Managing PM_{10} in the Las Vegas Valley

Stephanie Fincher and Krystyna Stave[1]
Department of Environmental Studies
University of Nevada, Las Vegas
fincher@unlv.nevada.edu, krystyna.stave@unlv.edu
[1] *Graduate Student and Associate Professor, respectively*

Abstract

This paper describes the process for integrating a system dynamics (SD) model for managing coarse particulate matter (PM_{10}) in the Las Vegas Valley (LVV). The LVV is currently categorized as a serious non-attainment area for PM_{10} by the U.S. Environmental Protection Agency (EPA). The project client, the Clark County Department of Air Quality and Environmental Management (DAQEM), must provide a predictive model to show future levels of PM_{10} will be below EPA limits. The previous "proportional rollback" model is described along with its limitations. Three different approaches to modeling the problem, including advantages and disadvantages of each approach are described. The chosen approach, a modification of the original system conceptualization, improves many of the drawbacks of the previous model but still has many limitations (including not approaching the problem from a systems perspective and lack of dynamics). Unfortunately, although the client is open to system dynamics and an approach that focuses on causality, there are restrictions to what may be instituted based on prior EPA approval. One interesting reflection of the study is that it shows first hand some of the barriers in implementing system dynamics for environmental management.

Keywords
air pollution, pollution management, particulate matter, air quality, urban air quality

Problem Definition

The Las Vegas Valley (LVV) has been in consistent violation of standards for a number of air quality pollutants since 1970, when air quality standards were set by amendments to the Clean Air Act. One pollutant that has been a regular contributor to these violations is particulate matter (PM). Currently, the United States Environmental Protection Agency (EPA) lists Clark County, the governmental entity encompassing all of the LVV, as one of only eight U.S. "serious nonattainment areas" for PM_{10}, the coarse fraction of PM. City planners of the Clark County Department of Air Quality and Environmental Management (DAQEM), the authority responsible for managing air quality in the LVV, must show by December 2006 that it can reduce PM_{10} levels below National Ambient Air Quality Standards (NAAQS).

This paper describes the use of system dynamics modeling to explore mitigation measures for PM_{10} in the LVV with the expertise of Clark County's Air Quality planners. Improved management of this pollutant will require not only a better understanding and conceptualization of the system but also the development of a predictive model that will be accepted by both the client and their regulating authority, the EPA. Although the client previously created a model to manage this problem, there are certain drawbacks to the approach that limit its applicability. DAQEM's goals for the new model are simple, it must: (1) display information in a manner comfortable for the EPA, (2) be fully documented, (3) meet EPA requirements, (4) allow for evaluation of multiple scenarios, (5) include known and future land development, (6) be flexible enough to do predictive modeling of emissions, (7) and finally, be easy to expand or modify with new data.

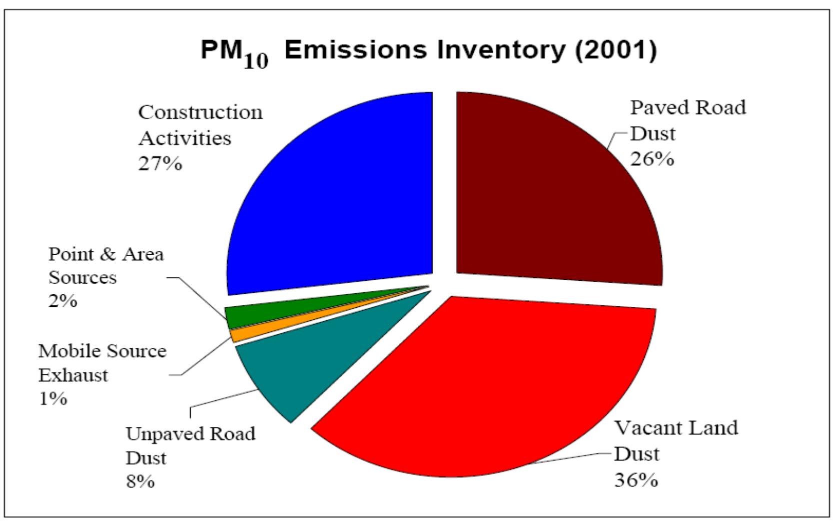
The following sections describe the significance of PM_{10} pollution—primarily focusing on the health and legal reasons for its management, the proportional rollback method and its limitations, how the previous model's methodology can be improved, the designed approach, and finally model development, policy options, and how the model was received throughout the process.

What is PM_{10}?

Particulate matter is dust, soot and other pieces of small, solid or liquid materials or chemicals suspended in the air (EPA-3, DAQEM). PM is described in reference to the size of the particles with PM_{10} having particles with a diameter equal to or smaller than ten micrometers (10µm), which includes the new standard of $PM_{2.5}$ particles with diameters smaller than 2.5µm. To understand the relative size of these particles, 10 micrometers is roughly equivalent to 1/7th the size of the diameter of a human hair and 2.5µm only 1/28th (DAQEM FAQ).

The major sources for coarse particles in the LVV are shown in Figure 1. While there is a certain amount of geologic or background emissions of PM_{10} the majority of particles are too large to fit into the size category and we are far more concerned with anthropogenic emissions. Human-caused emissions include point, area, and mobile sources. Point sources come from facilities with a fixed location. In Las Vegas, these sources include sand and gravel operations, asphalt and concrete manufacture, and some utilities and industrial processes. Area sources are both stationary and mobile (but do not include on-road vehicles), which are too numerous to be treated individually but have significant impacts when aggregated. An example of area sources is residential woodburning in winter months. Mobile sources come mostly from on-road sources and include direct emissions from vehicles, brake dust, and particles that are kicked up from road surfaces. (DAQEM, Solomon 1994)

Figure 1 Emissions sources for 2001 emissions inventory in the LVV (DAQEM)



Why manage it?

Health and Environmental Issues

Particulate matter in its largest form (geologic PM of sizes >10µm) can cause strong fits of coughing during exposure but is temporary with little further health consequence. Smaller particles (<10µm) are inhaled into the lungs and accumulate in the bronchia, leading to a variety of more serious health issues including: increased incidence of respiratory disease and symptoms, like coughing, painful breathing, and decreased lung function; aggravation/increased potency of pre-existing respiratory conditions (such as asthma or bronchitis); increased frequency of absences from work/school; area-wide increased hospital admissions and emergency room visits for heart and lung disease; and even, premature death. Particulates of all sizes can be harmful to humans but currently the smallest particles (<2.5µm, $PM_{2.5}$) are considered to be the most dangerous because they travel much deeper into the lungs, bypassing filtration. (CCBC 2001, EPA-2 2003).

The most vulnerable segments of the population for this pollutant are the very young and the very old, as well as people with weakened immune systems. Based on the susceptibility of these groups there are two federal health-based standards, an annual standard to limit total PM_{10} exposure (chronic) and a 24-hour standard to provide protection from temporarily elevated levels (acute exposure). (EPA-2, 2003)

In addition to health problems, PM can have aesthetic effects on an area by causing haze and reducing visibility, a potentially significant problem for a tourism-based city such as Las Vegas. PM also degrades vegetation and ecosystems, and causes damage to structures (EPA-4 2004). Although relatively recent studies into $PM_{2.5}$ have lead to separate air quality standards for just the fine fraction of particles, Las Vegas currently shows $PM_{2.5}$ levels well within standards (DAQEM) and PM_{10} as the primary pollutant of concern (CDSN and DAQEM 2003). Nevertheless, $PM_{2.5}$ continues to be monitored within the valley and may need future management for the reasons listed above and to prevent secondary particle formation of ozone (another criteria pollutant for which the LVV currently exceeds standards).

Lawful Obligations

National Ambient Air Quality Standards (NAAQS) are set for not only PM, but 5 other criteria air pollutants. The responsibility of meeting air quality standards in the United States falls on individual states through the Clean Air Act (CAA) legislation, regulated by the EPA. States are divided into air quality areas according to county lines or other, sometimes physical boundaries (such as watersheds or airsheds). States are regularly assigned deadlines by which they must demonstrate air pollution levels meeting the existing or new air quality standards. Deadlines are set according to the criteria pollutant above limits (called an “exceedance”) and by how severely the area exceeds the standards (including the extent and duration of the exceedance and projected time necessary to bring levels below standards). To demonstrate pollution levels and practices within established standards, states are required to complete a State Implementation Plan (SIP). The plan details total emissions and sources, monitoring activities and methodologies, and any implementation of mitigating actions (and in some cases technologies) an area will establish to stay below the NAAQS. (EPA-3, Plater *et al.* 1998)

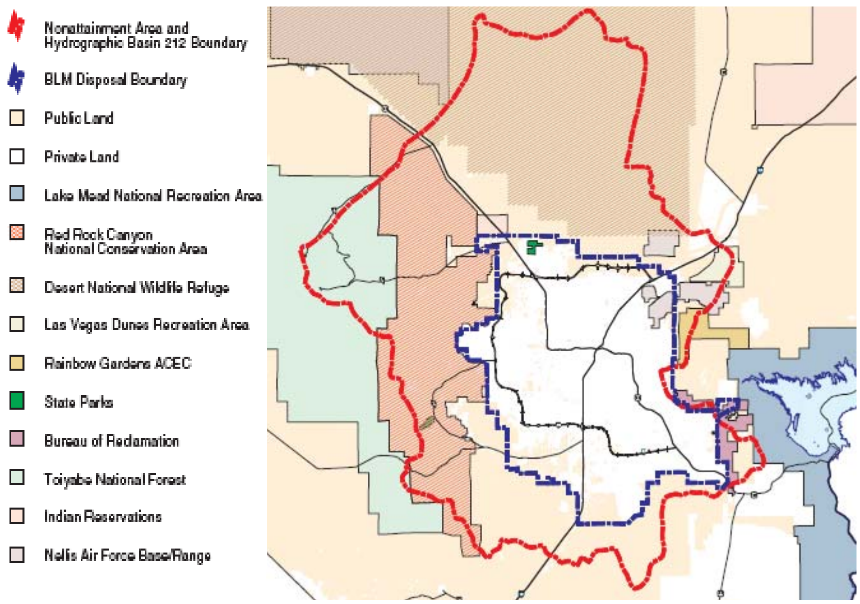
States were put in charge of these air quality plans on the rationale that they would more efficiently regulate their own industries and unique air quality situations than a blanket draconian policy. Of course, areas must practice certain minimum practices, established technologies, and EPA methodologies for individual pollutants. Outside of these general guidelines, however, an area can determine what industries to place more pressure to reduce emissions, any incentive programs and conditions, as well as many of the fines for local violations. Yet, this allowance is not unconditional, continued exceedance of any of the NAAQS (or failure to comply with SIP requirements) may lead to a Federal Implementation Plan (FIP) which would dictate mitigation regulations to bring states into attainment, regardless of costs or impacts on local industries.

Therefore, while there are no direct financial penalties to Clark County for exceeding PM_{10} standards, there are very serious consequences for not meeting PM_{10} standards. (Kubasek 2005, Plater *et al.* 1998)

Air Quality in the Las Vegas Valley

The LVV has an area of approximately 4000 km², sits in the southwestern side of the Great Basin, and is surrounded by mountains up to 3,600m in elevation (DRI 2002). This area is known as Hydrographic Basin 212, which, as a result of the 1990 Amendments to the CAA, became the boundary used to determine regional air quality areas (Federal Register 9-jul-2004). Figure 2 shows this area and the types of lands that it includes, from public Bureau of Land Management (BLM) lands to private land, state parks and forests, refuges and conservation areas, and an Air Force base. This diversity of land uses causes a wide variety of impacts on air quality, especially on PM_{10} levels.

Figure 2 Map of the Las Vegas Valley



Air quality in the LVV has been a consistent concern of citizens, and an increasing one during recent years. Although EPA reports indicate air quality is improving in the country as a whole (EPA-4), many areas and counties are starting to demonstrate enduring pollution problems. These air quality issues are often unique to an area due to local topographical, meteorological, and industrial aspects. Although immediate improvements are made when controls are first implemented, it can be quite difficult to make further progress beyond initial reductions in air pollution. This is exactly the case in Las Vegas, which has both inherent and human-induced aspects that are driving PM_{10} to exceed safe levels.

An area either completely or partially surrounded by mountains often exhibits more problematic air pollution issues than areas without mountains. Lower elevations in the valley are more likely to have worse local air quality than the rest of the valley and many of the exceedances seen in the valley have occurred in monitors in these areas. In winter months, the LVV is prone to inversions and low wind velocities, resulting in trapped pollutants. Additionally, while wind will remove pollutants from the valley, they might also lead to windblown dust, further impacting PM. Pollutants have also been found to travel hundreds of miles from where they originated in neighboring states into the valley where they can be trapped, exacerbating the problem. (CDSN and DAQEM 2003)

Although many might consider dust to be a natural and regular occurrence in the desert, this is actually not the case. In fact, native desert land forms a crust on the topmost layer that traps dust particles underneath. Although this can be disturbed by animals and natural events, the desert crust is replaced with each rain event when disturbance is minimal (CDSN and DAQEM 2003). In Las Vegas, anthropomorphic activities are causing a dramatic change to the composition of the landscape. Construction of land area disturbs not only the protective layer but also results in large additions or removal of dirt for razing or infill. Piles of dirt are often left exposed and are thus blown by winds as well as tracked onto roads by construction vehicles. Disturbed vacant lots are often left uncontrolled until construction actually takes place, adding to potential sources of dust.

Figure 2 shows the BLM disposal boundary, which is a block of public land that will eventually be divided and sold to land developers. The EPA wants this area to be included in any future models but all previous calculations were not able to meet the standards when this area was included. Fugitive dust, regardless of its source, is a major problem for Clark County and also one of the reasons why previous SIPs were not approved (DAQEM). In a study by Chow *et al*. (1999), fugitive dust accounted for 80-90% of PM-10 and motor vehicle exhaust 3-9% of all PM emissions in residential study areas of the LVV. Air quality planners believe levels will be even higher if the BLM land area is incorporated to emissions calculations.

Despite these obstacles, as of 2001, Clark County began reaching levels below the annual standard for PM_{10}. At this time, Clark County submitted a SIP requesting an extension to demonstrate that the 24-hour standard could be reached and assuring a submittal by 2004 (EPA-2, Federal Register 2004). Clark County and the State of Nevada have had a rough track record of submissions and withdrawals over the years but, fortunately, the 2001 plan was provisionally accepted by the EPA (Federal Register 9-jul-2004). The commitments required demonstrations of Reasonable Further Progress (RFP), mostly studies on improving PM monitoring, management, and enforcement (Federal Register 9-jul-2004, CCBC 2001). The EPA approved the five-year extension of the deadline for attainment, from 2001 to December 2006 (*ibid*). Finally, the EPA called for improvements to the previously accepted proportional rollback model (meeting notes 11/2/05).

Approach

Improving the Proportional Rollback Model

The proportional rollback method uses monitored emissions from a base year (1998) and standardizes them throughout the valley. All land in the valley is categorized into native desert, stabilized land, and unstable land (as well as the implied "built environment" which would not be contributing dust). Total emissions are then proportionally attributed to the various activities (disturbances) that occurred in that year. Emissions factors are then calculated (tons/year) for various disturbances including wind erosion and construction for each land type. From here, projected population growth drives construction of new homes, changing the distribution of native desert and disturbed land, which leads to increased emissions from disturbance and estimated values for annual and 24-hr PM_{10} levels for the final year of calculations (in this case, 2006).

There are several limitations to this model. Format and ease-of-use problems are the most obvious issue because the model itself is cumbersome—made up of various spreadsheets saved as separate files. Additionally the manual nature of the model is not only time consuming and prone to errors in transferring values, but the ability to run multiple policy plans is limited because each scenario must be saved as another series of sheets, essentially a new model. Conceptually, the model is static and linear, following a series of non-dynamic computations to project PM_{10} emissions for the target year. Representation of the system also lacks several important mechanisms with the only driving factor for future emissions being population change (assuming all else constant), yet no calculations go back to impact population or growth.

DAQEM has hired UNLV to expand the representation of dynamics in the model and allow projections beyond the target year to twenty years into the future. Part of the role we have taken with this project is to demonstrate to the client that many of the assumptions about how the system works could be greatly improved and that "dynamics" is not simply carrying out calculations (i.e., numbers that change) but rather feedback between variables.

Other Modeling Alternatives

Although there are spatially explicit, EPA-approved models using advanced programming, meteorological modeling, and chemical/physical transformations to track and predict pollution levels and dispersion, they are not suitable for PM_{10} management. First, as DAQEM has demonstrated to the EPA, larger particles do not act as gases or diffuse in a predictable manner. PM_{10} levels can be vastly diverse in even the small distance between two receptors, indicating a great sensitivity to surface composition. Particles vary in size and shape so that some particles have a propensity to stay aloft and settling time for particles depends on both how aerodynamic they are as well as the initial disturbance that displaced particles into the air. The main benefit of using these models is for ozone and other gaseous pollution problems that actually can be tracked through dispersion with relative accuracy.

Most parts of the country are focusing on ozone and $PM_{2.5}$ problems and not coarse PM, making widely accepted, customizable models much more difficult to come by than those for other pollutants. However one collaborative effort, the Western Regional Air Partnership (WRAP), is starting to offer promise for technical and policy tools, specifically tailored to western states. The focus of this organization is on meeting new regional haze and visibility requirements enacted by 1999 legislation to improve 156 national parks and wilderness areas. However, many of the studies and recommendations of this site are in preliminary stages and currently Nevada is not listed as a member of WRAP. (EPA-4 2004, wrapair.org)

System Dynamics Approach

The use of a system dynamics model will meet the majority of the DAQEM's goals. System dynamics models are very fast, giving results from inputs in just moments. Scenarios do not lead to duplicate models and there are virtually no limitations on the numbers of scenarios that can be run. Results can be easily displayed graphically as well as in tabular form or even exported. System dynamics models also provide easy future adaptations, as new information becomes available it can easily be inputted into the existing structure of the system. Because of their ease of use, others can easily be trained on how to use the system dynamics model without requiring any extensive knowledge of system dynamics modeling.

However, the main reasons a system dynamics approach is more effective for this problem is that they go beyond isolated linear calculations and focus on relationships among variables. Therefore, instead of numerous exogenous data inputs, the model produces values based on known relationships and understanding of processes in the system. Another advantage of using a system dynamics approach is that they typically focus on policy levers and how to bring the problematic trend into a more desired trend, in this case reduce emissions.

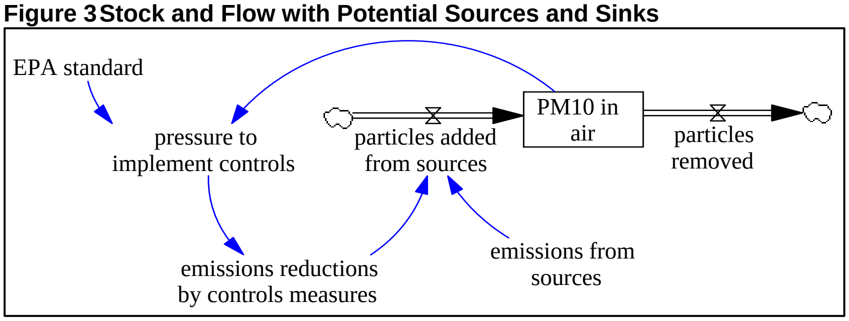
Model Development

The process of model development was split into two phases. The first phase was the conceptualization phase where alternative ways of structuring the system were explored. The second phase takes the conceptualization accepted by DAQEM, expands and modifies it, and then uses this model for policy analysis. Because the county had already completed many important studies with regard to PM, they wanted to ensure that this information was carried over into the new model. The first step of developing the new model was to examine the old model and supporting SIP in order to determine its drawbacks and how it calculates emissions. This process proved very difficult, as the documentation of the SIP was in a physical document spanning several three-inch binders. Assumptions and calculations were not always described and unit conversions were not explicitly carried out either in the model or the documentation. Therefore, during the course of this conversion, UNLV concurrently developed a conceptualization of the problem completely separate from the Rollback model. These two models were then presented to DAQEM, along with a model that somewhat modified the Rollback model but used the same conceptualization. The three resulting models were described according to their advantages/ disadvantages, and DAQEM determined which model was to be carried through to the final stages of model development and policy analysis.

Basic System Conceptualization

The simplest way to envision the main components for PM_{10} is shown as the simple stock and flow model in Figure 3, with "PM_{10} in air" as a stock that accumulates from emissions from sources and decreases from removal of these particles. Several examples of sources and sinks as well as the mechanisms of addition or removal are listed.

Figure 3 Stock and Flow with Potential Sources and Sinks



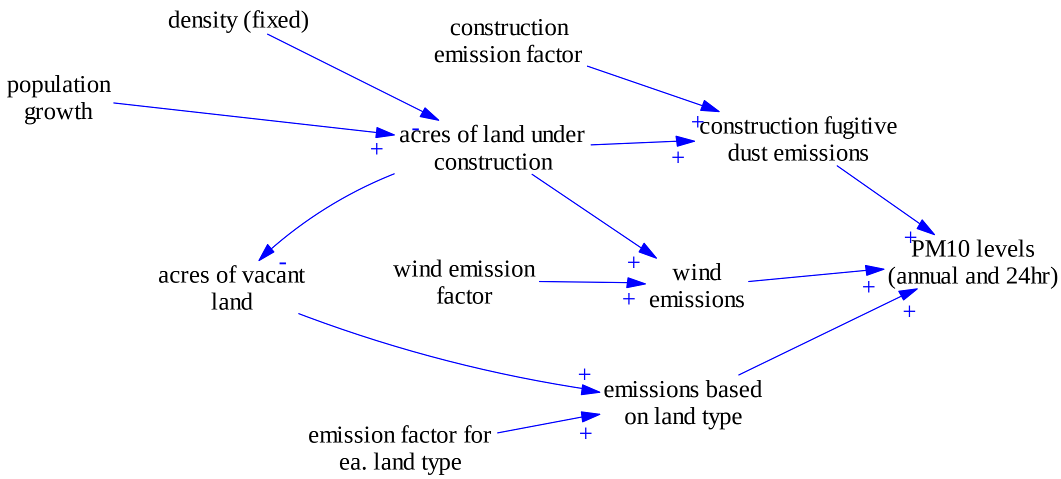
ADDITION		REMOVAL	
Sources	**Mechanism**	**Sinks**	**Mechanism**
mineral/geologic	construction	vacant land	settling
organic	industrial emissions	disturbed land	transport (wind)
chemical	wind erosion	roads	precipitation
	other disturbance		

Emissions

Rollback Model

The basic causal framework of the rollback model as it is represented in the excel spreadsheets is shown in Figure 4 and described in the preceding section. The linear nature of this model can be clearly seen. There are many important problems with this conceptualization,

Figure 4 CLD of Rollback model

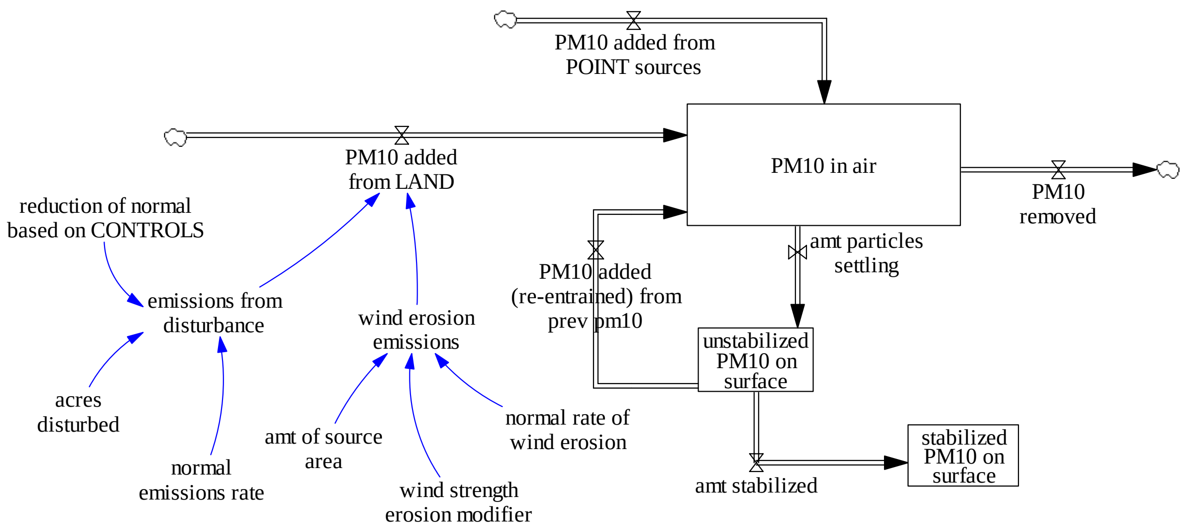


including that density is a fixed number set as an average from real density values in 1999 through 2003. Currently, the LVV is seeing a drastic change in density values and this should be represented in the system. Another problem is that population growth is an independent variable that is not influenced by any other variable. Even considering assumptions that poor air quality would not affect immigration to the valley, there should at least be a connection recognizing the physical limitations of land development since there is only a fixed amount of it remaining.

Particle Tracking Model

This model was created separate from the previous model and attempts to generate the variables causing emissions, instead of detailing numerous fixed exogenous variables. This conceptualization expands the basic stock and flow as shown in Figure 3 and starts to look more at meteorology and transport. The previous model requires a flushing variable in order to only track the accumulation of a year, whereas this model includes how particles are removed from the air.

Figure 5 Stock and Flow Diagram of Particle Tracking model

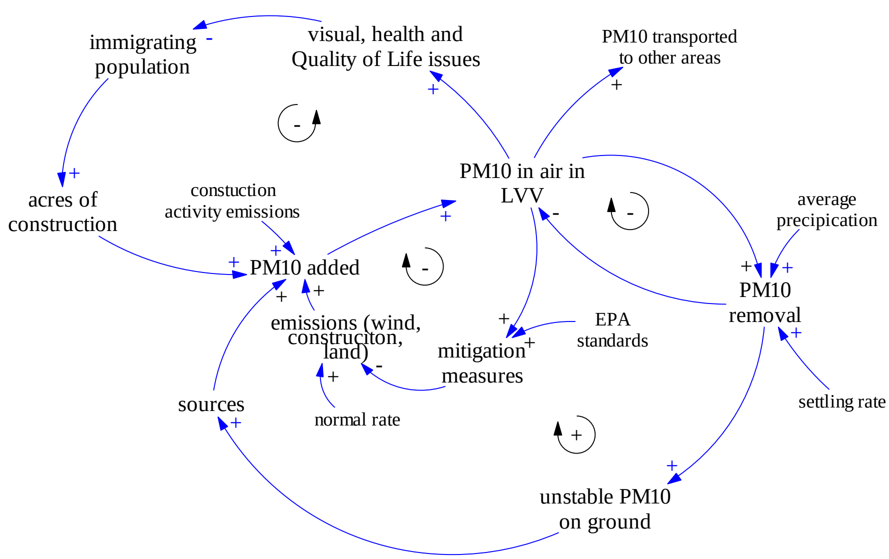


One interesting component of feedback that emerges from this description of the system is with the sink of “roads” which would then become an additional source that could be emitted into the air.

Solomon (1994) outlines the main components necessary to conceptualize the system and pollutant(s) in question: emissions, meteorology and transport, chemical and physical transformations, and removal processes. In many areas, meteorology is a very complicated component of the model leading to several chemical transformations. However, in the arid southwest, PM_{10} becomes more important than in other climates because very few rain events occur to wash particles from the atmosphere and wind, which is another typical removal process, is also the cause of particle emissions (especially on disturbed land). Therefore, the transformation section is not a necessary component. Meteorological factors of primary concern are wind and rain; with so few days of rain, a simple rate could be used and wind conditions could either be set to a randomly generated variable (within seasonal ranges determined from historic data) or broken down into low wind days and high wind event days, the frequency of which have been basically determined.

The causal structure shown in Figure 6 below illustrates that PM_{10} in the air is removed by two primary mechanism, dry deposition (settling) and precipitation. However, once particles are removed, a certain amount of the particles will settle onto roads and other land sources and remain loose. These unstable particles then become sources which are re-emitted into the air. Once particles reach a level close to the EPA standards, additional mitigation measures will be implemented, thereby reducing the amount of particles given off by an area and thus PM_{10} added to the air. Another feature of this representation of the system is that as PM_{10} levels rise, there will be increasing visibility and health issues as a result of PM. This, in turn will reduce the net amount of people moving to the LVV annually and the acres of construction and therefore the emissions from construction activities.

Figure 6 CLD of Particle Tracking model



The final model was a combination between the two of these representations. It does not contain as much feedback as the structure shown in Figure 6, but it is not nearly as linear as the first diagram shows. The advantages and disadvantages of each of these different methods of representing the system are shown in Figure 7.

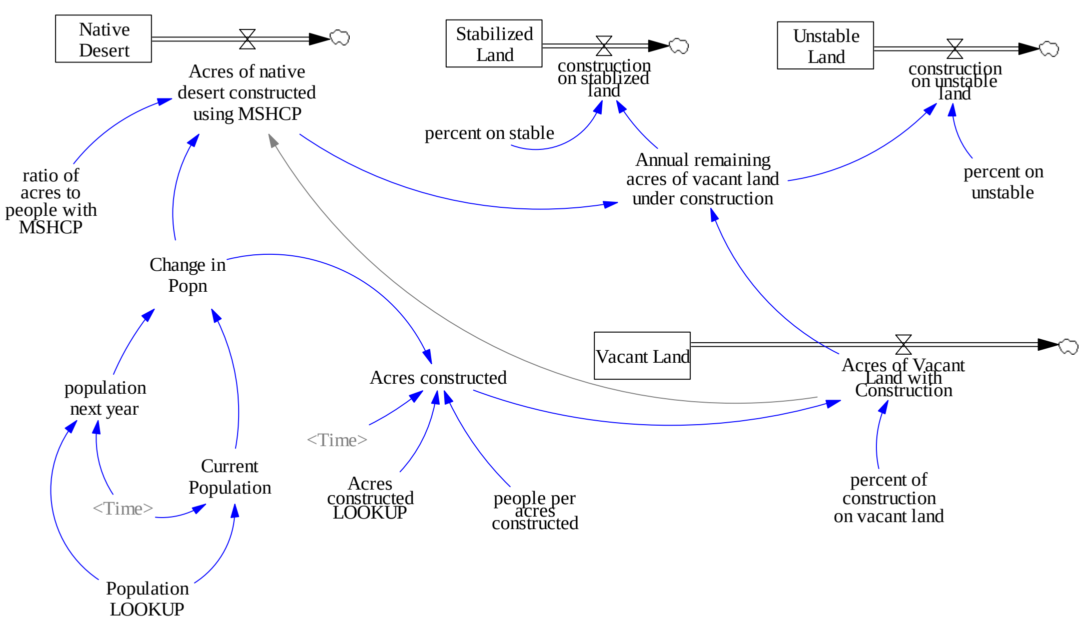
Figure 7 Benefits and Drawbacks of each model

Model	Benefits	Drawbacks
1. Rollback—individual spreadsheets as isolated views	Individual views for each source, easier to follow for users of previous model and EPA reviewers	Retains many limitations of previous model: lacking important components,
2. Modified rollback—combined view, adds some important aspects but mostly original conceptualizations	Less cumbersome, easier to navigate, all components on one page, contains some important mechanisms (e.g, land flows, density)	Still lacks important feedbacks (such as the impact on population if air quality worsens), most calculations still very linear
3. Particulate tracking—tracks PM_{10} in air as a stock	Clearer, causal conceptualization, much simpler model, reflects feedback of particles going from being emitted back to a source	Possibly more difficult for client and EPA officials to follow, requires Las Vegas specific inputs

Land Sector

The land component of the model is very important because construction and disturbance on the different types of lands has different impacts. Land is broken down into two large categories, vacant land and the built environment. However, vacant land includes a further breakdown of native desert, stabilized land, and unstable land—all of which have very different emissions factors. In the proportional rollback model, all of these types of lands were tracked as separate stocks and there was no representation of the flow of reconstruction back into the system (Figure 7).

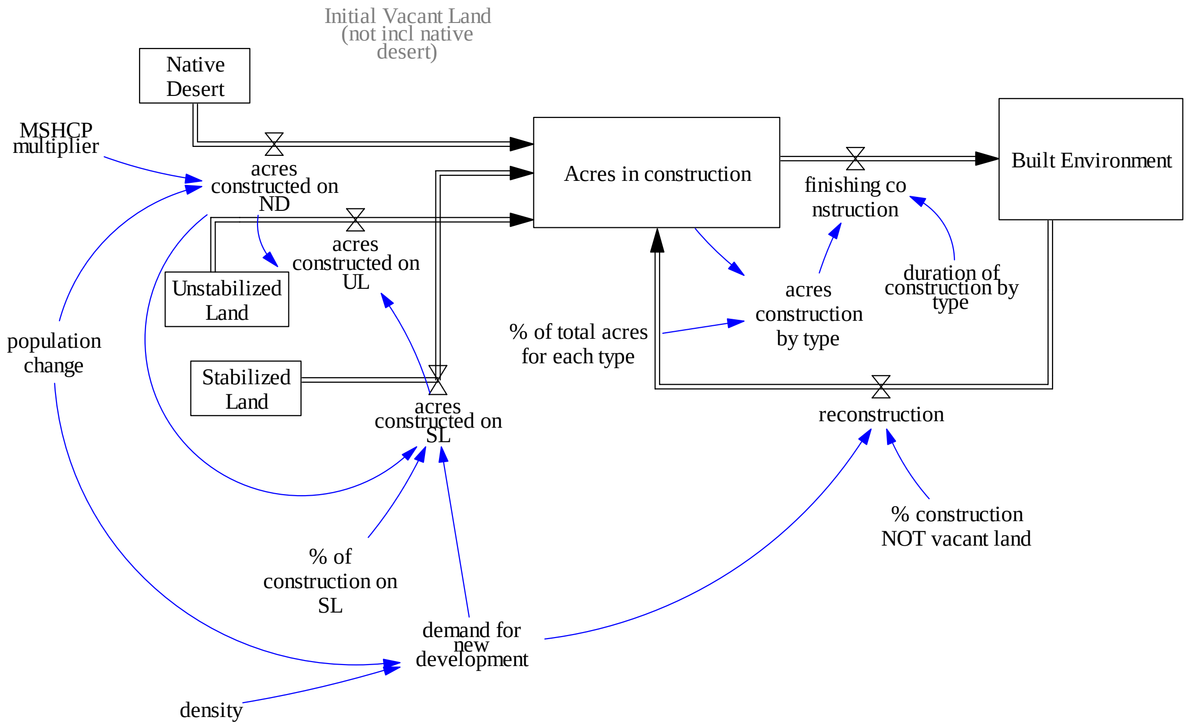
Figure 8 Land Sector of Rollback model



Most emissions in the model are based on the acres of land in construction. However, according to the structure of this system, all of these types of land are separate stocks that do not flow into each other. In addition, although stabilized and unstable land are both parts of the stock of "vacant land", in this representation all stocks are listed separately. Figure 8 shows a more systems perspective of the land sector, showing the flows that are possible between these stocks and resulting in a stock called "built environment."

They gray variable at the top, "Initial Vacant Land," allows for changes to how much of the BLM disposal boundary is included, which is shown on the map of the LVV. In other sectors of the model, emissions factors tied to each stock of land types are used to calculate fugitive dust emissions that occur on land areas. Other types of additions to PM_{10} are similarly calculated in other sectors, including wind erosion and construction activity. These calculations all feed into a stock that tracks annual and daily PM10 levels in the air.

Figure 9 Stock and Flow diagram of Land Sector



Final Phase

DAQEM chose the modified rollback model as their chosen representation of the system. The next steps for this project will be taking monitoring data from the valley's stations and using them to calibrate the model. Although the emissions factors were portioned out according to disturbance, there is still some uncertainty about how well the initial emissions inventory was calculated. Most planners feel that at all stages of the original Rollback model and emissions inventory, values were constantly rounded up or taken from an upper value bound in order to prevent projected emissions from being lower than they would be realistically. This resulted in a great exaggeration of model results so that, while current monitoring data shows the LVV within limits for the annual standard, the model still gives values significantly larger than current observed data.

Initial model validation tests have primarily checked to see whether results generated are the same as the original model, as well as additional work on conversions and units plus documentation. The final stage will look more closely at the control section of the model, policy analysis, and how DAQEM wants to represent the final output for the EPA.

Reflections on Process

There are few policy levers in the system. Implementation of control measures to reduce emission of dust is the main leverage point, but its potential effect is limited. The effect of control measures is a function of both control method efficiency (for example, how well water sprayed onto disturbed ground reduces dust) and rule penetration (how many sites are actually implementing controls). The former option is set by standards for control methods and the latter will require significant and consistent resource investment.

Additional Reflections:

- Part of our role was demonstrating that "dynamics" is not simply carrying out calculations (i.e., numbers that change) but rather feedback between variables
- DAQEM planners were limited in how they could change the current model framework, partly based on prior EPA approval of their method and also on lack of new variable data.
- While planners recognized dynamic limitations in their model, the focus was on updating data and calculations of the rollback model
- Phase one of the process revealed several inaccurate assumptions in the current model and made modifications of results explicit, sparking discussion
- The modeling process lead to insights about how DAQEM was structuring the system and framing the problem.
- Current air quality planners inherited this model and many of the original modelers are no longer available to help in determining how to use and improve its workings
- Data was originally collected but not used for smaller scales, in the vicinity of PM_{10} monitors, indicating a possible area of refinement for the model

Effectively introducing system dynamics perspectives and methods into the management of environmental issues and problems in governments in the U.S. requires some degree of flexibility that many government agencies and political entities do not have, but progress is being made in many areas, especially Las Vegas and the surrounding area.

What This Project is Doing

This project focuses on re-conceptualizing PM_{10} management in the Las Vegas Valley. Any advances in conceptualizing the system and refining the model will have very positive outcomes on the management of PM_{10} in the valley by improving the understanding of managers responsible for air quality. This model will not only meet the requirements the DAQEM must complete for the EPA, but also greatly expands the capabilities of the previous model by: projecting values twenty years into the future, refining understanding of processes, incorporating missing components of the system, and allowing for identification of policy levers.

According to Molina and Molina (2004), "strong political will coupled with public dialog is essential to effectively implement the regulations required to address air quality problems." Luckily, this study utilizes DAQEM, the region's regulating entity for air quality, which should lead to good enforcement of policies. Additionally, there is strong reason to believe that the county will focus on public participation and education to further reduce emissions. This hope comes from the precedents of other important issues in the valley that lead to valley-wide public information campaigns. Some examples include the "Water Smart" campaign which helped implement drought induced watering restrictions; "Club Ride" offers several incentives for using alternate transportation such as mass transit or bicycles to get to work. In fact, there has already been a campaign specifically addressed at reducing particulates in the areas of the valley with the most unpaved roads. This campaign informs residents and small business owners of the impact of kicking dust into the air and steps they can take to prevent or reduce dust.

This project brings the Las Vegas Valley another step closer to having more integrated management of air quality. There are already very powerful resources for air quality in general and PM_{10} specifically that could be further integrated into the policy-making process. Monitoring stations capture current levels of pollutants across the valley, for some pollutants hourly but all at least several times a day. Solomon (1994) recommends that regional air quality planners incorporate monitoring into their modeling framework in order to better manage problems and target problem areas. In addition to monitoring data, DAQEM already uses Mobile6, an EPA model for calculating on-road mobile source emissions for criteria air pollutants. Future projects should work toward further integration of these tools and models, as well as spatial information and specific management strategies as variables.

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