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Increasing the recycling rate in Clark County, Nevada

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INCREASING THE RECYCLING RATE IN CLARK COUNTY, NEVADA

by

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Bachelor of Science
University of Texas at El Paso
2005

A thesis submitted in partial fulfillment
of the requirements for the

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ABSTRACT

Increasing the Recycling Rate in Clark County, Nevada

by

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Professor of Environmental Studies
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The purpose of this study was to identify and evaluate policies that could increase the amount of municipal solid waste recycled in Clark County, Nevada. Clark County has not met the Nevada State goal of a 25% recycling rate since it was established by the Nevada Legislature in 1991. Using the system dynamics problem solving approach, a model for Clark County was adapted from a model developed by Stave (2008) to test policy options. There was no feedback in the model due to the long lifespan of the landfill servicing Clark County and the relatively shorter time horizon of the model. Since there is limited manufacturing of products in Clark County, there is a low demand for recyclable material, which is a driving factor behind the low recycling rate. The scenarios that increased the recycling rate beyond 25% were: (1) increasing residential and multi-family recycling to 34%, which represents the recyclable portion of material in those waste streams and (2) increasing residential and multi-family recycling to 25% and increasing commercial diversion to 30% from small businesses and material collected by roll-off services.

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CHAPTER I

INTRODUCTION

Problem Statement

The purpose of this study was to identify and evaluate policies that could increase the amount of municipal solid waste recycled in Clark County, Nevada.

The Resource Conservation and Recovery Act (RCRA) defines solid waste as:

“garbage, refuse, sludge ... and other discarded material, including solid, liquid, [and] semisolid ... material resulting from industrial, commercial, mining, and agricultural operations, and from community activities... (42 USC 6903 (27))”

Municipal solid waste is the waste resulting from residential and commercial activities. The Environmental Protection Agency (EPA) defines municipal solid waste as the “common garbage or trash generated by industries, businesses, institutions, and homes” (1997). For the purpose of this study, municipal solid waste was defined as material generated in Clark County from residential, commercial, and construction activity that was discarded for disposal or diverted for recycling. The clarification between material and waste was to show that the material generated from residential, commercial, and construction activities includes a significant portion of that material is recyclable. Waste is the

portion of the material generated that is no longer useful, meaning it is not reusable, recyclable, or compostable. Figure 1 shows how discarded residential and commercial material consists of recyclable, compostable, and waste material.

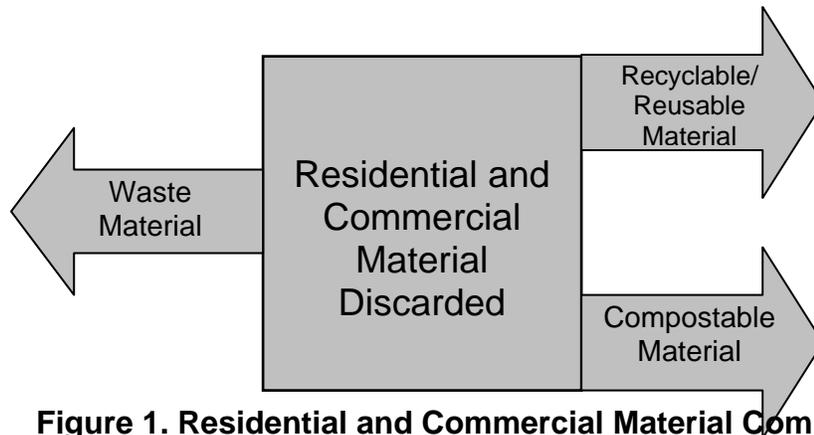


Figure 1. Residential and Commercial Material Components

Nevada’s recycling goal is to recycle 25% of the residential and commercial material generated in the State; however, this rate is currently only at 19% (NDEP, 2007). The Nevada Division of Environmental Protection (NDEP) uses the following equation to determine the recycling rate (2007):

$$\text{Recycling Rate} = \frac{\text{Material Recycled}}{(\text{Material Disposed} + \text{Material Recycled})} \times 100\%$$

Recycling rates refer to the amount of material diverted for recycling from residential and commercial sources. However, there is a difference between the diversion of material and the recycling of material. A common misconception is that all the material diverted through residential and commercial recycling

programs is automatically considered to be recycled. However, recycling does not actually take place until the material that was diverted has been processed to remove non-recyclable and contaminated material that cannot be reprocessed to make new products. Figure 2 shows that the Clark County diversion rate, which the county calls the recycling rate, has consistently been below the State's goal.

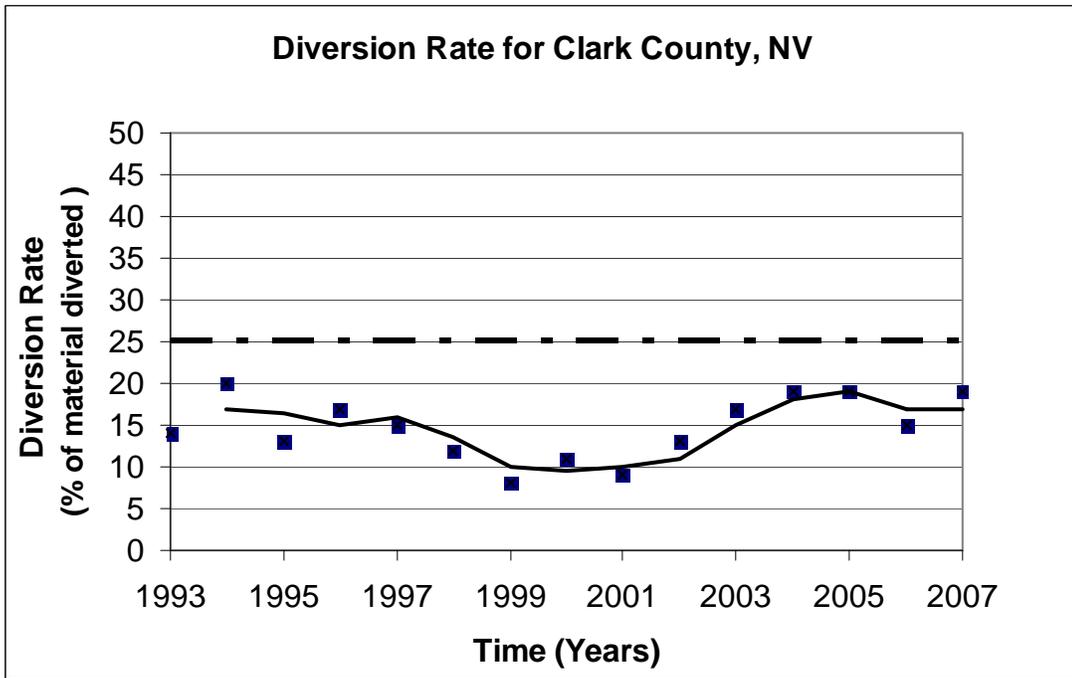


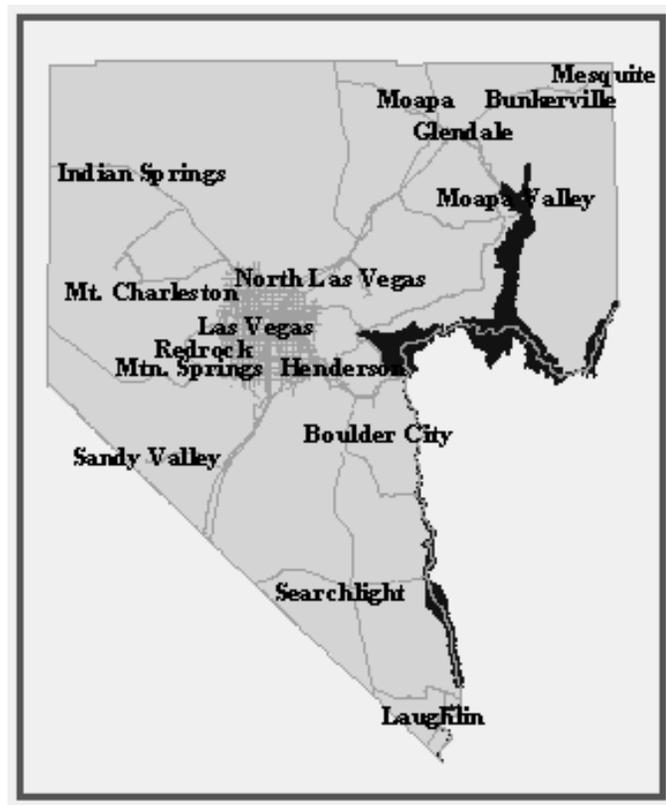
Figure 2. Diversion Rate for Clark County, Nevada from 1991 to 2007. The dashed line represents the State goal of a 25% recycling rate. Source: Southern Nevada Health District, 2008

Although the Clark County recycling rate appears to have increased since 2001, it has increased at a very slow rate and may even have leveled off in recent years. Clark County has not met the State goal of a 25% recycling rate since it was established by the Nevada Legislature in 1991. This is a problem because the population of Clark County makes up the majority of Nevada's total

population, thus contributing the most to the state's production of solid waste material. This also means that Clark County has the greatest potential to improve recycling on a statewide level (NDEP, 2007). The question, therefore, is how to increase the recycling rate in Clark County.

Recycling in Clark County

Clark County covers approximately 7,910 square miles of southern Nevada (U.S. Census Bureau, 2000) and as of 2007 had an estimated population of 1,996,542 people (Clark County Department of Comprehensive Planning, 2007). As shown in Figure 3, Clark County consists of the following



**Figure 3. Map of Clark County, Nevada
Used with permission from the Clark County Department of Technology**

areas: the cities of Mesquite, North Las Vegas, Las Vegas, Henderson, and Boulder City and unincorporated Clark County which is made up of rural areas such as Searchlight and Laughlin (Clark County Department of Comprehensive Planning, 2007). Chapter 444A of the Nevada Revised Statutes states the requirements of recycling programs are based on the size of a county's population. Counties that have a population greater than 100,000, such as Clark County, are required to offer curbside recycling to single-family residences (NDEP, 2007). Bi-weekly collection of recyclables is provided for participating single-family homes in Clark County (NDEP, 2007). The amount of material diverted through residential recycling depends not only the number of households who have enrolled in recycling services, but also on the frequency of their participation on collection days and the amount of material they divert. There is no requirement to provide curbside recycling to multi-dwelling units such as apartments or condominiums. First established in 1991, the Nevada Revised Statutes 444A.101 through 444A.110 charge each Nevadan municipality with recycling a minimum 25% of its solid material. Clark County recycled 19% of its solid material in 2007 (SNHD, 2008). Two percent of all material collected from residential and commercial sources was collected through the curbside residential recycling program for the years 2005 through 2007 (R. Coyle, personal communication, March 13, 2008). I interviewed Tara Pike-Nordstrom for this research because of her involvement in recycling efforts in Clark County. Pike-Nordstrom established the recycling program at the University of Nevada, Las Vegas in 1995. The recycling program has evolved to be able to handle

larger amounts of waste since its inception. Pike-Nordstrom (personal communication, March 6, 2008) stated that part of the reason for the variability in Clark County recycling rate is that it is difficult to determine how much material is being recycled by businesses. Businesses are not required to report the amounts of material they process for recycling to the Southern Nevada Health District. The number of businesses that report to the Southern Nevada Health District can vary each year, meaning the amount of material diverted and processed for recycling in Clark County is not accurately represented. Figure 4 shows that while the amount of material diverted in Clark County has slightly increased over time, the majority of material is sent to the landfill for disposal.

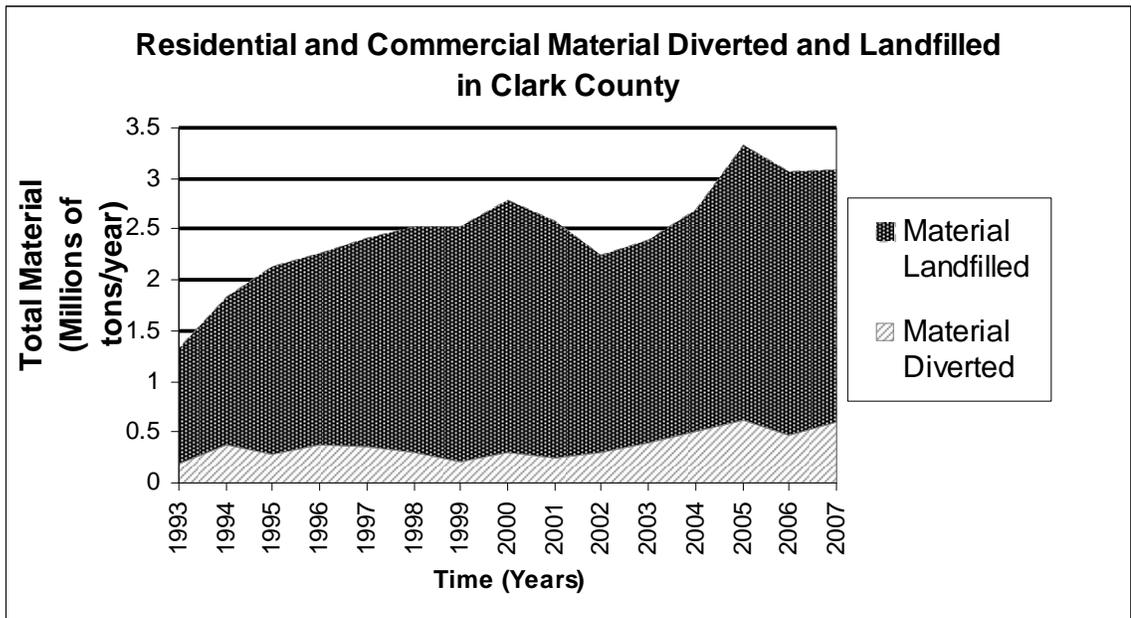


Figure 4. Material Diverted and Landfilled in Clark County
Source: Southern Nevada Health District, 2008

Republic Services hold an exclusive franchise waste collection agreement contract with Clark County which extends through 2035 (Tellus, 2002). This agreement between Clark County and Republic states that all waste is to be handled by Republic except for hazardous waste, non-curbside recyclables, self-hauled waste, construction and demolition waste, septic tank and grease trap waste, and yard waste. While the agreement gives Republic rights over all collection of waste, including recyclables from residential customers, generators of commercial waste are allowed to contract other service providers to handle their recyclables (Tellus, 2002). These types of contracts for public services limit the original authority held by municipal governments to promote solid waste management policies such as recycling programs by levying taxes or assessments, for example (NDEP, 2004).

Waste Disposal in Clark County

Before the 1990s, there were several landfills located in Nevada. However, once the EPA established more stringent landfill regulations in the early 1990s, a number of landfills that could not comply were forced to close, resulting in the regionalization of solid waste collection and disposal across Nevada (NDEP, 2007). After this regionalization, a permit for the Apex landfill located slightly north of Las Vegas was issued in 1994 with an estimated closure date of 2150 (NDEP, 2007). This landfill serves the Las Vegas Valley and is one of two landfills in Nevada, receiving approximately 90% of the State's solid waste (NDEP, 2007). It is also one of the largest landfills in the nation with an estimated 865 million cubic yard capacity (NDEP, 2007). Republic owns Apex landfill. The

franchise agreement between Clark County and Republic means a single waste service provider has extensive control over all residential and commercial waste and the landfill that receives this material. Typically, the service providers who collect municipal waste are different from those who manage the landfills. This competition between service providers and landfill owners motivates them to manage their resources as efficiently as possible while making maximum profits. Waste collectors bill residents and businesses for their services while landfill owners charge waste collectors tipping fees for each load of waste delivered. Competition between service providers and landfill owners is not applicable here since Republic owns Apex landfill and is Clark County's contracted waste collection provider.

Waste Generation in Clark County

Clark County has experienced a rapid increase in population growth, averaging 5.6% per year from 1990 to 2006, yielding a population in 2007 of approximately 1.9 million residents (CCDCP, 2007). The amount of municipal solid waste sent to landfills has increased steadily since 1993, increasing significantly beyond the State's population growth rate (NDEP, 2004 & 2007). Per capita waste generation was determined by taking the total amount of residential and commercial material generated and dividing it by the number of residents in the area. As of 2005, the average amount of waste generated per person in Clark County was estimated at 10 lbs per day (NDEP, 2007) up from 7 lbs per day in 2002 (NDEP, 2004). Besides the growing Clark County population, the number of tourists visiting the Las Vegas area increased from approximately 35 million

visitors in 2002 to 38.5 million visitors in 2005 (CBER, 2006). Each tourist is an additional waste generator while in the area (Lord, 2005). Per capita generation tends to be higher in cities with a high-tourism economy (NDEP, 2007). The additional waste resulting from tourism activities could partially explain why the Clark County per capita waste generation is noticeable higher than the national 2006 value of 4.6 lbs/person/day (EPA, 2007). Shapek (1993) attributed a similar increase in Florida in the late 1990's to tourism. The average per capita rate waste generation rates for the state of Florida increased from 7 lbs/person/day in 1988 to 8.3 lbs/person/day in 1991 (Florida Department of Environmental Regulation, 1991).

Significance of Study

This study is important because Clark County needs to find ways to meet the State recycling goal. This study will examine possible ways to increase the recycling rate in Clark County. The benefits of recycling include the conservation of natural resources through reducing the need for virgin materials and reducing the amount of waste that is landfilled. Considering the large population of Clark County and the resulting waste generation, methods that can promote these benefits are useful to achieving more sustainable practices. Although Apex landfill, which services the Clark County area, is predicted to have a long lifespan, there is ultimately limited capacity for land disposal on Earth due to the finite amount of space available. Increasing the amount of waste recycled in Clark County will increase the lifespan of the Apex landfill and reduce the need

for additional landfill space in Nevada. Increasing recycling programs can also provide jobs to the local economy

Benefits of Recycling

Recycling offers multiple economic and environmental benefits such as (Ackerman, 1997; Gandy, 1994):

- reduced need for disposal capacity
- reduced emissions from landfills and incinerators
- reduced litter pollution
- conservation of finite resources
- reduction in energy consumption
- more control over pollution from industrial activities
- environmental education of the public.

Recycling uses less energy and saves more natural resources than other types of waste disposal (Batool *et al.*, 2007.)

Potential for Diversion

Waste management options include source reduction, recycling, incineration, and landfilling (Strong, 1997). Although a large portion of material generated in the United States could potentially be recycled, more than half of the material generated in 2006 was discarded and sent to landfills for final disposal (EPA, 2007). Figure 5 shows the portions of material generated in the

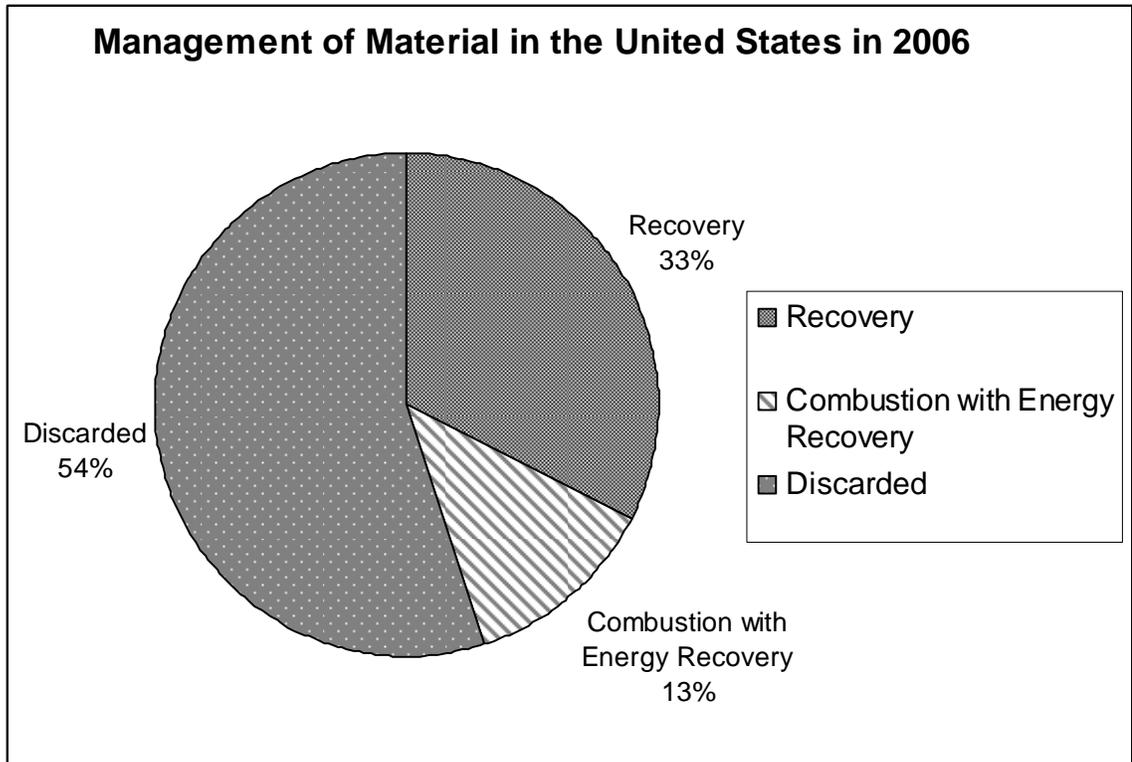


Figure 5. Management of Material in the United States in 2006
Source: EPA, 2007

United States in 2006 that were recovered by recycling, combusted with energy recovery through incineration, or through landfill disposal. The recyclable portion of residential and commercial material generated is dependent on the types of material being discarded. The amount of recyclable material in discarded residential and commercial material represents the potential for diversion. The exact percentages of recyclable material in Clark County are not known since there have not been any waste characterization studies for the area. However, there is data available on national levels and from cities with similar population sizes and climate as Clark County. Shown in Figure 6 are the national percentages of types of waste generated in 2006: 33.9% paper; 25.3% organic

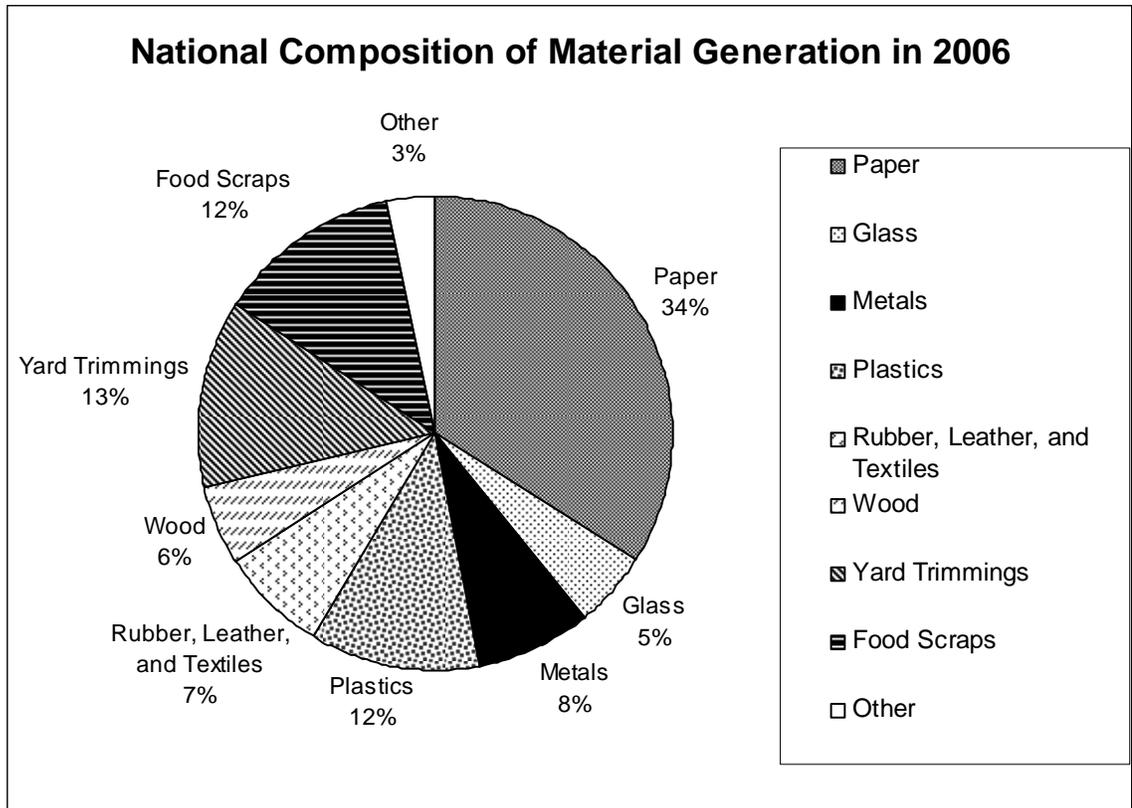


Figure 6. National Composition of Material Generation in 2006
Source: EPA, 2007

material; 11.7% plastics; 7.6% metals, and 5.3% glass (EPA 2007). These percentages are for the types of waste generated before diversion for recycling occurs. Approximately 59% of the material generated was recyclable.

Issues with Landfills

As the amount of material in Apex landfill increases, environmental dangers to Clark County also increase. There are two major threats from landfill disposal: landfill gas and leachate (Tammemagi, 1999; Westlake, 1995). In a study on the mechanisms of gas and leachate formation at solid waste landfills, El-Fadel, *et. al* (1997) identified microbial decomposition, climatic conditions, and waste characteristics as factors that affect landfill gas and leachate formation and

associated their formation with adverse environmental effects such as potential health hazards, fires, explosions, groundwater pollution, air pollution, and global warming (El-Fadel, *et. al*, 1997).

Precipitation greatly determines the possibility of leachate formation in landfills. Landfill leachate is a threat to groundwater quality due to the contaminants that it carries. Blight and Fourie (1999) studied landfill leachate generation in several landfills near Johannesburg, South Africa located in semi-arid and arid climates. From their analysis of soil and leachate characteristics, they concluded that landfills located in these in semi-arid and arid climates produce little to no leachate as a result of the limited amount of precipitation these areas receive (Blight & Fourie, 1999). This would suggest that landfills in arid climates, such as Clark County, would pose less danger to the environment from landfill leachate. However, landfills in arid areas are still capable of producing leachate if there is sufficient moisture in landfill waste. This moisture can come from liquid material discarded from household or commercial activities. For example, Al-Yaqout and Hamoda (2003) conducted a case study on two solid waste landfills located in Kuwait. Due to the co-disposal of solid and liquid wastes, the leachate that was produced at these landfills was heavily contaminated with organics, salts, and heavy metals (Al-Yaqout & Hamoda, 2003).

Gaseous emissions from landfills have a complex composition with the main components in the form of methane and carbon dioxide (Westlake, 1995; Brandl, 2003; Christensen, *et. al*, 1996). Methane and carbon dioxide are listed

as two of the four main greenhouse gasses that contribute to increasing global temperatures since the mid-twentieth century (IPCC, 2007). The amount of landfill gas produced at Apex landfill increases as the amount of material sent to the landfill increases. Landfill gas is dangerous due to its flammability and resulting fires and explosions (Christensen, *et. al*, 1996; El-Fadel, *et. al*, 1997) Pressure gradients within landfills result in the migration of landfill gas, causing it to rise to the surface or spread out laterally from the disposal area (Campbell, 1996; El-Fadel, *et. al*, 1997). While the collection and flaring of gas produced at Apex landfill is done to avoid possible explosions (NDEP, 2007), this does not stop the release of greenhouse gasses into the atmosphere.

Motivation to Recycle

Ruiz (2001) suggests that there are three basic reasons that individuals recycle: altruistic motivation, economic imperatives, and legal considerations. Altruistic motivation refers to the selfless actions of an individual that benefit the welfare of others. Such motivation can be based on the personal satisfaction gained from recycling and a better sense of well-being without the need for financial incentives (Gandy, 1994). Historically, recycling was driven mostly by economic factors and self-benefit while modern recycling offers no to little personal economic benefits (Ackerman, 1997; Strong, 1997). Economic motivation refers to decreased waste disposal costs and disincentives such as monetary penalties for failure to follow proper waste disposal methods. For the commercial sector, the cost of recycling and the benefits provided by recycling are the key factors in recycling participation by businesses (Bacot *et al.*, 2002).

Legal considerations refer to the requirements established by local governments to meet a certain level of recycling.

Overview of Study

This study intended to answer the following question: what are the most effective ways to increase the Clark County recycling rate? I hypothesized the most effective way to increase the recycling rate would be to (1) increase tourist-related material diversion, (2) increase multi-family material diversion, or (3) build a material recovery facility to process discarded material. The system dynamics problem solving approach was used to develop a model that was used as a tool for policy evaluation of the proposed policies of my hypotheses. Policies were evaluated by the effect each had on the recycling rate, the amount of material accumulating in Apex landfill, the amount of recyclable material diverted, and the amount of material collected for disposal.

CHAPTER II

HYPOTHESES AND APPROACH

Hypotheses

Commercial and Residential Recycling

Several cities across the United States have implemented successful recycling programs. Waste News, a waste management magazine, conducted a municipal recycling survey in 2006 for the thirty largest U.S. cities. The cities that had the highest recycling rates based on residential and commercial diversion were Los Angeles, California, Chicago, Illinois, and Portland, Oregon. Table 1 shows the recycling rates and shared characteristics of the recycling programs in these cities. These programs include the provision of curbside recycling for single-family units, recycling services at multi-dwelling units, commercial recycling programs, and mandated recycling requirements. Cities with low recycling rates also share certain characteristics. The municipal recycling survey identified Houston, Texas, Oklahoma City, Oklahoma, and San Antonio, Texas as the cities with the lowest recycling rates in the nation in 2005 (Waste News, 2008). Table 2 shows the recycling rates and similarities for these recycling programs. These recycling programs do not have recycling services at multi-unit dwellings, commercial recycling programs, or mandated recycling goal

Table 1. Characteristics of Recycling Programs Generating Recycling Rates Over 50% Source: Waste News, 2008			
	Los Angeles	Chicago	Portland
2005 Recycling Rates	62%	55%	62%
Materials Collected	Paper, cardboard, aluminum, glass, plastic, yard trimmings, food scraps	Paper, cardboard, aluminum, plastic, glass, yard trimmings	Paper, cardboard, aluminum, plastic, glass, food scraps
Residential Collection Point	Curbside & drop-off	Curbside & drop-off	Curbside & drop-off
Curbside collection frequency	Weekly	Weekly	Weekly
Services at multi-dwelling units	Yes	Yes	Yes, up to 5 units
Commercial recycling program offered	Yes	Yes	Yes
Mandated recycling goals	Yes	Yes	Yes

Table 2. Characteristics of Recycling Programs Generating Recycling Rates Less than 5% Source: Waste News, 2008			
	Houston	Oklahoma City	San Antonio
2005 Recycling Rates	3%	3%	4%
Materials Collected	Paper, cardboard, aluminum, plastic, glass, yard trimmings	Paper, aluminum, plastic, glass	Paper, cardboard, aluminum, plastic, glass
Residential Collection Point	Curbside & drop-off	Curbside	Curbside & drop-off
Curbside collection frequency	Weekly	Weekly	Weekly
Services at multi-dwelling units	No	No	No
Commercial recycling program offered	(No information available)	No	No
Mandated recycling goals	None	None	None

In Clark County, recycling is provided for residents living in single-family units and businesses can contract Republic or other recycling service providers to handle their recyclable material. Table 3 summarizes the characteristics of the Clark County recycling program. Similar to other cities with low recycling rates programs, Clark County does not offer recycling services at multi-family units or have mandated recycling goals.

Table 3. Characteristics of Clark County Recycling Program Source: NDEP, 2007						
2005 Recycling Rate	Materials Collected	Residential Collection Point	Curbside collection frequency	Services at multi-dwelling units	Commercial recycling program offered	Mandated recycling goals
19%	Paper, cardboard, aluminum, plastic, glass, food scraps*	Curbside & drop-off	Bi-weekly	No	Yes	None
*Businesses can contract service providers to collect organic material						

Proposed Policy Options

Based on the differences in characteristics of recycling programs that generated low and high recycling rates, I proposed that the most effective ways to increase the Clark County recycling rate would be to (1) increase tourist-related material diversion, (2) increase multi-family material diversion, or (3) build a material recovery facility to process discarded material. Clark County has a large tourist economy, which indicates a high potential for diversion. Recycling services are not currently provided at multi-dwelling locations; thus, the only way these residents can recycling is by transporting their recyclables to Republic's

drop-off recycling center or privately owned recycling businesses that only accept certain materials. Although Clark County has a curbside recycling program for residential homes, this program was responsible for approximately 2% of the 19% recycling rate in 2007 (R. Coyle, personal communication, March 13, 2008). I hypothesized that the creation of a material recovery facility would increase the amount of material diverted for recycling by removing the responsibility to separate material from the resident.

Approach

I followed three main steps to examine the question of how best to increase recycling in Clark County: (1) reviewed scientific journals, government documents, and public media to identify the factors that affect the amount of solid waste that is diverted for recycling; (2) organized the conceptual relationships between those factors using the system dynamics problem solving approach; (3) used the recycling model to evaluate possible policy options to increase the recycling rate in Clark County. I used the system dynamics problem solving approach to examine options for improving the Clark County recycling rate. The goal of this approach is to identify and evaluate potential solutions. The fundamental principle of system dynamics is that the structure of a system generates its behavior (Sterman, 2000). Therefore, to change problematic behavior, it is necessary to examine the system's structure. The steps of the system dynamics problem solving process are as follows (Stave, 2003; Sterman, 2000):

1. Articulate the problem: The problem being studied must be represented as a problematic behavior over time. The purpose of the model must also be clearly articulated. This helps in identifying the key variables and time horizon that define the problematic behavior. Figure 1 provides a graphical description of the problematic behavior over time. It shows the Clark County recycling rate is below the Nevada state goal and is rising slowly or possibly leveling off. This gap between the actual diversion rate and the desired rate defines the problem I am studying. The Clark County recycling rate is a function of the amount of material produced in Clark County and the amount that is diverted for recycling. For this study, I addressed the question of how best to increase recycling in Clark County. The purpose of my model was to identify and evaluate policies that would increase the amount of municipal solid waste recycled in Clark County.

2. Develop a hypothesis about what is causing the problem: This requires researching the literature, gathering other available information, and interviewing the appropriate professionals in order to identify the critical relationships and interdependencies between the factors that determine the Clark County recycling rate. With this understanding, an initial description of the system structure, also known as the dynamic hypothesis, can be created.

3. Create the simulation model: Based on the dynamic hypothesis, a simulation model is created. This is done by converting the dynamic hypothesis into a set of stocks and flows connected by mathematical relationships. These flows can be informational or physical in nature. The simulation model represents the material flows and other important factors that affect the recycling rate in Clark County.

4. Build confidence in the model: The model must be tested for validity before it can be used to identify and test policy options. This is done by comparing the results of the model with the behavior seen in the real world as represented by the reference mode presented in Figure 1. If the model is not able to reproduce the real world behavior, then it cannot be considered valid. In other words, if the model cannot produce the behavior seen in the real world, then the model does not fully represent the structure of the system generating the observed behavior. The model must also be able to produce realistic results when tested under extreme conditions. After the model passes a number of tests, its validity as an accurate representation of the real world system can be supported.

5. Use the model to design and evaluate policy options to address the problem: This step requires identifying possible points in the system that can be manipulated to change the problematic behavior. The effects of various policy options can be simulated and tested by using the model. The possible policy options identified through my literature review as well as other possible policies will be tested to see how they will affect the Clark County recycling rate. The five steps to this approach are iterative and require going back to each step as often as needed (Sterman, 2000).

In order to represent the structure of the system causing the problematic behavior, called the dynamic hypothesis, I had to identify the important variables within the system. Figure 7 shows the major sectors in the waste management system and key variables within each sector. Each major sector identified affects other sectors of waste management. As this figure illustrates, the generation of

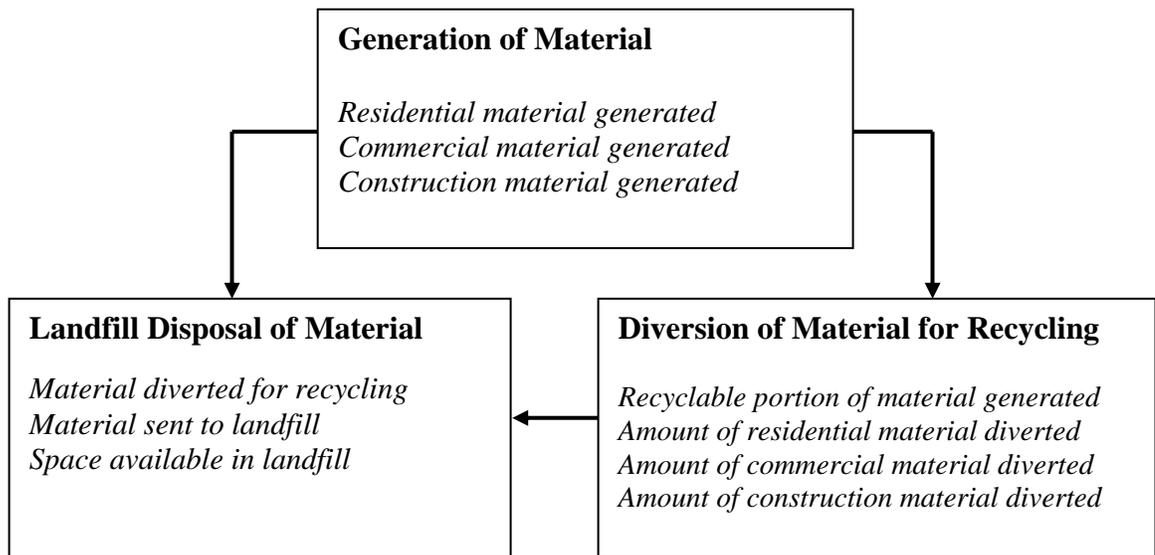


Figure 7. Major Sectors of Material Management and Recycling
Each major sector is in bold and each section’s key variables are in italics.

residential, commercial, and construction material affects the diversion of material for recycling and landfill disposal. The diversion of material for recycling is determined by the recyclable portion of material generated and the amount of residential, commercial, and construction material that is diverted for recycling. The diversion of material for recycling affects landfill disposal in two ways. First, as more material is diverted for recycling, less material is being sent directly to landfills. Second, although material is diverted, some of that material will ultimately be disposed of instead of recycled for a variety of reasons such as contamination or ineffective recycling program methods. Landfill disposal is dependent on the amount of space available in the landfill. This usually is a limiting factor for landfill disposal as disposal fees usually increase significantly when landfill space becomes limited. However, the Apex landfill in Nevada has a high capacity and the potential for expansion. Hence, landfill disposal remains

less expensive and more attractive. Figure 8 below is a simplified representation of my hypothesis about the structure of the system based on a review of the literature on factors that influence recycling. The key variables listed in Figure 7 are presented in Figure 8 in a manner that demonstrates the relationships between each variable. A “+” sign means that when a change occurs in the variable at the end of the arrow, the variable at the head of the arrow will change in the same direction. A “-” sign means that the variable at the head of the arrow will change in the opposite direction. My key variable of interest is the Clark County recycling rate.

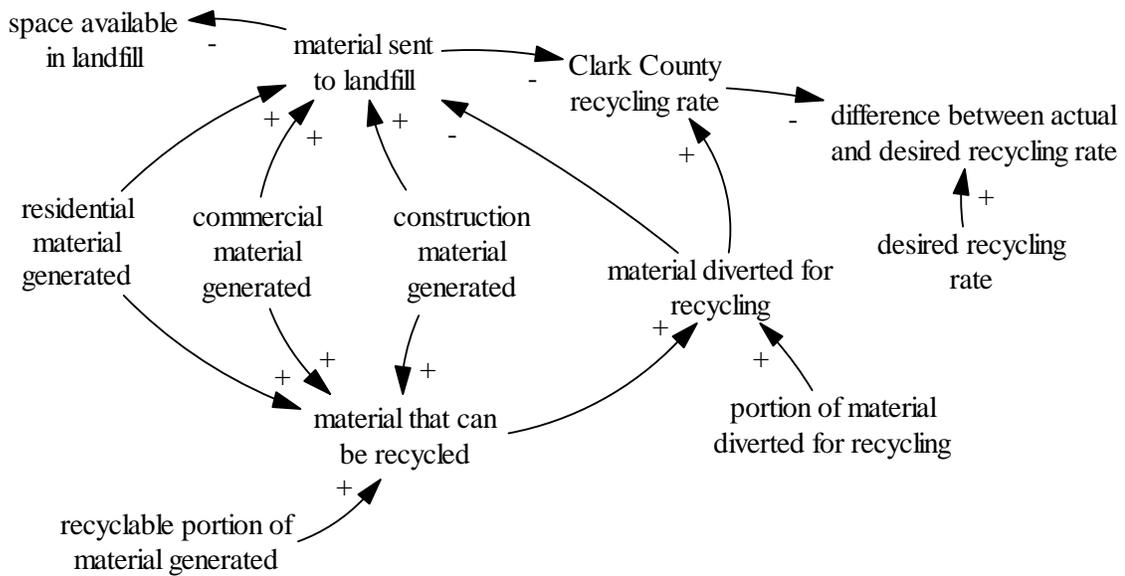


Figure 8. Causal Map of the Factors that Influence the Clark County Recycling Rate.

Figure 8 shows that the *difference between the actual and desired recycling rate* is dependent on the *desired recycling rate*, which is the State goal of 25% waste diversion for recycling, and the actual *Clark County recycling rate*. This represents the problem I am studying, where the Clark County recycling rate is below the desired goal. The *amount of material that can be recycled* depends on the *recyclable portion of material generated*, and the amount of residential, commercial, and construction material diverted for recycling. The actual amount of *material diverted for recycling* is dependent on the portion of that recyclable material diverted for recycling. Although we could potentially divert all of the material generated for recycling, we can only successfully divert the recyclable portion of the material.

CHAPTER III

METHODOLOGY

Methods

To identify and evaluate policy options that would increase the Clark County recycling rate I (1) developed and validated a model based on the system structure generating the problematic trend and (2) used the model as a tool to test the effects of different policies on the recycling rate.

Model Development

I created a simulation model by converting the dynamic hypothesis into a simulation or stock and flow model. This type of model distinguishes variables that are stocks and can accumulate over time from those that deal with material and informational flows. For example, my stock and flow model represents the amount of material that is produced in Clark County as a stock while the material that is diverted for recycling will be a material flow from that stock. To create the simulation model, I identified the mathematical relationships between the variables. In cases where there is no obvious way to measure a variable, I used qualitative methods to assign values to those variables according to the methods suggested by Luna-Reyes and Andersen (2003). They state the importance of qualitative data in the modeling process and suggest conducting interviews as

one useful method for collecting qualitative data. I then built confidence in the model. Creating an accurate representation of the problem required making changes as needed to my hypothesis about the structure of the system. This part of the process required reanalyzing the hypothesized relationships between variables in the model and making changes to the structure. I then used the model to design and evaluate policy options to address the problem.

Model Boundaries

There are three waste service providers in this area: Republic Service which services most of Clark County, Boulder City Disposal which services Boulder City, and Virgin Valley Disposal which services Mesquite. Since the waste material generated in Boulder City and Mesquite is collected by separate service providers and taken to their own respective landfills, these areas were excluded from the study. Organic material that could be used for composting was not studied since Republic Services does not collect organic material through its recycling programs. The Clark County recycling model was adapted from the Zero Waste model created by Stave (2008). Zero Waste is a designing principle that proposes using as little natural resources and energy to make consumer products that will ultimately be reused, recycled, repaired, or composted; thus, eliminating waste rather than managing it (Platt & Seldman, 2000).

The intangible factors that affect the amount of material diverted by residents, such as convenience of recycling and motivation to recycle, are beyond the scope of this study. While these factors are important, it is more

efficient to identify which sources would have the largest impact on the recycling rate and then determine how to best increase diversion from those sources. The model was built to evaluate how changes in the amount of material diverted from specific sources would affect the Clark County recycling rate; it does not calculate how difficult it would be to implement those changes. Determining the effort required to implement different policy options could be the next step in this research.

Model Variables

The purpose of the model was to identify and evaluate policies that will increase the amount of material recycled in Clark County. The boundaries of the model are summarized in Table 4. The endogenous variables are those that are determined by the relationships within the model. The exogenous variables are those that are represented as constants and are not determined by the model. The variables that are excluded are beyond the scope of this model. Appendix I is a complete list of the types of variables used in the model.

Table 4. Model Boundary Chart		
Endogenous	Exogenous	Excluded
Material disposed	Clark County Population	Factors affecting population growth
Material generated	Material diversion rates	Motivational factors for recycling
Material diverted	Material generation rates	Economic factors affecting material generation rates

The model runs over a time scale from 1993, when Apex landfill opened, to 2100. I chose a time scale of approximately 100 years because the management of material could change greatly after that period. I set the time step, or the interval at which the model is simulated, to .125 years. Although a

smaller time step could have been used, the increased calculations did not significantly change the behavior produced by the model.

Availability of Information

There was limited information available on the composition of material generated in total and by different sources in the Clark County area. Assumptions had to be made on the percentages of recyclable and non-recyclable material. A waste characterization study would help fill this information gap. It was difficult to get information from private recycling businesses regarding the amount and types of material they process. This information would also be useful to improving the model.

During the development of the model, variable values were determined by examining available data. When data was not available, reasonable connections were created. For example, material generation rates are treated as exogenous variables in the model. In reality, material generation rates are affected by economic factors. In a study conducted by Daskalopoulos and Probert (1998), they created a model to predict the generation rate and composition of waste in European Union countries and the United States. Their model calculated the generation of waste as a function of a country's gross domestic product (GDP) and population size. Waste generation is often related to population size and the mean living standards for an area (Wertz, 1976; Grossmann *et al*, 1974). Hockett (1995) conducted a study in the southeastern United States by analyzing data from 100 North Carolina counties to identify the significant determinants of waste production which included economic, structural, and demographic variables. The

significant determinants of waste generation were determined to be per capita retail sales and landfill tipping fees (Hockett, 1995). In Clark County, Republic Services is both the service provider and landfill owner; thus, tipping fees are not considered to be a determinant of waste generation for this model. Per capita retail sales in Clark County were compared against waste generation rates per capita to determine whether there was a correlation between them. The results are shown in Figure 9. The graph shows that there was not a significant correlation between retail revenue and waste generation per capita in Clark County. This suggests that while these factors are connected, there are other factors affecting waste generation rates in Clark County. Due to the complexity of

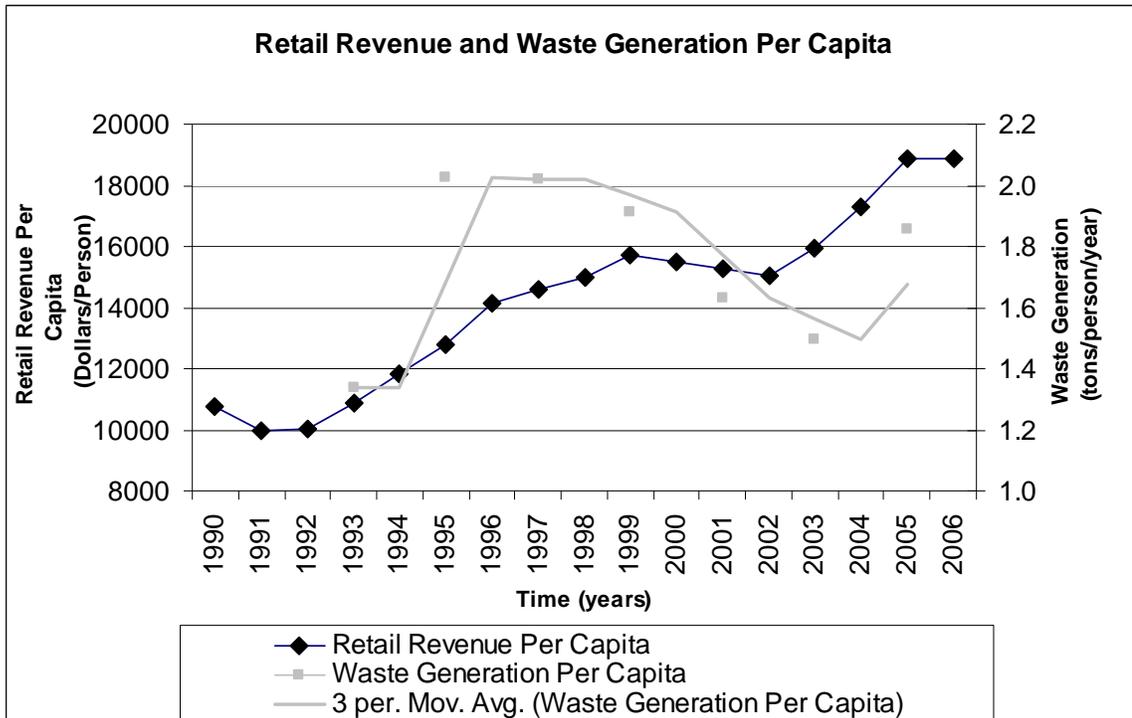


Figure 9. Retail Revenue and Waste Generation Per Capita in Clark County from 1990-2006. Sources: DETR, 2008; SNHD, 2007.

the factors that determine waste generation rates, these variables are as constants in this model.

Structural Description

Figure 10 is a high level sector diagram of the model. The double lines represent the flow of material through the system. The boxes represent stocks where material can accumulate over time. The process begins with material generation on the left side of Figure 10. Material is generated by residential, commercial, and construction activity. The material generated is either discarded and collected for disposal or diverted for recycling. The discarded material collected is sent to a material transfer station where it is then sent to the landfill

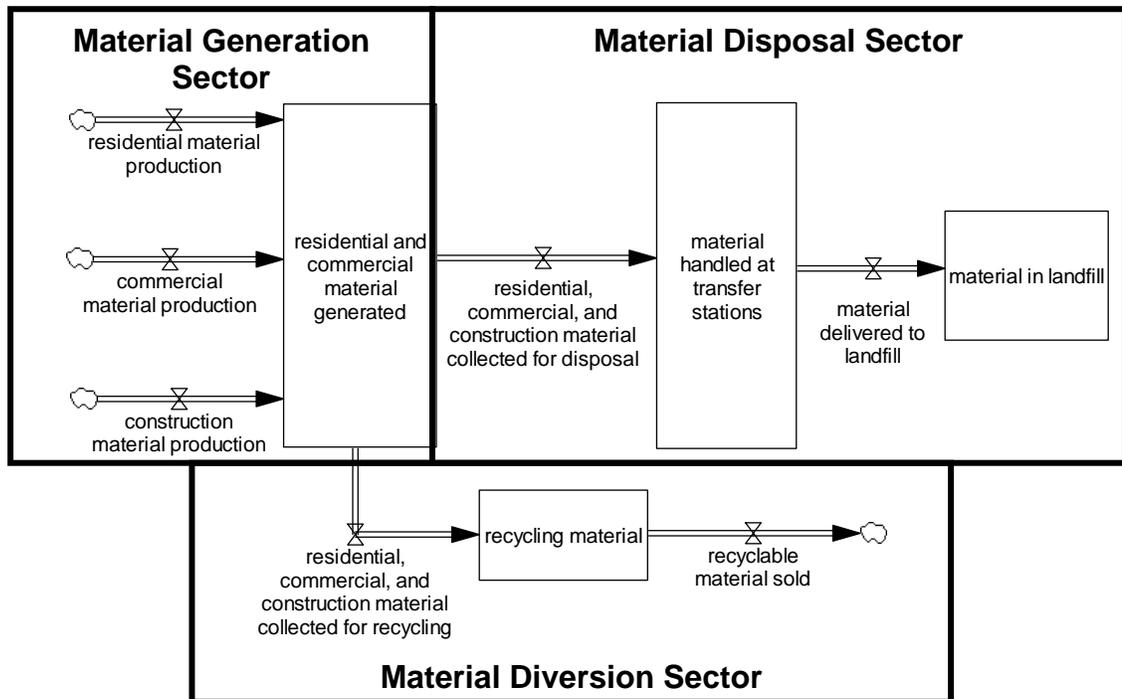


Figure 10. High Level Sector Diagram

for disposal. The recyclable portion of the material diverted for recycling is separated and sold. The non-recyclable portion of diverted material is sent to the landfill for disposal. The main subsystems within the model are the following: material generation; material disposal; and material diversion.

Material Generation Subsystem

Material is generated from residential, commercial, and construction activities. The rates of generation, that is, the amount generated from each source per box shown are referred to as “material production” in Figure 11. Residential, commercial, and construction material production flows determine the total amount of material generated as a result of those activities.

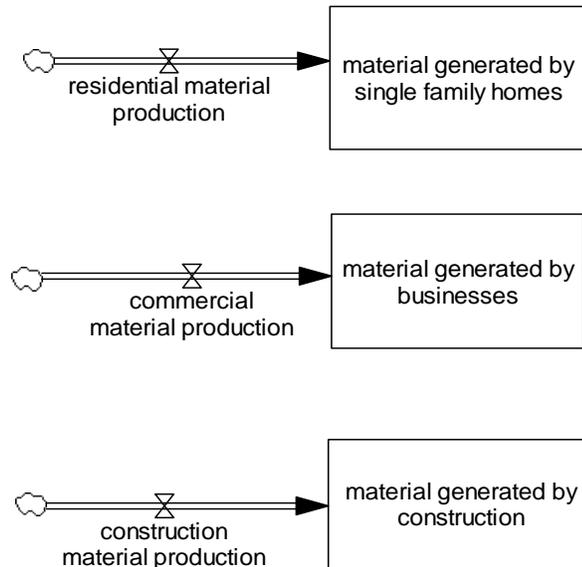


Figure 11. Material Generation Subsystem

Table 5 lists the key equations that were used to determine residential material production. Appendix III is a complete list of all the equations used in the model. Material production activities were divided into residential, commercial, and construction categories. The amount of material produced by each of these activities was estimated based on available data. Residential material production was a function of the size of the Clark County population, but it does not include the material produced by people living in multi-family units such as apartments or duplexes. Material generation from multi-family units was categorized as commercial material. The number of single-family households was determined by taking the percentage of the population estimated to live in single-family homes and dividing that population by the average number of people per household. Clark County estimates 65% of the population lives in single family homes (CCDCP, 2007). The average number of people per household in Clark County is approximately 2.65 people per household (U.S. Census Bureau, 2002). The estimated number of single-family households in Clark County was multiplied by the household material generation rate. Based on data from 2005 and 2007, this rate is about 1.8 tons/ household/ year (R. Coyle, personal communication, March 13, 2008).

Table 5. Residential Material Generation				
Variable Name	Units	Equation	Description	Sources
amount of residential material generated	tons/year	IF THEN ELSE(Time>=2010, "number of single-family households"*change in household material generation rate, "number of single-family households"*household material generation rate)	The number of single-family households is multiplied by the household material generation rate. The IF THEN ELSE statement is used so that any policies tested would take place after 2010.	
household material generation rate	tons/household/year	1.8	This is based on data provided by Republic Services for 2005 and 2007.	Interview with Bob Coyle, 2008
number of single-family households	household	(CC population*fraction of population living in single family homes)/"avg. number of people in a household"	In 2007, 65% of the Clark County population lived in single-family homes. This fraction of the population living in single family homes is used in the model. The number of households is determined by using 2.65 as the average number of people per household.	CCDCP, 2007; U.S. Census Bureau, 2002
Clark County population	people	CC population LOOKUP(Time)	Information from 2008 to 2036 is based on estimated population growth forecasts from CBER. Values after 2035 are based on a 1.1% growth rate.	CCDCP, 2007; CBER, 2007

Figure 12 shows the causal relationships between these key variables. In the model, an increase in the household material generation rate or in the number of single-family households would cause the amount of residential material generated to increase. If the Clark County population in the model increased, the

number of single-family households would increase, which would, in turn, increase amount of residential material generated calculated in the model.

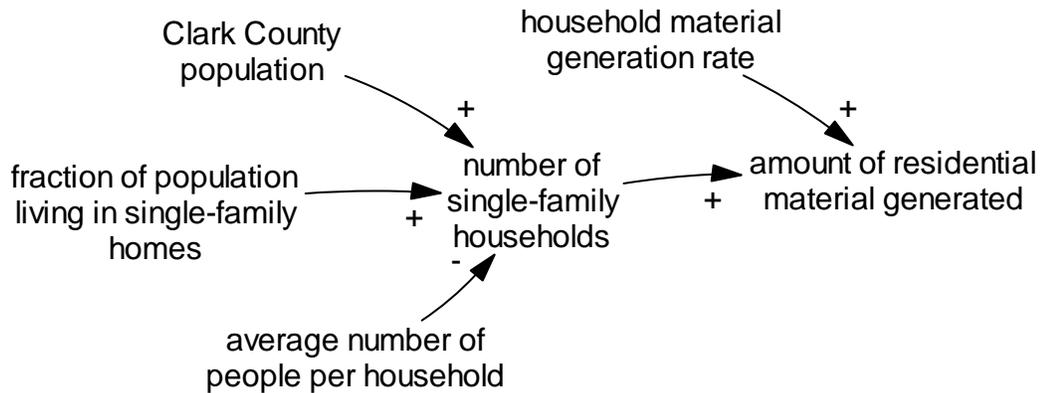


Figure 12: Causal Influence Diagram of the Factors that Influence Residential Material Generation

Table 6 lists the key variables used to determine commercial material production. In the model, commercial material production was equal to the total amount of material generated from commercial activity which includes multi-family, K-12 education, and tourist-related activities. Material generated from construction activities was considered as part of commercial material production when the construction material generated was collected in roll-off disposal bins by Republic Services. Roll-off material is the material that is collected through large bins contracted through Republic Services. These types of bins are used for small scale construction projects such as house renovations to large scale activities such as conferences held at hotels. Any construction material that is hauled by businesses to the Apex landfill was not included in recycling rate of material diverted for recycling and the amount of residential and commercial

Table 6. Commercial Material Generation				
Variable Name	Units	Equation	Description	Sources
Amount of multi-family material generated	tons/year	IF THEN ELSE(Time>=2010, "change in material generated per multi-family unit"*"number of multi-family units" , "material generated per multi-family unit"*"number of multi-family units")	It is assumed that 35% of the population lives in multi-family units. The number of units is determined by using 2.59 as the average number of people per unit. The IF THEN ELSE statement is used so that any policies tested would take place after 2010.	CCDCP, 2007; U.S. Census Bureau, 2006
amount of K-12 material generated	tons/year	IF THEN ELSE(Time>=2010, "number of students in K-12 Education"*change in material generated per student/lbs to tons conversion *days in school per year, "number of students in K-12 Education"*material generated per student/lbs to tons conversion*days in school per year)	The number of students in K-12 education is estimated to be 16% of the population based on available data. Little data is available on student material generation. Each student is estimated to generate 1.2 lbs of material per day and spend 180 days in school per year. The IF THEN ELSE statement is used so that any policies tested would take place after 2010.	CCSD, 2007; CCDCP, 2007
amount of tourist-related material generated	tons/year	IF THEN ELSE(Time>=2010, number of tourists visiting per year*change in waste generated per tourist*average length of tourist visit/lbs to tons conversion , number of tourists visiting per year*material generated per tourist*average length of tourist visit/lbs to tons conversion)	The number of tourists is based on historical data from CBER. A constant value of 3.92×10^7 is used after 2007, assuming that will be the minimum number of tourists visiting Clark County. It is estimated that each tourist produces 2 lbs of waste per day. Clark County data shows that tourists stay an average of 3.6 days. The IF THEN ELSE statement is used so that any policies tested would take place after 2010.	CBER, 2007; CC website; 2007
amount of all other commercial material generated	tons/year	IF THEN ELSE(Time>=2010, "multi-family, K-12, and tourism material generated"*change in portion commercial waste from other sources, "multi-family, K-12, and tourism material generated"*portion of commercial waste from other sources)	The material produced by small businesses is estimated to be about 33% of the total commercial material produced. The IF THEN ELSE statement is used so that any policies tested would take place after 2010.	

calculations. The Clark County recycling rate was calculated using the amount of material collected for disposal through Republic Services.

In the model, the amount of multi-family material generated was calculated by multiplying the total number of multi-family units by the material generated per unit. Figure 13 shows the causal relationships between these variables. An increase in either the material generated per unit or the number of multi-family

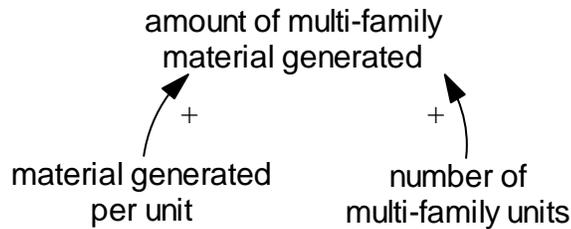


Figure 13. Causal Influence Diagram of Multi-Family Material Generated

units would cause the amount of multi-family material generated calculated by the model to increase. The number of multi-family units was determined by taking the percentage of the population estimated to live in multi-family buildings such as apartments and dividing that population by the average number of people per multi-family unit. An estimated 35% of the Clark County population lives in multi-family units (CCDCP, 2007). Approximately 2.56 people live in each multi-family unit in Clark County, on average (U.S. Census Bureau, 2006). Appendix IV is a complete list of the estimates made in the model. While there is data available on national waste generation rates per individual and for households in Clark County, there is limited data available on the amount of material generated per

multi-family unit. Material discarded by multi-family units is collected in the same fashion as other commercial waste. Commercial disposal trucks collect commercial waste from a variety of sources. Thus, there is no way to determine how much material was collected from each source. The same is true for K-12 education waste and other institutions such as hospitals and prisons. I estimated the material generated per unit rate to be 1.2 tons/ unit/ year, slightly less than the 1.8 tons/household/year rate for single-family homes. I estimated that multi-family units generated less waste because they do not generate landscaping waste on the same scale as residents living in single-family homes.

In the model, the amount of K-12 education material generated depends on the number of students in K-12 education in Clark County and the amount of material generated per student. The number of students enrolled in K-12 education was estimated to be 16% of the Clark County population. This was based on the number of students enrolled and population values from 2003 to 2007 (CCSD, 2007; CCDCP, 2007). Figure 14 shows the causal relationships between the variables that determine the amount of K-12 material generated. In the model, an increase in either the material generated per student or the

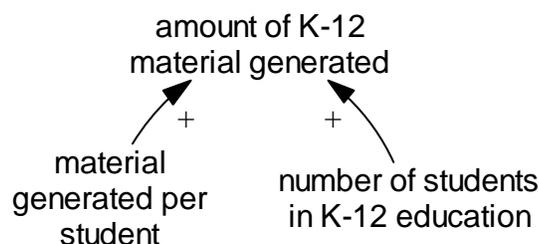


Figure 14. Causal Influence Diagram of K-12 Material Generated

number of students in K-12 education will cause the amount of K-12 material generated to increase. There is little information available on the amount of material generated at K-12 facilities. As a proxy, I estimated that each student generates 1.2 lbs/ material/ day. I based this estimate on the assumption that students dispose of most of their school-related material at their home, which would be attributed to household or multi-family material generation, instead of at schools. Students in Nevada are in school at least 180 days out of the year (Nev. Rev. Stat. 388.090), which limits the amount of material generated at K-12 facilities. Similar to multi-family generated waste, there is little data available the amount of material generated by K-12 education activities since the discarded material is collected with material generated by other sources.

As a proxy for the amount of tourist-related material generated, I estimated the amount of material generated per tourist at 2 lbs/ person/ day. In the model, the amount of material generated from tourist-related activities was dependent on the number of tourists visiting Clark County each year, the average length of stay per tourist visit, and the material generated per tourist. Figure 15 shows that an increase in the number of tourists visiting per year will cause the

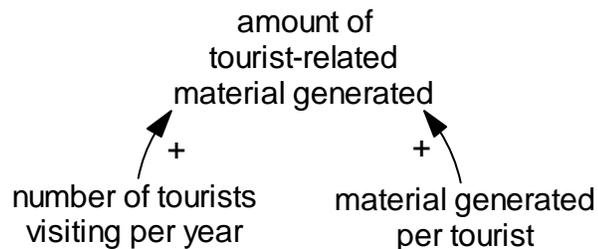


Figure 15. Causal Influence Diagram of Tourist-Related Material Generated

amount of tourist-related material generated calculated by the model to increase. The number of tourists visiting each year from 1993 to 2007 was taken from CBER tourist statistics (CBER, 2007). In the model, a constant value of about 39 million tourists per year was used after 2007 since it is difficult to determine how tourist numbers will fluctuate in the future. I estimated that Clark County would have a similar number of tourists visiting in future years as it did in 2007. The average length of a tourist visit is 3.6 days (Clark County website, 2007). Similar to other types of commercial waste generation, it is difficult to determine the amount of material generated from tourist-related activity. Not only are tourists participating in activities that generate waste, but the entertainment industry which caters to tourists also produces waste from renovation and conference activities.

Commercial material includes the material generated by other businesses such as convenience stores and restaurants. The amount of material generated by each business can vary greatly. I estimated that the amount of material generated by other businesses would be relative to the amount of material produced by multi-family, K-12 education, and tourist-related activities. I used the data on how much material was generated in Clark County from 1993 to 2007 (SNHD, 2007) and my estimates on the amount of multi-family, K-12 education, and tourist-related material generated to determine how much of the material generated in Clark County was not accounted for. The unaccounted amount, the amount of all other commercial material generated, was equal to about 33% of the material generated by multi-family, K-12 education, and tourist-

related activities. For the model, I calculated the amount of all other commercial material generated as equal to 33% of the material generated by identified sources. Figure 16 shows the relationships between the key variables that affect the amount of commercial material generated as represented in the model. It shows that an increase in the amount of tourist-related, K-12, or multi-family material generated would result in an increase in the amount of commercial material generated as calculated by the model.

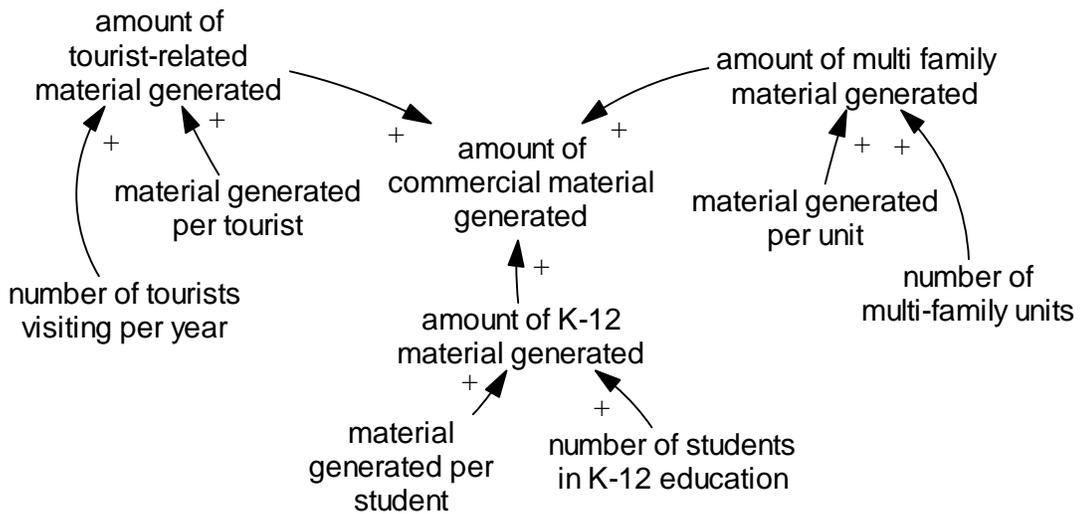


Figure 16. Causal Influence Diagram of the Factors that Influence Commercial Material Generation

I assumed that the amount of construction material generated depends on the Clark County population growth rate. I reasoned that higher population growth rates would indicate a higher amount of construction activity as new homes and businesses are built. There are many factors that affect the level of construction activity in a city; however, due to their complexity, those factors are

outside the scope of this study. Table 7 lists the key equations used to determine construction material generation. Population growth rates from 1993 to 2007 were taken from historic data from the Clark County Department of Comprehensive Planning (CCDCP, 2007). Population growth rates from 2008 to 2035 were taken from population growth forecasts from the Center for Business and Economic Research at the University of Nevada, Las Vegas (CBER, 2007).

Table 7. Construction Material Generation				
Variable Name	Units	Equation	Description	Sources
amount of construction material generated	tons/year	construction material LOOKUP(CC population growth rate)	This is equal to Construction Material Production. These variables were separated to increase simplicity in the model.	
Clark County population growth rate	(%)	IF THEN ELSE(Time=1990, 4, (CC population-CC population at previous year)/CC population at previous year*100)	Values from 1993-2007 are based on historic data. Values after 2007 are based on a 1.1% growth rate.	CCDCP, 2007; CBER, 2007
amount of construction and other material handled by rolloff	tons/year	construction material production*fraction of construction material collected by rolloff	The fraction of construction material collected by rolloff was determined from 2005-2007 data for rolloff collection and self-hauled tonnage values. It is about 50% of the material produced.	Interview with Bob Coyle, 2008

After 2007, I assumed that the growth rate of Clark County will continue to grow at a 1.1% growth rate as forecasted by CBER from 2030 to 2100. The population growth rate varies from about 1% to 8%. In the model, when the population growth rate was less than 4.5%, the amount of construction material generated was about 2 million tons /year. When the growth rate was higher than 4.5%, the amount of construction material generated was about 2.5 million

tons/year. The amount of construction material generated was based on the known values of material collected by Republic through roll-off services and material self-hauled to the Apex landfill by businesses. These values for 2005 to 2007 were 2.8 million tons, 2.7 million tons, and 2.4 million tons with respective growth rates of 4.4%, 5.2%, and 4.9% (R. Coyle, personal communication, March 13, 2008). NDEP does not include the amount of material self-hauled to Apex landfill when calculating the Clark County recycling rate. Only the amount of material collected by Republic is used to calculate the recycling rate. I estimated that the amount of construction material collected by roll-off is 50% of the total amount of construction material produced. This is also based on the 2005 to 2007 values for roll-off and self-hauled material (R. Coyle, personal communication, March 13 2008).

Material Diversion Subsystem

Part of the material generated by residential, commercial, and construction activities is diverted for recycling. Figure 17 shows structure of the material diversion subsystem. Diverted residential material is collected at single-family homes through curbside services by Republic. Diverted commercial and construction material is collected by Republic or other contracted companies. The contract between Republic and Clark County allows commercial businesses The residual and material beyond recycling facilities' processing capacity is the amount of contaminated or non-recyclable material that was diverted for recycling and the material that could not be processed due to the limitations of recycling facilities. Material diverted for recycling by residents living in single-

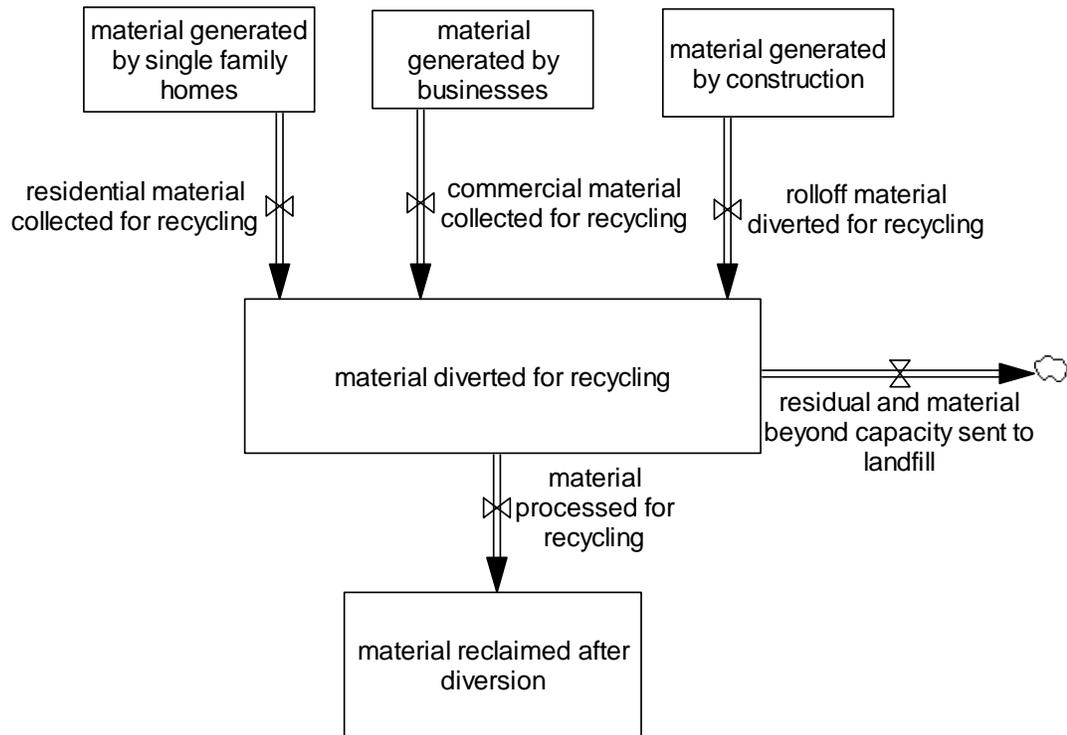


Figure 17. Material Diversion Subsystem

family homes is collected bi-weekly. Table 8 lists the key equations used to determine residential material diversion. The amount of residential material diverted for recycling depends on the amount of residential material generated and the portion, or percentage, of residential material that is diverted. The model allows users to test the potential effect of increasing the frequency of residential recycling material collection from bi-weekly to weekly on the amount of material diverted. The amount of residential material that is recyclable was amount of recyclable material, not all of it can be recycled. This amount of recyclable material depends on the composition of residential material generated. Republic Services collects paper, plastic, metal, and glass items for recycling.

Table 8. Residential Material Diversion			
Variable Name	Units	Equation	Description
amount of recyclable residential material diverted for recycling	tons/year	MIN(amount of residential material diverted for recycling, amount of residential material that is recyclable)	This represents the amount of recyclable material in the total material diverted for recycling.
Amount of residential material that is recyclable	tons/year	amount of residential material generated*recyclable portion of residential material	This is the maximum amount of residential material that can be diverted and successfully reprocessed for recycling.
Amount of residential material diverted for recycling	tons/year	IF THEN ELSE(Time>=2010, effect of recycling collection multiplier*change in portion of residential diversion*amount of residential material generated , portion of residential material usually diverted*amount of residential material generated)	The amount of residential material diverted depends on the portion of material diverted. The IF THEN ELSE statement is used so that any policies tested would take place after 2010.

Although the composition of material generated in Clark County is not available since a waste characterization study has not been conducted for the area, a residential waste characterization conducted in Phoenix, AZ showed that 33.5% of residential material was made up of paper, plastic, metal, and glass in material (Cascadia Consulting Group, 2003). Phoenix has a similar climate and population size to Clark County; thus, I assumed that recyclable portion of residential material generated in Clark County would be near the same value. Climate partially determines the amount of landscaping material contributed to the total amount of material generated as areas that receive more precipitation can support larger amounts of vegetation. Figure 18 shows the causal relationships used in the model to determine the amount of recyclable residential

material diverted for recycling. Figure 18 shows an increase in the amount of residential material generated would cause the amount of residential material diverted for recycling and the amount of residential material that is recyclable to increase; this, in turn, would cause the amount of recyclable residential material diverted for recycling calculated in the model to increase. Table 9 lists the key equations used to determine the amount of commercial material diverted for

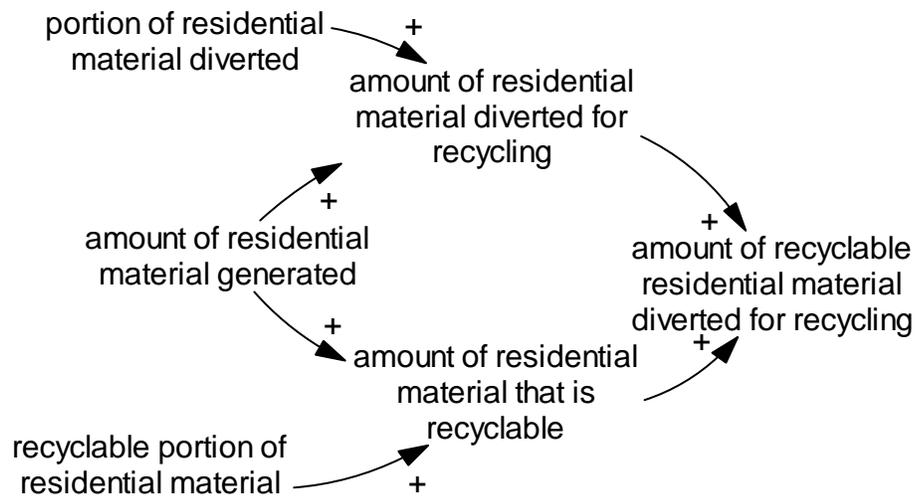


Figure 18. Causal Influence Diagram of the Factors that Influence Residential Material Diversion

recycling. There are several sources of commercial material diversion. There are no recycling services offered at multi-family units, but it was assumed that a small portion of people who live in multi-family units will participate in recycling through use of private recycling companies or through Republic's drop-off center. In order to avoid over-estimating the amount of commercial material diverted, the recyclable portion of commercial material was determined. Although businesses could divert more than the amount of recyclable material, only the recyclable

Table 9. Commercial Material Diversion			
Variable Name	Units	Equation	Description
amount of recyclable commercial material diverted for recycling	tons/year	amount of other recyclable commercial material diverted for recycling+"amount of recyclable K-12 material diverted for recycling"+amount of recyclable multi-family material diverted for recycling"+amount of recyclable tourist waste diverted for recycling+amount of recyclable rolloff material diverted for recycling	<p>This represents the commercial material diverted for recycling. It is the sum of all commercial, roll-off, K-12 education, multi-family, and tourist-related material.</p> <p>The MIN function is used to avoid over-counting of diverted material. Since only a percentage of the material diverted is recyclable, it is assumed that no more than that recyclable portion can be reprocessed for recycling. Anything larger than that amount is considered to be residual material that cannot be reprocessed.</p>
Amount of recyclable tourist material diverted for recycling	tons/year	MIN(amount of tourist waste diverted for recycling ,amount of tourist waste that is recyclable)	
Amount of recyclable multi-family material diverted for recycling	tons/year	MIN("amount of multi-family material diverted for recycling", "amount of multi-family material that is recyclable")	
amount of recyclable K-12 material diverted for recycling	tons/year	MIN("amount of K-12 material diverted for recycling", "amount of K-12 material that is recyclable")	
amount of other recyclable commercial material diverted for recycling	tons/year	MIN(amount of other commercial material diverted for recycling, amount of other commercial material that is recyclable)	
amount of recyclable rolloff material diverted for recycling	tons/year	MIN(amount of construction and other rolloff material diverted for recycling, amount of rolloff material that is recyclable)	

material can be successfully diverted. The model was built to limit the material that can be successfully diverted and reprocessed to the amount of recyclable material. For example, if a business diverted all of its material for recycling, that does not mean that all of that material is recyclable. The types of materials that are diverted are as important as the amount of material diverted. Figure 19 shows causal relationships used in the model to determine the amount of recyclable commercial material diverted for recycling.

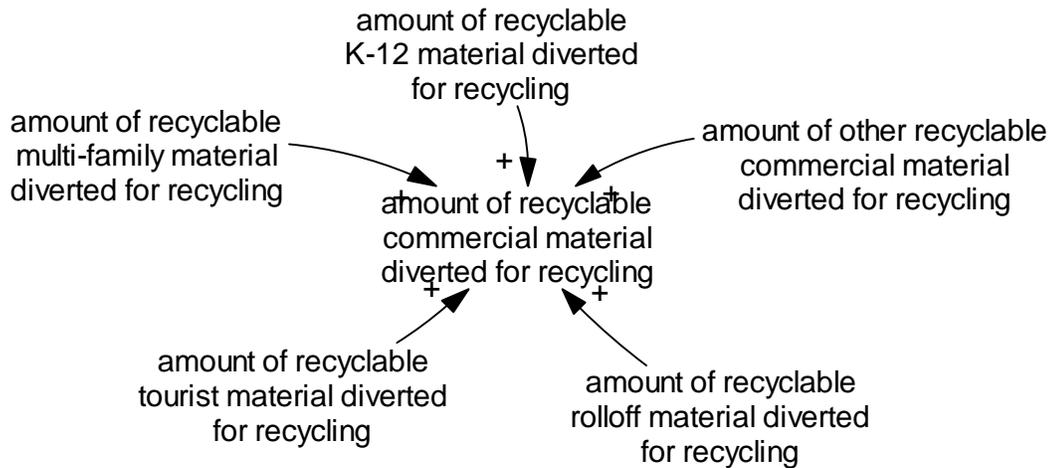


Figure 19. Causal Influence Diagram of the Factors that Influence Commercial Material Diversion

Material Disposal Subsystem

Part of the material generated by residential, commercial, and construction activities is discarded by generators and collected for disposal by Republic Services. Disposal trucks collect the material on daily residential and commercial collection routes and transport the material to three transfer station facilities in Clark County. Larger trucks then collect that material from the transfer stations

and deliver it to Apex landfill. Figure 20 shows the structure of the material disposal subsystem.

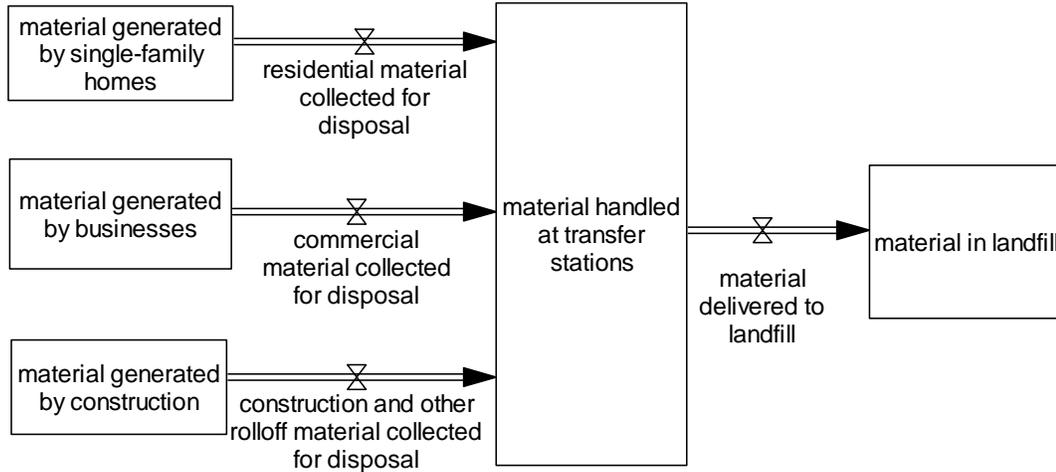


Figure 20. Material Disposal Subsystem

The amount of material collected for disposal depends on the amount of material that is diverted for recycling and the amount of material generated. Table 10 lists the key equations used to determine material disposal. The amount of residential material disposed refers to the material collected from single-family homes. Residential material is collected twice a week by Republic Services. A separate collection system is used for diverted material intended for recycling. The amount of commercial material disposed is the discarded material collected from a variety of businesses, multi-family buildings, schools and other institutions. Once the self-hauled material is taken to Apex landfill, it is weighed and then disposed. Residual material is material that was diverted for recycling but is either non-recyclable or contaminated by non-recyclable substances and

Table 10. Material Disposal			
Variable Name	Units	Equation	Description
amount of commercial material disposed by Republic	tons/year	amount of all commercial material generated excluding rolloff+amount of construction and other material handled by rolloff-amount of recyclable commercial material diverted for recycling	Only construction material collected by roll-off is counted towards commercial material. The diverted commercial material is subtracted from the commercial material generated.
amount of construction material self-hauled	tons/year	construction material production*"fraction of construction material self-hauled"	The fraction of construction material self-hauled was determined from 2005-2007 data for roll-off collection and self-hauled tonnage values. It is about 50% of the construction material produced (Interview with Bob Coyle, 2008).
total residual and material beyond capacity	tons/year	amount of residual and material beyond private capacity+amount of residual and material beyond Republic capacity+MRF material beyond capacity and residual sent to landfill	Residual material, which is non-recyclable and contaminated material, is discarded for disposal. Any material greater than a facility's capacity is assumed to be discarded for disposal.
total amount of material disposed	tons/year	amount of construction material self-hauled+residential and commercial material collected by Republic+total residual and material beyond capacity-amount of material sent to MRF	This is equal to the sum of all the material discarded for disposal. This is the amount of material that is delivered to Apex landfill.

will be discarded for disposal. Contamination can occur when recyclable material is exposed to food substances or broken glass and porcelain. Material beyond a facility's processing capacity is the material that a facility is not able to process in a given time frame. There are fifteen privately-owned recycling companies that accept specified recyclable materials from the public (SNHD, 2005). Republic

Services has one material recovery facility that processes diverted material and there are four other privately-owned material recovery facilities. A material recovery facility, abbreviated as MRF, is a facility that extracts recyclable items from mixed material that contains both recyclable and non-recyclable items. The total amount of material disposed is delivered to Apex landfill for final disposal. Currently, there is not an MRF in Clark County that accepts residential material. This could be due to the contract between Clark County and Republic Services which gives Republic Services control over all residential material generated. In the model, I included an option that looks at the effects of having an MRF that can accept both residential and commercial waste as a possible policy option.

Figure 21 shows the causal relationships used in the model to determine the total

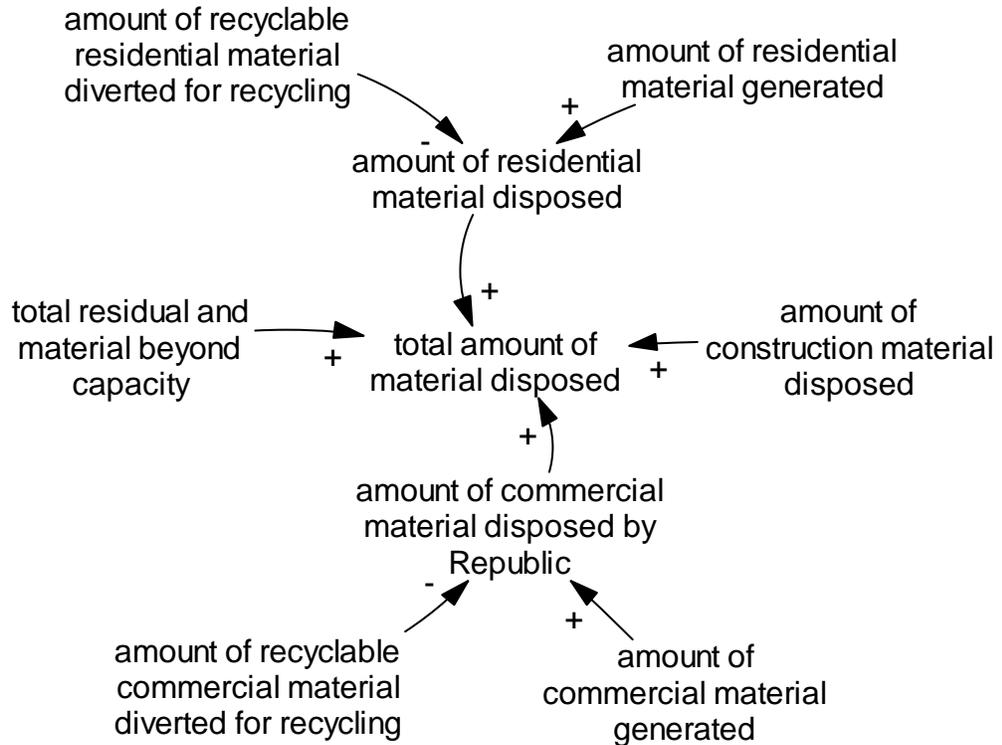


Figure 21. Causal Influence Diagram of the Factors that Influence Material Disposal

amount of material disposed. In the model, an increase in the amount of recyclable residential material diverted for recycling will cause the amount of residential material disposed to decrease; and an increase in the amount of residential material generated will cause the amount of residential material disposed to increase. The same relationship was assumed for recyclable commercial material diverted and generated.

CHAPTER IV

RESULTS

System dynamics models are a useful tool for making informed policy decisions. They provide model users with a tool to understand feedback and nonlinear behavior of complex systems. A model can be tested for its accuracy as a representation of reality and its usefulness as a tool for decision-making. When a model is determined to be an accurate representation, it can be used by decision-makers to identify the possible outcomes of policy scenarios instead of implementing costly and time-intensive policies that might not be effective. The model I created for this study was developed to answer the question of how best to increase the Clark County recycling rate. The model was designed to test the effect policy options had on the recycling rate. This model's accuracy as a representation of reality was tested by a number of behavior reproduction tests, extreme conditions tests, and sensitivity analysis.

Behavior Comparison

Behavior reproduction tests are an important first step to assess whether the model can reproduce the behavior of a system (Sterman, 2000). This helps build confidence that the model represents the structure of the real system and can be used as a decision-making tool. Figure 22 compares data on the amount

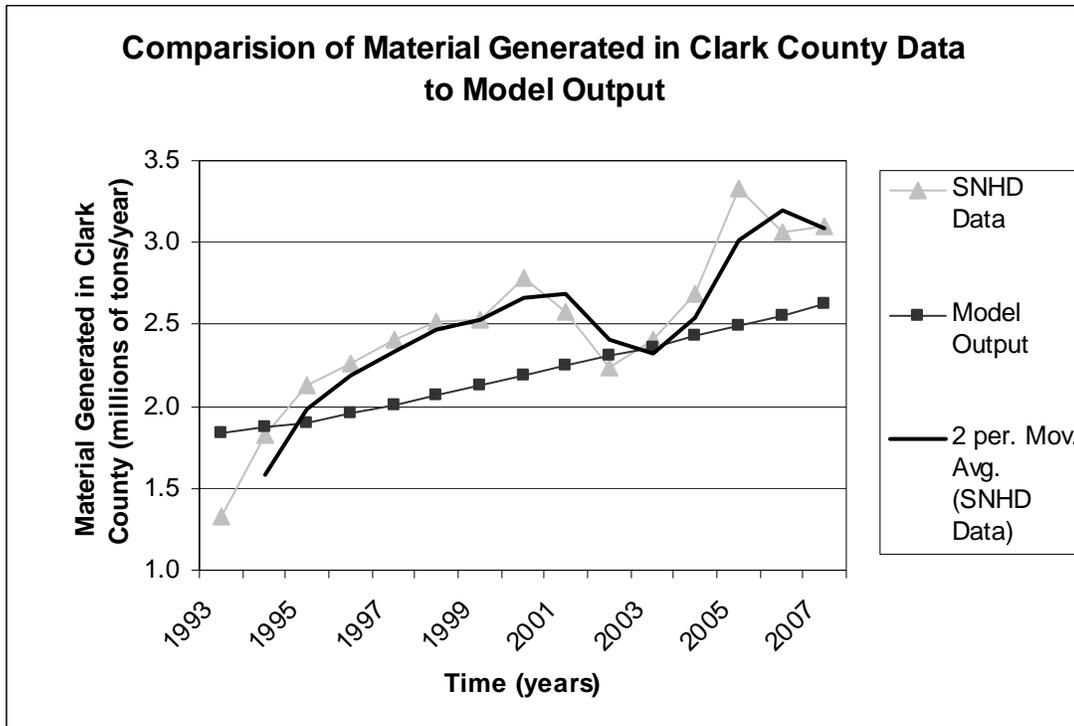


Figure 22. Comparison of Material Generated in Clark County Data to Model Output. Source: Southern Nevada Health District

of material generated in Clark County (SNHD, 2007) and the values generated by the model. Even though the amount of material generated in Clark County decreased in certain time periods such as from 2001 to 2003, the trend line shows an overall increasing trend in the amount of material generated. The trend line is a two period moving average of the Southern Nevada Health District data. The goal of the model is to generate data points and behavior that is comparable to real word data. The model output in Figure 22 displays an increasing trend in the amount of material generated in Clark County over time at a rate similar to the historic data.

Figure 23 compares data on the Clark County recycling rate (SNHD, 2007) to values generated by the model. The recycling rate has varied between

9% and 20% from 1993 to 2007. The recycling rate decreased from 1993 to 1999 seems to have leveled off since 2004. These fluctuations are determined by

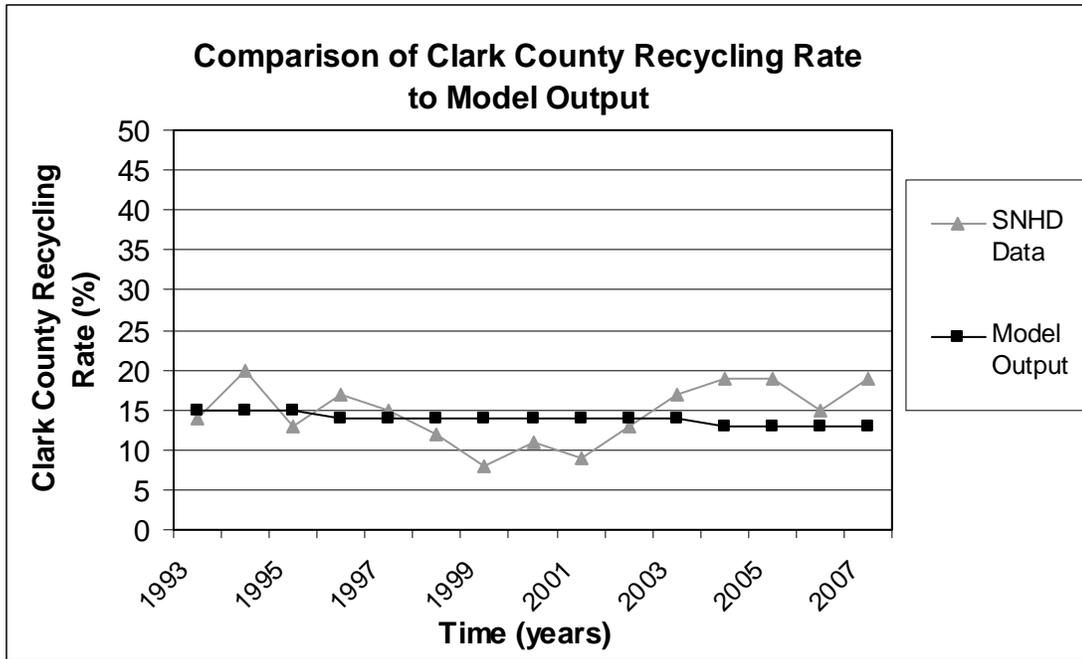


Figure 23. Comparison Clark County Recycling Rate Data to Model Output. Source: Southern Nevada Health District

changes in the amount of material generated and diverted for recycling. The cause of these fluctuations can be due to economic changes in consumption which are not represented in the model. It can also be due to the accuracy of businesses' reports on the amount of material diverted each year. The model output generated a recycling rate that is slowly decreasing over time and is within the range of the actual recycling rate. This supports that the model is representative of the structure of the system and can be used for policy testing.

Baseline Model Simulation

Figure 24 shows the model output when no changes are made to the system. The material delivered to Apex landfill is not removed, causing the

amount of material in the landfill to accumulate over time The Material in Landfill graph shows the amount of material accumulating in Apex landfill is steadily increasing over time. The Clark County recycling rate graph represents the amount of recyclable material that is diverted. The Clark County recycling rate is slowing decreasing over time as the amount of material generated increases

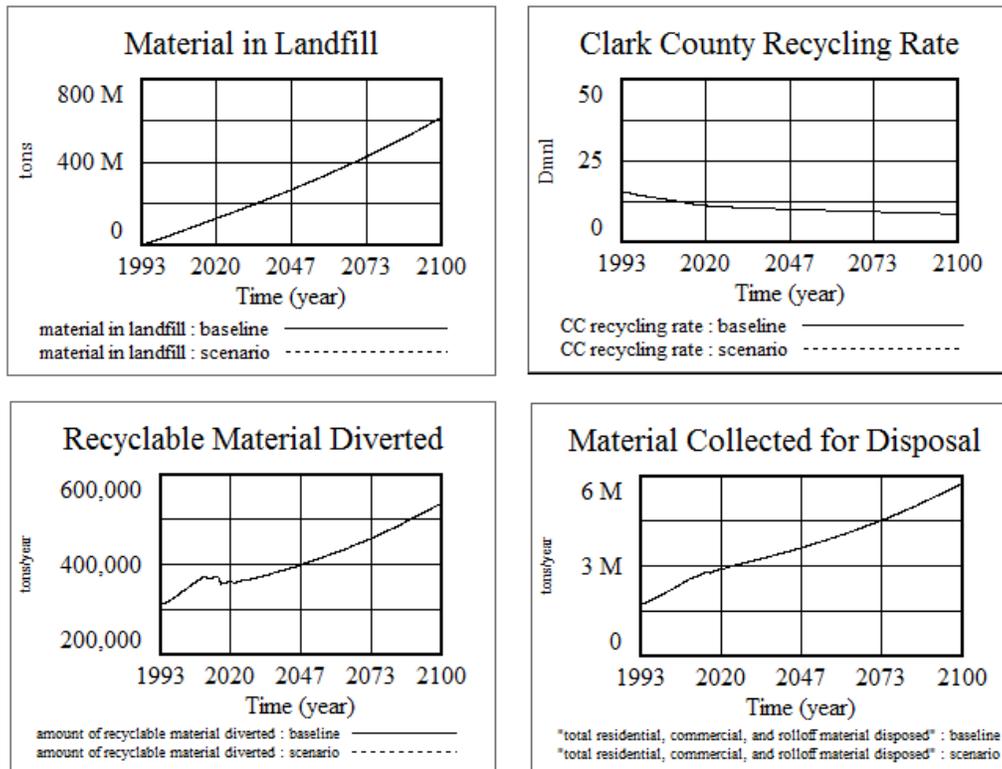


Figure 24. Baseline Model Output

more quickly than the amount of material diverted. The Recyclable Material Diverted graph shows that the amount of recyclable material diverted by residential and commercial sources is increasing over time. The fluctuation at 2016 is due to a decline in the amount of construction material generated as the

population growth rate changes from 2% in 2020 to 1.1% in 2035. The Material Collected for Disposal graph that the amount of material collected each year for disposal is increasing over time.

Extreme Conditions

Extreme condition testing is used to ensure that the model behaves realistically when minimum and maximum variable values are used (Sternan, 2000). Although extreme situations are not likely to happen in reality, it is still important that the model output be consistent with what would logically be expected to happen. This supports that the model is an accurate representation of the system and can be used as a tool for decision-making. In the first extreme condition test the amount of material generated by all sources was set to zero. If there is no material being generated, then consequently there would be no material disposed or diverted. As expected, this caused the amount of material diverted for recycling and collected for disposal to equal zero in the model since there was no inflow of material into the system.

For the next extreme condition test, I increased the Clark County population to ten times its size. With a larger population size, I expected that there would be a larger amount of material generated. Figure 25 shows the model output generated by this test. The amount of material in the landfill under the extreme test is much larger than in baseline simulation. This was a logical response to the increase in population size and material generated. The amount of recyclable material diverted was calculated as a portion of the total amount of

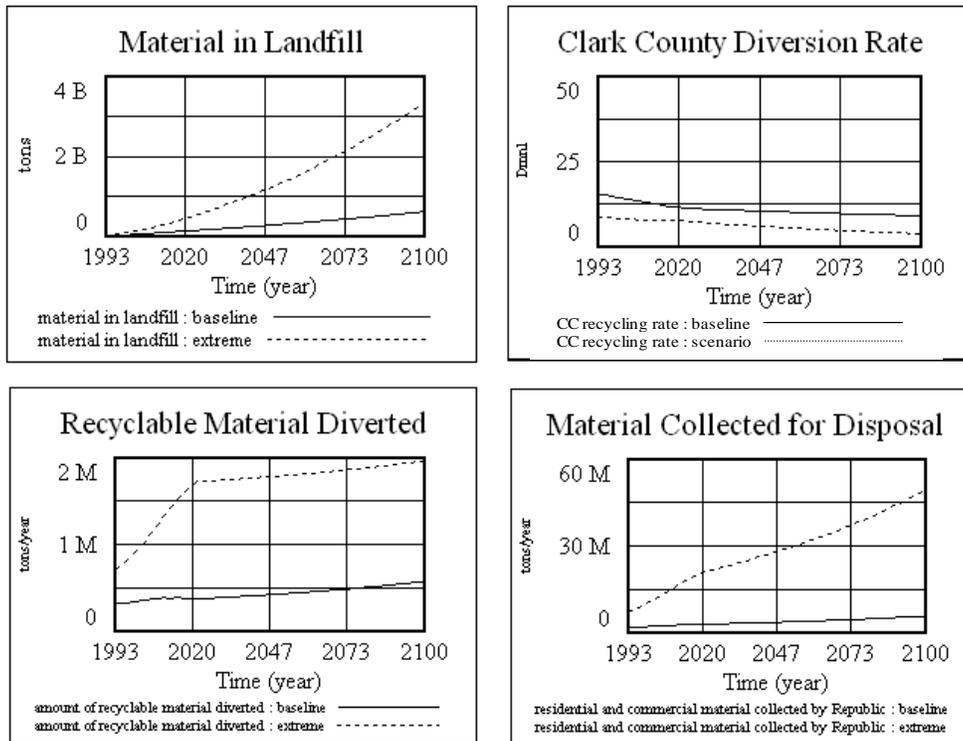


Figure 25. Extreme Condition Testing: Change in Population Size. The solid line is the baseline output. The dashed line is the extreme condition output.

material generated. Since the amount of material generated increased, the amount of recyclable material diverted increased. After 2020, the amount of recyclable material diverted begins to level out when the processing capacity of the Republic material recovery facility was reached. The increase in recyclable material diverted after 2020 was due to the processing of material by private recycling businesses.

For the next extreme condition test, I changed all the values for residential and commercial material diversion rates after 2010 to 100%. I expected the recycling rate to increase significantly under this test. Figure 26 shows how the recycling rate increased when all diversion rates were set to 100%.

Clark County Recycling Rate

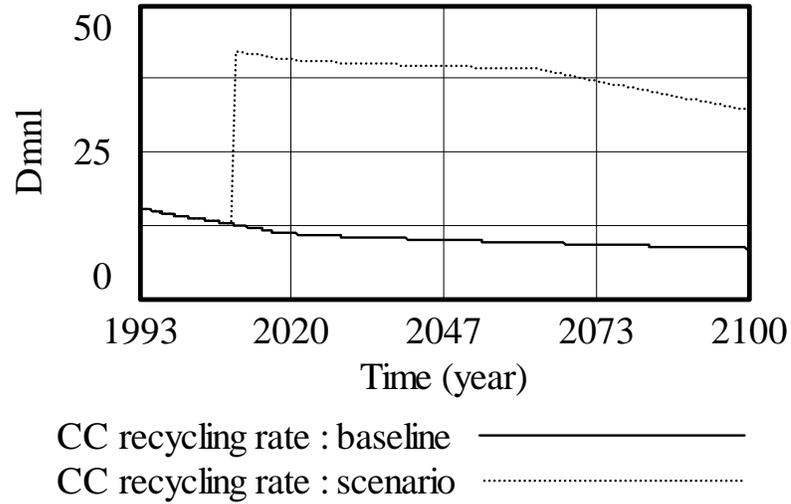


Figure 26. Recycling Rate under Maximized Diversion Rates. The solid line is the baseline output. The dashed line is the extreme condition output.

In 2010, this recycling rate increases to approximately 42% and steadily decreases over time until 2065. Although the amount of material diverted increased, the decrease in the recycling rate during this period was due to an increasing amount of material being generated by the growing population. The sharper decrease in the recycling rate after 2065 is due to the limitations of the processing capacities for diverted material of recycling businesses. Once their capacity is reached, recycling businesses are not able to process a higher quantify of material. All residential and commercial material being generated in Clark County, with the exception of material that was self-hauled to Apex landfill, was being diverted for recycling in this test. In reality, it would be difficult for this to occur. While residents and businesses could potentially divert all of the

material they generate, it is not possible to reprocess non-recyclable or compost material in Clark County. Figure 27 shows that the amount of recyclable material diverted increases to 1.3 million tons/year in 2010 under this scenario. The fluctuation around 2016 was due to a decrease in the amount of construction material generated. The slowing of recyclable material diverted near 2055 was due to the limitations of the processing capacity of the Republic material recovery facility, which processes the residential and commercial material collected through Republic recycling programs. This extreme test shows that the model generated the expected behavior for this extreme condition test, supporting that the model is an accurate representation of the system and can be used in policy testing.

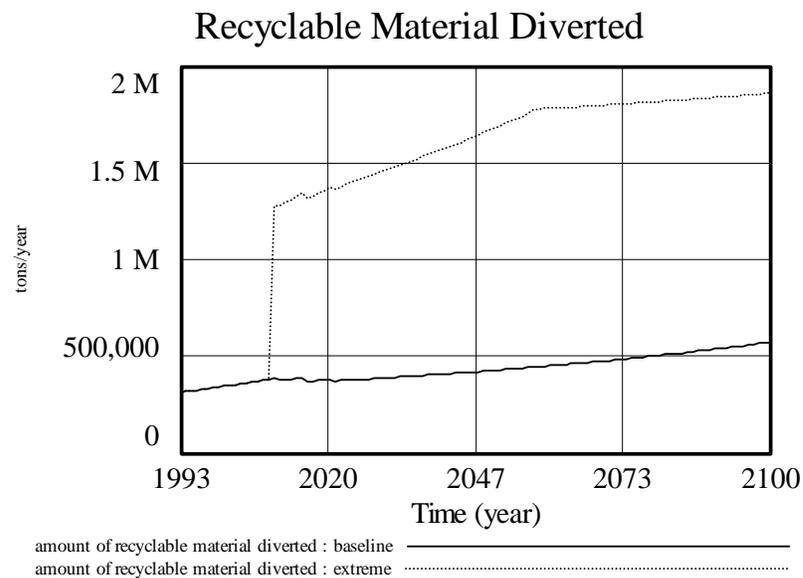


Figure 27. Recyclable Material Diverted with Maximized Diversion Rates. The solid line is the baseline output. The dashed line is the extreme condition output.

Sensitivity Analysis

Sensitivity analysis is used to test the sensitivity of the model's output to changes in variable values. I studied changes in model output for the recycling rate, which is my key variable of interest. Variable values that are uncertain must be tested to determine if that variable requires further research for use in the model. Uncertain variables that have a large effect on the behavior of the variable of interest warrant more attention, while those with a small effect do not require further research for use in the model. The model can still be considered an accurate representation of reality if changes in uncertain variable values do not have a strong impact on the behavior of the variable of interest.

I identified the recyclable portion of material from each material source as an uncertain variable that could potentially affect recycling rate model output. Changing the recyclable portion of material for each material source did not affect the recycling rate output. This was due to the low amount of material currently being diverted from each source. The recyclable portions of material from each source will not affect the recycling rate until diversion is near these approximated values.

The amount of material generated influences the amount of material collected for disposal and diverted for recycling, which affects the recycling rate. Thus, the recycling rate is potentially sensitive to changes in material generation rates. Conducting sensitivity analysis tests showed that changing material generation rates caused less than a 5% change in the recycling rate in the model. Figure 28 shows changes to the recycling rate when the residential

material generation rate was increased by three times its value from 1.2 tons/ year/ household to 3.6 tons/ year/ household. This caused the recycling rate to be approximately 3% less than its original value since there was a larger amount of material being collected for disposal due to the increase in material generation. Based on these changes in model output, I concluded that the recycling rate is not sensitive to the residential material generation rate used in the model.

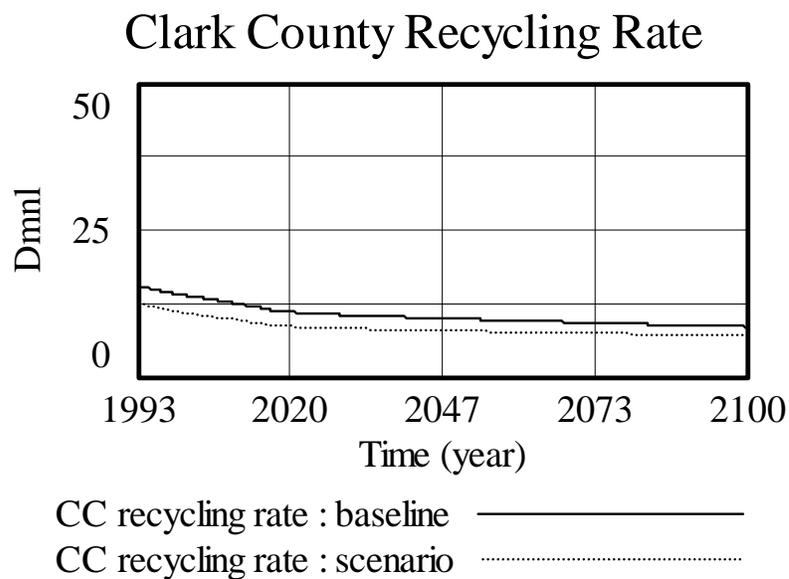


Figure 28. Changes in Recycling Rate with Increased Residential Material Generation

Figure 28 shows changes to the recycling rate when the multi-family material generation rate was increased by three times its value from 1.2 tons/ year/ unit to 3.6 tons/ year/ unit. This resulted in a recycling rate that was slightly lower than the baseline data. Changing the material generation rates for students and tourists in the model had no discernable effect on the recycling rate. Based on these tests, I concluded that the recycling rate is not sensitive changes in

multi-family, tourist-related, and K-12 education-related material generation rates used in the model.

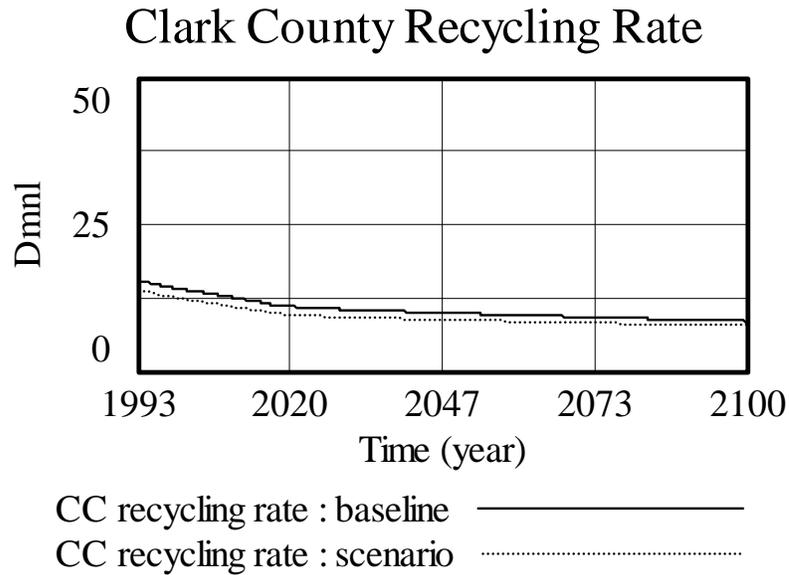


Figure 29. Changes in Recycling Rate with Increased Multi-family Material Generation

Policy Analysis

I examined the model and tested my policy hypotheses. Figure 30 shows the policy option screen I created to run the model. On the left hand side are the options for changing material generation and implementing the use of a material recovery facility. On the right hand side of the screen are the options for changing diversion rates by source. Each policy's effectiveness was measured by model output for four variables: (1) material in landfill, which represents the amount of material accumulating in Apex landfill; (2) Clark County recycling rate; (3) recyclable material diverted annually; and (4) the amount of material collected

for disposal annually. The baseline model output is shown on the graphs in the center of Figure 30.

The policies tested were the following: changing material generation rates; changing diversion rates; and implementing the use of a material recovery facility. After examining each possible policy lever in isolation, I evaluated the effect of changing multiple policy levers in order to identify the most effective policy options.

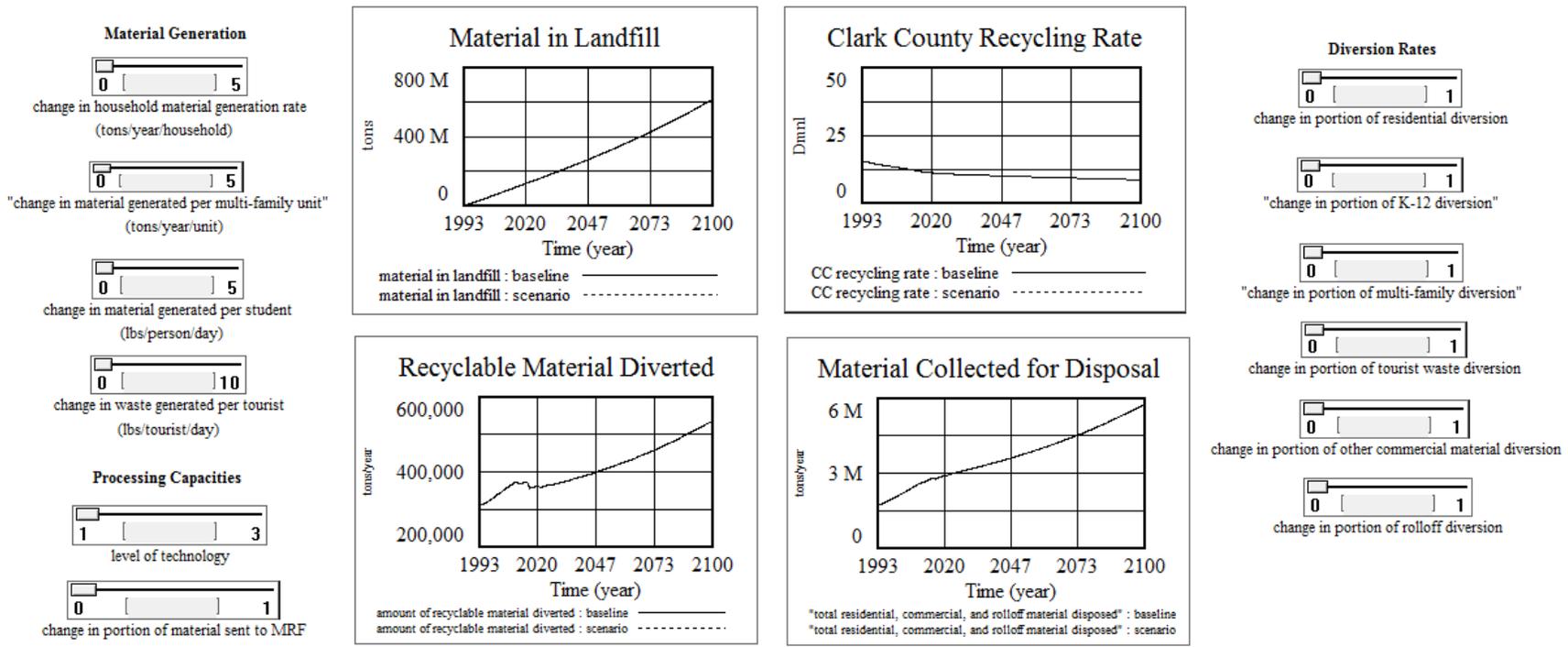


Figure 30. Policy Option Screen
 Policy options can include changes in material generation, diversion rates, and the use of a material recovery facility.

Changes in Material Generation

The Scenario 1 policy option was to decrease the total amount of material generated in Clark County. Table 11 show values that were used in Scenario 1. The model was designed to implement changes in policy in 2010. Figure 31 shows the model output when the residential, multi-family, student, and tourist material generation rates were decreased by about 25%.

	Household Material Generation Rate (tons/year/household)	Multi-Family Unit Generation Rate (tons/year/unit)	Material Generated per Student (lbs/person/day)	Material Generated per Tourist (lbs/tourist/day)
Original Value	1.8	1.2	1.2	2
Scenario Value	1.4	0.8	0.8	1.5

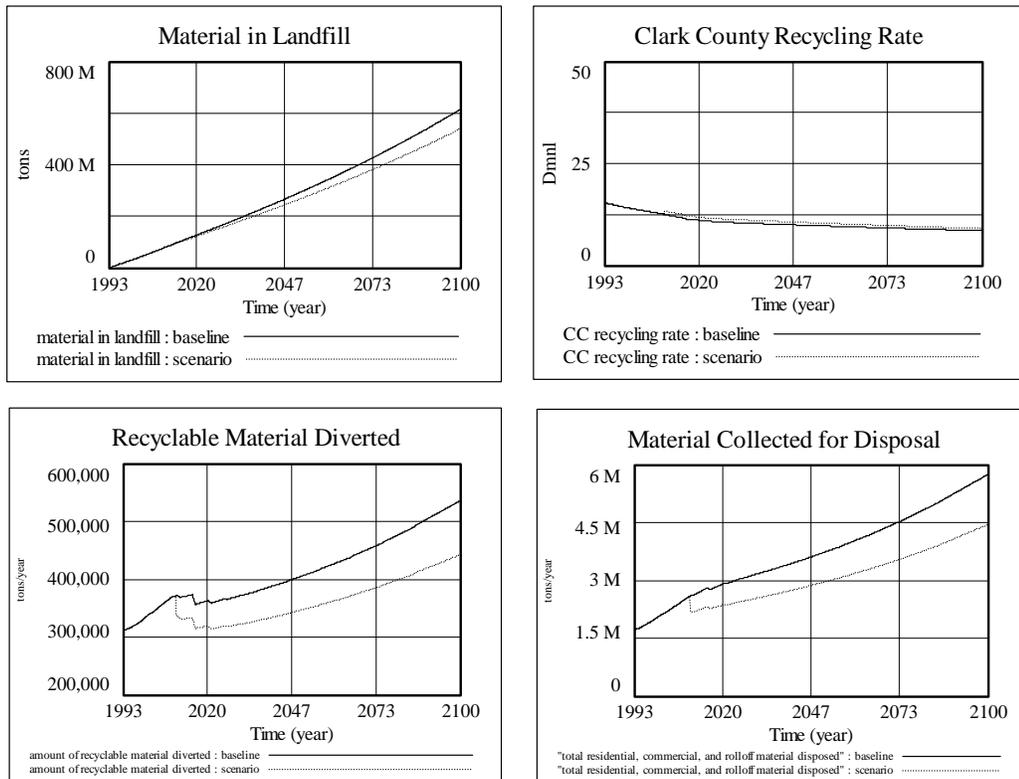


Figure 31. Scenario 1 Model Output: Changes in Material Generation

In Figure 31, the amount of material sent to the landfill decreased due to a decrease in the amount of material generated. This also increased the Clark County recycling rate by less than 1%. The amount of recyclable material diverted was calculated as a percent of the total amount of material generated. Since the amount of material generated decreased, the amount of recyclable material diverted also decreased. A decrease in the amount of material collected for disposal was expected under this scenario, since less material was being generated. In the model, the amount of recyclable material diverted is calculated as a fraction of the amount of material generated; thus, I did not expect to see a change in the recycling rate.

Changes in Diversion

The next policy option I tested was increasing the residential and multi-family diversion rates to 34%, which was the value of the recyclable portion of residential and multi-family material used in the model. Scenario 2 tests what would happen if residents living in single-family homes and multi-dwelling units diverted all of their recyclable material. For this scenario, I assumed residents are only diverting recyclable material through their respective recycling programs with average residual rates of 5%. Table 12 shows the original values used to generate the baseline data, 5.9% for residential diversion and 2% for multi-family diversion, and the values used in Scenario 2. Figure 32 shows that the amount of recyclable material diverted increased in 2010 when the changes are implemented in the model. This was expected since the diversion rates were increased. This amount continued to increase steadily along with the increase in

material generated. This was driven by the growing Clark County population. The slight decrease in 2085 occurred when the Republic material recovery facility processing capacity was reached. The processing of material by private recycling businesses was what caused the slight increase in the recyclable material diverted after 2085. The amount of material collected for disposal decreases by the amount of material being diverted. This, in turn, decreased the amount of

Table 12. Inputs for Scenario 2: Changes in Diversion Rates		
	Residential Diversion (%)	Multi-Family Unit Diversion (%)
Original Value	5.9	2
Scenario Value	34	34

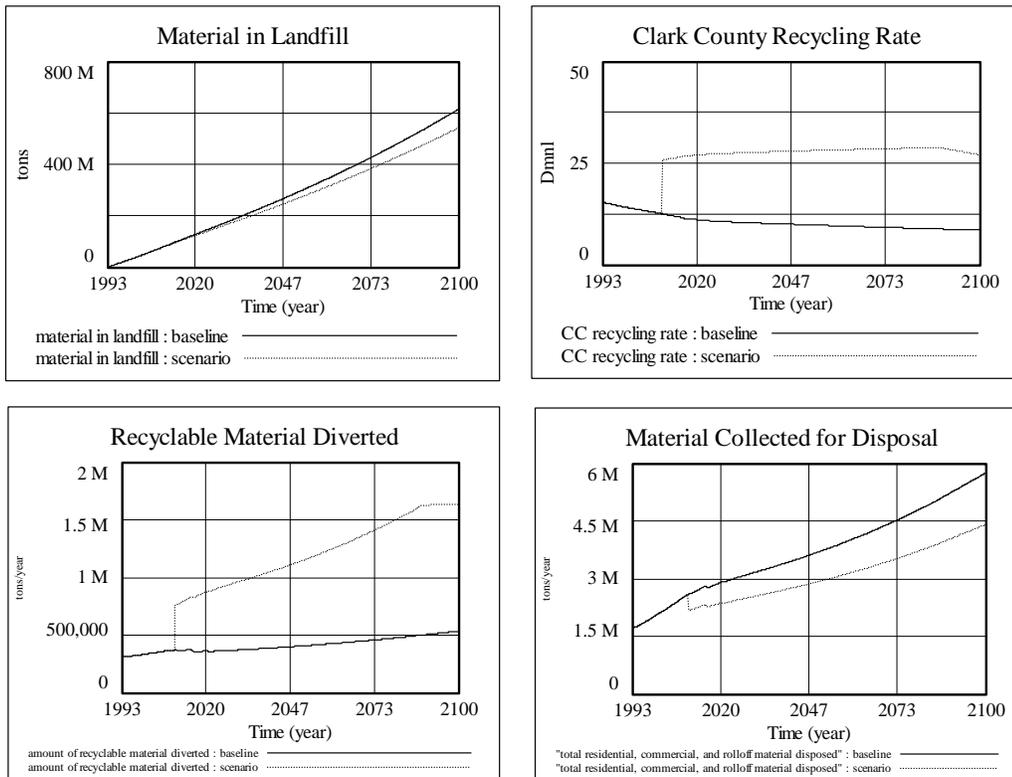


Figure 32. Scenario 2 Model Output: Changes in Residential and Multi-Family Material Diversion

material sent to the landfill. The recycling rate increased to 26% in 2010 as a result of the increase in diversion of recyclable material. When the amount of recyclable material diverted decreased in 2085, the recycling rate decreased.

For Scenario 3, I tested increasing the amount of K-12 education-related, tourist-related, other commercial material, and roll-off material diversion by 10% each. I chose an overall 10% increase since it seemed a reasonable policy option that could be implemented as compared to higher diversion rates. Table 13 shows the original values used to generate the baseline data and the values used in Scenario 3. Figure 33 shows the model output for this scenario. The amount of recyclable material diverted increased in 2010 when the changes are implemented. The fluctuation around 2018 was due to a change in amount of construction material generated. This fluctuation was explained in the Baseline Model Simulation section. The increase in recyclable material diverted after 2020 was due to the increase in the amount of material generated as a result of a growing population. The amount of material collected for disposal and sent to the landfill decreased as the amount of recyclable material diverted increased, while the recycling rate increased. This was expected to be a result of the increased diversion rates.

	K-12 Diversion (%)	Tourist Diversion (%)	Other Commercial Diversion (%)	Roll-off Diversion (%)
Original Value	10	25	20	20
Scenario Value	20	35	30	30

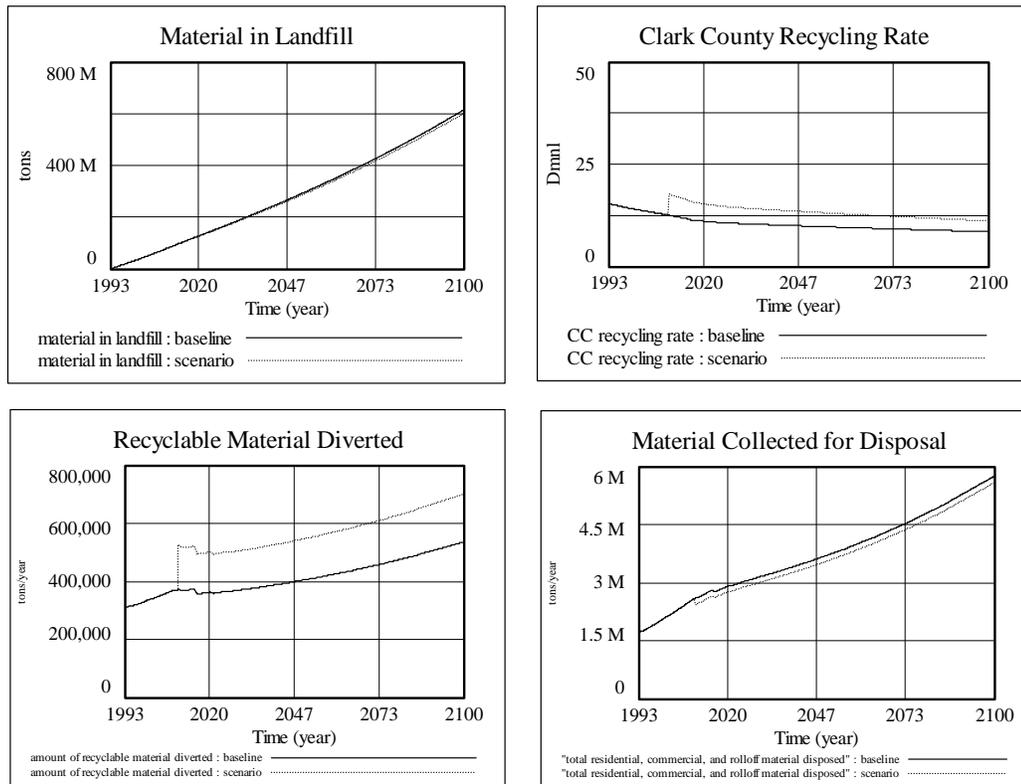


Figure 33. Scenario 3 Model Output: Changes in Commercial Material Diversion

Table 14 shows the original values used to generate the baseline data and the values used in this Scenario 4. I tested increasing the diversion rates of K-12 education-related, tourist-related, other commercial diversion, and roll-off diversion to their respective portions of recyclable material. I assumed that those groups participating in commercial recycling programs are only diverting recyclable material through their programs with an average residual rate of 5%. This scenario tests what would happen if commercial sources diverted all of the recyclable material they generate, only disposing of material that is non-recyclable or which is compostable. Figure 34 shows the model output for this

scenario. Although the amount of recyclable material diverted increased, the recycling rate peaked at 27% in 2018 and decreased over time. This was due to the amount of material collected for disposal increasing faster than the amount of recyclable material diverted. This scenario was expected to have a larger impact

Table 14. Inputs for Scenario 4: Increased Changes in Commercial Diversion Rates				
	K-12 Diversion (%)	Tourist Diversion (%)	Other Commercial Diversion (%)	Roll-off Diversion (%)
Original Value	10	25	20	20
Scenario Value	40	50	64	50

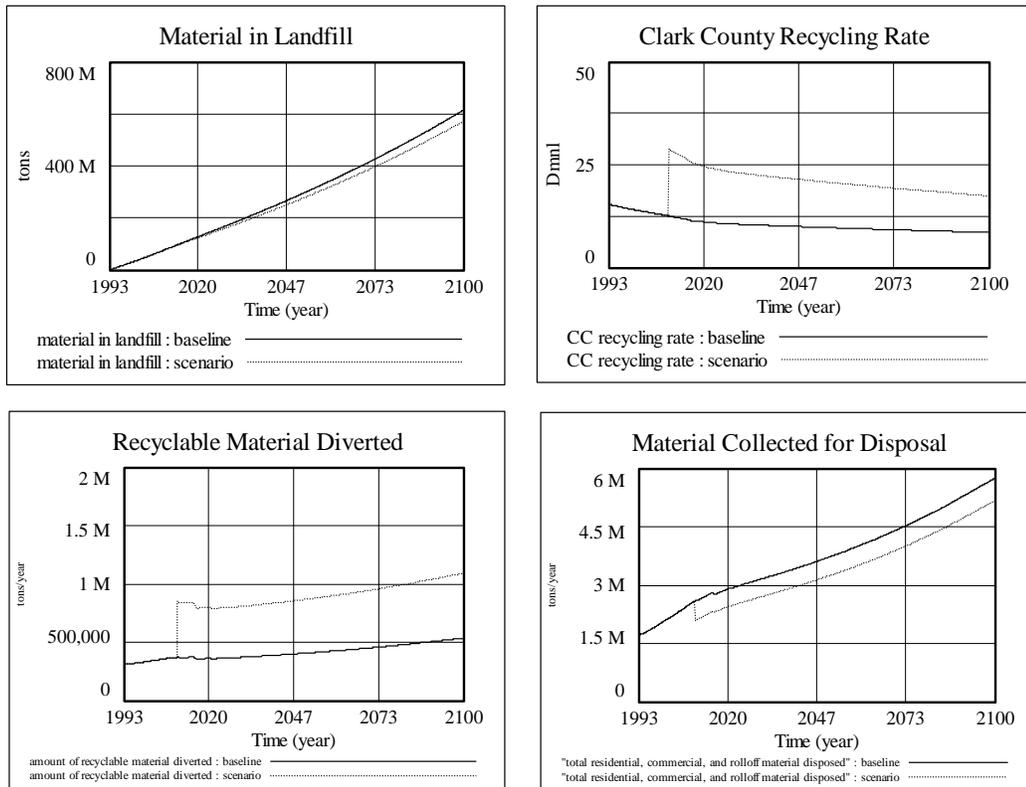


Figure 34. Scenario 4 Model Output: Changes in Commercial Material Diversion to Maximum Recyclable Portions

on the recycling rate since more material was being diverted through commercial recycling programs.

I tested increasing the amount of residential, multi-family, other commercial material, and roll-off material diversion rates. Table 15 shows that residential and multi-family diversion rates were increased to 25% and other

	Residential Diversion (%)	Multi-Family Unit Diversion (%)	Other Commercial Diversion (%)	Roll-off Diversion (%)
Original Value	5.9	2	20	20
Scenario Value	25	25	30	30

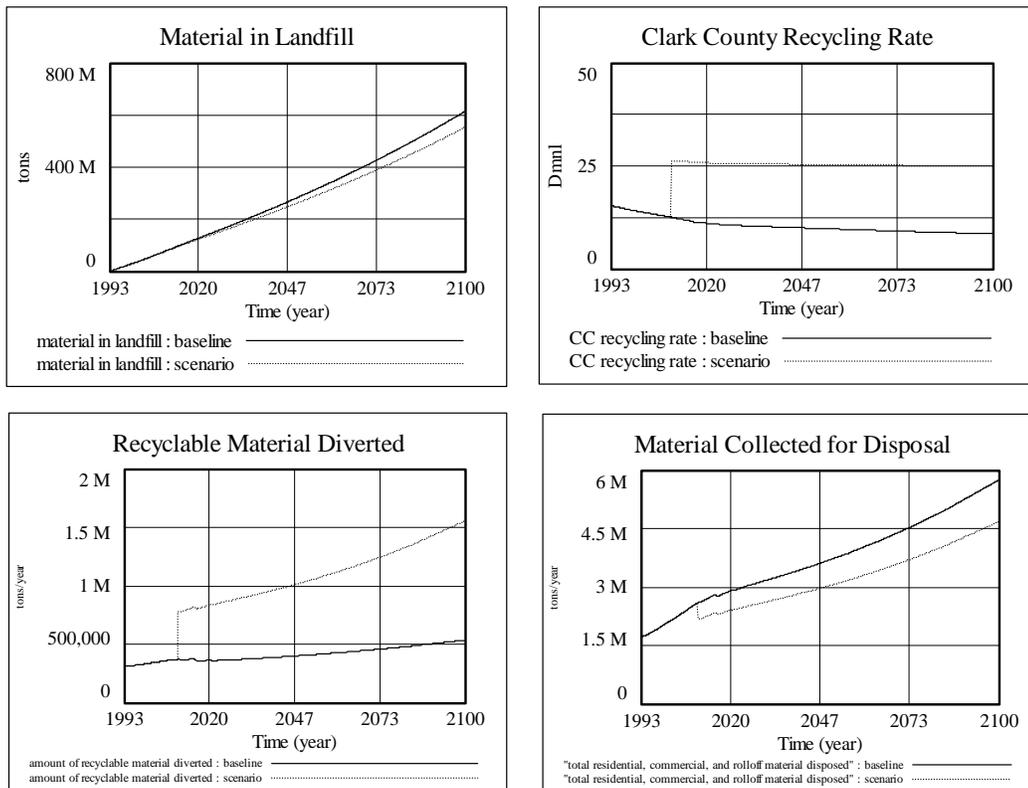


Figure 35. Scenario 5 Model Output: Combined Changes in Diversion

commercial and roll-off material diversion rates were increased to 30% in Scenario 5. Figure 34 shows the increase in recyclable material diverted and the decrease in the material collected for disposal and in the landfill. The recycling rate peaked just over 25% in 2018 and stabilizes near that value. This was expected since material generated by residential homes and multi-family units is increasing as the Clark County population increases. Additionally, roll-off material constitutes a large portion of material generated. Increasing diversion in these areas caused the recycling rate to significantly increase.

Implementation of Material Recovery Facility

The model includes an option to test the implementation of a material recovery facility that would process material collected for disposal. The characteristics of the facility can be determined by selecting the level of technology, which determines the processing capacity and efficiency of the facility. The level of technology was simplified to low, medium, and high values that correspond to technology levels of 1, 2, and 3, respectively. For Scenario 6, the level of technology selected was high, which meant the processing capacity of the facility was approximately 150,000 tons/year with an efficiency rate of 95%. This means the facility is able to remove 95% of recyclable material from the total amount of material processed. 5% of the total amount of material collected for disposal was sent to the material recovery facility. Figure 36 shows an 80,000 ton/year increase in the amount of recyclable material diverted. This did not significantly affect the amount of material collected for disposal or in the landfill. The recycling rate increased by less than 1%. Considering the limitations of the

processing capacity of the facility, the small impact on the recycling rate is a logical response to the implementation of a material recovery facility.

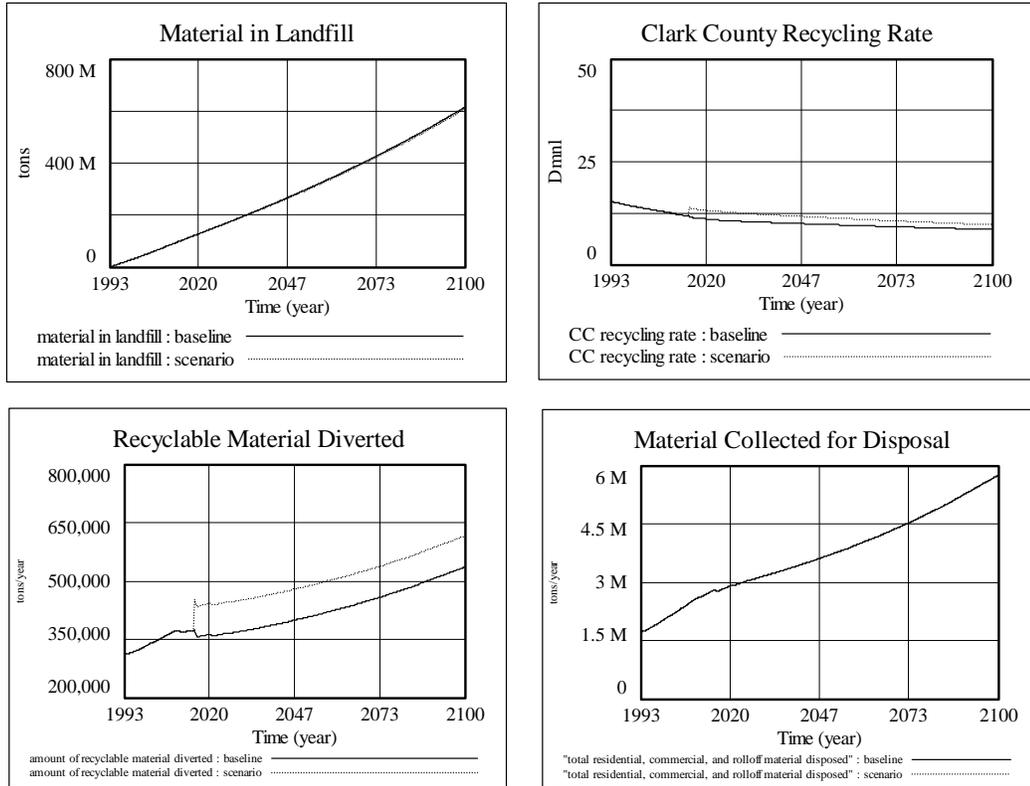


Figure 36. Scenario 6 Model Output: Implementation of Material Recovery Facility

Chapter V

DISCUSSION

Evaluation of Results

I hypothesized that one way to increase the Clark County recycling rate was to increase tourist-related material diversion. After using the model, I found that this did not have as large an impact as I expected; the effect was relatively small compared to changes in diversion from other sources. While the material generated by 39 million tourists is significant, there is more material being generated by the growing local population and businesses in Clark County. My second hypothesis was that an increase in multi-family material diversion would cause an increase in the recycling rate. This hypothesis was supported by my results. Increasing multi-family diversion, as was done in Scenario 2 and 5, contributed to increasing the recycling rate beyond the 25% State goal. My third hypothesis was that building a material recovery facility to process discarded material would increase the recycling rate. This hypothesis was not supported by my results. When I used the model to test the implementation of a material recovery facility as done in Scenario 6, this had little impact on the recycling rate. The limitations of the facility's processing capacity and the amount of residual material in discarded material resulted in only a slight increase in the amount recyclable material diverted.

Although Scenario 1, in which material generation was decreased, did not increase the recycling rate, it did have a similar effect on the amount of material collected for disposal and sent to the landfill as in Scenario 2. The ultimate goal of recycling is to reduce the amount of material sent to landfills and reduce our demand for virgin resources. Thus, decreasing the amount of material generated in Clark County is one potential way to decrease the amount of material sent to Apex landfill. Scenario 2, which tested the affect of increasing residential and multi-family diversion, and Scenario 5, which tested the affect of increasing residential, multi-family, other commercial diversion, and roll-off diversion, were the most effective in increasing the recycling rate. These are the material generators that should be focused on when developing policy options to increase the recycling rate.

I would recommend that decision-makers focus on residential and multi-family recycling programs as part of a policy to increase the recycling rate. The Clark County population is projected to continue growing into the future (CCDCP, 2007). It was assumed that as the population size increases, so will the amount of material generated. Thus, the amount of residential and multi-family material generated will be a constant source of material that could potentially be diverted.

Table 1 and Table 2 show that recycling programs which generated both high and low recycling rates provided weekly curbside collection of recyclables. The existence of a curbside residential recycling program is only the first step. The number of residents participating in the program and the amount of recyclable material diverted is also important. A common problem with recycling

programs at multi-family locations is that there is no control over the type of material that is placed in recycling bins. Often, recycling bins at apartments are treated as waste collection bins, making recycling efforts ineffective (T. Pike-Nordstrom, personal communication, March 6, 2008) However, effective multi-family recycling programs have been implemented across the U.S. The EPA suggests encouraging resident and management participation, making programs convenient, educating participants, and providing feedback to residents on their efforts (EPA, 1999). It would be possible to implement multi-family recycling programs to suit Clark County residents.

Decision-makers should also focus on increased diversion from roll-off and other commercial sources. A large amount of material is collected yearly from roll-off sources. Even if construction activities decrease, this will continue to be a large source for material generation. Implementing a recycling program to increase diversion from roll-off collection would increase the Clark County recycling rate.

It would be difficult to divert 100% of recyclable material from a single source. When looked at in isolation, tourist-related and K-12 education-related diversion had the least effect on the diversion rate, less than a 1% increase. However, residential and roll-off material had the strongest effect, causing the recycling rate to increase between 3 and 5%. The diversion of other commercial material caused the recycling rate to increase by about 2%. Hence, I recommend that tourist-related and K-12 education material diversion should not be the primary focus of any recycling policies. I would also advise against the

implementation of a material recovery facility. In 1992, the average cost of processing material and maintaining a material recovery facility was \$56 per ton (Chang & Wang, 1995) meaning it would be very expensive to maintain this type of facility. A fraction of those costs could potentially be used to increase the recycling rate through other methods. Increasing residential diversion would have a stronger impact on the recycling rate than implementing the use of a material recovery facility.

I interviewed Steven DeStefano, Recycling Manager at Republic Services, to see what Clark County is doing to increase the recycling rate. DeStefano stated that there are nine communities participating in pilot recycling programs being conducted in Clark County, which will last about 1-1.5 years. There are also pilot programs going on at two private schools and four multi-family communities. He also said that there is a large amount of control over the collection of recyclables in participating multi-family communities that are geared for elderly residents, making the recycling program very efficient (S. DeStefano, personal communication, May 27, 2008).

Role of Feedback

System dynamics models are useful for representing feedback processes in complex systems. By going through the system dynamics modeling process, I expected to identify feedback processes that were affecting the Clark County recycling rate. There was no feedback in the model due to the long lifespan of Apex landfill which services Clark County and the relatively shorter time horizon

of the model. In areas where there is limited space for waste disposal, the amount of material that can be sent to landfills is limited. Once the landfill capacities are reached, those populations will be forced to find alternative ways to manage their material. This creates motivation to extend the life of these landfills as long as possible. Landfill lifetimes can be extended by economic controls such as tipping fees at landfills or by increased recycling and incineration of material. In Clark County, there are no constraints on the amount of landfill space available in the approximate 100 year time horizon used in the model.

Due to the limited amount of industrial activity in Clark County, there is not a high demand for materials used during consumer product production. A demand for recyclable material is part of what drives the diversion of material. In Clark County, the relationship between supply and demand for recyclable items is not affecting diversion. For example, since there is a limited demand for recyclable glass material in Clark County, Republic transports the glass material to areas where there is a demand, such as California. It is more expensive for Republic to transport glass material since transportation costs are higher than the revenue generated from selling the glass material (R. Coyle, personal communication, March 13, 2008).

Use of Model

I developed the model to identify and evaluate policy options that could increase the Clark County recycling rate. The types of policies that can be tested

by the model are those that change material generation and diversion rates for residential, multi-family, tourist-related, K-12 education-related and commercial sources and the implementation of a material recovery facility. The model is not intended to answer questions about how specific changes or implementation of recycling programs will affect the recycling rate. For example, the model cannot test how increasing the size of residential recycling bins or the number of drop-off recycling centers would affect the recycling rate. The model is useful for answering questions regarding how changes in material generation and diversion rates affect the Clark County recycling rate. Overall, this is a simple model created to identify which sources of material generation should be studied further to increase the recycling rate. This model could be improved with more accurate information on the recyclable portions of material generated from different sources and on the amounts of material diverted through commercial recycling programs.

Concluding Remarks

This model serves as a first step in understanding how to increase the Clark County recycling rate. It provided the framework on the mechanics of how material could be diverted to increase the recycling rate. The next step would be to study how motivational factors affect residential and commercial recycling rates. This will help identify the difficulty of increasing diversion from different types of sources. For example, while increasing roll-off diversion may increase the recycling rate more than other types of diversion, it may be very challenging

to implement a roll-off material recycling program. With residential recycling, the curbside recycling program is already available; it could be easier to adapt an existing program than it is to create a new one. However, these types of conclusions can not be made until the system structure of the motivational drivers behind recycling and the difficulty of program implementation are further understood.

APPENDIX I

Types of Variables

Variable Names	Variable Type
amount of all commercial material generated excluding rolloff	Auxiliary
amount of all other commercial material generated	Auxiliary
amount of commercial material disposed by Republic	Auxiliary
amount of commercial material diverted for recycling by Republic	Auxiliary
amount of commercial material diverted through private businesses	Auxiliary
amount of construction and other material disposed by rolloff	Auxiliary
amount of construction and other material handled by rolloff	Auxiliary
amount of construction and other rolloff material diverted for recycling	Auxiliary
amount of construction material generated	Auxiliary
"amount of construction material self-hauled"	Auxiliary
"amount of K-12 material diverted for recycling"	Auxiliary
"amount of K-12 material generated"	Auxiliary
"amount of K-12 material that is recyclable"	Auxiliary
amount of material accepted by MRF	Auxiliary
amount of material diverted by source	Auxiliary
amount of material sent to MRF	Auxiliary
amount of MRF material processed	Auxiliary
amount of MRF material sold	Auxiliary
"amount of multi-family material diverted for recycling"	Auxiliary
"amount of multi-family material generated"	Auxiliary
"amount of multi-family material that is recyclable"	Auxiliary
amount of other commercial material diverted for recycling	Auxiliary
amount of other commercial material that is recyclable	Auxiliary
amount of other recyclable commercial material diverted for recycling	Auxiliary
amount of private material sold	Auxiliary

amount of recyclable commercial material diverted for recycling	Auxiliary
"amount of recyclable K-12 material diverted for recycling"	Auxiliary
amount of recyclable material diverted	Auxiliary
"amount of recyclable multi-family material diverted for recycling"	Auxiliary
amount of recyclable residential material diverted for recycling	Auxiliary
amount of recyclable rolloff material diverted for recycling	Auxiliary
amount of recyclable tourist material diverted for recycling	Auxiliary
amount of Republic material sold	Auxiliary
amount of residential material disposed	Auxiliary
amount of residential material diverted for recycling	Auxiliary
amount of residential material generated	Auxiliary
amount of residential material that is recyclable	Auxiliary
amount of residual and material beyond private capacity	Auxiliary
amount of residual and material beyond Republic capacity	Auxiliary
amount of residual material in private material	Auxiliary
amount of residual material in Republic material	Auxiliary
amount of rolloff material that is recyclable	Auxiliary
amount of tourist material diverted for recycling	Auxiliary
amount of tourist material that is recyclable	Auxiliary
"amount of tourist-related material generated"	Auxiliary
average capital costs for MRF construction	Constant
average length of tourist visit	Constant
average MRF processing capacity in tons per day	Constant
average operation and maintenance costs per ton	Constant
"avg. number of people in a household"	Constant
"avg. number of people in a multi-family unit"	Constant
capital costs for MRF construction	Auxiliary
CC diversion rate	Auxiliary
CC population	Auxiliary
CC population at previous year	Auxiliary
CC population growth rate	Auxiliary

CC population LOOKUP	Lookup
CC recycling rate	Auxiliary
change in household material generation rate	Constant
change in material generated per multi-family unit"	Constant
change in material generated per student	Constant
change in portion commercial waste from other sources	Constant
"change in portion of K-12 diversion"	Constant
change in portion of material sent to MRF	Constant
"change in portion of multi-family diversion"	Constant
change in portion of other commercial material diversion	Constant
change in portion of residential diversion	Constant
change in portion of rolloff diversion	Constant
change in portion of tourist waste diversion	Constant
change in waste generated per tourist	Constant
CO2 gas emissions per ton sent to landfill	Constant
commercial diversion rate	Auxiliary
commercial material collected by Republic	Auxiliary
commercial material collected for disposal	Auxiliary
commercial material collected for recycling by private businesses	Auxiliary
commercial material processed by private businesses	Auxiliary
commercial material production	Auxiliary
commercial recycling effectiveness ratio	Auxiliary
commercial material diverted for processing by private businesses	Level
construction and other rolloff material collected for disposal	Auxiliary
construction material LOOKUP	Lookup
construction material production	Auxiliary
"construction material self-hauled to landfill"	Auxiliary
construction related material diverted for recycling	Auxiliary
days in school per year	Constant
days to year conversion	Constant

effect of recycling collection LOOKUP	Lookup
effect of recycling collection multiplier	Auxiliary
efficiency at MRF	Auxiliary
efficiency at MRF LOOKUP	Lookup
FINAL TIME	Constant
fraction of construction material collected by rolloff	Constant
fraction of construction material self-hauled"	Auxiliary
"fraction of population living in multi-family units"	Auxiliary
fraction of population living in single family homes	Constant
GHG emissions due to landfill	Auxiliary
household material generation rate	Constant
INITIAL TIME	Constant
lbs to tons conversion	Constant
level of technology	Constant
material at MRF	Level
material beyond private processing capacity	Auxiliary
material beyond Republic processing capacity	Auxiliary
material collection runs per week	Constant
material delivered to landfill	Auxiliary
material diverted for processing by Republic	Level
material generated by businesses	Level
material generated by construction	Level
material generated by single family homes	Level
"material generated per multi-family unit"	Constant
material generated per student	Constant
material generated per tourist	Constant
material handled at transfer stations	Level
material in landfill	Level
material processed by MRF	Auxiliary
material processed by Republic	Auxiliary
material processed through private recycling businesses	Auxiliary

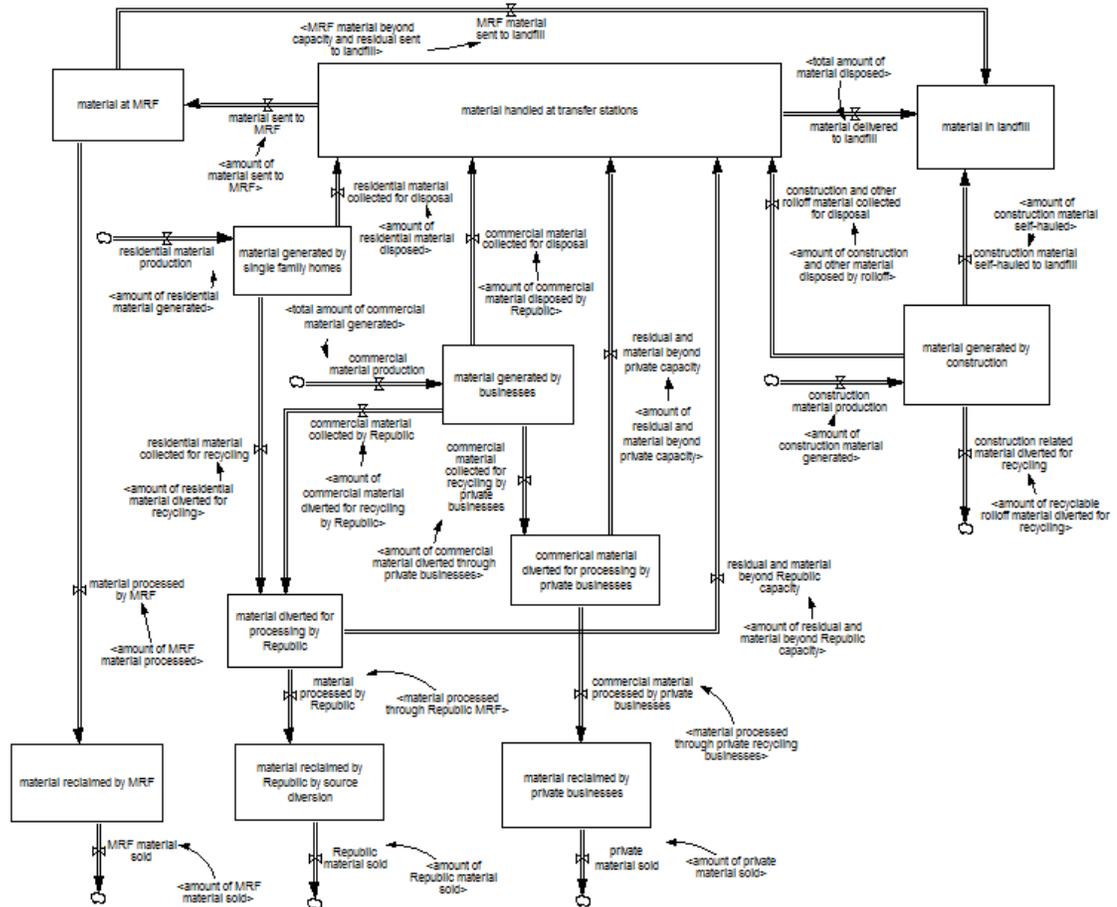
material processed through Republic MRF	Auxiliary
material reclaimed by MRF	Level
material reclaimed by private businesses	Level
material reclaimed by Republic by source diversion	Level
material sent to MRF	Auxiliary
methane gas emissions per ton sent to landfill	Constant
methane MTCE conversion value	Constant
MRF material beyond capacity	Auxiliary
MRF material beyond capacity and residual sent to landfill	Auxiliary
MRF material sent to landfill	Auxiliary
MRF material sold	Auxiliary
"multi-family, K-12, and tourism material generated"	Auxiliary
nonrecyclable portion of private material diverted for recycling	Constant
nonrecyclable portion of Republic material diverted for recycling	Constant
number of homes per collection route	Constant
"number of multi-family units"	Auxiliary
number of residential routes	Auxiliary
"number of single-family households"	Auxiliary
"number of students in K-12 Education"	Auxiliary
number of tourists visiting per year	Auxiliary
portion of commercial material diverted through private businesses	Auxiliary
portion of commercial material diverted through Republic	Constant
portion of commercial waste from other sources	Constant
"portion of K-12 material usually diverted"	Constant
portion of material sent to MRF	Constant
"portion of multi-family material usually diverted"	Constant
portion of other commercial material usually diverted	Constant
"portion of population in K-12 education"	Constant
portion of reclaimed material in market demand	Constant
portion of residential material usually diverted	Constant
portion of rolloff material usually diverted	Constant

portion of tourist material usually diverted	Constant
private material sold	Auxiliary
processing capacity of private recycling businesses	Constant
processing capacity of Republic MRF	Constant
recyclable material sent to MRF	Auxiliary
"recyclable portion of K-12 material"	Constant
recyclable portion of material sent to MRF	Constant
"recyclable portion of multi-family material"	Constant
recyclable portion of other commercial material	Constant
recyclable portion of residential material	Constant
recyclable portion of rolloff material	Constant
recyclable portion of tourist material	Constant
recycling collection runs per week	Constant
Republic material sold	Auxiliary
residential and commercial material collected by Republic	Auxiliary
residential diversion rate	Auxiliary
residential material collected for disposal	Auxiliary
residential material collected for recycling	Auxiliary
residential material production	Auxiliary
residential recycling effectiveness ratio	Auxiliary
residual and material beyond private capacity	Auxiliary
residual and material beyond Republic capacity	Auxiliary
residual MRF material	Auxiliary
SAVEPER	Auxiliary
technology multiplier on capacity	Auxiliary
technology multiplier on capacity LOOKUP	Lookup
technology multiplier on construction costs LOOKUP	Lookup
technology multiplier on construction costs	Auxiliary
technology multiplier on operation and maintenance costs	Auxiliary
technology multiplier on operation and maintenance costs LOOKUP	Lookup
TIME STEP	Constant

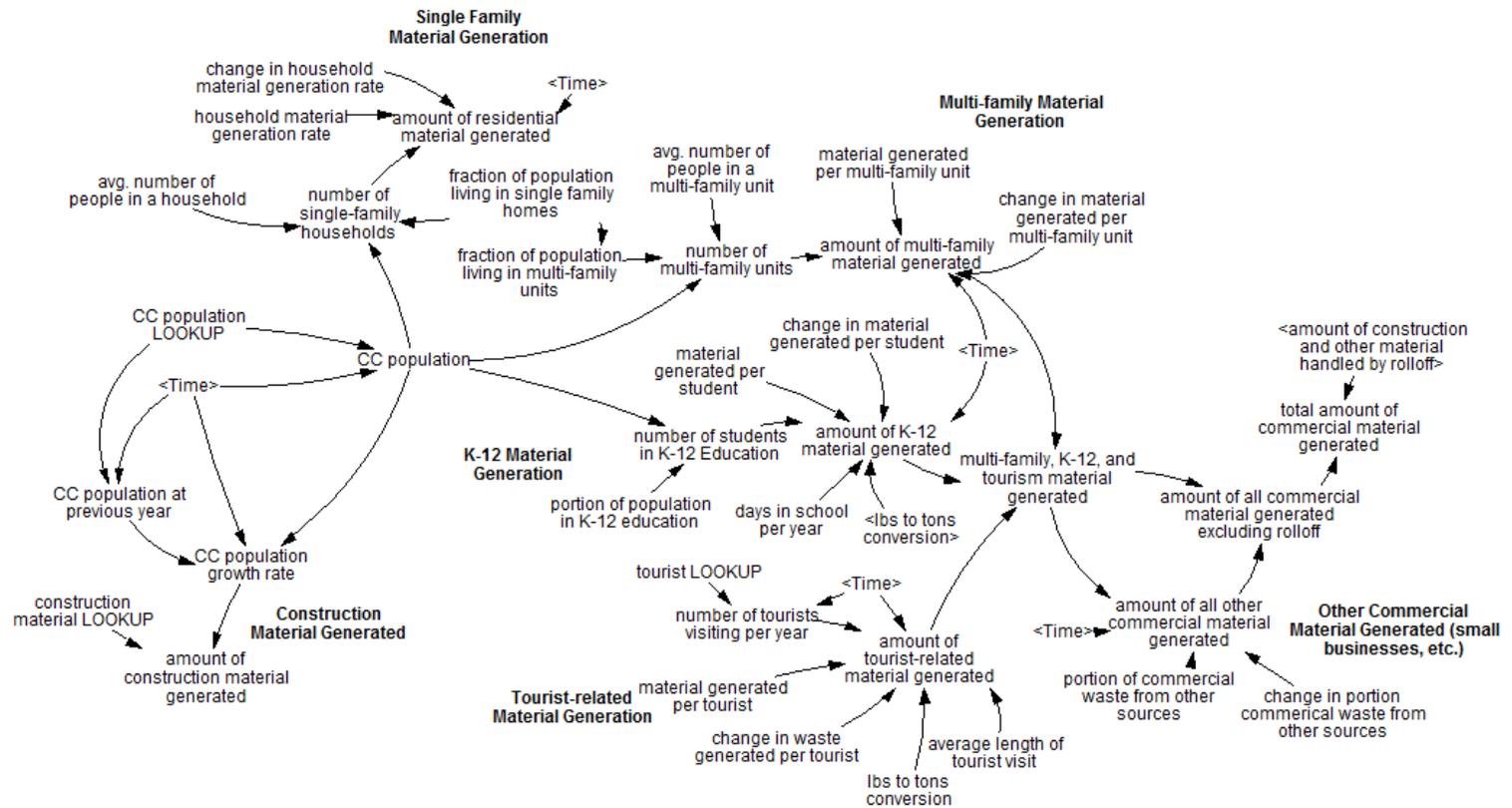
total amount of commercial material diverted for recycling	Auxiliary
total amount of commercial material generated	Auxiliary
total amount of commercial material that is recyclable	Auxiliary
total amount of material disposed	Auxiliary
"total amount of residential, commercial, construction material disposed"	Auxiliary
total amount of residual in recyclable material diverted by	Auxiliary
total MRF costs	Auxiliary
total MRF operation and maintenance costs	Auxiliary
total reclaimed material	Auxiliary
total residential route runs per week	Auxiliary
"total residential, commercial, and rolloff material disposed"	Auxiliary
total residual and material beyond capacity	Auxiliary
total runs per week	Auxiliary
tourist LOOKUP	Lookup
yearly processing capacity of MRF	Auxiliary

APPENDIX II

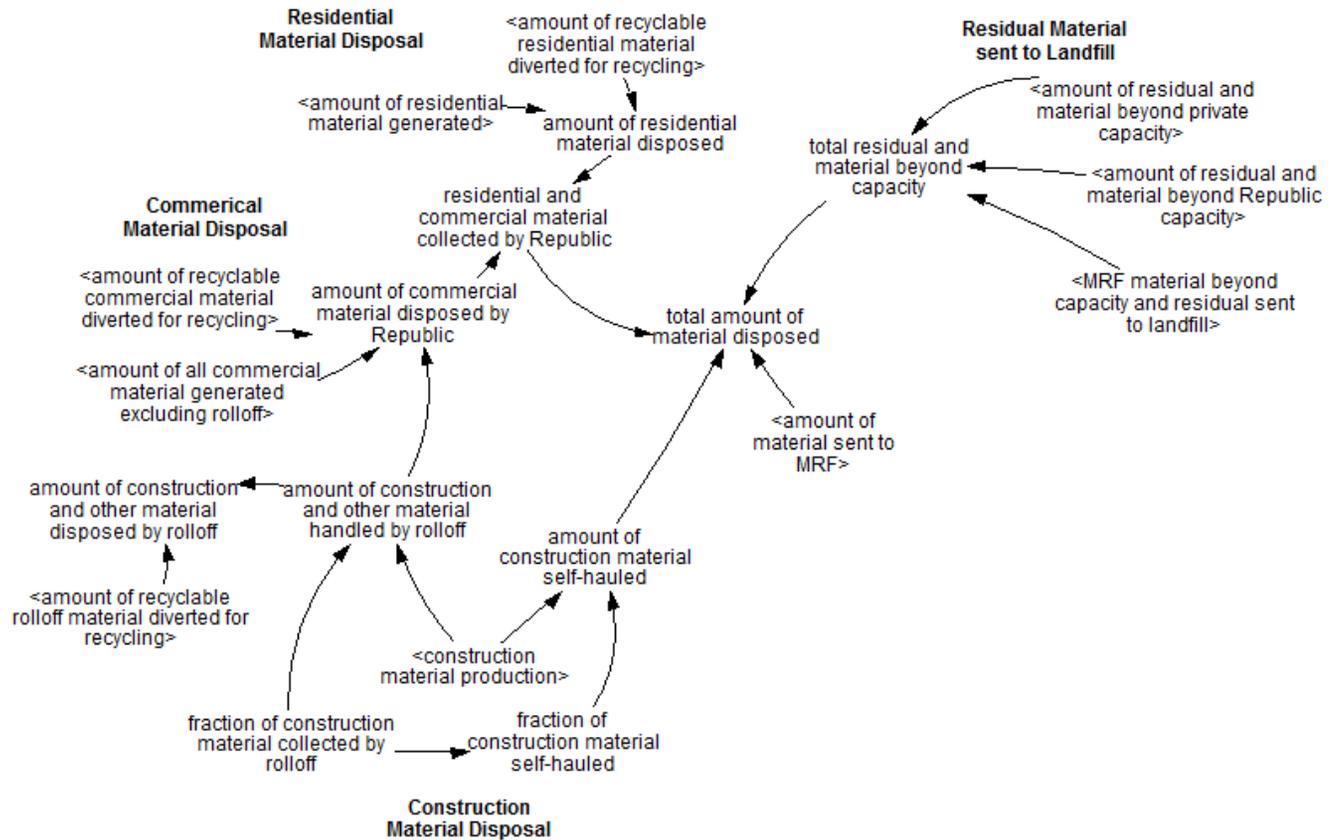
Clark County Diversion Model



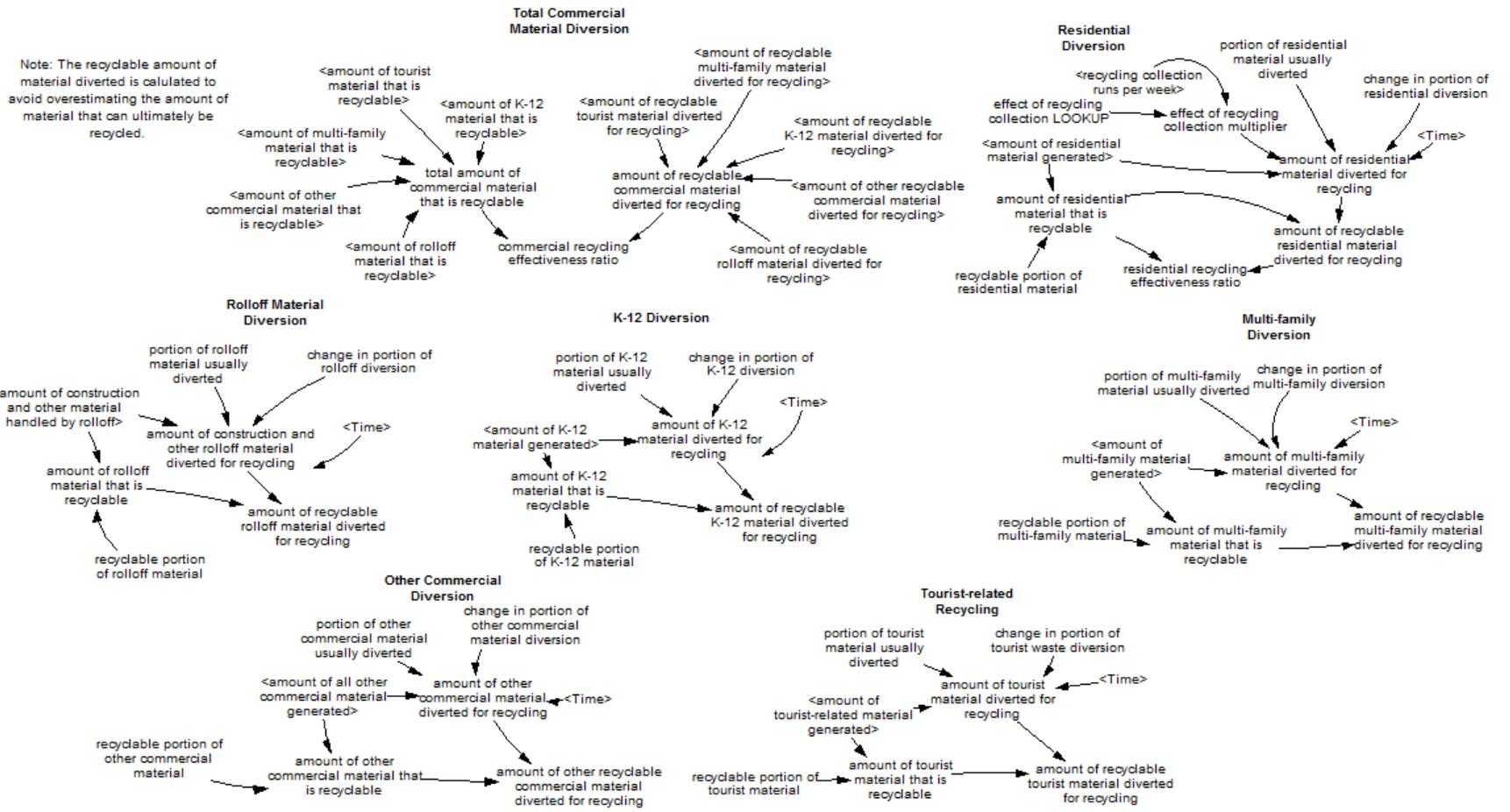
Clark County Diversion Model 1. Material Flow



Clark County Diversion Model
2. Material Generation

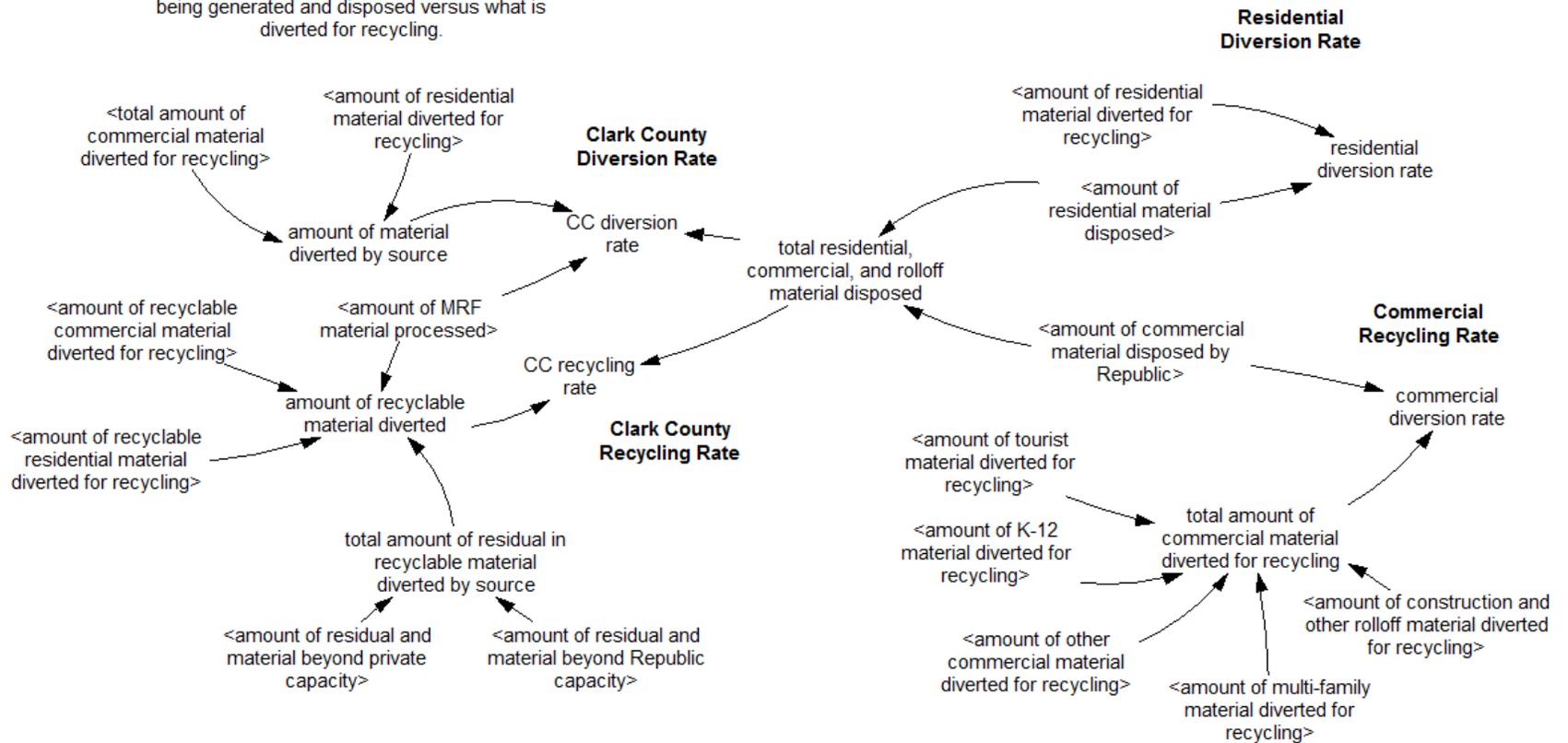


Clark County Diversion Model
3. Material Disposal

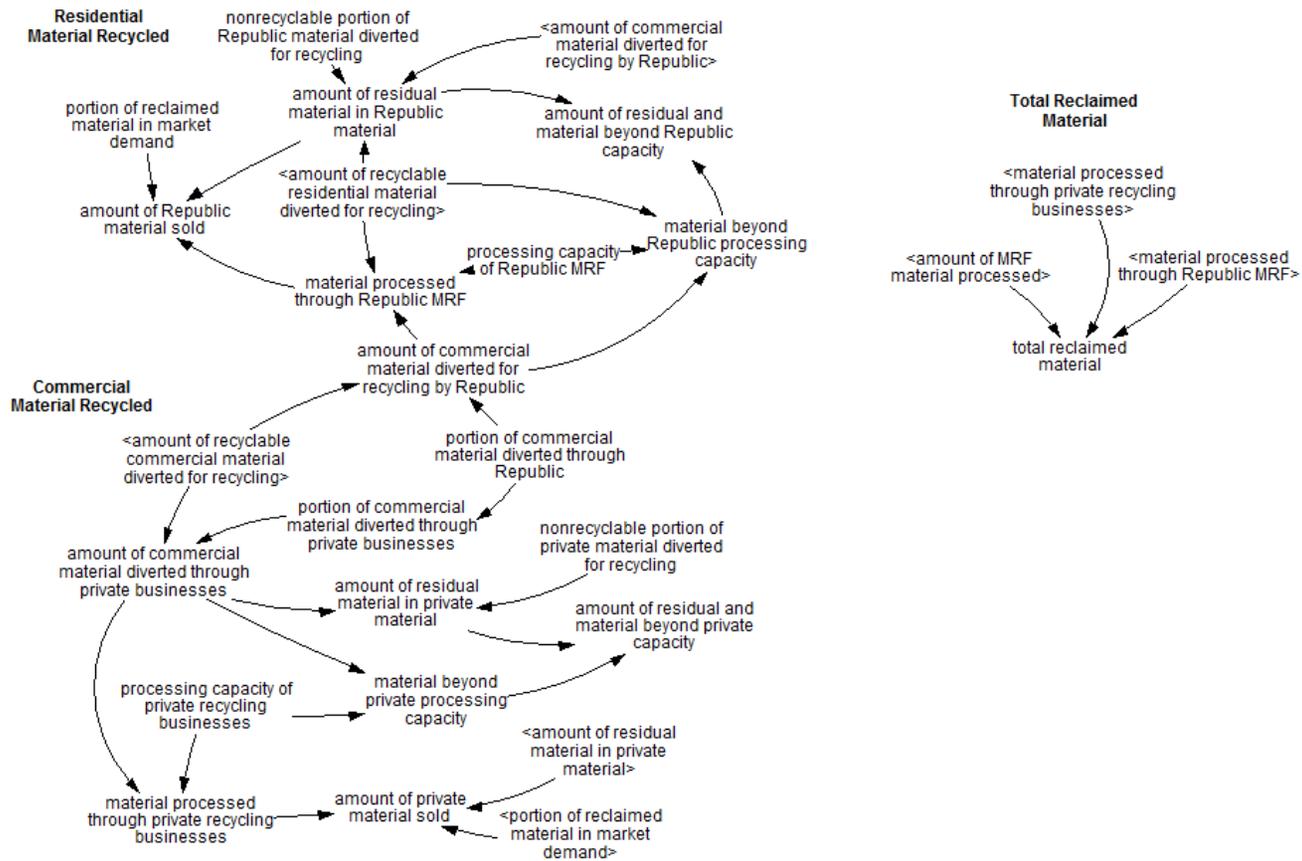


Clark County Diversion Model
4. Material Diversion

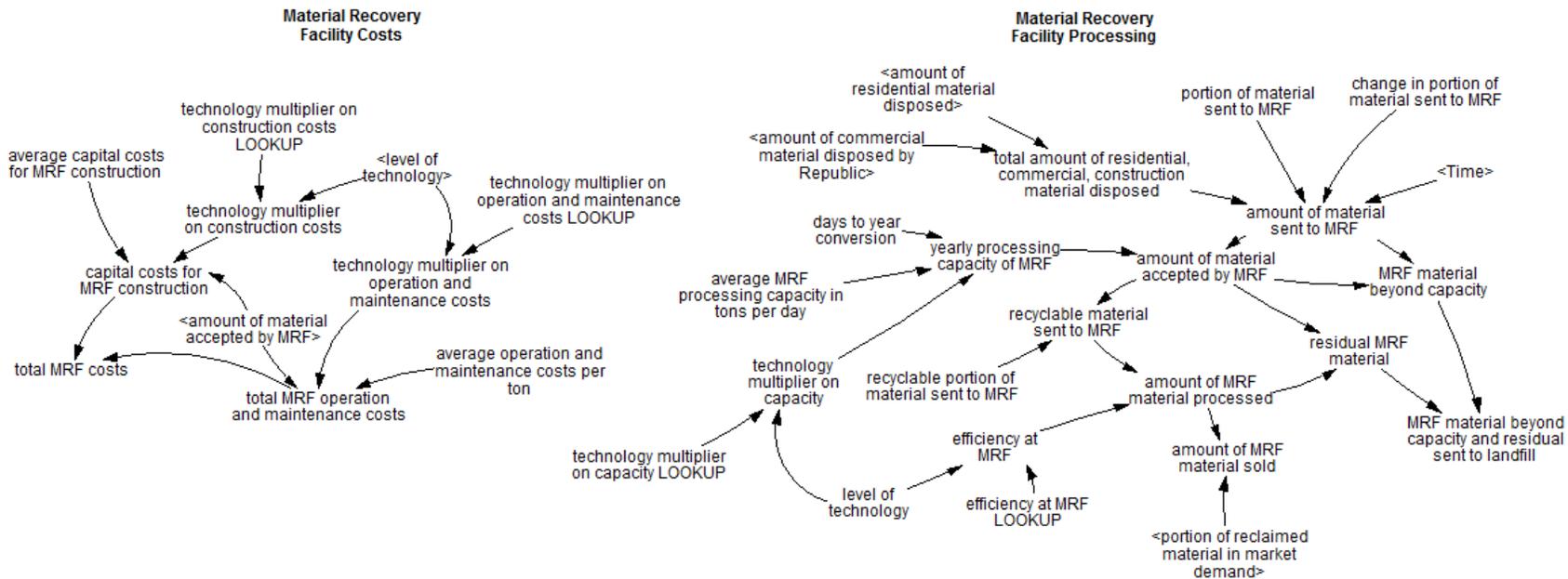
Note: The commercial recycling rate and the overall recycling rate are decreasing over time. This is due to the increasing amount of material being generated and disposed versus what is diverted for recycling.



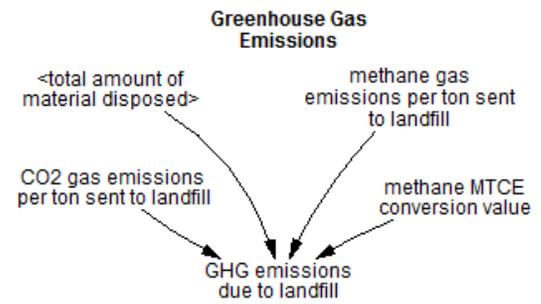
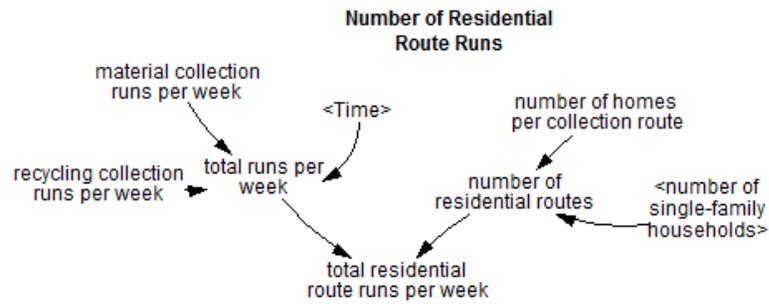
Clark County Diversion Model
5. Diversion Rates



Clark County Diversion Model
6. Material Processing



Clark County Diversion Model
7. MRF Cost and Processing



Clark County Diversion Model
8. Other Calculations

Material Generation

change in household material generation rate (tons/year/household)

"change in material generated per multi-family unit" (tons/year/unit)

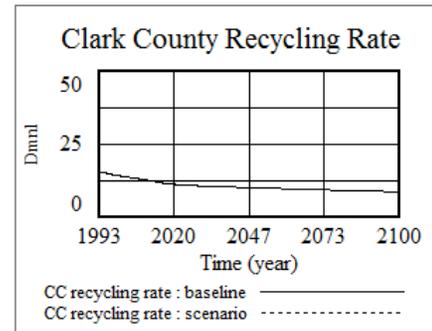
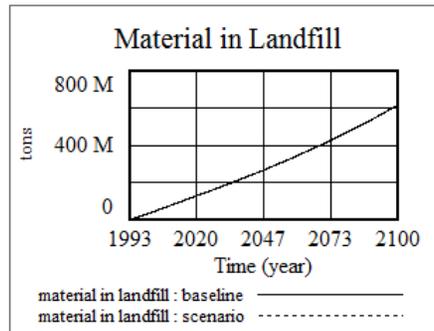
change in material generated per student (lbs/person/day)

change in waste generated per tourist (lbs/tourist/day)

Processing Capacities

level of technology

change in portion of material sent to MRF



Diversion Rates

change in portion of residential diversion

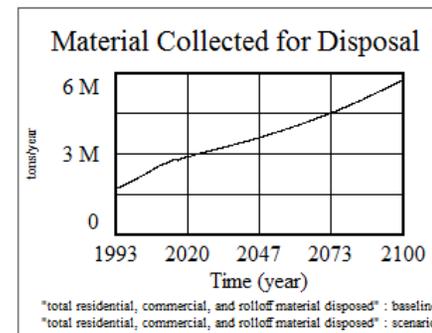
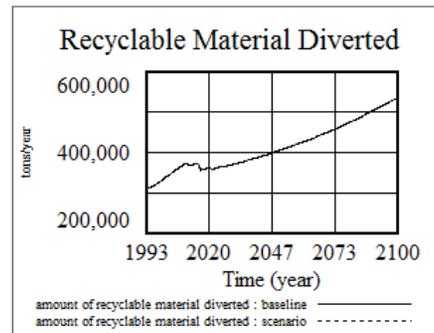
"change in portion of K-12 diversion"

"change in portion of multi-family diversion"

change in portion of tourist waste diversion

change in portion of other commercial material diversion

change in portion of rolloff diversion



Clark County Diversion Model 9. Policy Option Screen

APPENDIX III

Model Equations

- (001) amount of all commercial material generated excluding rolloff=
amount of all other commercial material generated+"multi-family, K-12,
and tourism material generated"
Units: tons/year
Comments: Represents the total amount of commercial material
generated except for material collected by roll-off disposal services.
- (002) amount of all other commercial material generated=
IF THEN ELSE(Time>=2010, "multi-family, K-12, and tourism material
generated"*change in portion commercial waste from other sources,
"multi-family, K-12, and tourism material generated"*portion of
commercial waste from other sources)
Units: tons/year
Comments: Determines the amount of all other commercial material
generated (such as from small businesses) by multiplying the amount of
multi-family, K-12, and tourist material generated by the portion of
commercial waste from other sources.
- (003) amount of commercial material disposed by Republic=
amount of all commercial material generated excluding rolloff+amount
of construction and other material handled by rolloff-amount of
recyclable commercial material diverted for recycling
Units: tons/year
Comments: Determined by subtracting the commercial waste diverted for
recycling from the amount of waste generated
- (004) amount of commercial material diverted for recycling by Republic=
amount of recyclable commercial material diverted for recycling*portion
of commercial material diverted through Republic
Units: tons/year
Comments: A portion of the commercial material diverted is from Republic
and the rest is from private businesses.
- (005) amount of commercial material diverted through private businesses=
amount of recyclable commercial material diverted for recycling*portion
of commercial material diverted through private businesses
Units: tons/year

- (006) amount of construction and other material disposed by rolloff=
amount of construction and other material handled by rolloff-amount of
recyclable rolloff material diverted for recycling
Units: tons/year
- (007) amount of construction and other material handled by rolloff=
construction material production*fraction of construction material
collected by rolloff
Units: tons/year
Comments: Represents the amount of commercial material collected by
roll-off services.
- (008) amount of construction and other rolloff material diverted for recycling=
IF THEN ELSE(Time>=2010, amount of construction and other
material handled by rolloff *change in portion of rolloff diversion,
amount of construction and other material handled by rolloff*portion of
rolloff material usually diverted)
Units: tons/year
Comments: Determined by multiplying the amount of rolloff material
generated by the portion diverted for recycling.
- (009) amount of construction material generated=
construction material LOOKUP(CC population growth rate)
Units: tons/year
Comments: Estimates the amount of construction material generated as a
function of the CC population growth rate
- (010) "amount of construction material self-hauled"=
construction material production*"fraction of construction material self-
hauled"
Units: tons/year
Comments: Represents construction material that is hauled by the
material generators to the landfill.
- (011) "amount of K-12 material diverted for recycling"=
IF THEN ELSE(Time>=2010, "change in portion of K-12
diversion"*"amount of K-12 material generated", "portion of K-12
material usually diverted"*"amount of K-12 material generated")
Units: tons/year
Comments: Determined by multiplying the amount of K-12 material
generated by the portion diverted for recycling.

- (012) "amount of K-12 material generated"=
 IF THEN ELSE(Time>=2010, "number of students in K-12 Education"*change in material generated per student/lbs to tons conversion *days in school per year, "number of students in K-12 Education"*material generated per student /lbs to tons conversion*days in school per year)
 Units: tons/year
 Comments: Determines K-12 material generated by multiplying the number of students by the student material generation rate.
- (013) "amount of K-12 material that is recyclable"=
 "amount of K-12 material generated"*"recyclable portion of K-12 material"
 Units: tons/year
 Comments: Amount of K-12 material generated the is recyclable.
- (014) amount of material accepted by MRF=
 MIN(yearly processing capacity of MRF, amount of material sent to MRF)
 Units: tons/year
- (015) amount of material diverted by source=
 total amount of commercial material diverted for recycling+amount of residential material diverted for recycling
 Units: tons/year
- (016) amount of material sent to MRF=
 IF THEN ELSE(Time>=2015, change in portion of material sent to MRF*"total amount of residential, commercial, construction material disposed", portion of material sent to MRF*"total amount of residential, commercial, construction material disposed")
 Units: tons/year
 Comments: Represents the implementation and use of a MRF in 2015 where material collected for disposal will be routed to the MRF.
- (017) amount of MRF material processed=
 recyclable material sent to MRF*efficiency at MRF
 Units: tons/year
- (018) amount of MRF material sold=
 amount of MRF material processed*portion of reclaimed material in market demand
 Units: tons/year
 Comments: Assumes a small portion of reclaimed material will not be sold due to changes in market demand.

- (019) "amount of multi-family material diverted for recycling"=
 IF THEN ELSE(Time>=2010, "change in portion of multi-family diversion"*"amount of multi-family material generated", "portion of multi-family material usually diverted"*"amount of multi-family material generated")
 Units: tons/year
 Comments: Determined by multiplying the amount of multi-family material generated by the portion diverted for recycling.
- (020) "amount of multi-family material generated"=
 IF THEN ELSE(Time>=2010, "change in material generated per multi-family unit"*"number of multi-family units" , "material generated per multi-family unit"*"number of multi-family units")
 Units: tons/year
 Comments: Determines the amount of multi-family material generated by multiplying the number of multi-family units by the multi-family material generation rate.
- (021) "amount of multi-family material that is recyclable"=
 "amount of multi-family material generated"*"recyclable portion of multi-family material"
 Units: tons/year
 Comments: Amount of multi-family material generated the is recyclable.
- (022) amount of other commercial material diverted for recycling=
 IF THEN ELSE(Time>=2010, amount of all other commercial material generated *change in portion of other commercial material diversion, amount of all other commercial material generated*portion of other commercial material usually diverted)
 Units: tons/year
 Comments: Determined by multiplying the amount of other commercial material generated by the portion diverted for recycling.
- (023) amount of other commercial material that is recyclable=
 amount of all other commercial material generated*recyclable portion of other commercial material
 Units: tons/year
 Comments: Amount of other commercial material generated that is recyclable.
- (024) amount of other recyclable commercial material diverted for recycling=
 MIN(amount of other commercial material diverted for recycling, amount of other commercial material that is recyclable)
 Units: tons/year
 Comments: Determines the amount of other commercial material that was diverted and is recyclable.

- (025) amount of private material sold=
 (material processed through private recycling businesses-amount of residual material in private material)*portion of reclaimed material in market demand
 Units: tons/year
 Comments: Assumes a small portion of reclaimed material will not be sold due to changes in market demand.
- (026) amount of recyclable commercial material diverted for recycling=
 amount of other recyclable commercial material diverted for recycling+"amount of recyclable K-12 material diverted for recycling"
 +"amount of recyclable multi-family material diverted for recycling"+amount of recyclable tourist material diverted for recycling
 +amount of recyclable rolloff material diverted for recycling
 Units: tons/year
 Comments: Calculates the total amount of recyclable commercial material diverted for recycling. The amount of material diverted cannot be more than the amount of recyclable material. Additional material will not be recyclable and will be sent for disposal.
- (027) "amount of recyclable K-12 material diverted for recycling"=
 MIN("amount of K-12 material diverted for recycling", "amount of K-12 material that is recyclable")
 Units: tons/year
 Comments: Determines the amount of K-12 material that was diverted and is recyclable.
- (028) amount of recyclable material diverted=
 amount of recyclable commercial material diverted for recycling+amount of recyclable residential material diverted for recycling+amount of MRF material processed-total amount of residual in recyclable material diverted by source
 Units: tons/year
- (029) "amount of recyclable multi-family material diverted for recycling"=
 MIN("amount of multi-family material diverted for recycling", "amount of multi-family material that is recyclable")
 Units: tons/year
 Comments: Determines the amount of multi-family material that was diverted and is recyclable.

- (030) amount of recyclable residential material diverted for recycling=
 MIN(amount of residential material diverted for recycling, amount of residential material that is recyclable)
 Units: tons/year
 Comments: The amount of material diverted cannot be more than the amount of recyclable material. Additional material will not be recyclable and will be sent for disposal.
- (031) amount of recyclable rolloff material diverted for recycling=
 MIN(amount of construction and other rolloff material diverted for recycling, amount of rolloff material that is recyclable)
 Units: tons/year
 Comments: Determines the amount of roll-off material that was diverted and is recyclable.
- (032) amount of recyclable tourist material diverted for recycling=
 MIN(amount of tourist material diverted for recycling ,amount of tourist material that is recyclable)
 Units: tons/year
 Comments: Determines the amount of tourist material that was diverted and is recyclable.
- (033) amount of Republic material sold=
 (material processed through Republic MRF-amount of residual material in Republic material)*portion of reclaimed material in market demand
 Units: tons/year
 Comments: Assumes a small portion of reclaimed material will not be sold due to changes in market demand.
- (034) amount of residential material disposed=
 amount of residential material generated-amount of recyclable residential material diverted for recycling
 Units: tons/year
 Comments: Determined by subtracting the residential waste diverted for recycling from the amount of waste generated from single family homes.
- (035) amount of residential material diverted for recycling=
 IF THEN ELSE(Time>=2010, effect of recycling collection multiplier *change in portion of residential diversion*amount of residential material generated, portion of residential material usually diverted *amount of residential material generated)
 Units: tons/year
 Comments: 2010 is the estimated year that changes in diversion would take be implemented.

- (036) amount of residential material generated=
 IF THEN ELSE(Time>=2010, "number of single-family households"*change in household material generation rate, "number of single-family households"*household material generation rate)
 Units: tons/year
 Comments: Determined by multiplying the number of households by the household waste generation rate
- (037) amount of residential material that is recyclable=
 amount of residential material generated*recyclable portion of residential material
 Units: tons/year
 Comments: Calculates the total amount of recyclable residential material
- (038) amount of residual and material beyond private capacity=
 amount of residual material in private material+material beyond private processing capacity
 Units: tons/year
 Comments: Represents what could not be processed by private businesses.
- (039) amount of residual and material beyond Republic capacity=
 amount of residual material in Republic material+material beyond Republic processing capacity
 Units: tons/year
 Comments: Represents contaminated, nonrecyclable material and material beyond Republic's MRF processing capacity.
- (040) amount of residual material in private material=
 amount of commercial material diverted through private businesses*nonrecyclable portion of private material diverted for recycling
 Units: tons/year
 Comments: Some of the material diverted will be contaminated or nonrecyclable.
- (041) amount of residual material in Republic material=
 nonrecyclable portion of Republic material diverted for recycling*(amount of recyclable residential material diverted for recycling+amount of commercial material diverted for recycling by Republic)
 Units: tons/year
 Comments: Some of the material diverted will be contaminated or nonrecyclable.

- (042) amount of rolloff material that is recyclable=
amount of construction and other material handled by rolloff*recyclable
portion of rolloff material
Units: tons/year
Comments: Amount of rolloff material generated the is recyclable.
- (043) amount of tourist material diverted for recycling=
IF THEN ELSE(Time>=2010 , change in portion of tourist waste
diversion*"amount of tourist-related material generated", portion of
tourist material usually diverted*"amount of tourist-related material
generated")
Units: tons/year
Comments: Determined by multiplying the amount of tourist material
generated by the portion diverted for recycling.
- (044) amount of tourist material that is recyclable=
"amount of tourist-related material generated"*recyclable portion of
tourist material
Units: tons/year
Comments: Amount of tourist material generated that is recyclable.
- (045) "amount of tourist-related material generated"=
IF THEN ELSE(Time>=2010, number of tourists visiting per
year*change in waste generated per tourist*average length of tourist
visit/lbs to tons conversion , number of tourists visiting per
year*material generated per tourist*average length of tourist visit/lbs to
tons conversion)
Units: tons/year
Comments: Determines the amount of tourist-related material generated
by multiplying the number of tourists by the amount of material
generated per tourist.
- (046) average capital costs for MRF construction=
3e+006
Units: dollars/year
Comments: Average capital cost of a MRF was 3.3 million US dollars in
1992. Source: Chang and Wang (1995)
- (047) average length of tourist visit=
3.6
Units: day/year
Comments: Taken from CC website. Average visit duration is 3.6 days.

- (048) average MRF processing capacity in tons per day=
130
Units: tons/day
Comments: On average, MRFs are processing 131.45 tons of material per day. Source: Chang & Wang, 1995.
- (049) average operation and maintenance costs per ton=
56
Units: dollars/tons
Comments: The approximate cost of processing 1 ton of material is about \$56 per ton. Source: Chang & Wang, 1995.
- (050) "avg. number of people in a household"=
2.65
Units: people/household
Comments: Taken from the U.S. Census Bureau (2002). 2.65 is the average number of people per household
- (051) "avg. number of people in a multi-family unit"=
2.56
Units: people/units
Comments: Based on data for average household size of renter-occupied unit. Source: US Census Bureau (2006)
- (052) capital costs for MRF construction=
IF THEN ELSE(amount of material accepted by MRF>0, average capital costs for MRF construction*technology multiplier on construction costs, 0)
Units: dollars/year
- (053) CC diversion rate=
((amount of material diverted by source+amount of MRF material processed)/("total residential, commercial, and rolloff material disposed"+amount of material diverted by source))*100
Units: Dmnl
Comments: Calculated using the total amount of material diverted for recycling, despite if it is recyclable or not.
- (054) CC population=
CC population LOOKUP(Time)
Units: people
Comments: Refer to LOOKUP table

- (055) CC population at previous year=
 IF THEN ELSE(Time=1990 , 797142 , CC population LOOKUP
 (Time-1))
 Units: people
 Comments: Population at previous year needed to determine population
 growth rate.
- (056) CC population growth rate=
 IF THEN ELSE(Time=1990, 4, (CC population-CC population at
 previous year)/CC population at previous year*100)
 Units: Dmnl
 Comments: Determine the % change in growth from one year to the next.
- (057) CC population LOOKUP
 ([(1990,0)(2100,8e+006)],(1990,797142),(1995,1.04069e+006),(2000,1.42
 869e+006),(2005,1.8157e+006),(2010,2.28894e+006),(2015,2.736e+006)
 ,(2020,3.05958e+006),(2025,3.30695e+006),(2030,3.51669e+006),(2035,
 3.71893e+006),(2045,4.14887e+006),(2055,4.62851e+006),(2065,5.1636
 e+006),(2075,5.76056e+006),(2085,6.42652e+006),(2100,7.57257e+006)
)
 Units: people
 Comments: Information from 1990-2008 is based on data from CC Dept.
 of Comprehensive Planning. Information from 2008 to 2036 is based
 on estimated CC population growth forecasts from CBER. Values
 after 2035 are based on a 1.1% growth rate. Sources: CCDCP,
 2007; CBER, 2007.\!\!\!
- (058) CC recycling rate=
 (amount of recyclable material diverted/("total residential, commercial,
 and rolloff material disposed"+amount of recyclable material
 diverted))*100
 Units: Dmnl
 Calculated using the recyclable amount of material diverted.
 Comments: This rate is lower than the diversion rate because it considers
 recyclable and residual material.
- (059) change in household material generation rate=
 1.8
 Units: tons/year/household
 Comments: Determines the effects of changing the household material
 generation rate.

- (060) "change in material generated per multi-family unit"=
1.2
Units: tons/year/units
Comments: Determines the effects of changing multi-family units material generation rate.
- (061) change in material generated per student=
1.2
Units: lbs/people/day
Comments: Determines the effects of changing the student material generation rate.
- (062) change in portion commercial waste from other sources=
0.33
Units: Dmnl
- (063) "change in portion of K-12 diversion"=
0.1
Units: Dmnl
Comments: Determines the effects of changing K-12 diversion.
- (064) change in portion of material sent to MRF=
0
Units: Dmnl
- (065) "change in portion of multi-family diversion"=
0.02
Units: Dmnl
Comments: Determines the effects of changing multi-family diversion.
- (066) change in portion of other commercial material diversion=
0.2
Units: Dmnl
Comments: Determines the effects of changing other commercial diversion.
- (067) change in portion of residential diversion=
0.059
Units: Dmnl
Comments: Represents a change in the percentage of residential material diverted for recycling.
- (068) change in portion of rolloff diversion=
0.2
Units: Dmnl
Comments: Determines the effects of changing the rolloff diversion.

- (069) change in portion of tourist waste diversion=
0.25
Units: Dmnl
Comments: Determines the effects of changing tourist diversion.
- (070) change in waste generated per tourist=
 $\frac{2}{2}$
Units: lbs/tourists/day
Comments: Determines the effects of changing the tourist material generation rate.
- (071) CO2 gas emissions per ton sent to landfill=
0.142
Units: MTCE/tons
Comments: Based on the landfill gas being 50% methane and 45% CO2.
Source: Themillis & Ulloa, 2006.
- (072) commercial diversion rate=

$$\left(\frac{\text{total amount of commercial material diverted for recycling}}{\text{total amount of commercial material diverted for recycling} + \text{amount of commercial material disposed by Republic}} \right) * 100$$
Units: Dmnl
- (073) commercial material collected by Republic=
amount of commercial material diverted for recycling by Republic
Units: tons/year
Comments: Represents the material collected through Republic commercial recycling programs.
- (074) commercial material collected for disposal=
amount of commercial material disposed by Republic
Units: tons/year
Comments: Represents the commercial material collected for disposal at the landfill.
- (075) commercial material collected for recycling by private businesses=
amount of commercial material diverted through private businesses
Units: tons/year
Comments: Represents the amount of commercial material diverted through private recycling businesses.
- (076) commercial material processed by private businesses=
material processed through private recycling businesses
Units: tons/year
Comments: Represents the private business material processed and ready for recycling.

- (077) commercial material production=
total amount of commercial material generated
Units: tons/year
- (078) commercial recycling effectiveness ratio=
amount of recyclable commercial material diverted for recycling/total
amount of commercial material that is recyclable
Units: Dmnl
Comments: Compares what is recyclable to what is actually diverted for
recycling.
- (079) commercial material diverted for processing by private businesses=
INTEG(commercial material collected for recycling by private
businesses-commercial material processed by private businesses-
residual and material beyond private capacity,0)
Units: tons
- (080) construction and other rolloff material collected for disposal=
amount of construction and other material disposed by rolloff
Units: tons/year
Comments: Represents the amount of construction material collected by
Republic.
- (081) construction material LOOKUP
((0,0)-
(20,4e+006)],(0,1.8e+006),(2,2e+006),(4.5,2.5e+006),(15,2.5e+006))
Units: tons/year
Comments: Estimates the amount of construction material generated as a
function of the CC population growth rate. Based on rolloff collection and
total material taken to landfill for 2005-2007. Source: Interview with Bob
Coyle.
- (082) construction material production=
amount of construction material generated
Units: tons/year
Comments: Represents the material generated through construction
activities.
- (083) "construction material self-hauled to landfill"=
"amount of construction material self-hauled"
Units: tons/year
Comments: Represents the amount of construction material self-hauled to
the landfill.

- (084) construction related material diverted for recycling=
amount of recyclable rolloff material diverted for recycling
Units: tons/year
- (085) days in school per year=
180
Units: day/year
Comments: Source: Nev. Rev. Stat. 388.090
- (086) days to year conversion=
365
Units: day/year
- (087) effect of recycling collection LOOKUP
((0,0)-(10,10]),(0.5,1),(1,1.5),(2,2))
Units: Dmnl
Comments: Represents that increasing the frequency of collection will increase the amount of residential material diverted. 1/wk: 50% increase. 2/wk: 100% increase.
- (088) effect of recycling collection multiplier=
effect of recycling collection LOOKUP(recycling collection runs per week)
Units: Dmnl
Comments: Represents that increased residential recycling collection will increase the amount of material diverted.
- (089) efficiency at MRF=
efficiency at MRF LOOKUP(level of technology)
Units: Dmnl
Comments: estimated efficiency
- (090) efficiency at MRF LOOKUP
((0,0)-(10,10]),(1,0.4),(2,0.7),(3,0.95))
Units: Dmnl
Comments: Estimate for increasing efficiency with increasing technology.
- (091) FINAL TIME =
2100
Units: year
Comments: The final time for the simulation.

- (092) fraction of construction material collected by rolloff=
0.5
Units: Dmnl
Comments: Approximated from 2005-2007 values for rolloff and self-hauled tons
- (093) "fraction of construction material self-hauled"=
1-fraction of construction material collected by rolloff
Units: Dmnl
Comments: Approximated from 2007 values for rolloff and self-hauled tons
- (094) "fraction of population living in multi-family units"=
1-fraction of population living in single family homes
Units: Dmnl
Comments: The portion of the population that does not live in single-family homes.
- (095) fraction of population living in single family homes=
0.65
Units: Dmnl
Comments: Based on 2006 & 2007 data that 65% of the CC population lived in single-family homes. Source: CC Dept. of Comprehensive Planning, 2007.
- (096) GHG emissions due to landfill=
(CO₂ gas emissions per ton sent to landfill*total amount of material disposed)+(methane gas emissions per ton sent to landfill*methane MTCE conversion value*total amount of material disposed)
Units: MTCE/year
- (097) household material generation rate=
1.8
Units: tons/year/household
Comments: Determined by data from Republic Services (interview with Bob Coyle) for 2005 and 2007. The amount of residential waste collected was divided by the number of single-family households. For 2005 the rate was 2.13 tons/year/household and for 2007 the rate was 1.74 tons/year/household.
- (098) INITIAL TIME =
1993
Units: year
Comments: The initial time for the simulation.

- (099) lbs to tons conversion=
2000
Units: lbs/tons
- (100) level of technology=
1
Units: Dmnl
Comments: Insert 1 for low level of technology. Insert 2 for medium level of technology. Insert 3 for high level of technology.
- (101) material at MRF=
INTEG (material sent to MRF-material processed by MRF-MRF material sent to landfill,0)
Units: tons
- (102) material beyond private processing capacity=
MAX(0, amount of commercial material diverted through private businesses-processing capacity of private recycling businesses)
Units: tons/year
Comments: Anything beyond the private businesses processing capacities.
- (103) material beyond Republic processing capacity=
MAX(0, amount of recyclable residential material diverted for recycling+amount of commercial material diverted for recycling by Republic-processing capacity of Republic MRF)
Units: tons/year
Comments: Anything beyond the Republic MRF processing capacity
- (104) material collection runs per week=
2
Units: runs/routes/week
Comments: Currently material collection is conducted 2 times a week.
- (105) material delivered to landfill=
total amount of material disposed
Units: tons/year
Comments: Represents all the material sent to be landfilled.
- (106) material diverted for processing by Republic =
INTEG (commercial material collected by Republic+residential material collected for recycling-material processed by Republic-residual and material beyond Republic capacity,0)
Units: tons

- (107) material generated by businesses=
 INTEG (commercial material production-commercial material collected by Republic-commercial material collected for disposal-commercial material collected for recycling by private businesses, 279000)
 Units: tons
- (108) material generated by construction=
 INTEG (construction material production-construction and other rolloff material collected for disposal-"construction material self-hauled to landfill"-construction related material diverted for recycling, 438428)
 Units: tons
- (109) material generated by single family homes=
 INTEG (residential material production-residential material collected for recycling-residential material collected for disposal, 233206)
 Units: tons
- (110) "material generated per multi-family unit"=
 1.2
 Units: tons/year/units
 Comments: Estimated to be lower than 1.8 tons/year generated by households.
- (111) material generated per student=
 1.2
 Units: lbs/people/day
 Comments: Estimate. Limited data available on student material generation rates.
- (112) material generated per tourist=
 2
 Units: lbs/tourists/day
 Comments: Estimate. Limited data available on tourist material generation rates.
- (113) material handled at transfer stations=
 INTEG (commercial material collected for disposal+construction and other rolloff material collected for disposal+residential material collected for disposal+residual and material beyond private capacity+residual and material beyond Republic capacity-material delivered to landfill-material sent to MRF, 0)
 Units: tons

- (114) material in landfill=
 INTEG ("construction material self-hauled to landfill"+material delivered to landfill+MRF material sent to landfill-MRF material sent to landfill, 0)
 Units: tons
 Comments: Represents the total material collecting in the Apex landfill.
- (115) material processed by MRF=
 amount of MRF material processed
 Units: tons/year
 Comments: Represents the MRF material processed and ready for recycling.
- (116) material processed by Republic=
 material processed through Republic MRF
 Units: tons/year
 Comments: Represents Republic material processed and ready for recycling.
- (117) material processed through private recycling businesses=
 MIN(processing capacity of private recycling businesses, amount of commercial material diverted through private businesses)
 Units: tons/year
 Comments: Private businesses cannot process material beyond their processing capacity.
- (118) material processed through Republic MRF=
 MIN(processing capacity of Republic MRF, amount of commercial material diverted for recycling by Republic+amount of recyclable residential material diverted for recycling)
 Units: tons/year
 Comments: Material processed cannot surpass MRF capacity.
- (119) material reclaimed by MRF=
 INTEG (material processed by MRF-MRF material sold, 0)
 Units: tons
- (120) material reclaimed by private businesses=
 INTEG (commercial material processed by private businesses-private material sold, 0)
 Units: tons
- (121) material reclaimed by Republic by source diversion=
 INTEG (material processed by Republic-Republic material sold, 0)
 Units: tons

- (122) material sent to MRF=
 amount of material sent to MRF
 Units: tons/year
 Comments: Represents the amount of unsorted material collected for disposal that is sent to the MRF.
- (123) methane gas emissions per ton sent to landfill=
 0.149
 Units: MTCE/tons
 Comments: Source: Themillis & Ulloa, 2006.149 tons of methane are released for each ton of MSW.
- (124) methane MTCE conversion value=
 21
 Units: Dmnl
 Comments: Source: EPA. Emissions Facts available at <http://www.epa.gov/OMS/climate/420f05002.htm>
- (125) MRF material beyond capacity=
 amount of material sent to MRF-amount of material accepted by MRF
 Units: tons/year
- (126) MRF material beyond capacity and residual sent to landfill=
 MRF material beyond capacity+residual MRF material
 Units: tons/year
 Comments: Represents MRF material that was nonrecyclable, contaminated, or beyond the MRF recycling capacity.
- (127) MRF material sent to landfill=
 MRF material beyond capacity and residual sent to landfill
 Units: tons/year
 Represents MRF material that was nonrecyclable, contaminated, or beyond the MRF recycling capacity.
- (128) MRF material sold=
 amount of MRF material sold
 Units: tons/year
 Comments: Represents material processed and sold for recycling.
- (129) "multi-family, K-12, and tourism material generated"=
 "amount of K-12 material generated"+"amount of multi-family material generated" +"amount of tourist-related material generated"
 Units: tons/year
 Comments: Determines the total amount of K-12, multi-family, and tourist material generated.

- (130) nonrecyclable portion of private material diverted for recycling=
0.025
Units: Dmnl
Comments: Estimate. Set at half the value of Republic portion of nonrecyclable material. Assuming private businesses are more selective about the material they collect.
- (131) nonrecyclable portion of Republic material diverted for recycling=
0.05
Units: Dmnl
Comments: Based on residual value for material processed by Republic Services (Interview with Bob Coyle)
- (132) number of homes per collection route=
1150
Units: household/routes
Comments: There are approximately 1000 homes on a residential route.
Source: In Business Las Vegas article: Interview with Bob Coyle, 2007
- (133) "number of multi-family units"=
(CC population*"fraction of population living in multi-family units")/"avg. number of people in a multi-family unit"
Units: units
Takes the number of people living in multi-family units and divides it by the average number of people per unit to determine the total number of multi-family units.
- (134) number of residential routes=
"number of single-family households"/number of homes per collection route
Units: routes
- (135) "number of single-family households"=
(CC population*fraction of population living in single family homes)/"avg. number of people in a household"
Units: household
Comments: Determines the approximate number of single-family households.
- (136) "number of students in K-12 Education"=
CC population*"portion of population in K-12 education"
Units: people
Comments: Determines the number of students enrolled in K-12 education in the Clark County School District.

- (137) number of tourists visiting per year=
tourist LOOKUP(Time)
Units: tourists
- (138) portion of commercial material diverted through private businesses=
1-portion of commercial material diverted through Republic
Units: Dmnl
Comments: Material not diverted through Republic will go through private businesses.
- (139) portion of commercial material diverted through Republic=
0.65
Units: Dmnl
Comments: In 2005, 63% of commercial material was diverted through Republic. Using 15% rate, 2006 & 2007 had 82% and 62% Republic diversion rates. Using 65% as a conservative estimate. 2005 data taken from Source: Interview with Bob Coyle.
- (140) portion of commercial waste from other sources=
0.33
Units: Dmnl
Comments: Estimated that commercial material from other sources is equal to 33% of material from multi-family, K-12, and tourism.
- (141) "portion of K-12 material usually diverted"=
0.1
Units: Dmnl
Comments: Estimate. Limited data available on K-12 diversion.
- (142) portion of material sent to MRF=
0
Units: Dmnl
Comments: Currently, Clark County does not have an MRF.
- (143) "portion of multi-family material usually diverted"=
0.02
Units: Dmnl
Comments: Estimate. Limited data available on multi-family diversion.
- (144) portion of other commercial material usually diverted=
0.2
Units: Dmnl
Comments: Estimate. Limited data available on commercial diversion.

- (145) "portion of population in K-12 education"=
 0.16
 Units: Dmnl
 Comments: Based on enrollment of student in the Clark County School District and CCDPC population values for 2003-2007. Student population ranged from 15.5 to 16.3 % with an average of 16%.
- (146) portion of reclaimed material in market demand=
 0.95
 Units: Dmnl
 Comments: Estimate of the amount of material that will be sold on the market due to changes in market demand
- (147) portion of residential material usually diverted=
 0.057
 Units: Dmnl
 Comments: Determined by taking the fraction of residential waste diverted for residential recycling. Data points for 2005-2007 taken from data from Republic Services (interview with Bob Coyle). Amounts determined were 2005: 5.9%; 2006: 5.8%; 2007: 5.7%.
- (148) portion of rolloff material usually diverted=
 0.2
 Units: Dmnl
 Comments: Estimate. Limited data available on roll-off recycling.
- (149) portion of tourist material usually diverted=
 0.25
 Units: Dmnl
 Comments: Estimate. Limited data available on tourist diversion.
- (150) private material sold=
 amount of private material sold
 Units: tons/year
 Comments: Represents material processed and sold for recycling.
- (151) processing capacity of private recycling businesses=
 2e+006
 Units: tons/year
 Comments: Estimated to be slightly higher than Republic MRF. Processing capacities for individual recycling businesses are unknown.
- (152) processing capacity of Republic MRF=
 1.46e+006
 Units: tons/year
 Comments: Based on 4000 tons/day value taken from SNHD permit request records. 1.46e+006 tons/year

- (153) recyclable material sent to MRF=
amount of material accepted by MRF*recyclable portion of material
sent to MRF
Units: tons/year
- (154) "recyclable portion of K-12 material"=
0.4
Units: Dmnl
Comments: Estimate. Limited data available on Clark County waste
characterization.
- (155) recyclable portion of material sent to MRF=
0.59
Units: Dmnl
Comments: Based on percentage of national material that was recyclable.
(EPA, 2007).
- (156) "recyclable portion of multi-family material"=
0.34
Units: Dmnl
Comments: Estimated to be the same as residential material.
- (157) recyclable portion of other commercial material=
0.64
Units: Dmnl
Comments: Minimum value of 37% based on values for commercial waste
stream composition taken from CA.gov available at
<http://www.ciwmb.ca.gov/WasteChar/wcabscrn.asp>. Other possible value
of 64% taken by EPA, 2006
- (158) recyclable portion of residential material=
0.34
Units: Dmnl
Comments: Residential waste characterization in Phoenix, AZ stated
33.5% of residential material was made up of paper, plastic, metal,
and glass in material. Source: Cascadia Consulting Group, 2003.
- (159) recyclable portion of rolloff material=
0.5
Units: Dmnl
Comments: Estimate. Limited data available on Clark County waste
characterization.

- (160) recyclable portion of tourist material=
 0.5
 Units: Dmnl
 Comments: Estimate. Limited data available on Clark County waste characterization.
- (161) recycling collection runs per week=
 0.5
 Units: runs/routes/week
 Comments: Currently recycling collection is biweekly. Source: Republic Services.
- (162) Republic material sold=
 amount of Republic material sold
 Units: tons/year
 Comments: Represents material processed and sold for recycling.
- (163) residential and commercial material collected by Republic=
 amount of commercial material disposed by Republic+amount of residential material disposed
 Units: tons/year
 Comments: Represents the total material collected by Republic's residential and commercial services.
- (164) residential diversion rate=

$$\frac{\text{amount of residential material diverted for recycling}}{\text{amount of residential material disposed} + \text{amount of residential material diverted for recycling}} * 100$$
 Units: Dmnl
- (165) residential material collected for disposal=
 amount of residential material disposed
 Units: tons/year
 Comments: Represents the residential material collected for disposal at the landfill.
- (166) residential material collected for recycling=
 amount of residential material diverted for recycling
 Units: tons/year
 Comments: Represents residential material collected through Republic curbside recycling program.
- (167) residential material production=
 amount of residential material generated
 Units: tons/year
 Comments: Represents the total amount of residential material generated.

- (168) residential recycling effectiveness ratio=
amount of recyclable residential material diverted for recycling/amount
of residential material that is recyclable
Units: Dmnl
Comments: Compares what is recyclable to what is actually diverted for
recycling.
- (169) residual and material beyond private capacity=
amount of residual and material beyond private capacity
Units: tons/year
Comments: Represents contaminated and nonrecyclable material that
was diverted and material beyond the processing capacity of private
businesses.
- (170) residual and material beyond Republic capacity=
amount of residual and material beyond Republic capacity
Units: tons/year
Comments: Represents contaminated and nonrecyclable material that
was diverted and material beyond the processing capacity of Republic
MRF.
- (171) residual MRF material=
amount of material accepted by MRF-amount of MRF material
processed
Units: tons/year
- (172) SAVEPER = 1
Units: year [0,?]
The frequency with which output is stored.
- (173) technology multiplier on capacity=
technology multiplier on capacity LOOKUP(level of technology)
Units: Dmnl
- (174) technology multiplier on capacity LOOKUP
([(0,0)-(10,10)],(1,0.6),(2,1),(3,3))
Units: Dmnl
Comments: Estimated to show that as technology increases, the capacity
will increase.
- (175) technology multiplier on construction costs LOOKUP
([(0,0)-(10,10)],(1,0.5),(2,1),(3,3))
Units: Dmnl
Comments: Level of technology will determine if construction costs will be
below, at, or above average costs.

- (176) technology multiplier on construction costs=
 technology multiplier on construction costs LOOKUP(level of
 technology)
 Units: Dmnl
- (177) technology multiplier on operation and maintenance costs=
 technology multiplier on operation and maintenance costs
 LOOKUP(level of technology)
 Units: Dmnl
- (178) technology multiplier on operation and maintenance costs LOOKUP(
 [(0,0)-(10,10)],(1,1.25),(2,1),(3,0.75))
 Units: Dmnl
 Comments: A higher level of technology is expected to reduce operation
 and maintenance costs.
- (179) TIME STEP = 0.125
 Units: year [0,?]
 The time step for the simulation.
- (180) total amount of commercial material diverted for recycling=
 "amount of K-12 material diverted for recycling"+"amount of multi-
 family material diverted for recycling"+amount of other commercial
 material diverted for recycling
 +amount of tourist material diverted for recycling+amount of
 construction and other rolloff material diverted for recycling
 Units: tons/year
- (181) total amount of commercial material generated=
 amount of all commercial material generated excluding rolloff+amount
 of construction and other material handled by rolloff
 Units: tons/year
 Comments: Determines the total amount of commercial material
 generated, including roll-off material.
- (182) total amount of commercial material that is recyclable=
 "amount of K-12 material that is recyclable"+"amount of multi-family
 material that is recyclable"+amount of other commercial material that is
 recyclable+amount of tourist material that is recyclable+amount of
 rolloff material that is recyclable
 Units: tons/year
 Comments: Calculates the total amount of recyclable commercial material

- (183) total amount of material disposed=
 "amount of construction material self-hauled"+residential and
 commercial material collected by Republic+total residual and material
 beyond capacity-amount of material sent to MRF
 Units: tons/year
 Comments: Represents all the material sent to the landfill from
 commercial and residential generators and material that is self-hauled.
- (184) "total amount of residential, commercial, construction material disposed"=
 amount of commercial material disposed by Republic+amount of
 residential material disposed
 Units: tons/year
- (185) total amount of residual in recyclable material diverted by source=
 amount of residual and material beyond private capacity+amount of
 residual and material beyond Republic capacity
 Units: tons/year
- (186) total MRF costs=
 capital costs for MRF construction+total MRF operation and
 maintenance costs
 Units: dollars/year
- (187) total MRF operation and maintenance costs=
 average operation and maintenance costs per ton*technology
 multiplier on operation and maintenance costs*amount of material
 accepted by MRF
 Units: dollars/year
- (188) total reclaimed material=
 amount of MRF material processed+material processed through
 private recycling businesses+material processed through Republic
 MRF
 Units: tons/year
- (189) total residential route runs per week=
 number of residential routes*total runs per week
 Units: runs/week
 Comments: total number of residential route runs per week
- (190) "total residential, commercial, and rolloff material disposed"=
 amount of commercial material disposed by Republic+amount of
 residential material disposed
 Units: tons/year
 Comments: Calculates the total amount of material commercial and
 residential material disposed by Republic.

- (191) total residual and material beyond capacity=
amount of residual and material beyond private capacity+amount of
residual and material beyond Republic capacity+MRF material beyond
capacity and residual sent to landfill
Units: tons/year
Comments: Determines the total amount of residual material and material
that was beyond the processing capacities of material recovery facilities.
- (192) total runs per week=
IF THEN ELSE(Time>=2010, material collection runs per
week+recycling collection runs per week, 2.5)
Units: runs/routes/week
Comments: Represents changes in collection runs being implemented in
2010.
- (193) tourist LOOKUP
((1990,0)-(2100,4e+007)],(1990,3.061e+007),(1998,3.06051e+007),
(2001,3.50173e+007),(2002,3.50715e+007),(2003,3.55401e+007),(20
04,3.73888e+007),(2005,3.85667e+007),(2006,3.89149e+007),(2007,
3.91968e+007),(2100,3.92e+007))
Units: tourists
Comments: Bases on historical information from CBER, 2007
- (194) yearly processing capacity of MRF=
average MRF processing capacity in tons per day*technology multiplier
on capacity*days to year conversion
Units: tons/year

APPENDIX IV

Estimation of Variables

Variable	Estimate
average capital costs for MRF construction	Average capital cost of a MRF was 3.3 million US dollars in 1992. Source: Chang and Wang, 1995
average length of tourist visit	The average tourist visit lasts 3.6 days Source: Clark County, 2008
average MRF processing capacity in tons per day	MRFs process an average of 131.45 tons of material per day. Source: Chang & Wang, 1995
average operation and maintenance costs per ton	The cost of processing 1 ton of material is about \$56 per ton. Source: Chang & Wang, 1995
"avg. number of people in a household"	The average number of people per household is 2.65. Source: U.S. Census Bureau, 2002
"avg. number of people in a multi-family unit"	The average number of people per renter-occupied unit is 2.56. Source: U.S. Census Bureau, 2006
CO2 gas emissions per ton sent to landfill	Landfill gas is composed of 50% methane and 45% CO2. Source: Themillis & Ulloa, 2006.
days in school per year	Nevada schools are in session 180 days out of the year. Source: Nev. Rev. Stat. 388.090
fraction of construction material collected by rolloff	Rolloff tons for 2005-2007 were approximately the same amount as material self-hauled to the landfill. Source: Personal communication with Bob Coyle, 2008
fraction of population living in single family homes	Based on 2006 & 2007 data that 65% of the CC population lived in single-family homes. Source: CC Dept. of Comprehensive Planning, 2007
household material generation rate	In 2005, the household rate was 2.13 tons/year/household; 2007 the rate was 1.74 tons/year/household. Source: Personal communication with Bob Coyle, 2008
material collection runs per week	Material is collected twice a week. Source: Republic Services, 2008
"material generated per multi-family unit"	Assumed to be lower than the 1.8 tons/year generated by households at 1.2 tons/year. Assumed that multi-family units generate less material since they do not generate as much yard waste.

material generated per student	Assumed to be 1.2 lbs/student/day. Limited data is available on student material generation rates.
material generated per tourist	Assumed at 2 lbs/tourist/day. Limited data available on tourist material generation rates.
methane gas emissions per ton sent to landfill	149 tons of methane are released for each ton of material in a landfill. Source: Themillis & Ulloa, 2006.
nonrecyclable portion of private material diverted for recycling	Assumed to be 2.5%. Set at half the value of the Republic portion of nonrecyclable material. Assumed private businesses are more selective about the material they collect.
nonrecyclable portion of Republic material diverted for recycling	Based on 5% residual value for material processed by Republic. Source: Personal communication with Bob Coyle, 2008
number of homes per collection route	There are approximately 1000 homes on a residential collection route. Source: In Business Las Vegas, 2007
portion of commercial material diverted through Republic	In 2005, 63% of commercial material was diverted through Republic. Used 65% in the model. Source: Personal communication with Bob Coyle, 2008
portion of commercial waste from other sources	Assumed that commercial material from other sources is equal to 33% of material from multi-family, K-12, and tourism. Assumed that equations for multi-family, K-12, and tourism generation is accurate.
"portion of K-12 material usually diverted"	Assumed to be 1%. Clark County schools are not required to implement recycling programs.
"portion of multi-family material usually diverted"	Assumed to be 2%. Multi-family recycling programs are not provided in Clark County.
portion of other commercial material usually diverted	Assumed to be 20%. The commercial recycling rate was about 17% in 2007. Source: Personal communication with Bob Coyle, 2008
"portion of population in K-12 education"	Based on enrollment of student in the Clark County School District and population values for 2003-2007. Student population ranged from 15.5 to 16.3 % with an average of 16%. Source: CCSD, 2007; CCDPC, 2008.

portion of reclaimed material in market demand	Assumed to be 95%. Assumed most of the material will be sold on the market.
portion of residential material usually diverted	Determined by taking the fraction of residential waste diverted for residential recycling. Amounts determined were 2005: 5.9%; 2006: 5.8%; 2007: 5.7%. Source: Personal communication with Bob Coyle, 2008
portion of rolloff material usually diverted	Assumed to be 20%. Limited data available.
portion of tourist material usually diverted	Assumed to be 25%. Limited data available.
processing capacity of private recycling businesses	Assumed to be 2 million tons/year. Assumed to be slightly higher than Republic MRF. Processing capacities for individual recycling businesses are unknown.
processing capacity of Republic MRF	Based on 4000 tons/day value taken from SNHD permit request records. es1.46e+006 tons/year
"recyclable portion of K-12 material"	Assumed to be 40%. Assumption based on paper portion of school material.
recyclable portion of material sent to MRF	Based on 59% of national material that was recyclable. Source: EPA, 2007
"recyclable portion of multi-family material"	Assumed to have the same 34% value as residential material.
recyclable portion of other commercial material	Minimum value of 37% based on values for commercial waste
recyclable portion of residential material	Residential waste characterization in Phoenix, AZ stated 33.5% of residential material was made up of paper, plastic, metal, and glass in material. Source: Cascadia Consulting Group, 2003.
recyclable portion of rolloff material	Assumed to be 50%. Limited data available.
recyclable portion of tourist material	Assumed to be 50%. Limited data available.
recycling collection runs per week	Recycling material is collected bi-weekly. Source: Republic Services, 2008

CC population LOOKUP	Information from 1990-2008 is based on data from CC Dept. of Comprehensive Planning. Information from 2008 to 2036 is based on estimated CC population growth forecasts from CBER. Values after 2035 are based on a 1.1% growth rate. Sources: CCDCP, 2007; CBER, 2007.
construction material LOOKUP	Assumes the amount of construction material generated is a function of the CC population growth rate. Based on rolloff collection and total material taken to landfill for 2005-2007. Source: Personal communication with Bob Coyle, 2008
effect of recycling collection LOOKUP	Assumes that increasing the frequency of collection will increase the amount of residential material diverted. 1/wk: 50% increase. 2/wk: 100% increase.
efficiency at MRF LOOKUP	Assumes that better technology increases efficiency.
technology multiplier on capacity LOOKUP	Assumes that better technology increases capacity.
technology multiplier on construction costs LOOKUP	Assumed that the level of technology will determine if construction costs will be below, at, or above average costs.
technology multiplier on operation and maintenance costs LOOKUP	Assumed a higher level of technology will reduce operation and maintenance costs.
tourist LOOKUP	Bases on historical information on number of tourist visitors. Source: CBER, 2007

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