	t Stat	P-value	
Intercept	-3739.93	-0.95	0.36	
YWprgLFban	4307.77	3.21	0.01	
MSWtip	139.47	3.94	0.00	
AnnlPrecip	338.02	5.06	0.00	

Figure 2.8: C&D Generation

Label	MultiR	AdjR	F	Sig F
C&D Gen16	0.74	0.49	10.26	0.00
	Co-effec.	t Stat	P-value	
Intercept	-55164.55	47779.53	-1.15	
Construction Employ	27.45	10.97	2.50	
#NewHH	31.75	20.15	1.58	

Figure 2.9: C&D Recycling

Label	MultiR	AdjR	F	Sig F
MV6 Prg & HH	0.76	0.53	11.26	0.00
	Co-effec.	t Stat	P-value	
Intercept	39436	3.10	0.01	
PrgC&D2015	29419	3.11	0.01	
#NewHH	36.35	1.70	0.11	

Elasticities – Relative Size of Impacts in the Models

To examine the relative 'importance' of the explanatory variables included in the MSW and C&D material stream models, additional calculations were needed, because the estimated coefficient does not provide this information. For most types of quantitative variables (income, population, etc.), the size of the effect depends on both the "units" for the underlying variable, and the amount of variation found in that variable over time. As a straightforward example, note that a coefficient for a variable expressed in dollars would be 1/1000th of the coefficient for the same variable expressed in thousands of dollars. Because the size of the coefficient depends on the units for the underlying variable, we estimated the "elasticity" instead, a relative metric that is independent of units. Our indicators of importance of variables are described below.

- **Elasticities**: For economic / demographic variables we estimated the relative impacts using elasticities. Elasticities estimate the percentage change in tonnage that results when each individual explanatory variable is changed (increased) by 1%. Those variables showing negative impacts mean when the explanatory variable increases, projected tonnage decreases (for example tipping fee).

- **Impacts for other variables**: For policy variables expressed as a zero or one (e.g. implementation of new mandatory materials, the estimated regression coefficient directly identifies the tonnage impact that occurs when that program is in place. For policy variables expressed in dollars (e.g. tipping fees), the coefficient shows the tons added (or subtracted) when the tipping fee is increased by $1.[5]

Figure 2.10 summarizes the economic and policy variables that were included in the MSW and C&D models selected as the best for each stream. The figure shows both variable's name, as well as the impact of that variable on the resulting tonnage estimate.

The first two columns illustrate the range of variation in the explanatory variable itself over the 10-year period. These data are followed by sets of three columns for each material stream. The elasticity is the first value, the coefficient is the second value, and the t-statistic (indicating whether the coefficient is significantly different from zero) is third. Note that the selected models generally have only one or two economic variables; including multiple variables often confounds effects, causing one or another variable to result in a "wrong" sign because of collinearities and other statistical reasons. Figure 2.10 shows the following.

- MSW generation: a one percent change (increase) in construction employment leads to a 0.26% change (increase) in generation tonnage, and a one percent change in housing units increases generation by 0.59%.
- MSW recycling: a one percent increase in housing units increases recycling by 0.3%, and the District's 2005 initiative to add more mandatory recyclables increased the recycling rate by six percentage points.
- MSW organics: a one percent increase in annual inches of precipitation increases organics tonnage diverted by 0.4%, and the organics landfill ban added about 4,300 tons to the organics diversion stream.
- C&D generation: a one percent change in construction employment increases C&D generation by 1.2%, and a one percent increase in new households increases C&D generation by 0.2%.
- C&D Recycling: a one percent change in new households increases C&D recycling by 0.3%, and the C&D program refinements made in 2015 increased C&D recycling tonnage by 29,400 tons.

Figure 2.10: Elasticities for Variables included in Selected Models

Stream: MSW			MSW Generation Gen 24			RECYC RATE 22			Organics MV6		
Variable	**Max change** in input variable over 10yrs**	**Avg change** in input variable over 10yrs	% ton impact / change input variable 1%	Co-eff	t-Stat	% ton impact / change input variable 1%	Co-eff	t-Stat	% ton impact / change input variable 1%	Co-eff	t-Stat
AnnlPrecip (# not %)	51	38							0.4%	338	5.06
ConstructionEmploy	8.8%	0.03%	0.3%	8.58	1.56						
HousingUnits	1.5%	1.0%	0.6%	1.45	2.62	0.3%	0.000002	1.04			
DummyV12_13	N/A	N/A									
PrgRecy_AdjMand_2005*	N/A	N/A					0.06	5.03			
PrgYW_Lfban	N/A	N/A								4308	3.21

**Same as R_Prg_AdjMand2005* *Program or recession variables only have 1's or 0's as inputs. They do not have calculated/ historical elasticities and have an N/A in the Max and Average columns.*

[5] We provide tipping fee impact in both elasticity terms and impact terms because both are easily interpreted and provide useful information. In addition, some tip fees may be internal (policy) but others external (economic conditions).

Stream: C&D			C&D Gen 16			C&D Recycling; MV6 (Prgs & HH)		
Variable	**Max change** in input variable over 10yrs**	**Avg change** in input variable over 10yrs	% ton impact / change input variable 1%	Co-eff	t-Stat	% ton impact / change input variable 1%	Co-eff	t-Stat
#NewHH	44.5%	5.3%	0.2%	31.75	20.15	0.3%	36.35	1.70
Construction Employ	8.8%	0.03%	1.2%	27.45	10.97			
PrgC&D2015	N/A	N/A					29,419	3.11

For more details on the elasticities, including values for candidate models that were not selected, see Appendix B.[6] A review of the estimates for these other models provides additional information on (and confidence in) the estimated impact of various policy changes undertaken by the District over the last two decades. Since these models "pull out" confounding impacts from other variables, the coefficients are indications of the attributable impacts from these policies, excluding other factors. A review of the models shows some indicative patterns, some of which may be useful as the District considers implementing programs and policies in the future:

- The 2005 policy changes increased MSW recycling by about 13,000-15,000 tons and organics diversion by about 2,000-3,000 tons.
- The 2015 C&D program changes increased C&D recycling by about 23,000-30,000 tons.
- One percent changes in the MSW tipping fee[7] increase organics diversion by about 0.5%.

2.3 Results and Forecasts

Comparison of Fitted to Actual Values: Some of the models fit the historical tonnages very well, such as for Organics tonnages. Some of the models cannot easily explain the increases and decreases in actual historical tonnages due to greater yearly fluctuations or single events. C&D Recycling is a good example of this fluctuation. Figure 2.11 shows the fit between the historical data and the selected regression models for MSW. Identifying models that well-explained MSW recycling was particularly problematic. To find the best fits, we used two different specifications of the equation; one set were designed to explain recycling tons, and other models focused on explaining recycling percent.[8] Ultimately, the model selected explained recycling percent, which was then translated into tons using the forecasts of generation and organics. Figure 2.12 shows the actual, fitted, and projected values for the C&D streams.

Note that the forecasts are fairly smooth in each case. This is because the base projections were developed using median values for the variables into the future. Cycles or increases / decreases would

[6] More detailed information on alternative estimated models that were considered for inclusion is included on specific tabs included in the Excel model. A separate memo of strong and weak models to illustrate the range of what models were tested was provided to the District under separate cover.
[7] Although disposal models were not ultimately used (disposal was estimated as the remainder of generation minus diversion), initial disposal models were estimated, and indicated that increases in the MSW tipping fee decreased disposal by about 0.8%. With similar caveats, increases of 1% in the C&D tipping fee decreased C&D disposal by about 0.04%.
[8] We wanted to focus on explaining only the relationship of recycling, and not consider variations in organics, so we focused on recycling as the share of the non-organics streams. Therefore, this variable was calculated as recycling divided by (recycling plus disposal). In our model, this is identical to recycling divided by (generation minus organics), and this was how the final tons were calculated. This was used to avoid making the recycling equation dependent on a stream that was calculated as a remainder (disposal).

result if the assumptions about economic conditions in the future were varied over time, for example introducing periods of high growth and low growth over certain periods.

Figure 2.11: Actual, Fitted, and Projected Values for all MSW Streams, Base Case

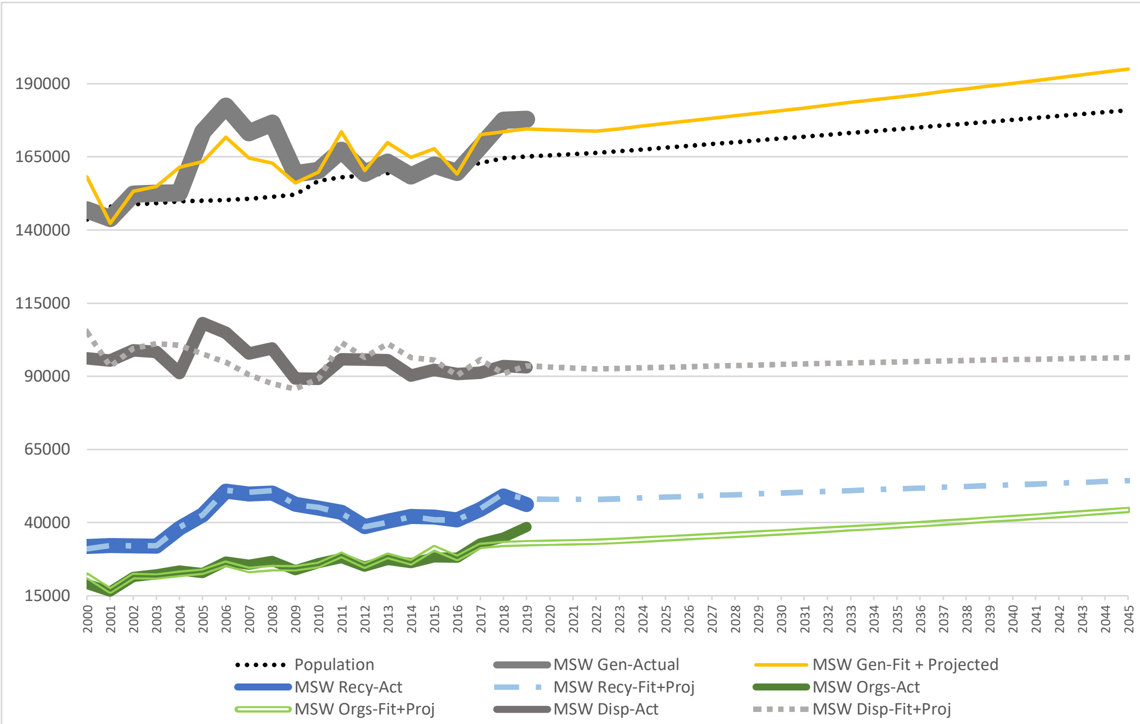
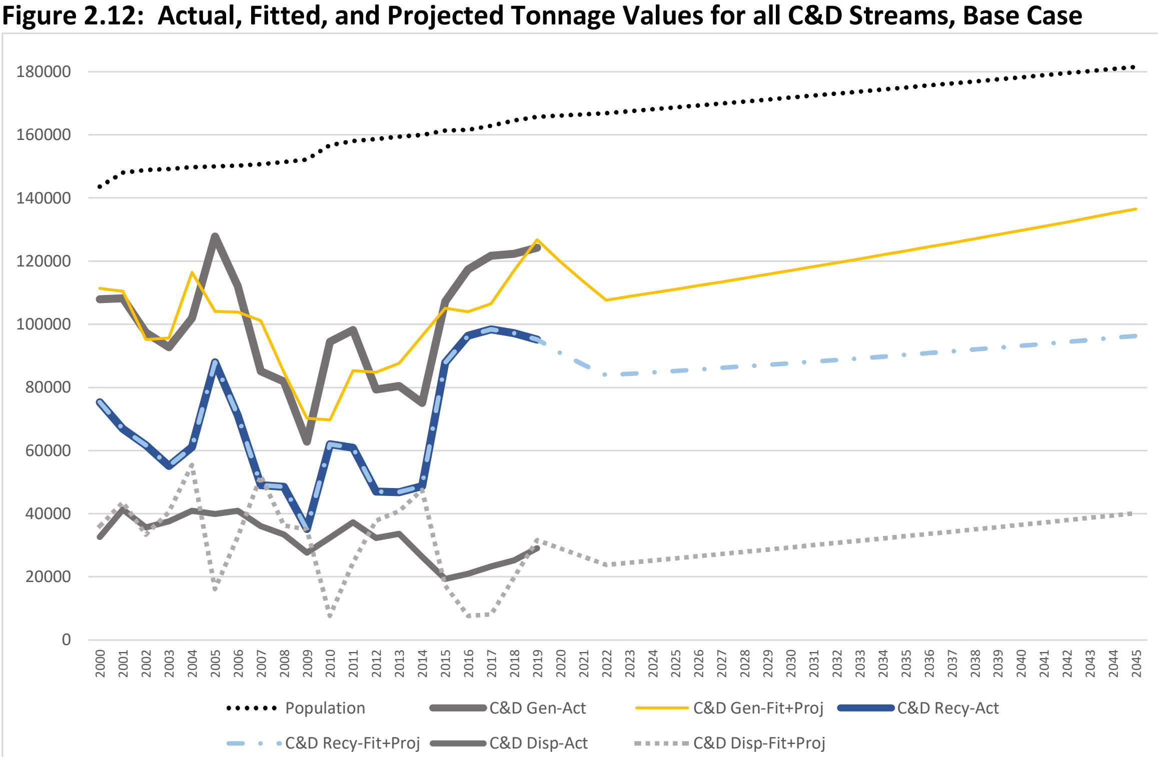


Figure 2.12: Actual, Fitted, and Projected Tonnage Values for all C&D Streams, Base Case



Approach for Calculating Projections into the Future: To project tonnages into the future, the estimated equation is used, but the calculations use *projections* of *future* annual values for each of the explanatory variables to calculate estimates for future tonnage values. Therefore, it is impossible to calculate tonnages into the future without future values for the explanatory variables. Forecasts of some economic variables are available (at considerable expense) from forecasting services (DRI and others). Counties and states sometimes provide projections of a few variables (population, etc.). However, a longer list of explanatory variables is needed to support these tonnage forecasts.

In this work, we used a two-step process to generate these projections of annual explanatory values. First, the historical data for each explanatory variable was analyzed, estimating six levels of growth rates for each variable over the available 2000-2019 period. An example is provided below in Figure 2.13.

Figure 2.13: Yearly Percent Changes in Population, 2000-2019

Very High	Maximum	3.1%
High	75% quartile	0.8%
Average	Average	0.8%
Medium	Median	0.5%
Low	25% quartile	0.3%
Very Low	Minimum	0.2%

We assumed past growth rates over the last ten years could guide expectations about the ranges for future changes in these explanatory variables. If the economics for the next three years is expected to be low, and then rebound to "average" for the next 15 years (perhaps based on information indicated by the state or county planning sources), the model uses those assumptions in projecting future values for each explanatory factor. With these assumptions, projections of each explanatory variable are calculated using "low" growth rate for 3 years, and "medium" or "average" for the next 15[9].

For our Base Case Scenario for this project, we assumed growth rates for underlying economic variables would be: Low for the 2020-2022 period, and median values thereafter out to 2045.

Note, we used one important simplification in the assignment of growth rates. If the future growth is expected to be "low"[10], all of the future values for the explanatory variables are calculated using their "low" growth rates for that period, even though in real life, not all "low" values would be expected to occur exactly simultaneously or in lock-step. Some may lead or lag others, or when some are very low, others might be low. However, this simplification considerably reduces the assumptions needed to drive future projections.[11]

[9] To illustrate, for future values of the explanatory variable "population", multiply actual 2019 values by 1.008 for each of the first 3 years (through 2022), and then multiply the 2022 value by 1.005 annually for 15 more years.

[10] Note we also made a modification to make sense of "negative" variables. When "economics" are high, changes in unemployment growth shouldn't be the highest change in unemployment, but rather, the lowest growth, and vice versa. We made the same reassignment for number of persons in poverty; we assume high economics corresponds to the minimum rather than maximum changes. Strong economics leads to changes in unemployment and poverty counts of, respectively, -11.5% and -7.3%, not +8% and +13%, respectively.

[11] It is very possible to model any set or combination of values within the model, but the user assumptions needed to identify and justify those variations would be complicated, especially projecting for periods of up to 25 years and perhaps a dozen explanatory variables.

Using the Forecasts: Once these growth choices are made and are populated across all the explanatory variables, the same regression-derived calculation equation used by the backcast can be used into the future for each material stream – out as long as 2045 using the mechanics of the model. Note, however, that forecasts are not considered reliable for periods longer than the "fitted period", and are most reliable for near-term horizons. Given this model used 19 - 20 years of data for the "fitted period", we would not want to rely on forecasts past 2038, with more confidence in the nearer years. Furthermore, the projections of tonnage are only as good as the projections of the input variables out that far. Therefore, models are useful for scenario analysis, but are somewhat weaker at specifying the exact tons that can be expected in a particular year if the underlying explanatory variables are not known in fact either. However, forecasts from scenarios can provide information on baseline tonnage increases given assumptions about the underlying causes, and provides useful data for identifying the need for program revisions or incentives, facility changes, or similar information – and point out how the dates for these changes may vary based on the expected economic conditions.

Note, in addition, the models include explanatory variables that incorporate the impacts of both

- Economic and demographic variables, which the District cannot affect, and
- Policy variables, which the District can affect.

The policy variables that were included relate to mandates, bans, enforcement, and in some cases, tip fees. These variables affected the variations in tonnages noted during the historical period and led to the parameters defining the "base case" tonnages for each stream that the model projects out into the future. The relative importance of each of these variables – economic and policy – in affecting the tons for each stream were discussed above under "elasticities".

2.4 Derivation of Material Stream Characterizations by Constituents

Waste (or materials stream) compositions or characterizations are a percentage or share breakdown of constituent materials in samples of a material stream. They are derived from statistical "sorts" conducted on the stream, and most commonly focus on the disposal, or waste stream, but can be conducted on any stream, including recycling, composting, C&D, etc. They can be from residential, commercial, or construction and demolition landfill waste or diverted waste. It is common to have a waste characterization of "MSW" or all waste together. In this report, we use the term waste composition and material composition/ characterization relatively interchangeably. Some waste "comps" are broken down into dozens of categories separated into items such as "green glass" or "office paper" and others have only major categories such as paper, plastic, and glass.

Within the model, we provide approximately 35 waste characterizations, and select the most appropriate local characterization for each stream being estimated. The model allows the user to select a waste composition from each sector (residential, commercial, or C&D) and from each stream (landfill, recycling, or organics). The state and the year of each composition are also provided and can be selected by the model user. The user can also add new compositions. This information can be used to determine changes in tonnages and composition.

On the MSW side, data on CSWD and Vermont State characterizations of the trash "disposal" stream were gathered. In addition, details on the tonnages for CSWD diversion by materials were also gathered. Because the disaggregation of the CSWD diversion tonnages into materials was not very granular (containers, bottle bill, etc.), data from recycling stream "sorts" from other states and communities were gathered. These data allowed us to disaggregate the aggregated commodities into shares of individual materials based on real data. This work was conducted for both the recycling and the composting stream. Generally, sorts are only available for disposal and diversion; no actual sorts are available for "generation". However, we used the sum of individual materials from disposal and diversion for historical years to identify the "starting" material stream characterizations for CSWD for generation.

The C&D stream material characterization was derived from two sources, again, informed by data from other locations. The State of Vermont conducted a waste characterization of C&D from construction sites. CSWD provided data on the C&D recycling stream at Myers Recycling Center, the largest C&D site in the County. This work developed gross estimates of the composition of the materials being recycled. A few adjustments to these gross numbers were made to help make numbers for some materials more reasonable, including adjustments related to materials that were banned from disposal. This was accomplished using comparisons to composition studies from C&D recycling sorts conducted in other locations, including compositions contributed by CDRA (Construction & Demolition Recycling Association), King County in Washington, and Massachusetts.

In all cases, we compared the material stream characterizations to sorts from other locations to make sure the "starting period" percentages being used for organics, recycling, and disposal streams were credible, defensible, and "local".[12]

This work was used to develop the "starting" materials stream composition by percentage for each forecasted material stream, as follows:

- MSW disposal
- MSW recycling
- MSW composting
- And from the sum of individual materials in the diversion & disposal elements, MSW generation.
- C&D disposal
- C&D recycling
- And from the sum of individual materials in diversion and disposal elements, C&D generation

Evolving Ton

Because the model was expected to provide forecasts well into the future, the research team included trends into the material compositions for the recyclable materials. Research over the past 15-20 years indicated some trends, which were provided by team member RRS. The information on these trends follows. These trends were continued into the future within the model.

- Plastic up 55% in 22 years and continuing at rate
- Food up 18%, trending a little lower recently
- Metals up 13%, fairly steady after initial decline
- Paper down 21%, still declining
- Glass down 30%, steady decline

[12] To facilitate comparisons and updates, materials compositions from other locations remain in the model for consultation by users.

2.5 Derivation of the Material Tonnage Estimates in the Model for the "Base Case"

Figure 2.14 below shows the flow of the derivation of the model's estimates. The general design is very straightforward:

- The forecasting models provide a "row" of annual values for each tonnage stream (MSW recycling, C&D generation, etc.).
- The composition results provide a "column" of percentages by individual materials.

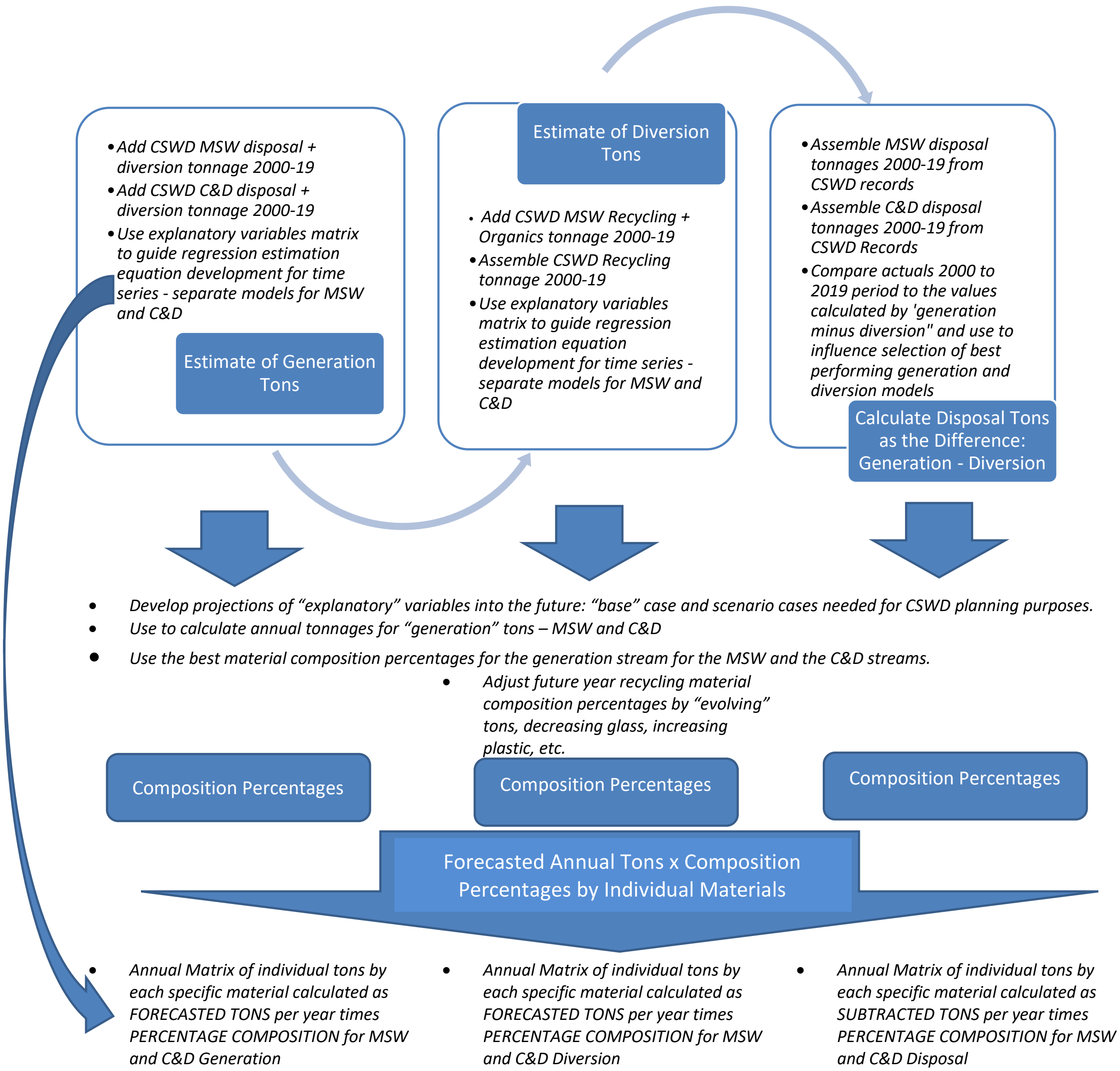
The product of the two provides a matrix of tonnages for every single material for the stream for the years.

The estimation work for the model produces a "base case" projection that is, the tonnage and distribution that is consistent with the same recycling programs that are in place now, going forward in time. This provides CSWD with an estimate of:

- Total tonnages by stream by year, assuming similar programs,
- The amount of material that would be in a stream to be delivered to various facilities (MRF, composting, landfill, etc.), and the associated cost for those fees, and
- Individual materials available for capture for any year, assuming the same basic programs that were in place over the estimation period.

The District can then use these tonnages to identify target materials for new programs, identify the total tons available, and other analyses.

Figure 2.14: Calculation Method and Flow for Tonnage and Material Forecasts



2.6 Capabilities of the Model

The Excel-based workbook model accompanying this report is internally documented, assembles instructions on one sheet (repeated as well on individual sheets), and includes "go to" buttons to navigate the model. The model is made of several sheets, addressing tonnage forecasting, waste composition, projecting materials out over time, and summary results tables. Two sets of material projections and summary tables are supported by the model – one without the "evolving ton" applied to recyclable materials, and one incorporating that adjustment. Both are calculated simultaneously without additional effort, and the user may choose to use either output.

The model is set up with the following results and capabilities.

Results	**Capabilities**
• Tonnage forecasts by each of the 7 key sectors and material streams (4 streams for MSW, 3 streams for C&D) • Waste compositions for each key sector and material stream into the future, with and without "evolving ton" adjustments • Projections of tons, by material, that remain available for diversion by CSWD programs • Estimates of the metric tons and value of GHG carbon, by material, diverted and available to be diverted	• User-variable economic growth rates for modeling likely base economic conditions and resulting tons • User settings for scenario analysis for alternative growth rates and resulting tonnage changes • Waste composition setting changes • Allows the "base case" to be modified to allow modeling of new bans, mandates, or new programs to estimate associated impacts on tonnage and capture • Allows for updating with most recent reported "actual" tonnage or economic data, and updates forecasts automatically

3. Summary of Results

This section presents the results from the model using the "base case". The base case assumes no change in the structure, delivery, or regulations surrounding disposal, recycling, and diversion. As a reminder, the landfilled tonnage is calculated as the remainder of generation minus recycling and any organics diversion. The data within this report focus on MSW and C&D; the model includes additional breakdowns for residential vs. commercial MSW.

This base case is selected to approximate the slowdown from COVID (very low growth rate for 3 years), followed by a recovery to median growth rates in the economy thereafter. We note that producing these projections in the midst of the COVID period is problematic. The economy is struggling, but the tonnages are not falling in many locations. Additional scenarios can be modeled that assume more average growth rates, if the County expects more robust disposal than the historical forecast relationships would predict.

The results in this section include:

- Graphs of tonnages for MSW and C&D streams from 2000-2045 (Figure 3.1 and 3.2)
- Table of annual tonnage forecasts by sector and stream for 2020-2045 (Figure 3.3)
- Table of starting waste compositions for major subcategories (Figure 3.4)
- Table of tonnages for 5-year increments between 2000 and 2045 (Figure 3.5)
- Tables of tonnage forecasts for MSW and C&D by major material subgroups for 2021, with associated GHG values (Figure 3.6)

3.1 Tonnage and Material Forecast Results for CSWD – Base Case

Figures 2.11 and 2.12, replicated below as Figures 3.1 and 3.2, demonstrate the actual and fitted tonnage values from 2000-2045 for the sub-streams involved in the MSW and C&D sectors, respectively.

In each case, the fit over the historical period is reasonably close.[13] In the MSW case, recycling and organics diversion rise approximately on par or slightly greater than population growth (the dotted line is included for comparison). Landfilled tonnage grows slightly over time. In the C&D case, the forecasts show generation and recycling increase (about even with population), and disposal falls over time.

[13] As mentioned elsewhere, the reader can examine the statistical fit statistics from within the model itself.

Figure 3.1: MSW Fitted and Forecasted Tonnages – All Streams (tons per year, 2000-2045) Base Case

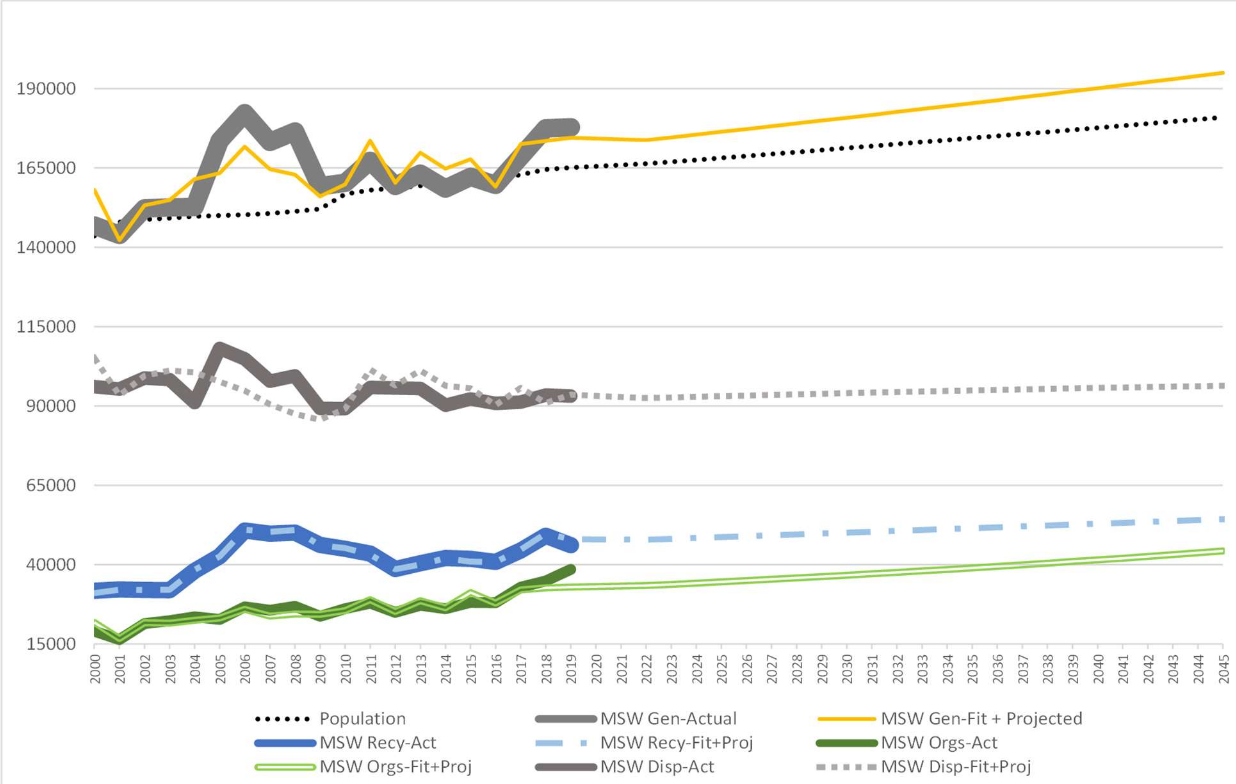
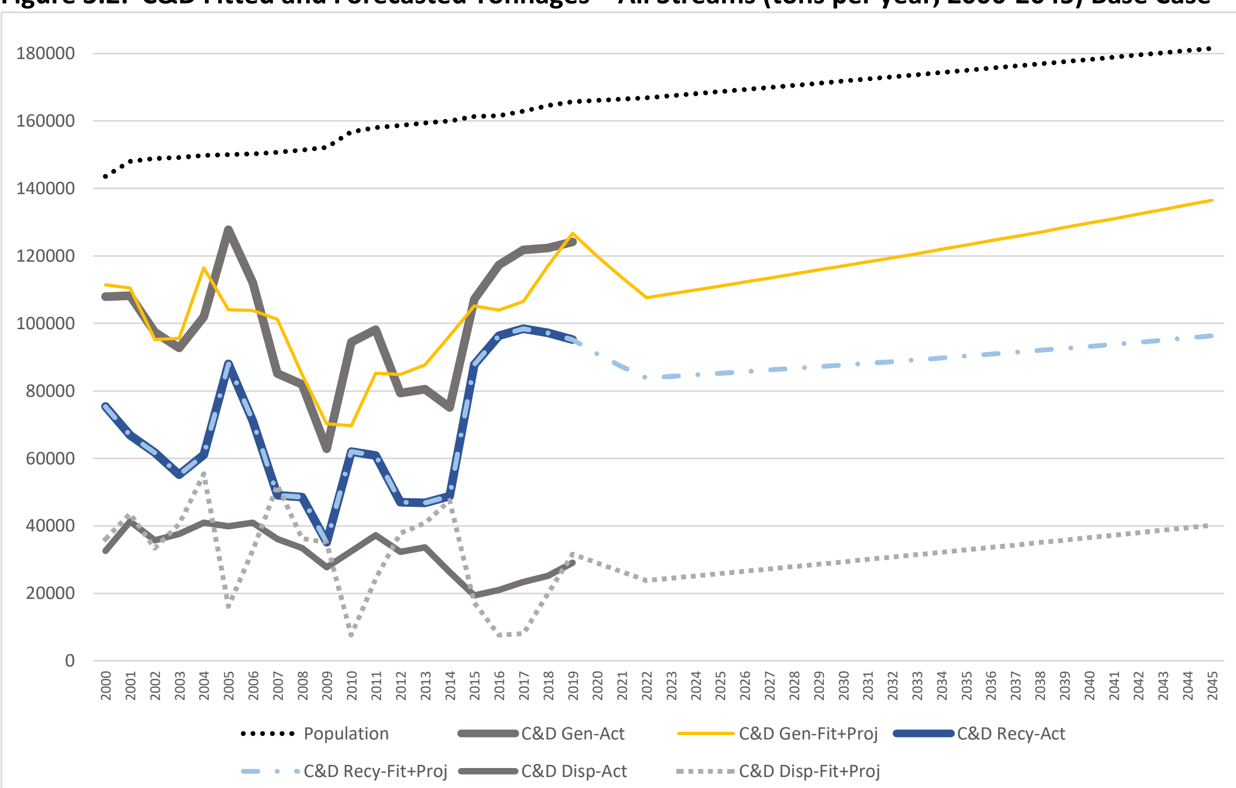


Figure 3.2: C&D Fitted and Forecasted Tonnages – All Streams (tons per year, 2000-2045) Base Case



3.2 Annual Tonnage Forecasts, 2000-2045 – Base Case Scenario

Figure 3.3 presents annual total tonnages for the major MSW and C&D streams from the model using the assumptions for the base scenario (low growth 2019-2022, median growth thereafter). The detailed Excel model provides the baseline tonnages available and removed, by material by year. Note that the Figure includes the growth rate for population as a comparison factor. While population doesn't reflect all the economic trends of interest, it provides a useful metric against which to compare the pattern in growth for the tonnage streams of interest.

- **Generation Grows More than Proportionally**: The models indicate that MSW Generation increases over time a bit more than the growth in population, indicating continued and growing consumption of "things" by residents and businesses. The C&D generation figures grow about even with population.

- **Recycling Remains a Fairly Constant Percent**: Note that the model projects that recycling program tonnages or percentages for the base case for median economic conditions do not grow substantially from the current program diversion levels. This is true for both MSW recycling and C&D recycling. This is because the model is fitted to represent current program designs (baseline program features). New incentives, mandates, improvements in convenience, and other changes would lead to increases in tonnages going forward; without changes, little will change in tonnage diversion rates. The model provides data on the estimated recycling tons that would result if current programs are continued "as-is". These are the tons that the District can work to increase with improved convenience, incentives, programs, mandates, tipping fee, other program and policy enhancements.

- **C&D recycling shows very high starting values** and grows relatively modestly from there.

- **Organics growth is similar to population.** Note however, that this is partly an artifact of setting all explanatory values to their median values. Organics will vary year-to-year with variations in rainfall.

As a result, the following impacts are noted on disposal.

- **MSW disposal stays fairly constant.** This is largely due to generation (consumption) that is expected to increase more than population, and diversion forecasts that grow slightly over time under base case program designs.

- **C&D disposal shows very low values.** This relates directly to the recent (4-plus year) surge in C&D recycling. Because disposal is the remainder after subtracting C&D recycling from the generation stream, changes in recycling directly affect this remainder, landfilled, segment.[14]

[14] Review how close the forecast is for C&D recycling and generation; this drives the small values for landfilling.

Figure 3.3: Base Case Scenario Tonnage 2000-2045: Low Growth for 2020-2022, Median growth thereafter

BASELINE TOTAL MSW ONLY								C&D RESULTS				
Year	Generation	Disposal	Recycling	Organics	Waste Red'n	Recy %	Diversion %	Year	Generation	Disposal	Recycling	Recy %
2000	146,886	96,789	31,088	19,009	0	21.2%	34.1%	2000	107,972	32,639	75,333	69.8%
2001	143,944	95,420	32,094	16,430	0	22.3%	33.7%	2001	108,174	41,349	66,825	61.8%
2002	152,290	98,875	32,006	21,409	0	21.0%	35.1%	2002	97,382	35,644	61,738	63.4%
2003	152,608	98,128	32,133	22,348	0	21.1%	35.7%	2003	92,697	37,608	55,089	59.4%
2004	152,724	90,758	38,397	23,569	0	25.1%	40.6%	2004	102,004	40,939	61,065	59.9%
2005	173,625	108,298	42,583	22,744	0	24.5%	37.6%	2005	127,826	39,886	87,940	68.8%
2006	182,329	104,574	51,060	26,696	0	28.0%	42.6%	2006	112,096	40,992	71,104	63.4%
2007	173,254	97,225	50,382	25,647	0	29.1%	43.9%	2007	85,129	36,037	49,092	57.7%
2008	176,500	98,709	50,929	26,863	0	28.9%	44.1%	2008	81,959	33,418	48,541	59.2%
2009	159,308	89,501	46,039	23,768	0	28.9%	43.8%	2009	62,875	27,740	35,134	55.9%
2010	160,335	88,989	45,228	26,118	0	28.2%	44.5%	2010	94,483	32,444	62,038	65.7%
2011	167,251	96,185	43,182	27,884	0	25.8%	42.5%	2011	98,182	37,307	60,875	62.0%
2012	159,390	95,806	38,572	25,012	0	24.2%	39.9%	2012	79,281	32,268	47,012	59.3%
2013	163,241	95,936	40,048	27,257	0	24.5%	41.2%	2013	80,472	33,639	46,833	58.2%
2014	158,544	90,346	42,031	26,167	0	26.5%	43.0%	2014	75,085	26,299	48,786	65.0%
2015	162,249	93,176	40,925	28,148	0	25.2%	42.6%	2015	107,196	19,397	87,799	81.9%
2016	159,705	90,811	40,889	28,005	0	25.6%	43.1%	2016	117,310	20,956	96,354	82.1%
2017	168,612	90,984	44,752	32,876	0	26.5%	46.0%	2017	121,734	23,330	98,404	80.8%
2018	177,476	92,691	49,864	34,921	0	28.1%	47.8%	2018	122,360	25,179	97,181	79.4%
2019	177,880	91,387	47,981	38,512	0	27.0%	48.6%	2019	124,221	29,085	95,136	76.6%
2020	177,601	90,971	47,919	38,710	0	27.0%	48.8%	2020	117,534	26,612	90,923	77.4%
2021	177,339	90,565	47,863	38,911	0	27.0%	48.9%	2021	111,319	24,137	87,182	78.3%
2022	177,095	90,170	47,812	39,113	0	27.0%	49.1%	2022	105,527	21,667	83,860	79.5%
2023	177,975	90,330	48,086	39,560	0	27.0%	49.2%	2023	106,634	22,327	84,307	79.1%
2024	178,861	90,485	48,360	40,016	0	27.0%	49.4%	2024	107,751	22,990	84,762	78.7%
2025	179,751	90,635	48,635	40,481	0	27.1%	49.6%	2025	108,879	23,654	85,225	78.3%
2026	180,647	90,782	48,910	40,955	0	27.1%	49.7%	2026	110,017	24,322	85,695	77.9%
2027	181,549	90,924	49,186	41,438	0	27.1%	49.9%	2027	111,165	24,991	86,174	77.5%
2028	182,456	91,062	49,463	41,931	0	27.1%	50.1%	2028	112,324	25,663	86,660	77.2%
2029	183,368	91,195	49,740	42,433	0	27.1%	50.3%	2029	113,493	26,337	87,155	76.8%
2030	184,286	91,323	50,018	42,944	0	27.1%	50.4%	2030	114,673	27,014	87,659	76.4%
2031	185,209	91,447	50,296	43,466	0	27.2%	50.6%	2031	115,864	27,693	88,171	76.1%
2032	186,137	91,565	50,575	43,997	0	27.2%	50.8%	2032	117,066	28,375	88,691	75.8%
2033	187,072	91,679	50,854	44,539	0	27.2%	51.0%	2033	118,279	29,058	89,221	75.4%
2034	188,011	91,787	51,134	45,091	0	27.2%	51.2%	2034	119,504	29,745	89,759	75.1%
2035	188,957	91,890	51,414	45,653	0	27.2%	51.4%	2035	120,740	30,433	90,307	74.8%
2036	189,908	91,987	51,694	46,227	0	27.2%	51.6%	2036	121,988	31,124	90,864	74.5%
2037	190,865	92,079	51,974	46,812	0	27.2%	51.8%	2037	123,248	31,817	91,430	74.2%
2038	191,827	92,165	52,255	47,408	0	27.2%	52.0%	2038	124,519	32,513	92,006	73.9%
2039	192,796	92,246	52,535	48,015	0	27.2%	52.2%	2039	125,803	33,211	92,592	73.6%
2040	193,770	92,320	52,816	48,634	0	27.3%	52.4%	2040	127,099	33,911	93,188	73.3%
2041	194,750	92,388	53,097	49,265	0	27.3%	52.6%	2041	128,408	34,614	93,794	73.0%
2042	195,736	92,450	53,377	49,908	0	27.3%	52.8%	2042	129,729	35,319	94,410	72.8%
2043	196,727	92,506	53,658	50,564	0	27.3%	53.0%	2043	131,063	36,026	95,037	72.5%
2044	197,725	92,555	53,938	51,232	0	27.3%	53.2%	2044	132,410	36,736	95,674	72.3%
2045	198,729	92,597	54,219	51,913	0	27.3%	53.4%	2045	133,770	37,448	96,322	72.0%

3.3 Initial / Starting Period Material Compositions

The subtotal material composition shares for the key sectors and streams are included in Figure 3.4 below. The results for all individual categories are provided in the model.

Figure 3.4: Starting Waste Compositions, Major Subgroups (percent of material stream tons)
Each column adds to share of 100%, and is normalized.

	1	2	3	4	5	6	7	8	9	10
Material	RES-LF	RES-Recy	RES-Org	CML-LF	CML-Recy	CML-Org	C&D-LF	C&D-Recy	Generation - MSW	Generation - C&D
Paper	31.0%	71.6%	0.0%	30.9%	71.6%	0.0%	0.0%	0.0%	35.2%	0.0%
Plastic	11.1%	5.6%	0.0%	14.0%	5.6%	0.0%	0.0%	0.0%	7.9%	0.0%
Glass	2.1%	19.6%	0.0%	1.7%	19.6%	0.0%	0.0%	0.0%	6.3%	0.0%
Metal	2.5%	3.2%	0.0%	2.6%	3.2%	0.0%	0.0%	0.0%	2.1%	0.0%
Organics	26.0%	0.0%	84.1%	21.9%	0.0%	84.1%	0.0%	0.0%	30.7%	0.0%
Electronics	1.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%
Textile	12.2%	0.0%	0.0%	10.5%	0.0%	0.0%	0.0%	0.0%	5.9%	0.0%
Inerts (Lumber/concrete)	8.4%	0.0%	15.9%	13.1%	0.0%	15.9%	0.0%	0.0%	8.8%	0.0%
Household Hazardous Waste	0.5%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%
Special Waste / Other	1.8%	0.0%	0.0%	2.6%	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%
Mixed/ Remainder/Trash	3.5%	0.0%	0.0%	2.1%	0.0%	0.0%	0.0%	0.0%	1.5%	0.0%
C&D	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%	100%	0.0%	100.0%

3.4 Resulting Calculations of Materials Generated, Diverted, and Available for Diversion

Figure 3.5 presents annual tonnage data for MSW and C&D for 5-year increments between 2000 and 2045. Figure 3.6 presents data for 2021, detailing tonnages for specific material subsectors of interest to CSWD, and the amount of associated Greenhouse gas and the value of GHG associated with the recovered and available materials.

The reported data from CSWD indicate about 27% MSW recycling, and another 23% organics diversion, for a diversion rate about 50%. The calculated diversion for the C&D sector, based on reported data, exceeds 80%. With its dedicated processing facilities,[15] this is higher than most other locations.

[15] Including 3 facilities that recycle asphalt, brick, and concrete.

The tables also indicate that the carbon value of the GHG avoided from recycling and diversion efforts already in place in CSWD is valued at more than $7 million annually, with another $2.3 million available to be recovered through new initiatives.

Figure 3.5: Data for Major Streams for MSW and C&D, 2000-2045

BASELINE TOTAL MSW ONLY							C&D RESULTS				
Year	Generatior	Disposal	Recycling	Organics	Recy %	Diversion %	Year	Generatior	Disposal	Recycling	Recy %
2000	146,886	96,789	31,088	19,009	21.2%	34.1%	2000	107,972	32,639	75,333	69.8%
2005	173,625	108,298	42,583	22,744	24.5%	37.6%	2005	127,826	39,886	87,940	68.8%
2010	160,335	88,989	45,228	26,118	28.2%	44.5%	2010	94,483	32,444	62,038	65.7%
2015	162,249	93,176	40,925	28,148	25.2%	42.6%	2015	107,196	19,397	87,799	81.9%
2020	177,601	90,971	47,919	38,710	27.0%	48.8%	2020	117,534	26,612	90,923	77.4%
2025	179,751	90,635	48,635	40,481	27.1%	49.6%	2025	108,879	23,654	85,225	78.3%
2030	184,286	91,323	50,018	42,944	27.1%	50.4%	2030	114,673	27,014	87,659	76.4%
2035	188,957	91,890	51,414	45,653	27.2%	51.4%	2035	120,740	30,433	90,307	74.8%
2040	193,770	92,320	52,816	48,634	27.3%	52.4%	2040	127,099	33,911	93,188	73.3%
2045	198,729	92,597	54,219	51,913	27.3%	53.4%	2045	133,770	37,448	96,322	72.0%

3.5 Greenhouse Gas and Carbon Value

The District is interested in the impact of different materials on greenhouse gases (GHG) and climate change. The model uses factors from EPA's "WARM" model for each individual material specified in the model to compute the Metric tons of carbon dioxide equivalent (MTCO2e) associated with the remaining or reduced tons. For the selected year, these factors are used to calculate the MTCO2e associated with each material type remaining in the waste stream. These values can be used to prioritize program development or refinement to address highest impact GHG contributors. In addition, the model calculates a dollar value associated with those avoided GHG emission.

Market Value and Social Cost of Carbon ($/MTCO2E): In addition to MTCO2e units, the model expresses the GHG impacts in dollar terms, allowing two choices that represent the literature on social value of carbon.

The environmental literature shows a lower-bound dollar value of about $37/ton for the simple environmental externalities[16] associated with the emissions.

A fairly recent study out of Stanford suggests that the low-estimate literature-based Market Value, $37/MTCO2E ($39 in 2018), is far lower than the true social cost of carbon. Instead, the Stanford study estimates the value to be $220/MTCO2E ($233 in 2018).[17] The study incorporates additional, previously

[16] EPA 2015 https://19january2017snapshot.epa.gov/climatechange_.html; discussed in more detail in Triple Bottom Line chapter.

[17] The EPA study (market value) designed an economic integrated assessment model (IAM) using empirical findings that concluded an additional ton of carbon dioxide emitted would cause $37 worth of economic damages, which are expected to take various forms including decreased agricultural yields, harm to human health and lower worker productivity related to climate change. The Stanford study (social cost of carbon) takes the Dynamic Integrated Climate Economy (DICE) model (an IAM model) and incorporates additional, previously unaccounted-for economic damages by assuming climate change will slow down GDP growth rates, particularly in less affluent areas. Social cost adds impacts related to: increased heat-related mortality,

unaccounted for economic damages by assuming that climate change will slow down economic growth rates, particularly in less affluent areas. The EPA value represents a more conservative approach. Both are respected sources and are in the range of other values from the literature.

Market Value of Carbon ($37) Includes: (all climate change related)

- Decreased agricultural yields
- Harm to human health
- Lower worker productivity

Stanford Social Cost of Carbon ($220) Includes all of the above PLUS:

- Market Value of Carbon (above)
- Increased heat related mortality
- Changed water supply and demand
- Decreased agricultural yields
- Decreased shellfish harvests
- Harm to human health
- Lower worker productivity
- Increased road damage
- Increased energy demand
- Increased coastal infrastructure damage

A comparison of the GHG value can help prioritize materials for new or revised District programs or initiatives, in combination with other criteria the District may consider.

changed water supply and demand, decreased agricultural yields, decreased shellfish harvests, harm to human health, lower worker productivity, increased road damage, increased energy demand, increased coastal infrastructure damage and other effects.

Figure 3.6: Annual Data by MSW Material Sector and GHG Values, 2021, Base Scenario

Scenario Name: S1: VL & L thru 2022; Median thereafter

																	C&D	MSW (Res&Com')	GHG Value/MT=>			$37	$37	$37	$37
Tons in Thousands	MSWOnly_Gen	MSWOnly_Recy	MSWOnly_Org	MSWOnly_BaseLF	Res_Gen	Res_Recy	Res_Org	Res_BaseLF	Cml_Gen	Cml_Recy	Cml_Org	Cml_BaseLF	C&D_Gen	C&D_Recy	C&D_BaseLF	C&D_Disp	Mat'l Recy Rate	Mat'l Recy Rate	Mat'l Diversion Rates	GHG Factor-Avoided MTCO2e/Ton (from WaRM)	GHG MTCO2e Avoided by tons currently recovered	Value of currently-avoided MTCO2e (thousands $)	$ GHG Value Landfilled - Residential (Million $)	$GHG Landfilled - Com'l (million $)	$ GHG Landfilled - C&D (million $)
TOTAL TONS (thous)	177	48	39	91	95	25	19	50	83	22	19	41	111	87	24	24	78%	27%	49%	2,938		$7,834	$1,017	$861	$567
MSW Materials Diverted & Disposed																									
Paper	43	34	0	9	23	18	0	5	20	16	0	4	0	0	0	0	0%	79%	79%	2,938	100,641	$3,724	$543	$438	$0
Plastic	5.1	1.8	0.0	3.3	2.6	1.0	0.0	1.6	2.5	0.9	0.0	1.6	0.0	0.0	0.0	0.0	0%	36%	36%	2,938	5,323	$197	$178	$176	$0
Glass	5.3	4.7	0.0	0.6	2.8	2.5	0.0	0.4	2.5	2.2	0.0	0.3	0.0	0.0	0.0	0.0	0%	89%	89%	2,938	13,752	$509	$38	$28	$0
Metal Cans & Foil	1.9	1.2	0.0	0.7	1.0	0.7	0.0	0.4	0.9	0.6	0.0	0.3	0.0	0.0	0.0	0.0	0%	64%	64%	2,938	3,604	$133	$38	$36	$0
Single Stream Recy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%	0%	2,938	0	$0	$0	$0	$0
Redeemed BB - Est	6.9	5.8	0.0	1.1	3.7	3.1	0.0	0.6	3.2	2.7	0.0	0.5	0.0	0.0	0.0	0.0	0%	85%	85%	2,938	17,164	$635	$67	$49	$0
Add'l Com'l Div - Est	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%	0%	2,938	0	$0	$0	$0	$0
Other Recyclables	2.7	0.0	0.0	2.7	1.3	0.0	0.0	1.3	1.4	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0%	0%	0%	2,938	0	$0	$139	$150	$0
BackYard Composting-Est	8.9	0.0	5.3	3.6	4.6	0.0	2.7	2.0	4.3	0.0	2.7	1.6	0.0	0.0	0.0	0.0	0%	0%	60%	2,938	15,598	$577	$213	$174	$0
Wood Orgs	6.1	0.0	6.2	0.0	3.1	0.0	3.1	0.0	3.1	0.0	3.1	0.0	0.0	0.0	0.0	0.0	0%	0%	101%	2,938	18,165	$672	-$2	-$2	$0
Yard Trim - Rept & Est	7.4	0.0	6.9	0.6	3.9	0.0	3.4	0.5	3.5	0.0	3.4	0.1	0.0	0.0	0.0	0.0	0%	0%	92%	2,938	20,148	$745	$55	$7	$0
Food & Non-Recy Paper	36	0	14	21	19	0	7	12	16	0	7	9	0	0	0	0	0%	0%	40%	2,938	42,243	$1,563	$1,310	$997	$0
Other Organics	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%	0%	2,938	0	$0	$0	$0	$0
Textiles	3.9	0.0	0.0	3.9	2.7	0.0	0.0	2.7	1.2	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0%	0%	0%	2,938	0	$0	$293	$126	$0
Scrap Metal	1.5	0.0	0.0	1.5	0.9	0.0	0.0	0.9	0.7	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0%	0%	0%	2,938	0	$0	$96	$71	$0
UHW	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%	0%	2,938	0	$0	$10	$4	$0
Electronics	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%	0%	2,938	0	$0	$0	$0	$0
Tires	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	101%	0%	0%	2,938	102	$4	$8	$2	$0
C&D																									
C&D-ABC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.6	7.2	0.4	0.4	95%	0%	0%	2,938	21,260	$787	$5	$0	$43
C&D Asphalt Shingles	0.2	0.0	0.0	0.2	0.2	0.0	0.0	0.2	0.1	0.0	0.0	0.1	32	28	4	4	87%	0%	0%	2,938	82,477	$3,052	$19	$8	$453
C&D Clean Wood	12.2	0.0	6.2	6.1	5.3	0.0	3.1	2.2	6.9	0.0	3.1	3.8	0.0	0.0	0.0	0.0	0%	0%	50%	2,938	18,165	$672	$243	$416	$0
C&D Unpainted / unstained OSB&Plywood	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20	18	2.1	2.1	89%	0%	0%	2,938	52,252	$1,933	$0	$0	$233
C&D Painted / treated wood	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.9	5.5	3.4	3.4	62%	0%	0%	2,938	16,142	$597	$0	$0	$366
C&D Scrap metal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.3	8.5	0.7	0.7	92%	0%	0%	2,938	25,102	$929	$0	$0	$80
C&D Drywall	0.4	0.0	0.0	0.4	0.2	0.0	0.0	0.2	0.2	0.0	0.0	0.2	7.0	6.9	0.1	0.1	98%	0%	0%	2,938	20,188	$747	$19	$20	$13
C&D OCC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	1.6	1.4	1.4	53%	0%	0%	2,938	4,611	$171	$0	$0	$152
C&D Remainder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%	0%	2,938	0	$0	$0	$0	$0
Other Landfilled MSW-Residue	24	0	0	24	14	0	0	14	10	0	0	10	0.2	0.0	0.2	0.2	0%	0%	0%	2,938	0	$0	$1,546	$1,108	$25
Other Landfilled C&D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22	11	10	10	52%	0%	0%	2,938	33,341	$1,234	$0	$0	$1,130
Other Recyc C&D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	1.2	1.2	0%	0%	0%	2,938	0	$0	$0	$0	$130
Currently Recy-Res	137	48	39	50	73	25	19	28	64	22	19	22	0	0	0	0	0	0	1	2938	254804	9428	3044	2398	0
Currently Recy - Coml	137	48	39	50	73	25	19	28	64	22	19	22	0	0	0	0	0	0	1	2938	254804	9428	3044	2398	0
Currently Recy-C&D	0	0	0	0	0	0	0	0	0	0	0	0	90	77	13	13	1	0	0	2938	225763	8353	0	0	1436

3.6 Next Steps and Recommendations

The model provides CSWD with a great deal of data to support its on-going waste management efforts. It supports scenario analyses, allowing the District to estimate generated, diverted, and disposed tonnages under different economic conditions in the future. Tables within the model mimic key regular tracking spreadsheets used by CSWD.

After vetting and using the results for upcoming analyses, the District's only upkeep assignments associated with this model are:

- Annual updates to MSW and C&D tonnages,
- Periodic updates to input data (1-3 years),
- Periodic updates to forecasting models (3-5 years), and
- Consider adding additional program modeling capabilities.

Appendix A: Waste Stream Definitions and Trends

The Chittenden Solid Waste District was created in 1987 in response to Act 78 from the State of Vermont. In 1992, CSWD enacted the Solid Waste Management Ordinance regulating solid waste collection, transportation, processing, and disposal among other things. It established a management fee for all solid waste generated within the District. The District has been tracking the flow of solid waste for various streams and sources of materials. Waste that is generated in, but disposed out of the District is required to be weighed and recorded; however, calculation of tonnage is not always straight forward as there are multiple sources and destinations for many of the solid waste materials.

The tonnages were consistently available from 2000-2019, and the explanatory variables were matched to this period.

Components of waste stream tonnages used for this analysis:

- **Municipal Solid Waste (MSW LF)** - tons of waste sent to landfill or incinerated. This includes both residential and commercial sources but does not include landfilled construction and demolition (C&D) waste or alternative daily landfill cover (ADC).
- **Recycling** – This includes both residential and commercial mandatory recyclables, single stream, and an estimated share of redeemed bottle bill materials. It also includes an estimated amount of additional commercial recycling for years 2000-2016. The following diverted materials are not included in this category:
    - Organics
    - Textiles
    - Scrap Metal
    - Hazardous Waste
    - Electronics
    - Tires
- **Organics** – This includes food and yard waste materials from curbside and drop-off and also estimates of materials composted on site / backyards (information collected through surveys).
    - Estimated Backyard Composting / On-site Management
    - Wood
    - Reported & Estimated Yard Trimmings
    - Food Residuals & Non-recyclable Paper
- **Construction and Demolition Recycled (C&D Recycled) -** This stream, includes construction materials from new construction and remodeling and any mandatory recyclables such as cardboard.
    - Plywood – clean & unpainted
    - OSB (Oriented Strand Board) – clean & unpainted
    - Asphalt shingles – asbestos-free
    - Scrap metal
    - Clean lumber & pallets
    - Drywall
    - Mandatory recyclables
- **Construction and Demolition Landfilled (C&D LF)** – This includes C&D materials landfilled and incinerated including fines from recycling processing.

Appendix B: Additional Elasticities

Interpreting Importance of Explanatory Variables using Elasticities

To examine the relative ‘importance’ of the explanatory variables included in the MSW and C&D material stream models, additional calculations were needed, because the estimated coefficient does not provide this information. For most types of quantitative variables (income, population, etc.), the size of the effect depends on both the “units” for the underlying variable, and the amount of variation found in that variable over time. As a straightforward example, note that a coefficient for a variable expressed in dollars would be 1/1000th of the coefficient for the same variable expressed in thousands of dollars. Because the size of the coefficient depends on the units for the underlying variable, we estimated the “elasticity” instead, a relative metric that is independent of units.

For economic / demographic variables we estimated the relative impacts using elasticities[18]. Elasticities estimate the percentage change in tonnage that results when each individual explanatory variable is changed (increased) by 1%. Those variables showing negative impacts mean when the explanatory variable increases, projected tonnage decreases (for example tipping fee).

Figure B.1 shows the elasticities from the equations that were estimated for the MSW streams. Figure B.2 shows the elasticities from the questions estimated for the C&D streams. Recall that, although some preliminary disposal models were estimated for exploratory purposes, they were not used in the final model; disposal was the calculated residual from generation minus diversion. More detailed expositions of the elasticities are presented in a dedicated tab in the Excel model.

Figure B.1: Elasticities for Semi-finalist Models for MSW Streams

Stream: MSW Generation			Equation: Gen 1	Equation: Gen 7	Equation: Gen 14	Equation: Gen 15	Equation: Gen 20	Equation: Gen 24^
Variable	**Max change** in input variable over 10yrs**	**Avg change** in input variable over 10yrs	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%
MSWtip	9.0%	2.4%	-1.0%	-0.9%	-1.32%	-0.98%	20.55%	
%over60	14.2%	3.4%	0.8%	1.0%				
AnnlPrecip (# not %)	50.92	38.47	0.1%	0.1%	0.07%	-0.95%	24.73%	0.22%
ConstructionEmploy	8.81%	0.00%		0.8%		0.22%		0.26%
UnEmplRate	40.00%	0.61%		0.2%				
MedHH_income	12.74%	2.35%						
Per Inc	7.67%	3.97%			0.93%	0.66%	26.76%	
#NewHH	44.50%	5.28%					24.93%	
HousingUnits	1.52%	0.98%						0.59%
PrgRecy_AdjMand_2005	N/A	N/A						
Recession 2YRLag10_11	N/A	N/A						
	*From Table 1-5: 1.Baseline Tab				^Currently Selected Equation in Model (Green)			

[18] Program or recession variables only have 1's or 0's as inputs. They do not have calculated/ historical elasticities and have an N/A in the Max and Average columns of the elasticity tables.

Stream: Recycling		Equation>	MV58^	MV Pop Variable	MV # Housing Units Variable	MV8	MV42	MV43	MV44	MV51
Variable	**Max change** in input variable over 10yrs**	**Avg change** in input variable over 10yrs	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%
$PersIncm	7.7%	4.0%				2.4%				
%over60	14.2%	3.4%								-0.2%
HousingUnits	1.5%	1.0%			1.6%					
MedAgeHoH_US	1.4%	0.6%				-11.4%	-2.0%	-2.9%	-1.7%	
MedHH_incm	12.7%	2.3%						0.7%		0.2%
ResPop	3.1%	0.8%		1.5%						
PrgRecy_AdjMand_2005	N/A	N/A								
DummyV12_13	N/A	N/A								
PrgRecy_AdjMand_2005 is the same as R_Prg_AdjMand2005			^Currently Selected Equation in Model (Green- only program & dummy variables)							

Stream: Recycling Rate		Equation>	RECYC RATE 22^	RECY RATE 18	RECYC RATE 20
Variable	**Max change** in input variable over 10yrs**	**Avg change** in input variable over 10yrs	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%
$PersIncm	7.7%	4.0%		0.00%	
%over60	14.2%	3.4%			
HousingUnits	1.5%	1.0%	0.3%		
MedAgeHoH_US	1.4%	0.6%			
MedHH_incm	12.7%	2.3%			
ResPop	3.1%	0.8%			0.19%
R_Prg_AdjMand2005	N/A	N/A			
PrgRecy_AdjMand_2005 is the same as R_Prg_AdjMand2005			*^Currently Selected Equation in Model (Green)*		

Stream: Organics		Equation>	MV Pop Variable	MV # Housing Units Variable	MV2	MV3	MV6^	(4) MV15	(6) MV17	MV19	MV21
Variable	**Max change** in input variable over 10yrs**	**Avg change** in input variable over 10yrs	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%	% ton impact / change input variable 1%
%over60	14.2%	3.4%							0.6%	0.8%	0.9%
AnnlPrecip (# not %)	51	38				0.5%	0.4%	0.4%	0.3%	0.5%	0.3%
ResPop	3.1%	0.8%	3.1%		1.5%						
HousingUnits	1.5%	1.0%		3%							
MSW Tip	9.0%	2.4%					0.6%	0.5%			
PrgRecy_AdjMand_2005	N/A	N/A									
PrgYW_Lfban**	N/A	N/A									
*From Table 1-5: 1.Baseline Tab		*^Currently Selected Equation in Model (Green)*				*** Variable reflects program changes to organic materials*					

Figure B.2: Elasticities for Semi-finalist Models for C&D Streams

Stream: C&D Generation		Equation>	C&D Gen 5	C&D Gen 6	C&D Gen 9	C&D Gen13	C&D Gen14	C&D Gen16
Variable	Max change in input variable over 10yrs*	Avg change in input variable over 10yrs	% ton impact / change input variable 1%	impact / change input variable	% ton impact / change input variable 1%	% ton impact / change input variable 1%	impact / change input variable 1%	impact / change input variable 1%
Construction Employ	8.8%	0.0%	1.8%	1.8%	1.8%	2.3%	1.8%	2.3%
C&D Tip Fee	13.2%	2.9%			-0.4%			
PersIncm	7.7%	4.0%					0.1%	
#NewHH	44.5%	5.3%					0.2%	0.0%
PrgC&D2015	N/A	N/A						
RecessionLag10_11	N/A	N/A						
PrgC&DLag2016	N/A	N/A						
*From Table 1-5: 1.Baseline Tab								

Stream: C&D Recycling		Equation>	MV Pop Variab	MV # Housi	MV1	MV7	MV6 (Prgs &	MV42	MV56
Variable	Max change in input variable over 10yrs	Avg change in input variable over 10yrs*	% ton impac	% ton imp	% ton impact	% ton impact	% ton impact / change input variable 1%	% ton impa	% ton impa
ResPop	3.1%	0.8%	4%						
C&Dtip	13.2%	2.9%							
#NewHH	44.5%	5.3%					0.3%		0.2%
HousingUnits	1.5%	1.0%		2%					
UnEmplRate	40.0%	0.6%			-0.2%			0.5%	-1%
PrgC&D2015	N/A	N/A							
Recession08_09	N/A	N/A							
C&D_DivLagged2yrs (2002)	N/A	N/A							

Appendix C: Model Summary and Basic Instructions

The following instructions are extracted directly from the accompanying Excel Model.

This model was developed for CSWD staff use by SERA. The purpose is to provide:

==> Forecasts of future tonnages for key CSWD sectors / streams

==> Waste compositions for key sectors / streams

==> Projections of available tonnages by detailed material into the future for targeting by future CSWD programs

==> Estimates of the GHG tons associated with diverted and available tons by material, and the dollar values associated with the social cost of carbon

==> Spreadsheets to identify progress toward maximum capture rate from current programs and potential program / policy initiatives CSWD may identify.

The model tries to balance user simplicity with transparency in calculations, and flexibility in integrating new information.
The model is not designed for the simplest possible user interface; it assumes users will be somewhat sophisticated.

MODEL's CONTENTS

The model focuses on several main sectors / streams:

==> MSW Generation, forecasting the overall MSW generation (defined as disposal plus recycling plus organics)

==> MSW LF Disposal, separated into residential and commercial streams

==> MSW Recycling, separated into residential and commercial streams

==> MSW Organics, separated into residential and commercial streams

==> MSW Composting tons projections

==> C&D Generation (defined as C&D disposal plus recycling)

==> C&D LF Disposal

==> C&D Recycling

The forecasts of landfilling are not used. Instead, the model identifies landfilling as the leftover from Generation Minus Recycling Minus Compost.
Note also, that the forecasting equations are for "baseline" -- that is, the continuation of the current, existing program structures.
The last sheet in the model allows the user to model "new" programs, or implications of increasing capture in specific materials, and estimating change from baseline.

The model has 4 main sheets. Highlights of the purpose of each sheet is included in the bullets below; detailed descriptions are provided on each sheet and are also reproduced lower on this sheet.

==> Sheet 0: Overall model structure and conventions. Sheet 0.1 provides variable definitions, and 0.2 provides a brief explanation of the regression sheets.

==> Sheet 1: Tonnage forecasts for each key sector / stream, based on underlying economic and policy drivers.

==> Sheets 1aa through 1f provide forecast underpinnings for each of the main sectors / streams listed above.

==> Sheet 2: Waste composition options for each key sector / stream

==> Sheet 3: Computations of annual tonnages by key sector and stream, for individual categories of materials, based on Sheet 1 & 2 data

==> Sheet 3b: Same contents as Sheet 3 but modifying the tonnages to incorporate the evolving trends in tonnage lightweighting and other material shifts.

==> Sheet 4: Provides output tables of tonnage and is the location for running scenarios for the tonnages (and capture rates) resulting from next programs / policies / materials.

==> Sheet 4b: Same contents as Sheet 4 but modifying the tonnages to incorporate the evolving trends in tonnage lightweighting and other material shifts.

Note that the user settings from Sheet 4 transfer automatically over to Sheet 4a (cells have been turned grey); user may break links for "new" program's diversion to not exceed 100%.

CONVENTIONS OF THE MODEL

The upper left of each sheet includes three sections: 1) Purpose / basic computations, 2) User Entry Descriptions, and 3) Useful Output Tables.

The model uses the following cell coloration and text coloration conventions.

Red Arrows	Information
ight yellow cells:	User entry cells, with default values currently in place. Users may review or replace these values.
ight yellow cells:	User entry cells, with default values currently in place. Users may review or replace these values.
Grey cells:	Model computations or table labels; do not change values, settings, or entries in these cells.
Blue cells	Model computations or table labels; do not change values, settings, or entries in these cells.
Green cells	Model computations or table labels; do not change values, settings, or entries in these cells.
Rose cells	Model computations or table labels; do not change values, settings, or entries in these cells.
Purple cells	Model computations or table labels; do not change values, settings, or entries in these cells.
White cells:	Model computations; do not change values, settings, or entries in these cells.
Blue Text:	User instructions or information - important
Red Arrows	User instructions or information - important

Be careful not to move or adjust lookup tables or lookup table codes (labeled).

USER QUICK-RUN INSTRUCTIONS

As mentioned, the model is not structured solely for "simple operation" for the user, but provides transparency and easy-update elements.
However, users will want to run scenarios quickly, once the model is populated, or the default values are confirmed.
At that point, for most runs, the user will only need to conduct the following steps:

1) Use Sheet 1 (1.BaselineTonForec&EconAssumpt) to revise growth rate scenarios (cell B29) to model high / low economics into the future; Future tip fees and mandate settings should be confirmed (starting cells J1-JP48).

Note the growth rate for precipitation is set in A29, and would normally be set at average or median.

2) Concentrate the rest of your efforts on Sheet 4 (4.Summary&TonsAvail) (or 4b to incorporate evolving ton). Select your scenario Calculation year (in 21) and dollars to value GHG (K22).

3) Main Efforts/Steps:

a. Define modifications to existing programs in inputs in Table 4.2 (starting CA30). First, by material, review the performance (capture rate) to date (grey cells)
b. Select the appropriate column pair in which you'll be defining this program (new program - yellow pairs; existing diversion - yellow / grey pair).
c. Jump to table 4.3a, fill in the correct sector for that program (starts in BS3).
d. Back to Table 4.2. Develop program refinements (new collections/convenience, new incentives, policies (enforcement/mandates/bans), new material additions, etc.)
e. Based on Step d, identify which materials will be affected (increased or added) and put a "1" in the 1st yellow column (Y/N)
f. Based on Step d, identify which materials will be affected (increased or added) and put the percentage points of additional diversion you expect and insert this percentage in the 2nd yellow column for that program.
g. Review results in Table 4.3 (in BX3) and determine if program achieves goals, or if changes are needed to materials included or refinements to added diversion and adjust your program plan assumptions via stronger incentives, etc. sufficient to achieve that goal diversion bump.
h. When you achieve the performance you want, be sure to document all your assumptions that you have made in Table 4.2, and your policy assumptions (not in model).
i. Run the next scenario.

DESCRIPTIONS OF / FROM THE INDIVIDUAL WORKBOOK SHEETS

The following descriptions from individual sheets are replicated below.

Sheet 1: Baseline Tons Forecasts and Economic Assumptions

Purpose *This sheet provides inputs into and develops forecasts of MSW (Residential and Commercial) and C&D Tonnage out 25 years*
These forecasts are driven by regression models & user settings for growth rates & distribution and, if desired, review of the multiple forecasts developed.

The forecasts are developed on individual supporting sheets (1a - 1f for, respectively, MSW LF, MSW recycling, MSW Organics, C&D Landfill, and C&D recycling. Those results are brought into Table 1.6 on this page.

USER Setting Areas:

Area 1.1: User reviews/re-sets economic condition forecasts -Mandatory review (cell B29)

Area 1.2: Optional user settings. Review settings for split of tons between sectors (starts cell AI7)

Area 1.3: Optional user settings. Table 1.2 and 1.3 display the economic growth rates and codes; they can be reviewed or manual settings may be defined (AP7 &AT7)

Area 1.4: If Future programs involve new tip fees or mandates / bans, review input forecast settings in JI48, described cell IF20.

Area 1.4b:Update the tonnage data as it becomes available (cell K27)

Area 1.5: Periodic review. Fitted forecasts in Table 1.6 (cell AP28) are selected on Individual forecast sheets 1a-1e and transferred to this table.

Area 1.10: Special instructions to run High and Low Scenarios addressing volatility adjustments in C&D Sector: Read instructions starting in Cell AB13. Review graphs on 1a-1e to assess performance; explanation in CD28.

Useful Output Tables.

Table 1.6 is the only output table directly on this page. It provides annual tons by sector and major stream (MSW Landfill, recycling, etc.) Other tables for transparency.

Sheets 1a-1g: Individual Sector / Waste Stream Forecast Development Sheets

Sheet Description: This sheet provides the fitted regression models for forecasting the sheet's sector waste stream, and forwards the user-selected equation to Sheet 1. Colors of equation match the color of the associated graphed line. Select preferred equation based on statistical performance, graphed fit, and projections.

USER Settings (Sheet 1a is used as an example; the others are parallel, but cell locations may shift slightly)

Users only select one preferred equation with a "1" in Table 1a.3, Cells AJ-AR9.

Or users may select a combination of equations (add to "1"). Description in AU10

Users should update actual disposal or recycling tonnage every year as it becomes available in the light-yellow cells

Output Tables

There are no output tables of interest. Values for the "selected" equation are transferred to Sheet 1.

NOTE: Sheets 1b1. and 1b2. both include forecasts of MSW Recycling. 1b1 calcuates models fitting MSW recycing TONS; 1b2 includes models fitting MSW recycling RATE.

NOTE: Sheets 1d (Backyard composting calculations), 1e (MSW landfill modeling), and 1g (C&D landfill modeling) are retained only FYI. They are not directly connected to other sheets.

Sheet 1i: Elasticities

This sheet includes the elasticity results for key MSW and C&D forecast equations.

Sheet 2: Starting Waste Compositions

Purpose: This sheet generates the starting waste compositions for each sector / stream in the model.
A total of 12 sector / stream combinations can be specified for the model; we use 8 at this time.

The user selects their preferred waste composition for each sector / stream of interest (in Table 1).
Each row highlights in *YELLOW* a candidate waste composition relevant to the row's sector / stream.
Select one (using a "1") or you may weight multiple candidates if the total of weights adds to 1.

The model then takes the raw waste composition Table 2.2), makes sure the total of the compositions for all the categories add to 1.0 (not all waste comps do because of rounding error) and outputs the waste comp for this starting year to the cells below in Table 2.1 and provides output table 2.3 (cell A56).
That waste composition is transferred to Sheet 3a, where it is married with the tonnage forecasts to provide a matrix of tons and materials by sector and stream, and add projections to 2045 (Sheet 3a)

USER Instructions
User input area 1.1: User selects the preferred / closest fit waste composition for each sector / stream estimated in the model. Instructions start cell P10. No other user settings.

Useful Output Tables
Table 2.3 (cell a56) provides the starting waste comps, by material,
for each sector and stream combination used in the model.
Other tables are 2.1 (normalized waste comps where user selections are made,

Sheet 3: Tonnage Calculations by Sector / Material Over Time to 2045

Purpose: This page uses the data on forecasted tons by sector & stream, and the selected waste comps, to estimate tonnages per year per stream.
This supports the ultimate computation of remaining tons.
The time series of tons assumes 2020 generation composition (adjusted by for new tons & evolving ton composition**), and then materials are removed from specific steps:

1) Forecasts of EXISTING recycling and organics programs

2) NEW reductions allowed for new waste reduction, recycling, and organics diversion. User specifies materials on Sheet 5 "New Programs".
OR may use disposal, recycling, and organics waste compositions, respectively.

There are 25 pairs of tables going across the page (upper & lower). The top table of each pair is tons; the bottom is the revised waste composition that is realized after pulling materials out of the stream annually.

User Settings:

No user settings occur on this page. User sets a sample year

Useful Output Tables

The tables for the year selected on Sheet 4 is transferred to that page

No useful tables from this page.

Sheet 3b: Tonnage Calculations by Sector / Material Over Time to 2045 - Adjusted for "Evolving Ton" / Material Trends

Purpose: This page modifies the tonnage by material calculations from Sheet 3a by applying changes due to "evolving ton" over time.

Elements of "evolving ton" include lightweighting of plastics, reductions in glass and paper, increases in food, etc. based on trends over 20 years, applied to the future.

The factors can be modified easily based on new trends, as the trends are introduced via a look-up table. The source for evolving ton is a published analysis of trends by RRS (see report).

Model uses two sets of inputs (which users may adjust). 1) apply trends by material over the 25 forecast years by revising annual trend/change factors (if material has increased

10% over 10 years, the factor would be calculated as 1.01, 1.02, 1.03, etc. over time).

into a lookup table with material codes at the left (space for up to 12 material trend codes), and 2) the look up table codes are assigned to each detailed material type (not the subtotals).

It is not applied to the subtotals / "roll-ups" because it allows trends to be applied to some, but not all, categories within a material type. Subtotals are calculated as the sum of those

individual materials, some of which are "trended" and some which may not.

As in Sheet 3a, there are 25 pairs of tables going across the page (upper & lower). The top table of each pair is tons; the bottom is the revised waste composition that is

realized after pulling materials out of the stream annually.

User Settings: Two OPTIONAL settings or reviews on this page.

User Setting Area 3b.1: Review trend material setting in lookup table

and review assignment of trend codes to specific materials (cell D21)

Useful Output Tables

The tables for the year selected on Sheet 4b is transferred to that page

No useful tables from this page except possibly the trends / trend assignments in Table 3b.0 (cell A24)

The Evolving ton directions are noted below.

Summary of Evolving Ton Trends from RRS Publication

Material Changes description (because waste comps & categories change per client)

Plastic up 55% in 22 years and continuing at rate

Food up 18% trending a little lower recently

Metals up 13% fairly steady after initial decline

Paper down 21%, still declining

Glass down 30%, steady decline

Mat'ls without change

Implementing Evolving Ton

This factor is SEPARATE from economics / forecasts. These multipliers
adjust forecast tons over time by individual material subcategory
by applying an annual trending multiplier from lookup table to the basic
tonnage forecasts developed in Sheet 3. If material increases 10% over 10 years, factor is set as 1.01, 1.02, etc.

User may look at tonnage forecasts from either Sheet 3 (not adjusted for evolving ton) or Sheet 3a.

Sheet 4: Summary and Tons Available Calculations

Purpose: This sheet displays one user-selected year of tonnage data to the material level, including GHG and values.

Also displays the performance of existing programs, and provides potential and capture rates for user-selected scenarios that allow user to:

ADD new materials to an existing program or make assumptions about "enhanced" capture, or define new program efforts in terms of materials & capture.

User Entry Areas (yellow):

4.1: Detailed year to display (Cell K20)

4.1: GHG valuation per MTCO2e (select any value; 2 defaults provided) (Cell K21)

4.1: Select specific materials to be rolled up into subtotal categories (Cells A55).

4.2a: User reviews default Capture Rates by Code, and reviews Capture rate code assignments for each submaterial (described cell CG16).

4.2b: User defines 1) name of program/scenario (BZ30 going across); and defines material and percent of material diverted from the existing or new program effort (reflects in Table 4.4) Described cell BX25.

4.3: User identifies the sector associate with the program scenarios defined in 4.2.

4.4: User selects maximum of any 10 years from period 2020-2045 to display in Table 4.4.

Outputs for Potential Display:

Table 4.1: Cell K26. Detailed tonnage report for 1 user-selected year, all materials, including performance of baseline / existing programs.

Table 4.3: Cell CK2. Main Output Table - Tonnages by sector streams, 10 user-selected years.

Table 4.4: Cell BX1. Main Output Table - Program Scenarios / Performance for User-defined programs.

Table 4.5: Cell AU221. Main Output Table - Tons Diverted and Disposed using Chittenden Subtotal Categories, with GHG performance metrics

Sheet 4b: Summary and Tons Available Calculations - with Evolving Ton Adjustments

Sheet 4b: Provides the same computations as Sheet 4, but using tons adjusted by the "Evolving Ton" trends.