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Stormwater Management for TMDLs in an Arid Climate: A Case Study Application of SUSTAIN in Albuquerque, New Mexico

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Stormwater Management for TMDLs in an Arid Climate: A Case Study Application of *SUSTAIN* in Albuquerque, New Mexico

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Abstract

This case study for the Albuquerque, New Mexico area was conducted under contract with the U.S. Environmental Protection Agency (EPA) Office of Research and Development using the System for Urban Stormwater Treatment and Integration Analysis (*SUSTAIN*). The effort focuses on investigating both site- and regional-scale stormwater management questions ahead of a pending watershed-based municipal separate storm sewer system (MS4) permit. The *SUSTAIN* modeling system integrates watershed modeling capabilities, best management practice (BMP) process simulation, and BMP cost representation within the context of a cost-benefit optimization framework (USEPA, 2009). The system can be used to evaluate complex decisions about green infrastructure selection and placement, performance, and costs for meeting flow or water quality targets or both.

With the large degree of variability in physical, hydrological, and chemical characteristic in a watershed, watershed-scale management for the nonpoint source component of MS4 permits quickly grows in complexity. Because different land uses had different pollutant levels, and because there were differences in BMP cost assumptions, there were differences in cost-effectiveness between management strategies that yielded comparable water quality outcomes. The objective of watershed management within an optimization framework like *SUSTAIN* is to identify strategies that meet water quality goals while minimizing cost.

Tetra Tech has developed two other *SUSTAIN* case studies for EPA in Kansas City, Missouri and Louisville, Kentucky, as part of this development phase (USEPA, 2012). These studies investigated the use of green or gray infrastructure practices to mitigate combined sewer overflows in temperate climate areas. In contrast, this Albuquerque case study focuses on *water quality* performance of different management practices for various storm sizes in an arid climate. The proposed approach documents the various phases of the *SUSTAIN* application process, including establishing baseline hydrology and water quality loads, identifying the critical condition for management, formulating management objectives on the basis of local design standards, and testing the sensitivity of optimization results to different formulations of the management objectives. The study estimates the potential range of benefits and impacts in light of existing *Escherichia coli* (*E. coli*) total maximum daily load (TMDL) targets. The results of this study provide quantitative technical guidance to support the pending watershed-based MS4 permit.

Executive Summary

This case study for the Albuquerque, New Mexico, area was conducted under contract with the U.S. Environmental Protection Agency's (EPA) Office of Research and Development using the System for Urban Stormwater Treatment and Integration Analysis (*SUSTAIN*). *SUSTAIN* extends the capabilities and functionality of traditionally available models by providing integrated analysis of water quantity, quality, and cost factors. *SUSTAIN* offers a unique evaluation platform for cost-benefit optimization to evaluate complex decisions about Best Management Practice (BMP) selection, placement, and performance for meeting specified flow or water quality targets or both. Two previous *SUSTAIN* case studies were published for applications in Kansas City, Missouri and Louisville, Kentucky, as part of this development phase (USEPA, 2012). Those studies investigated the use of green or gray infrastructure practices to mitigate combined sewer overflows in temperate climate areas. In contrast, this Albuquerque case study focuses on the *water quality* performance of both structural and nonstructural BMPs for managing runoff in an arid climate.

The focus area is in the Albuquerque metropolitan area in north-central New Mexico and lies along a portion of the Middle Rio Grande watershed that was listed for *Escherichia coli* impairment as part of a recent total maximum daily load (TMDL). The goal of this effort was to identify cost-effective stormwater management strategies through optimization that reduced *E. coli* loading by 66 percent, based on target requirements established by the Middle Rio Grande *E. coli* TMDL. Given that rainfall events are few and far between in this arid environment (annual average of about 9.5 inches), it was not surprising to find that continuous simulation models were neither widely used nor readily available. An alternative approach was applied to develop the baseline rainfall/runoff response for this case study. This case study had three primary objectives:

1. Develop a boundary condition using a simple hydrology method (TR-55 Method) in conjunction with event-mean concentrations
2. Evaluate the trade-offs in cost and management performance of both structural and nonstructural BMPs during the optimization process
3. Estimate the water quality performance benefits of proposed management practices, based on critical conditions identified in the Middle Rio Grande *E. coli* TMDL, to support a pilot municipal separate storm sewer system (MS4) watershed-based permit being developed by EPA Region 6.

Because different land uses had different pollutant levels, and because there were differences in BMP cost assumptions, there were differences in cost-effectiveness between management strategies that yielded comparable water quality outcomes. The structural BMPs considered included rainwater collection, xeriscaping, and extended detention ponds; the nonstructural BMPs included pet waste management and street sweeping. Due to the wide range between various literature-based and local implementation cost estimates for street sweeping, two scenarios were run to test model sensitivity at lower and higher cost estimates. Consequently, when street sweeping was weighed against other distributed and centralized management practices, it was found that the cost assumption affected the order in which the practices were selected. Given the range of conditions and constraints reflected in this modeling study, it was estimated that a cost-effective solution for achieving a 66 percent *E. coli* load reduction target would cost

between $8,736 and $12,955 per 100 acres per year (assuming a 20 year BMP lifecycle). At both ends of the modeled spectrum, rainwater conservation practices (collection and xeriscaping) are shown to be cost effective. When street sweeping costs are lower, its use reduces the overall need for structural practices by controlling loading at the source. The results also suggested that more infrequent sweeping (i.e., monthly) is not cost-effective compared to what can be achieved with rainwater conservation practices. When street sweeping costs are higher, centralized wet ponds become an attractive supplement to rainwater conservation practices. For the higher-cost scenario, street sweeping was not part of the recommended suite of practices needed to meet the 66 percent *E. coli* TMDL reduction target. In fact, it was only considered beyond the 75 percent load reduction point, and only after all other opportunities for structural practices had been exhausted.

This case study documents the various steps taken in developing this *SUSTAIN* application, including establishing baseline hydrology and water quality representation, identifying the critical condition for management, formulating management objectives, and synthesizing model outputs with a focus on the *E. coli* TMDL and pending watershed-based permit. Through this study a framework was established that can be applied to support the development of implementation strategies for meeting water quality targets associated with both the *E. coli* TMDL and pending watershed-based permit.

Abbreviations

ABCWUA	Albuquerque Bernalillo County Water Utility Authority
ASCII	American Standard Code for Information Interchange
BMP	Best management practice
CFS	Cubic feet per second
cfu/day	Colony forming units per day
CN	Curve Number
d6	Distribution of mean precipitation
DPM	Development Process Manual
E. coli	*Escherichia coli*
EMCs	Event mean concentrations
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute
FDCs	Flow duration curves
FIPS	Federal Information Processing Standards
FY	Fiscal Year
GIS	Geographic information systems
HARN	High Accuracy Reference Network
HRU	Hydrologic response units
HUC 12	12 digit hydrologic unit code
in.	Inches
LID	Low Impact Development
LSPC	Loading simulation program in C++
MFR	Multi-family residential
mg/L	milligrams per liter
mL	milliliter
MS4	Municipal separate storm sewer system
NAD	North American Datum
NCDC	National Climatic Data Center
NM0234	Climate station at Albuquerque International Airport
NM-60	New Mexico Type IIA – 60 – 24 hour storm
NMED-SWQB	New Mexico Environment Department – Surface Water Quality Bureau
NOI	Notice of Intent
NRC	National Research Council
NRCS	Natural Resources Conservation Service
O&M	Operation and maintenance
PEVT	Potential evapotranspiration
SFR	Single family residential
SSURGO	Soil Survey Geographic Database
SUSTAIN	System for Urban Stormwater Treatment and Integration Analysis
SWMM	Stormwater management model
TMDL	Total maximum daily load
TR-20/55	Technical Release 20/55
TR-55	Technical Release 55
TSS	Total suspended solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WBP	Watershed based permit

WIN TR-55	Windows version of TR-55
WQ	Water quality
WQCV	Water quality capture volume

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Chapter 1. Background

The case study began by first engaging a group of local stakeholders, in conjunction with EPA Region 6, to help (1) define the context of the study including location, (2) identify the pollutant(s) of interest, (3) set reasonable management objectives for evaluation, and (4) provide relevant models, data sets, and existing studies as supporting information for the case study.

The study area focused along a portion of the Middle Rio Grande watershed listed for *E. coli* impairment as part of a recent TMDL in the Albuquerque metropolitan area in north-central New Mexico. The Rio Grande watershed begins with headwaters in Colorado. By the time the river reaches Albuquerque, New Mexico, the drainage area encompasses approximately 14,000 square miles; however, the scope of this case study is limited to stormwater contributions originating from the Albuquerque metropolitan area rather than flow volumes and pollutant loads accumulated from upstream sources. Figure 1 presents a map of the general study area highlighting its spatial relation to the City of Albuquerque, Bernalillo County, and the larger Rio Grande watershed.

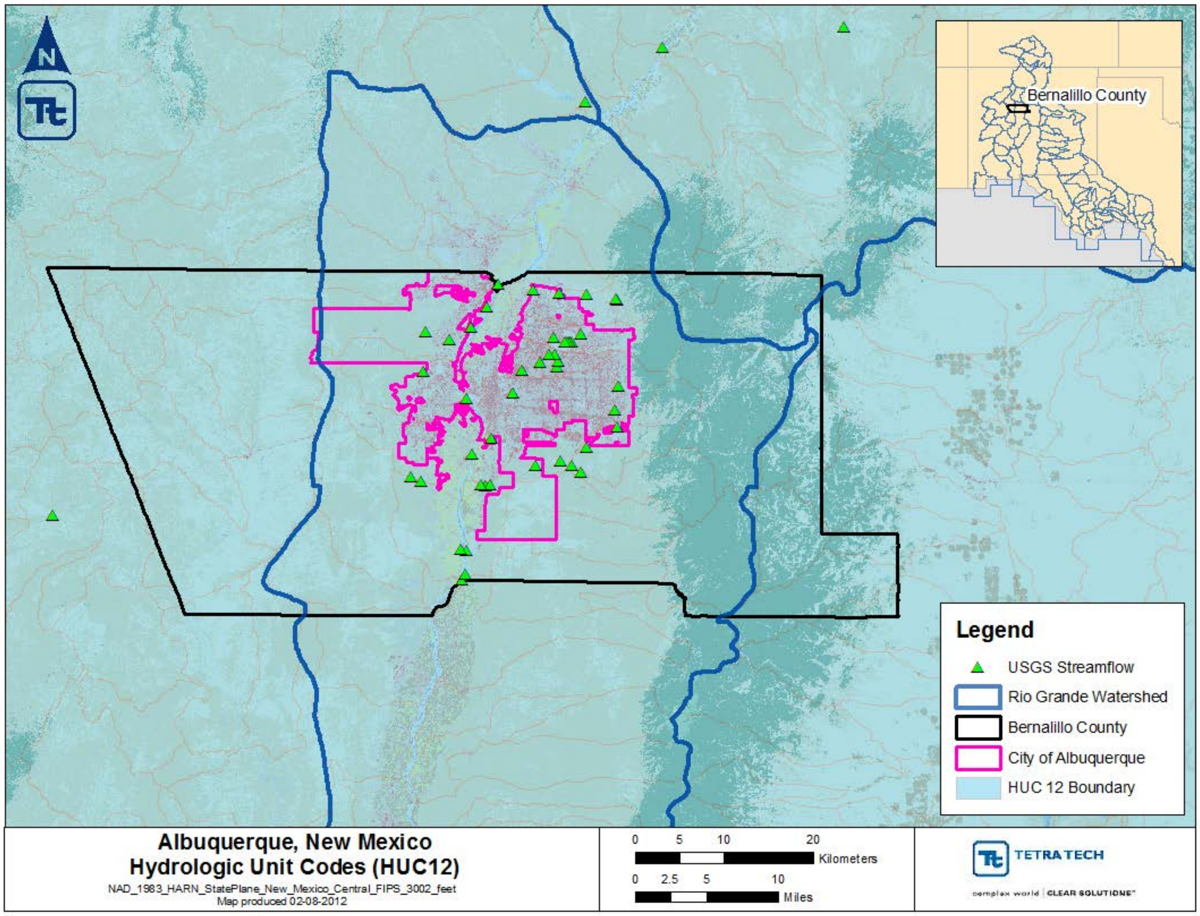


Figure 1. Map of Bernalillo County, Albuquerque, and the Rio Grande watershed.

Because the case study scope is limited to local stormwater contributions, it was essential to establish a framework that links surface water flow, water quality, and regulatory measures (i.e., TMDL, watershed-based permitting [WBP]) to watershed drivers such as precipitation, pollutant generation, and stormwater management strategies. The *SUSTAIN* platform provide a means for making this linkage and assessing cost-benefit relationships of various stormwater management strategies. The final exercise involved extrapolating *SUSTAIN* site-scale performance to the watershed scale to quantify potential regional impacts of widespread adoption of both structural and nonstructural management practices.

1.1. Overview of Objectives

A number of analytical objectives distinguish this study from previous *SUSTAIN* case studies. First, it represents management in an arid climate environment, which affects watershed behavior and changes the types of stormwater management approaches that work well. Collaboration with a stakeholder group was initiated early in the process to help set objectives and modeling direction. During discussion with this group a number of unique study features were either proposed or discovered through data collection. These items were substantial enough to develop into study objectives which are not only important to this study, but also are highly relevant and transferable to *SUSTAIN* applications in general.

Second, the other two case studies in Kansas City and Louisville focused on water quantity (flow volume or peak flow reduction) (USEPA, 2012); however, the focus of this case study is water quality. Unlike the other two case studies, no existing continuous simulation model was available to link with *SUSTAIN*. Given that rainfall events are few and far between in this arid environment, it was not surprising that no continuous simulation models had been developed. An alternative approach was explored for developing the baseline rainfall/runoff response. Finally, stakeholders were interested in evaluating structural BMPs and the tradeoffs between a mix of structural and nonstructural practices. On the basis of these findings, the following three modeling objectives were defined:

- Develop a boundary condition using a simple hydrology method (such as TR-20/55 or Rational Method), in conjunction with event-mean concentrations;
- Evaluate the trade-offs in cost and management performance of both structural and nonstructural (programmatic) BMPs during the optimization process; and
- Estimate water quality performance of proposed management practices based on critical conditions identified in the Middle Rio Grande *E. coli* TMDL to support a pilot MS4 watershed-based permit under development by EPA Region 6.

1.2. Watershed Based MS4 Permit

As documented by the National Research Council (NRC) in a report titled *Urban Stormwater Management in the United States,* stormwater discharges can negatively affect water quality through increases in stormwater volume and, consequently, pollutant loads to the receiving waters (NRC 2008). The NRC report concludes that adopting the MS4 permitting approach using the physical topography of watersheds is a more effective means to halt and reverse damage to waterbodies, rather than basing the permits on political boundaries. With this, the NRC recommends that EPA use a watershed based permit (WBP) approach to improve the stormwater program.

A pilot program was suggested as a first step to allow EPA to explore the many complexities of WBP. EPA selected Region 6 and EPA Region 6 subsequently selected the Middle Rio Grande valley as one of three pilot WBP projects nationwide. This area was chosen largely because of existing water quality impairment in the Rio Grande and the opportunity to work on the challenges of permitting unique to arid and semi-arid parts of the country.

The proposed watershed-based MS4 permit in the Middle Rio Grande is designed to accommodate a general permit approach using a Notice of Intent (NOI) to the general permit in lieu of an individual permit application. The operator of a regulated MS4 must include in its permit application, or NOI, chosen BMPs and measurable goals for each minimum control measure. The NOI can include schedules to fully develop and implement the stormwater program over the initial 5-year permit term. To help identify the most appropriate BMPs, EPA Region 6 is working with the Middle Rio Grande workgroup to develop a menu of BMPs to serve as guidance. The permit will encourage the use of green infrastructure, such as swales, rain gardens, and porous pavement.

According to EPA Region 6, Appendix A of the proposed permit will identify a number of implementation options for regulated MS4 operators. This includes sharing responsibility for program development with a nearby regulated small MS4, taking advantage of existing local or state programs, or participating in implementing an existing Phase I MS4's stormwater program as a committee. These options are intended to promote a regional approach to stormwater management coordinated on a watershed basis. Operators of regulated MS4s in the Middle Rio Grande are required to design their programs to do the following:

- Reduce the discharge of pollutants to the *maximum extent* practicable;
- Protect water quality; and
- Support the applicable water quality goals of the Clean Water Act.

This case study presents a methodology for applying *SUSTAIN* to support and inform certain aspects of permit implementation, which include refining the suite of proposed BMPs. In addition to providing different degrees of management practices on the basis of local design standards and practices, the model can highlight the merits of the various BMP options during the planning process. The conclusions from this case study can serve as documented guidance for those MS4 operators tasked with implementing management practices in fulfillment of the WBP. Recommendations and conclusions will be made that synthesize these case study findings related to the (1) cost-effectiveness of specific BMPs, (2) critical conditions under which BMPs are and are not effective, and (3) tradeoffs between structural and nonstructural BMPs. Although a representative subwatershed unit is evaluated for BMP implementation using *SUSTAIN*, the case study findings are not intended to be globally representative of all localized hydrologic, water quality, or land use context within the MS4 permit boundaries. This report presents a methodology for applying *SUSTAIN* to study management opportunities in a data-challenged environment.

Chapter 2. Data Review

The quality of a *SUSTAIN* model application, as is true of models in general, depends on the quality of the input data sets used during model development. Therefore, acquisition, review, and synthesis of a robust data set is critical for developing a sound, defensible model baseline representation of local hydrologic and water quality conditions. The initial data collection phase of this study involved an iterative process of collaboration and data request in conjunction with the local stakeholder group. The following items were requested:

- Geospatial data sets describing physical characteristics of the study area (land use, topography, soils, subwatershed/catchment boundaries);
- Local flow, water quality, and climate monitoring data sets;
- Documents with local BMP guidance; and
- Local BMP cost data.

Each provided data set was reviewed using a multi-step process, beginning with compiling all provided data in a centralized location. After this compilation, each data set was reviewed and assessed for specific utility to this case study application with a focus on the locations and pollutant constituents identified during stakeholder discussions. This section presents key data sets provided by Bernalillo County, the city of Albuquerque, EPA Region 6, and other stakeholder groups which have been identified through data review as critical to the baseline model development. The following items were specifically evaluated:

- Geospatial data sets describing the physical characteristics of the study area (land use and topography) provided by Bernalillo County and the city of Albuquerque;
- Local precipitation and climate data obtained from NCDC sources; and
- Water quality monitoring data provided by Bernalillo County.

Spatial data describing land use, slopes, and soils were evaluated in conjunction with watershed boundaries to construct the geospatial portion of the *SUSTAIN* model representation of the watershed. Precipitation data were used to evaluate representative storm volume, intensity, and duration for accurately reflecting baseline rainfall-runoff conditions. Water quality monitoring data were used to inform characterization of an appropriate pollutant loading response for selected storm intervals.

Two pollutants, *E. coli* and total suspended solids (TSS), were identified as the focus of this study during conference calls with the stakeholders. *E. coli* was selected as the primary pollutant of concern because of its relevance to an existing TMDL. TSS was also evaluated as a secondary pollutant; however, because no numeric target exists, it was not used as an objective for optimization. Monitoring data sets provided by Bernalillo County focus on four drainage basins ranging from 20 to 1,000 acres with mixed land use distributions. The four basins were (1) Adobe Acres, (2) Sanchez Farms, (3) Alameda Boulevard, and (4) Paseo Del Norte. These sites were considered as candidate locations for calibration efforts to establish a baseline watershed characterization, rainfall-runoff response, and water quality signature.

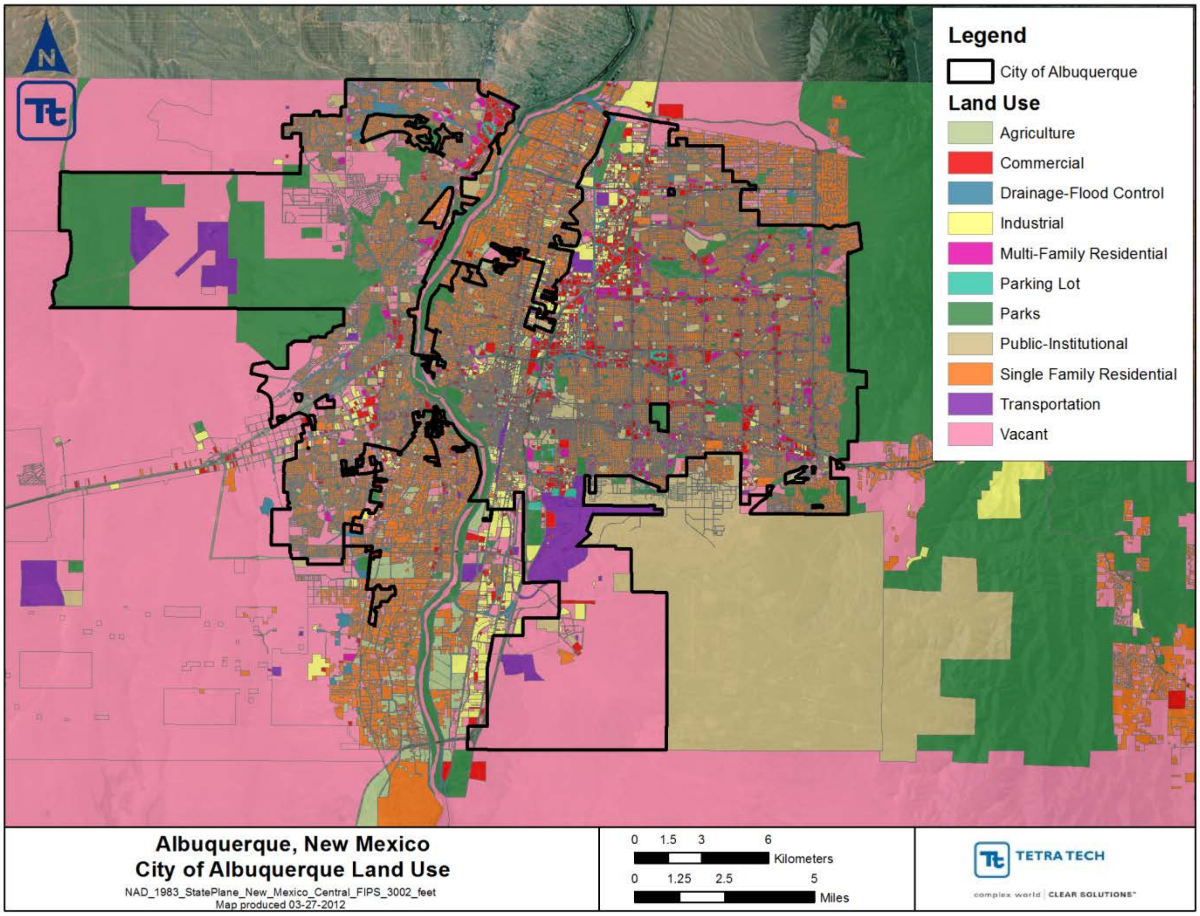
2.1. Spatial Data Sets

Representative characterization of physical aspects of the study area is important when modeling the local rainfall-runoff response in a watershed and developing hydrologic response units (HRUs) for organizing areas of similar response in the context of a model. During *SUSTAIN* model setup, these spatial data sets were used as the basis for representing HRUs. HRUs are discrete spatial units that embody unique physical or environmental characteristics and human influences that result in a unique hydrologic or water quality signature. HRUs are defined by physical characteristics such as slope or soil infiltration capacity, both of which affect the timing and magnitude of runoff. Anthropogenic elements such as impervious cover and land use often affect not just the hydrology but also pollutant loading.

Nationally scoped data sets are readily available as land use raster, digital elevation model, and soil surveys that provide a starting point for model development; however, local data sets maintained by local agencies often provide a higher resolution. Higher resolution, local data are more desirable than the coarse national data sets because they will usually provide more accurate, site specific representation of watershed characteristics. Bernalillo County provided drainage area boundaries for the four drainage areas with coincident water quality monitoring data. The following spatial data sets from Albuquerque's online geographic information systems (GIS) database were collected:

- Countywide Land Use;
- Land Use Categories Mapping Table; and
- Two-Foot Elevation Contours.

Two land use data sets were available: (1) National Land Cover Dataset 2006 hosted by the Multi-Resolution Land Characteristics Consortium, and (2) local Albuquerque land use. The Albuquerque local land use data set is divided into 13 categories. This locally sourced data set is more appropriate than the national data set because it is (1) updated continually and made public twice a month, and (2) more reflective of local nuances in the land use categorization. Figure 2 presents a map of Albuquerque's land use data set rendered using the predefined land use categories, and Figure 3 presents a detailed, site-specific view of the same data set zoomed in to the Adobe Acres drainage basin.



Source: Albuquerque GIS 2012

Figure 2. Albuquerque local land use map.

Source: Albuquerque GIS 2012

Figure 3. Land use map of the Adobe Acres drainage basin.

The land use distribution shown in Figure 3 for the Adobe Acres drainage basin includes 11 of the 13 land use categories included in the complete city of Albuquerque land use data set (Albuquerque GIS, 2012). Albuquerque land use data set provided a clear framework for representing the local HRU texture as it relates to this study and was preferred over the national Multi-Resolution Land Consortium coverage. The simplifying assumptions imposed while deriving the final HRU layer used in *SUSTAIN* were as follows:

- The existing commercial categories that distinguished between service and retail have been grouped into a single *Commercial* category.
- The warehousing category was reclassified as *Industrial*.
- Local roads were not represented explicitly as polygons in this data set; therefore, they rendered as void space between polygons. When the data set was converted to a raster for use in *SUSTAIN*, void spaces were assigned a unique value to represent the roads.

Topographic data can be used to derive slope, which affects the timing and magnitude of the rainfall-runoff relationship. Also, where water movement is determined by topography, the data are useful for establishing flow direction and delineating drainage areas. This information is generally important when developing detailed baseline hydrology models. Albuquerque provides a spatial data set of 2-foot topographic contours, which increases in resolution to 1-foot contours for some areas. Figure 4 presents a map of percent slope derived from 2-foot contours provided by the city (Albuquerque GIS, 2012). The map also locates the four monitored drainage basins with available water quality data referenced for guiding water quality representation in this study. Those four sites are all located close to the Middle Rio Grande in areas with generally lower slopes and lower elevation by over 1,000 feet than seen elsewhere in the city and county.

Soils spatial data sets provide a basis for assessing infiltration potential (1) from pervious land types when developing a baseline rainfall-runoff model, and (2) through infiltration-based BMPs. No soils data set was initially available through the Albuquerque or Bernalillo County websites. National soil survey data can be used to develop a general assessment of infiltration potential. The national data set, Soil Survey Geographic Database (SSURGO) is maintained by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). This data set was not available in digital format for all areas. Because this case study focuses on urban areas and New Mexico restricts stormwater harvesting and infiltration-based practices, a generalized soil survey data set is of lower importance than layers representing other physical characteristics. In addition, this case study focused primarily on urban water quality management for single events (instead of continuous simulation, which would involve inter-event dewatering). For those reasons, only the Albuquerque land use coverage was used as the basis of HRU representation. Applying the previously listed transformations and assumptions to the Albuquerque land use data set resulted in 12 unique HRU categories on which the *SUSTAIN* model will be based (Table 1). Conservative assumptions will be applied when developing runoff time series to address likely soil conditions.

Table 1. Mapping of Albuquerque land use categories to *SUSTAIN* case study HRUs

Albuquerque land use categories	*SUSTAIN* case study HRU
Agriculture	Agriculture
Commercial Retail	Commercial
Commercial Services	
Drainage/Flood Control	Drainage Flood Control
Industrial/Manufacturing	Industrial
Wholesale/Warehousing	
Multi-Family Residential	Multi-Family Residential
Parking Lots/Structures	Parking Lot
Parks/Recreation	Parks
Public/Institutional	Public/Institutional
Single-Family Residential	Single-Family Residential
Transpiration/Utilities	Transportation
Vacant/Other	Vacant
No Representation	Roads

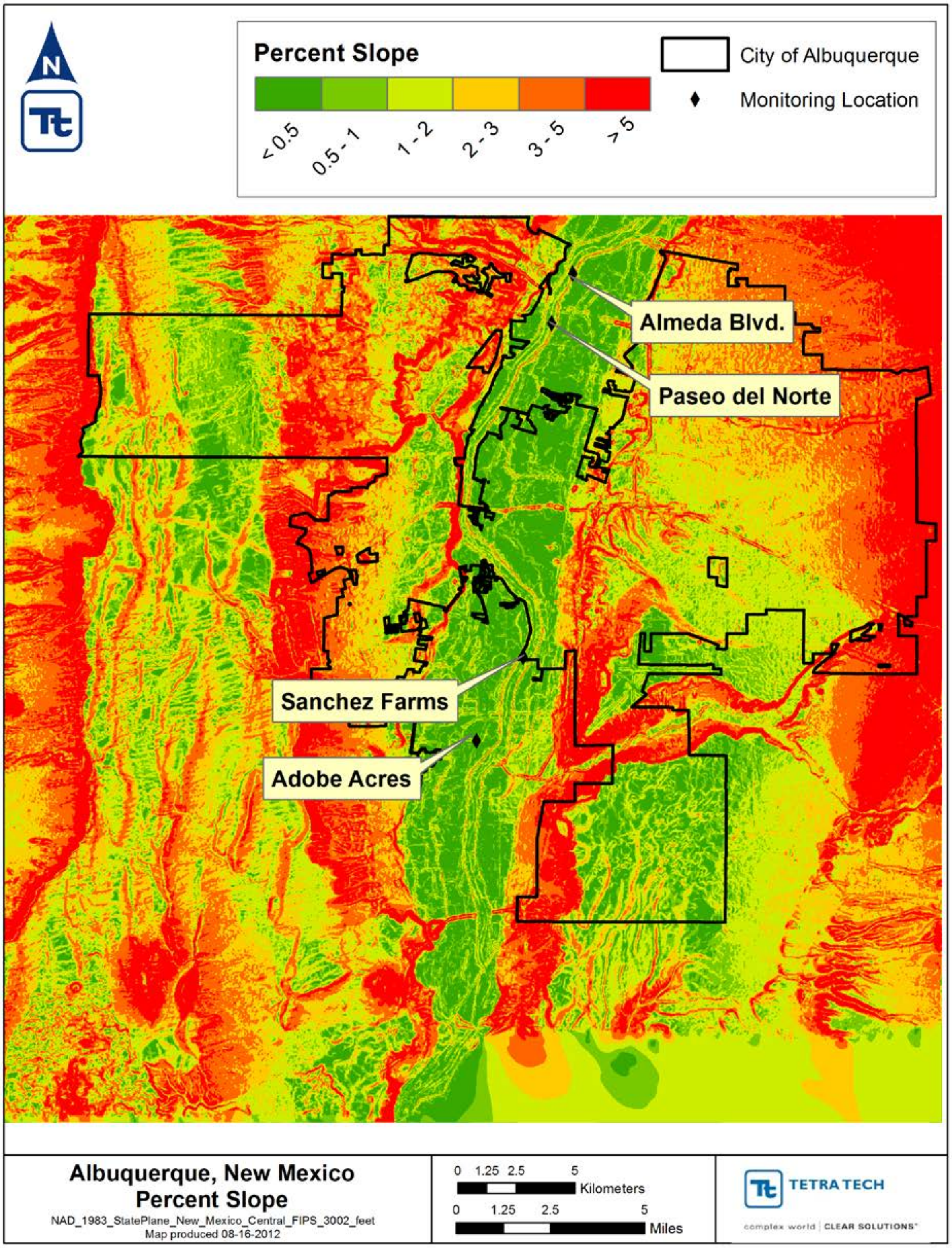


Figure 4. Two-foot topographic contour layer for Albuquerque.

2.2. Regional Weather Patterns

SUSTAIN requires runoff time series which represent the unique rainfall-runoff response of each HRU. These runoff time series serve as the primary input boundary condition. Understanding the regional weather patterns is essential to accurately reflect expected volume, intensity, and duration of expected storm events with high spatial variability in meteorology. As previously noted, Albuquerque is in the arid desert climate of the southwest, which differs from the wetter temperate climates from previous case study locations. On average, the area has 300 days of sunshine and about 9 inches of rainfall annually, with a 90th percentile storm depth estimated near 0.41 inch (Penttila, 2011). In such a unique environment, the typical practices for stormwater management (largely derived for more temperate climates) are not always applicable.

To categorize the uniqueness of Albuquerque's climate in the context of this case study, three NCDC daily precipitation gages were selected for further analysis. Selecting these stations was on the basis of the length of record, record quality, and proximity to the urbanized areas in Albuquerque and Bernalillo County.

- Albuquerque International Airport (NM290234)
- Albuquerque Valley (NM290231)
- Petroglyph National Monument (NM296754)

Analysis spanned in temporal resolutions from annual precipitation totals to the distribution of individual storm depths. Figure 5 and Figure 6 present the annual precipitation totals and average monthly precipitation distribution for these three NCDC stations.

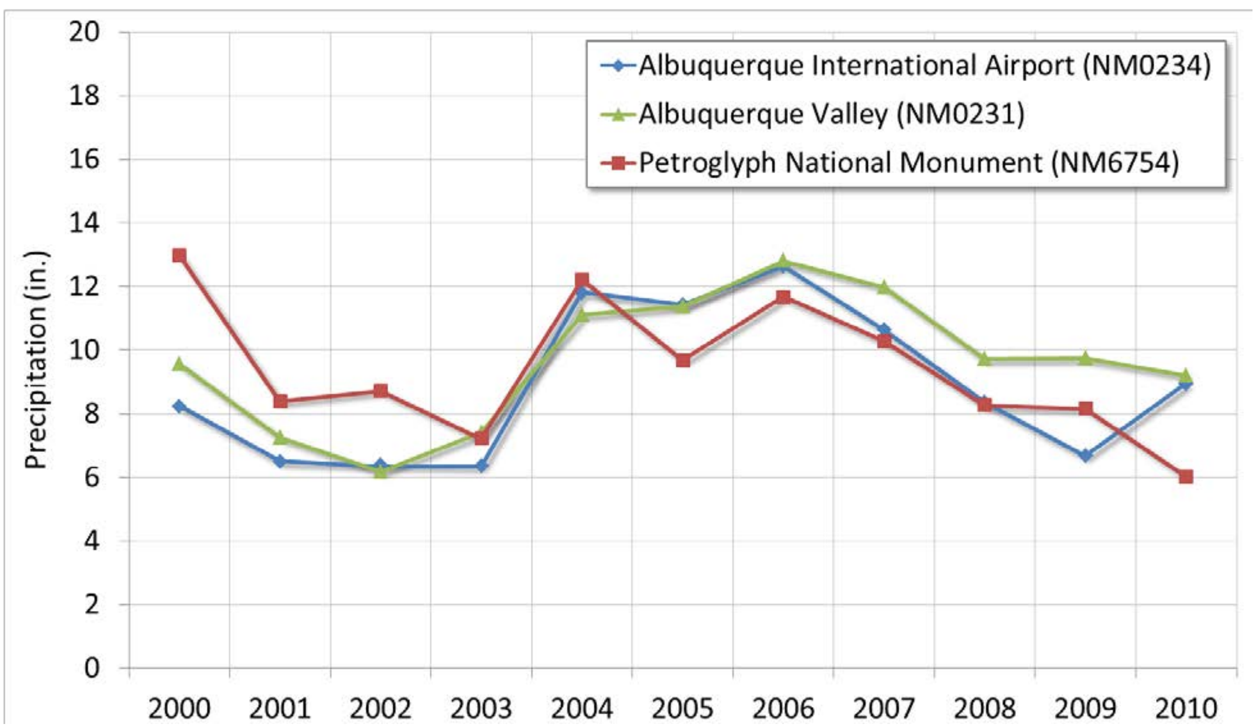


Figure 5. Annual precipitation totals (2000–2010) for selected NCDC precipitation gages.

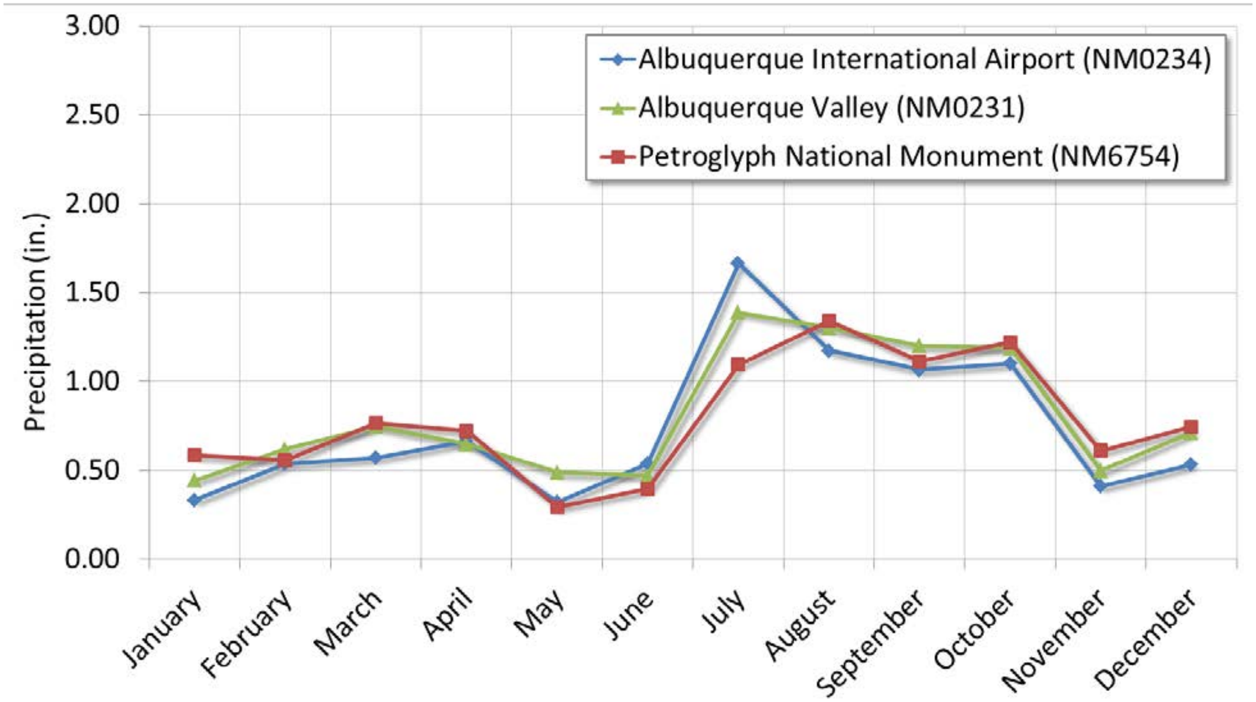


Figure 6. Average monthly precipitation distribution (2000–2010) for selected NCDC precipitation gages.

Figure 5 shows that the range of annual precipitation at the three NCDC gages from 2000 to 2010 varied between 6 and 14 inches, demonstrating the arid climate of this case study. The annualized monthly-aggregated plot in Figure 6 (for the same period of 2000–2010) shows that about 50 percent of annual precipitation volume occurs between July and October. Because of its proximity to the study area and relatively high data quality, rainfall data from the Albuquerque International Airport were selected for further analysis. Data for calendar years 2000–2009 were coincident with water quality monitoring data provided by Bernalillo County.

Using observed data from the Albuquerque International Airport from January 1, 2000, through December 31, 2009, individual precipitation events were categorized. A 72-hour antecedent period and a minimum of 0.1 inch were used to classify the hourly rainfall time series into discrete storm events. The resulting precipitations event distribution from that period is presented in Figure 7. Of the precipitation events summarized, over 80 percent were less than 0.75 inch, and almost 88 percent were less than 1 inch. Knowing this distribution of event magnitudes allows the focus of this study to be further refined. A summary of events has been included as Table 28 in the Appendix.

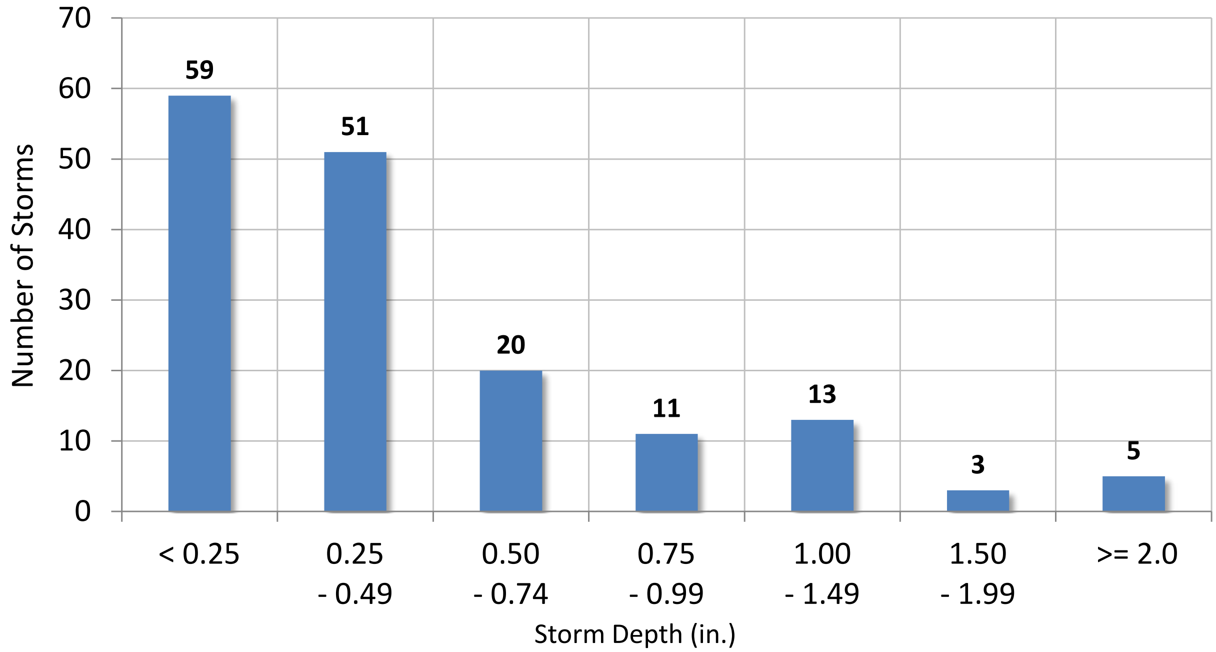


Figure 7. Distribution of event storm size at the Albuquerque International Airport (2000–2009).

Understanding the frequency and magnitude of precipitation events will help to reveal critical conditions when (1) formulating numeric objectives, (2) analyzing the water quality monitoring data, and (3) establishing a linking framework to flow duration curves (FDCs) developed for the Middle Rio Grande *E. coli* TMDL (NMED-SWQB, 2010). Coincident climate observations are also available from the Albuquerque International Airport for other parameters, including temperature, which can be used to estimate potential evapotranspiration (PEVT) rates for representing PEVT from the surface of some structural BMPs like extended detention basins as needed.

2.3. Water Quality Monitoring Data

Local water quality monitoring data are useful when characterizing the baseline pollutant loading time series representing each HRU category. These pollutant loading time series, in conjunction with the runoff time series discussed previously, act as the input boundary conditions for *SUSTAIN*. Additional observed water quality data help to validate assumptions used in generating these model inputs, ensuring that they are representative of the local conditions.

The U.S. Geological Survey (USGS) urban stormwater monitoring program was identified as a robust source of water quality data. From 2004 through 2009, Bernalillo County, in conjunction with the USGS, performed water quality monitoring of urban stormwater runoff at four sites discharging to the Middle Rio Grande mainstem. Bernalillo County provided a digital copy of this data set. Water quality monitoring data were analyzed to distinguish specific spatial and temporal patterns of TSS and *E. coli* water quality metrics. This data set was also evaluated in parallel with precipitation data to identify temporal patterns and ensure that an adequate range of event depths were sampled.

Figure 8 presents a map of raw sample counts from the Bernalillo County. Flow or runoff depth were not included as part of this monitoring effort; however, pumps are used at each of the four sites to convey collected stormwater to the Rio Grande. A log of pump hours was made available and pump rating curves are known, which allow for reasonable estimation of storm volumes (Glass 2012).

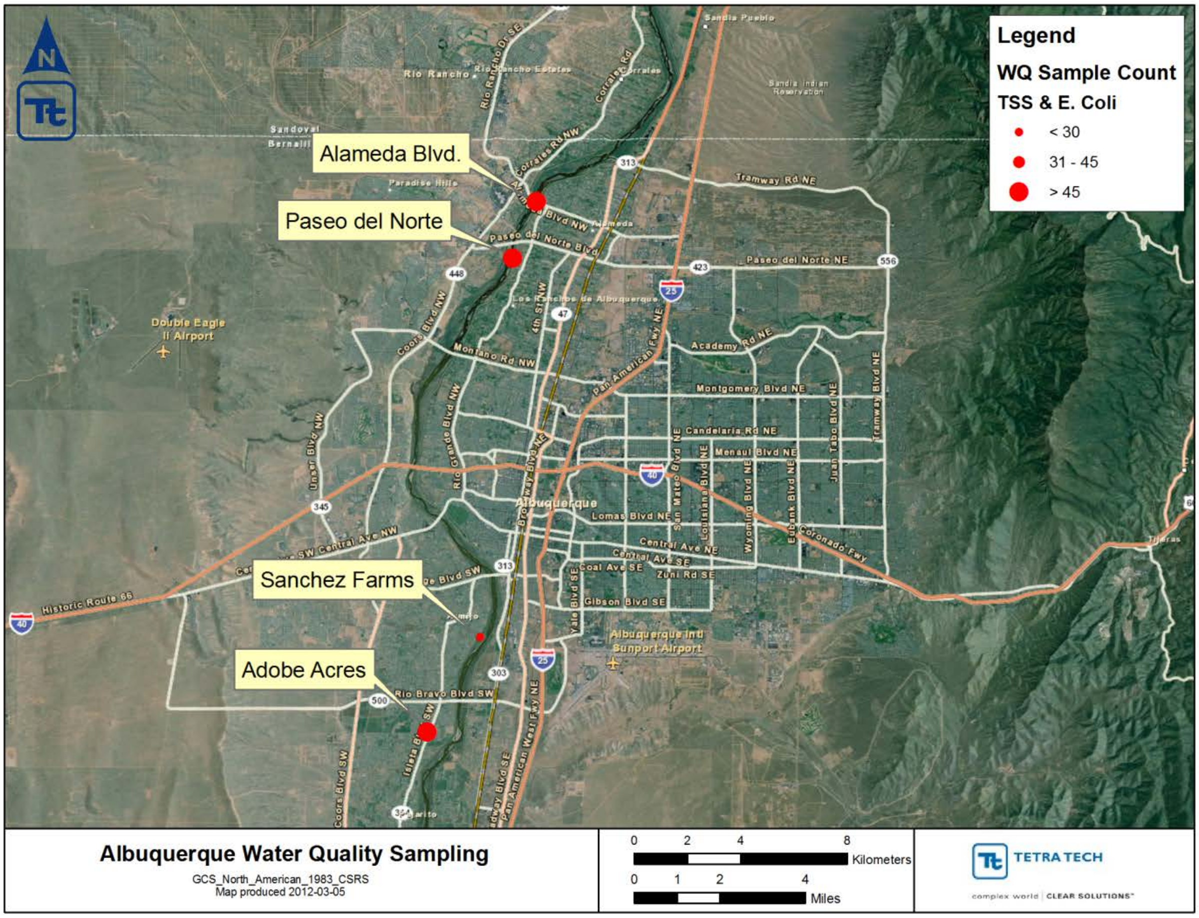


Figure 8. Albuquerque TSS and *E. coli* sample counts at each water quality monitoring gage.

The four unique sites represent a mix of land uses and drainage area sizes intended to reflect a near-complete distribution of the expected water quality response to the climate patterns in Albuquerque. After an initial review of the water quality monitoring data set and discussions with Bernalillo County, it was found that some samples were quality control flagged or designated as dry weather samples. The flagged values were removed from consideration. Water quality samples were tagged with only an analysis time but no sampling time. Table 2 presents summary statistics for the water quality monitoring data set for TSS, and Table 3 presents a similar summary for *E. coli*.

Table 2. Inventory of available TSS monitoring data

Description	Count	Start date	End date	Min. (mg/L)	Max. (mg/L)	Median (mg/L)	Mean (mg/L)
Alameda Blvd.	24	2/23/04	12/16/10	70	1,920	478	526
Paseo del Norte	23	2/23/04	8/23/09	100	3,216	524	703
Adobe Acres	24	3/4/04	12/16/10	80	2,096	604	670
Sanchez Farms	14	4/16/05	12/16/10	18	296	134	149

mg/L = milligrams per liter

Table 3. Inventory of available *E. coli* monitoring data

Description	Count	Start date	End date	Min. (#/100 mL)	Max. (#/100 mL)	Median (#/100 mL)	Mean (#/100 mL)
Alameda Blvd.	22	2/23/04	12/16/10	45	241,960	2,420	53,126
Paseo del Norte	22	2/23/04	8/23/09	220	241,960	1,497	12,664
Adobe Acres	18	3/4/04	12/16/10	286	51,720	2,566	7,085
Sanchez Farms	12	4/16/05	12/16/10	2,420	77,010	5,669	13,006

mL = milliliter

Those four monitoring sites are at lower elevation and lower sloped sites along the Middle Rio Grande. Some factors that potentially influence sample values include natural behaviors like higher seasonal groundwater levels and waterfowl population migrations in addition to anthropogenic influences. When considering the use of these samples for benchmarking a set of representative event mean concentrations (EMCs), it will be important to also compare against regional literature values to validate the applicability of the monitoring data.

Corresponding flow values for these samples were not reported, so nearby rainfall records were reviewed to associate samples taken with coincident storm size. Both TSS and *E. coli* water quality samples were mapped to associated rainfall events using observed rainfall data from the Albuquerque International Airport (NM0234). As noted previously, a 72-hour antecedent period and a minimum of 0.1 inch were used to classify the hourly rainfall time series into discrete storm events (as presented in Figure 7). The water quality samples were then associated with the storm that spanned the dates for which they were taken. Because the water quality monitoring events were not tagged with a sampling time, a 12-hour buffer was applied to either side of the sample date when associating with precipitation events. This analysis provides a context for evaluating the distribution of the monitoring data across the spectrum of observed storm events. Figure 9 presents a distribution of TSS and *E. coli* sample counts categorized by associated precipitation depth.

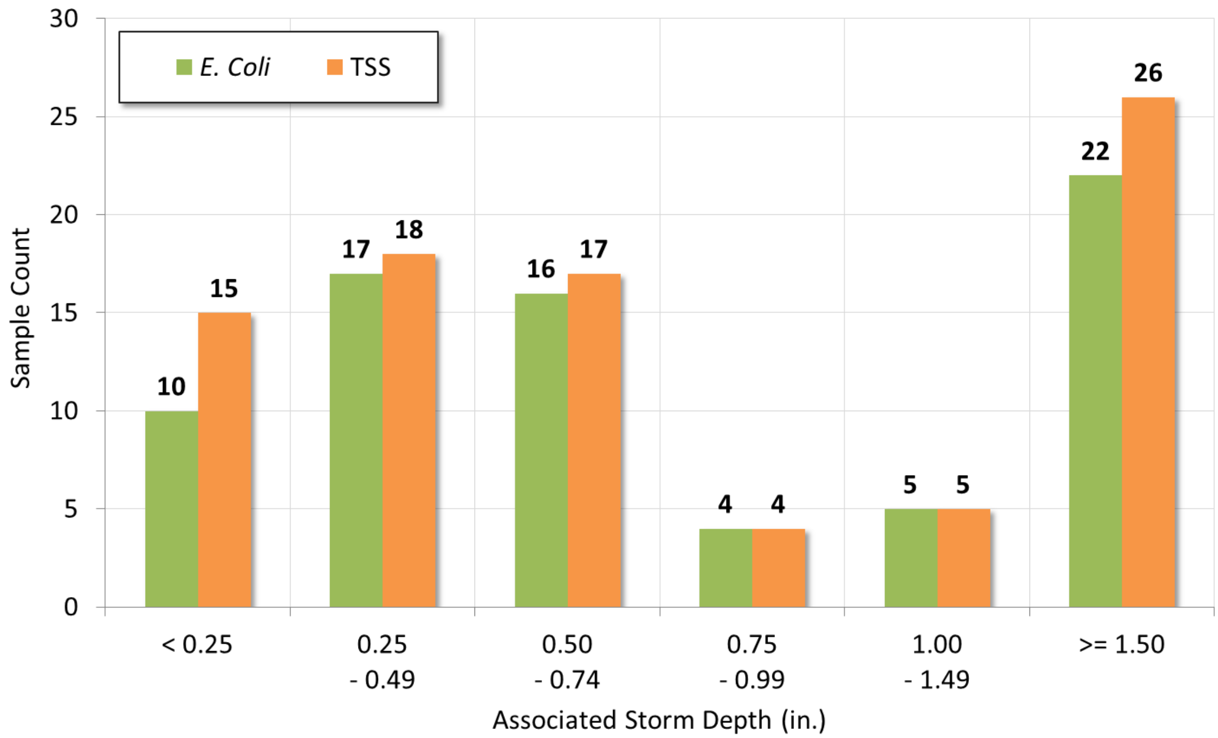


Figure 9. Histogram of monitored against the long-term historical precipitation record.

Figure 9 suggests that the Bernalillo County monitoring data set has samples taken across the full range of storm conditions; however, considerably more *E. coli* samples were taken for storms less than 0.75 inch. Nevertheless, several samples were collected for some of the largest storms. Using data that are well distributed across the full range of critical events gives confidence that the baseline runoff and water quality time series will represent the range of expected conditions in the watershed. Because sampling coincides with precipitation events that characterize a spectrum from less than 0.25 inch to more than 2 inches and 23 *E. coli* and 22 TSS samples were taken with wet intervals of more than 2 inches, this data set should be adequate for developing a robust model baseline.

2.4. Linkage to TMDL Framework

One objective of this case study is to create a linkage between management strategies evaluated with *SUSTAIN* and the recently adopted *E. coli* TMDL. This linkage will provide a context for interpreting case study findings in the broader, regional TMDL framework. Because the TMDL was developed using FDCs, the *SUSTAIN* model baseline must be structured in a way that provides a linkage or basis of comparison with the TMDL baseline. The TMDL was developed on the basis of 2005 monitoring data collected by the New Mexico Surface Water Quality Bureau. FDCs were developed for four assessment units, and five zones were identified along each FDC. These zones, corresponding to flow percentile ranges, help to classify the FDC on the basis of similar hydrologic conditions. Table 4 summarizes the five FDC zones used in developing the TMDL (NMED-SWQB, 2010).

Table 4. Summary of zones identified along the FDC for the TMDL

FDC zone	Flow exceedance percentile[a]
Low flows	90 to 100
Dry conditions	60 to 89
Mid-range flows	40 to 59
Moist conditions	10 to 39
High flows	0 to 9

[a] TMDL lists percentile ranges as High Flows (0–10), Moist conditions (10–40), Mid-range flows (40–60), Dry conditions (60–90), and Low flows (90–100). Percentile breaks used in Table 1 were selected to avoid data point overlapping.

For consistency with the established TMDL, the approach used for this study was to identify storms of varying magnitudes that are representative of critical zones along the FDC. Typically, TMDL impairments in the right-most zones indicate the influence of point sources; impairments in the left-most zones indicate pollutant contribution from nonpoint sources. This analysis focuses on the three highest zones representing the critical condition for nonpoint source impairment, which can be managed by stormwater BMPs. Representative storm depths will be selected for each zone, and hydrographs for these three storm depths will be generated for each HRU using a simplified modeling approach.

Identifying representative storm depths for the mid-range flow, moist condition, and high-flow zones began with reconstructing an FDC used in developing the TMDL with daily streamflow data for the USGS 08330000 Rio Grande at Albuquerque, New Mexico, gage. Streamflow records from January 1, 1974, through December 31, 2009, were used to ensure consistency with the TMDL. Because this streamflow gage collected data for a drainage area of more than 14,000 square miles, storm-influenced flows were parsed out of the data set using a sliding interval hydrograph separation technique (USGS, 1996). Daily values were matched with coincident daily precipitation at the Albuquerque International Airport (240234) from January 1, 1974, through December 31, 2009. The FDC is plotted with corresponding precipitation events in Figure 10.

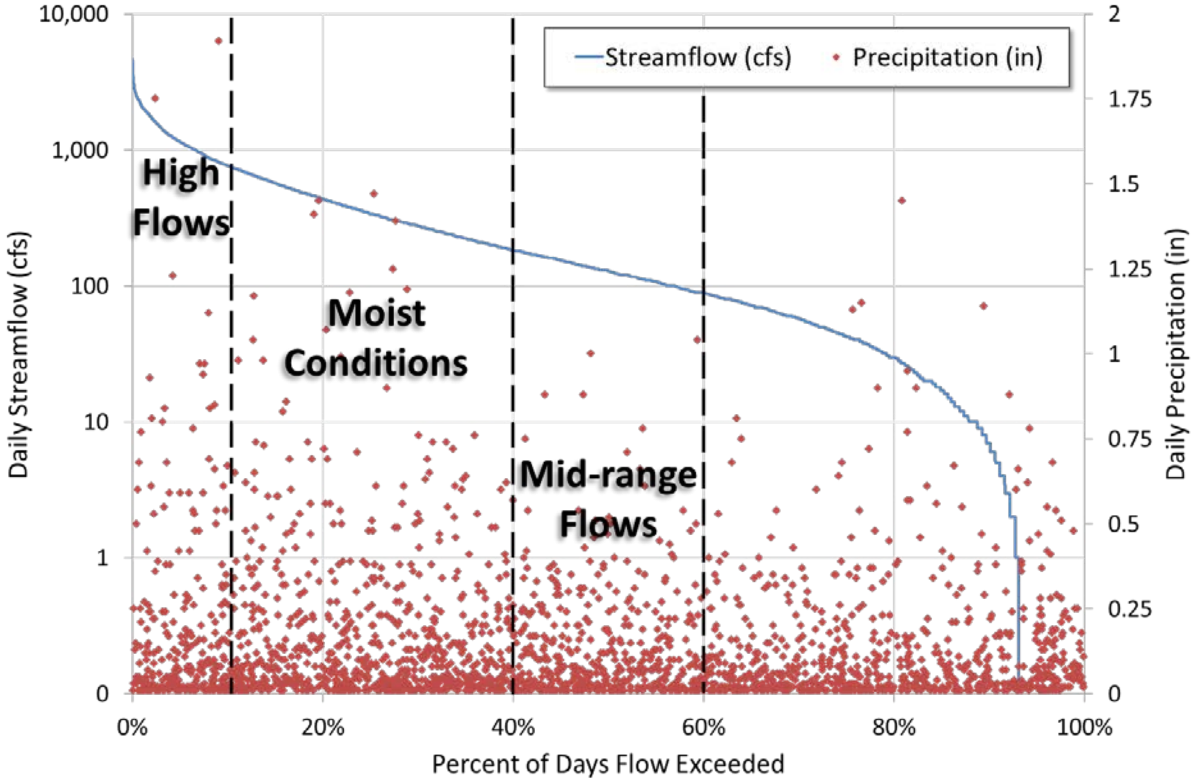


Figure 10. Plots of daily precipitation vs. daily streamflow after baseflow separation for USGS 08330000 Rio Grande at Albuquerque, New Mexico (1974–2009).

Several studies have attempted to quantify a BMP treatment depth for the Albuquerque area using a rainfall percentile analysis. One study presented by Albuquerque analyzed precipitation data from 1891 through 2009 and identified the 90th percentile storm depth as 0.44 inch (Penttila, 2011). A 24-hour rainfall water quality control volume for BMP design based on a 0.41-inch depth was identified in a recent Bernalillo County BMP study (Radian, 2011).

The objective of this analysis is to identify representative rainfall depths corresponding to each of the three critical-condition FDC zones for further evaluation with the management practices in *SUSTAIN*. Precipitation summary statistics were calculated uniquely by FDC zone from Figure 10 to reveal a correlation between the FDC and rainfall depth. Figure 11 presents the summary statistics for the mean, 75th, 85th, 90th, and 95th percentile precipitation events associated with the five FDC zones.

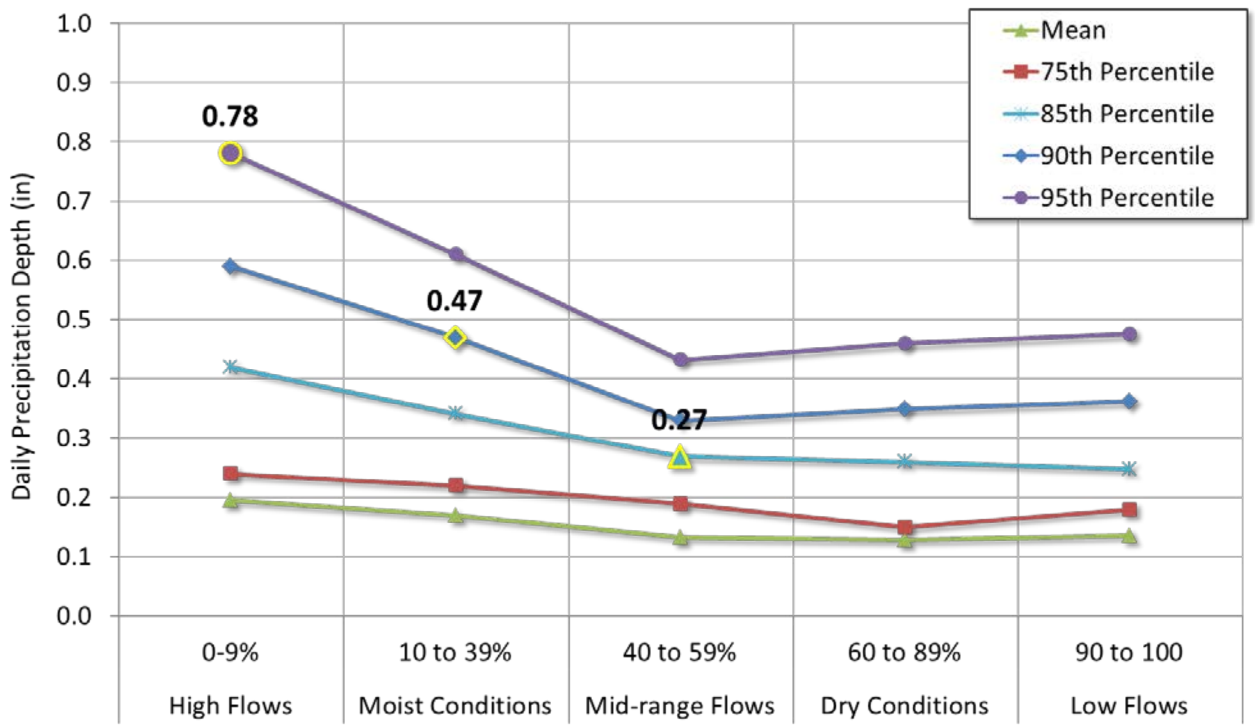


Figure 11. Summary of precipitation statistics by FDC zone.

Because the approximate 90th percentile rainfall depth (or 10th percentile flow exceedance) has loosely been identified for further evaluation as a potential threshold treatment depth for water quality purposes, it is recommended that this case study evaluate storm depths that bracket the 90th percentile value. Figure 11 highlights three depths that bracket the 90th percentile storm of 0.44 inch, providing insight on the range of expected BMP performance around this critical point. The 0.27-, 0.47-, and 0.78-inch storm depths are associated with the mid-range flows, moist conditions, and high-flow zones along the FDC, respectively. These depths brackets identify the 0.44-inch treatment depth of interest, and they correspond to critical precipitation conditions (Figure 7) and coincident water quality monitoring data (Figure 9). Developing runoff hydrographs for these three storm depths, which constitutes the *SUSTAIN* runoff baseline, is discussed in the next section.

Chapter 3. Establishing a Modeled Baseline Condition

In *SUSTAIN* stormwater runoff and pollutant washoff time series simulated using an external watershed model are typically the forcing functions that drive BMP simulation. Watershed models use site-specific spatial and temporal elements to characterize the rainfall runoff response, buildup-washoff of pollutants, or other water quality loading processes. The watershed model time series represent the existing condition (or baseline), which serves as the reference point from which water quality improvement will be evaluated.

A critical first step of a *SUSTAIN* application is to establish or confirm a representative baseline condition with a high degree of confidence in its applicability. Model baselines should be validated as vigorously as possible against a local, observed data set. This becomes especially important in the context of cost-benefit optimization of future management objectives, because the model baseline is foundational to results interpretation and resulting conclusions. It is important for the model baseline condition to appropriately represent variability throughout the study area. It needs to consider the influence of physical features associated with both surface and subsurface behavior and human activities that could affect pollutant load generation.

The following sections describe the process of developing baseline runoff and pollutant loading time series by HRU representative of the Albuquerque study area. Without an existing continuous-simulation watershed model, discussion is focused around an alternative method to runoff time series development using a design storm approach. An analysis of local water quality monitoring data, in conjunction with referenced literature, was used to inform the representation of pollutant loading by HRU. Fully developed runoff and pollutant time series were then used in a validation model of the Adobe Acres neighborhood to assess the distribution and magnitude of water quality responses against observed data. This validation was limited to a statistical assessment comparing model outputs against the central tendency of water quality monitoring data.

3.1. Baseline Hydrology

Hydrographs were developed for three storm depths as representative events along the FDC. These hydrographs were used as the hydrology boundary condition inputs representing surface runoff for the *SUSTAIN* baseline. *SUSTAIN* offers the flexibility to integrate with different external model output formats. In previous case studies, continuous-simulation watershed models (such as LSPC) or rainfall-runoff models (such as SWMM) have been the most widely integrated external data sets; however, the runoff and pollutant loading boundary conditions applied in *SUSTAIN* are not limited to continuous-simulation models. For example, the recent *E. coli* TMDL completed for the Middle Rio Grande that was established using flow and load duration curves did not require development of any continuous-simulation models.

Because rainfall in the area is relatively infrequent compared with other parts of the country, developing a continuous-simulation watershed model is not necessary to adequately characterize and represent the critical conditions for the *SUSTAIN* model baseline. An alternative approach involves developing hydrographs using a design storm approach. Albuquerque *Development Process Manual* (DPM), volume II, *Design Criteria*, Chapter 22, describes locally accepted methods that are used to generate design storms and hydrographs. These methods are mostly based on the Rational Method. The DPM also includes language describing accepted alternatives, including continuous simulation with SWMM and design storm approaches using TR-20/55.

The WinTR-55 computer model was used to generate runoff hydrographs for the three storm depths corresponding to the mid-range flow, moist condition, and high-flow zones along the FDC. WinTR-55 is a graphical version of the DOS-based TR-55, which is described as a small watershed hydrology application (NRCS 2012). WinTR-55 is used to generate a storm hydrograph response given a user-specified rainfall depth. Runoff can also be routed through channels or structures to an outlet location. An application can be developed with up to 10 subbasins. The program uses the Curve Number (CN) approach, which applies a unique CN by land use. The CN describes runoff generating potential of a site and can range between 0 (low runoff potential) and 100 (high runoff potential). This is a lumped parameter that considers physical characteristics such as soil infiltration capacity. Runoff is predicted in the TR-55 model using the following equation:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

where *Q* is the runoff depth in inches, *P* is the rainfall depth in inches, and *S* is the potential maximum retention depth (in inches) after runoff begins (NRCS, 2012).

In the above equation, *S* is largely a factor of the ground cover, vegetation, and soil conditions that affect infiltration capacity and initial abstraction. *S* is a function of *CN* via the following relationship in which *CN* can range between 0 and 100:

$$S = \frac{1000}{CN} - 10$$

A typical use of WinTR-55 is with user-specified, 24-hour rainfall totals for a specific return interval. A variety of rainfall distributions are included in the program; the user can also prescribe the rainfall distribution. This study applied the NM-60 24-hour rainfall distribution, a local variation of the Type-IIa 24-hour distribution, which is specified for use with the TR-20 program by Albuquerque's DPM, Chapter 22, Section E.1(4), *Programs for Alternative Procedure Acceptance*. Figure 12 presents the NM-60 rainfall distribution.

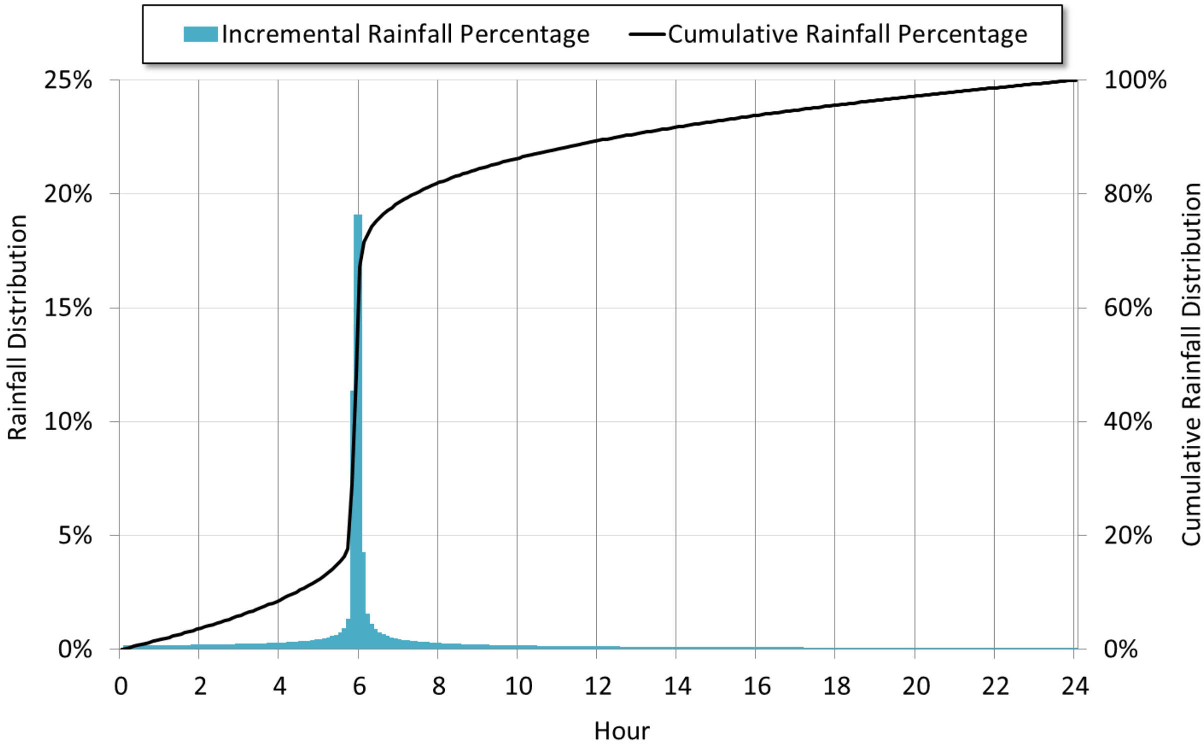


Figure 12. NM-60 rainfall distribution used in the WinTR-55 model.

A suite of WinTR-55 models were developed representing 12 HRUs as derived from Albuquerque's land use spatial data set (Albuquerque GIS, 2012). The objective was to generate a set of 1-minute hydrographs by land use, representing each of the three storm depths identified in Figure 11 (i.e., 0.27, 0.47, and 0.78 inch). These hydrographs will be used as model inputs for *SUSTAIN* to represent runoff from each model HRU. A number of simplifying assumptions were adopted while developing these runoff time series:

1. A square drainage area of 10 acres
2. There is an estimated time of concentration of 0.132 hour
3. A conservative infiltration (assuming Hydrologic Soil Group C) was applied

Future modeling studies could adjust the time of concentration to account for the effects of slope or unique drainage features. Case study HRUs were mapped to land use categories available in the WinTR-55 model as presented in Table 5. It should be noted that multiple HRUs with similar hydrologic surface characteristics can use the same curve number; however, they are represented by a separate hydrograph because of variations in water quality responses.

Table 5. Curve number assumptions by land use

Case study HRU	Win TR-55 land use	Curve number
Roads	Paved Curb	98
Drainage Flood Control	Paved Curb	98
Parking Lot	Paved Parking Lot	98
Commercial	Commercial and Business	94
Transportation	Paved Open Ditches	92

Case study HRU	Win TR-55 land use	Curve number
Industrial	Industrial	91
Vacant	Developed Urban	91
Multi-Family Residential	1/8-Acre Townhomes	90
Single-Family Residential	1/4-Acre Lots	87
Public-Institutional	Open Space, Poor	86
Agriculture	Pasture, Grassland, Range (Fair)	79
Parks	Open Space, Fair	79

The outputs from the WinTR-55 applications were post-processed to obtain the runoff results generated from the land before routing through the reach consistent with the input needed for *SUSTAIN*. Intermediate output hydrographs were reported on a 30-second timestep for the 10-acre WinTR-55 model. Final hydrographs were aggregated by averaging to a 1-minute reporting timestep and downscaled to 1-acre for use in *SUSTAIN*. Figure 13 presents hydrographs from the selected 0.27-, 0.47-, and 0.78-inch storm depths for the parking lot HRU.

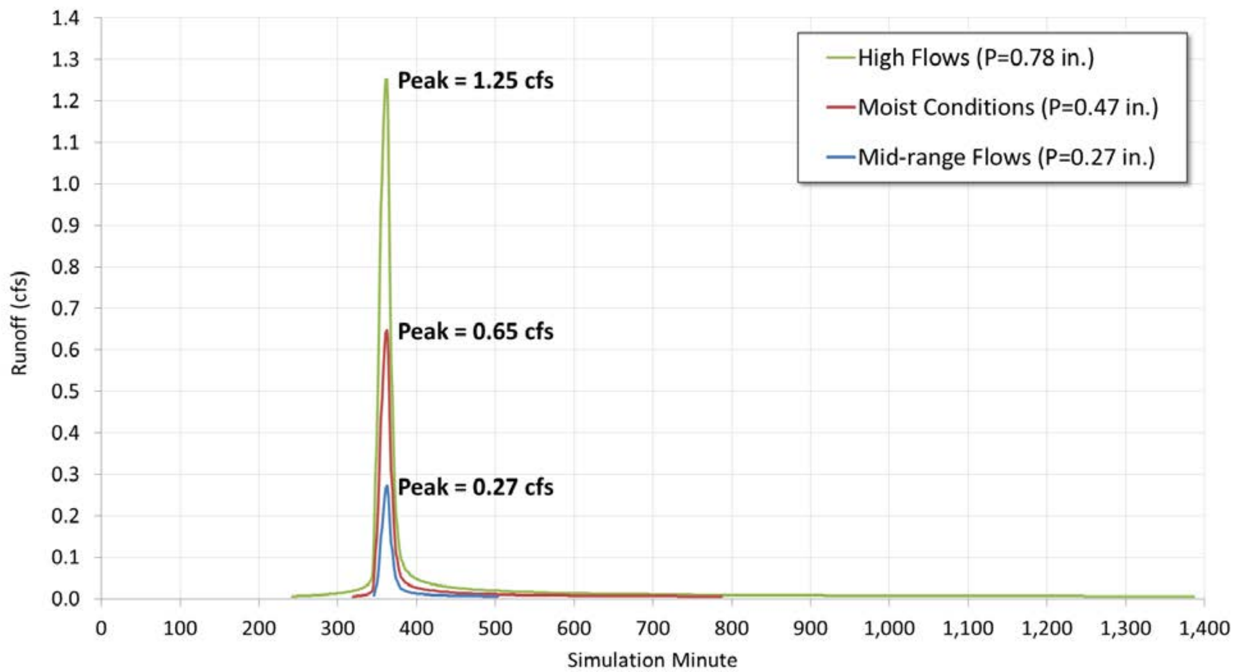


Figure 13. Unit-area (1 acre) runoff hydrographs representing the parking lot HRU.

Figure 13 shows three distinct hydrographs with varying peaks and timing for the selected storm depths. Although the parking lot HRU generated runoff for all three storms, note that not all HRUs generate runoff for all storms. As parameterized, some HRUs, such as Parks, do not generate any runoff—even for the 0.78-inch storm. It is probable that a storm with a larger return interval, such as the 2- or 5-year event, would produce runoff for all HRUs; however, those events fall within the highest 5^{th} percentile of rainfall events and are likely outside the focus of this case study evaluating stormwater quality management with BMPs. A complete set of hydrograph plots for all 12 HRUs is presented as Appendix A. Developing EMCs by HRU and storm depth for representing pollutant loading is discussed in the next section.

3.2. Baseline Water Quality

Pollutant loading time series were developed for use in parallel with the one-minute surface runoff hydrographs to represent the complete *SUSTAIN* model baseline. Local TSS and *E. coli* monitoring data provided by Bernalillo County were referenced to provide context for selecting a range of event-mean concentrations associated with different HRUs. These data sets were first assessed to determine whether the observed data are reflective of the range of critical conditions (0.27-, 0.47-, and 0.78-inch selected storm depths). Because the EMC values are unique by HRU and storm size, the monitoring data must capture at a minimum the magnitude of storms for which hydrographs were developed. Because coincident runoff flow values were not reported with these water quality samples, nearby rainfall records from the Albuquerque International Airport were used to map the TSS and *E. coli* samples to rainfall events.

Under natural conditions, *E. coli* bacteria can be killed off with exposure to light or other environmental factors; however, in certain urban settings, they can regrow between storms (a physical process that is not explicitly represented in *SUSTAIN*). Because the focus of this analysis is limited to the immediate storm events and their associated recession periods, it is reasonable to model the behavior of *E. coli* as that of a relatively conservative material that is mobilized with runoff energy and decays with time.

Because this case study evaluates both *E. coli* and TSS, a literature search was performed to see if any studies showing any linkages or interactive relationships between the two should be considered during modeling. With respect to the relationship between bacteria and sediment loadings, Reeves et al. (2004) examined fecal coliform loadings in the Talbert and Lower Santa Ana watersheds near Huntington Beach, California. Between 1999 and 2003, several field studies were conducted to sample fecal coliform (among other) bacteria in stormwater runoff throughout the watershed. The results of these studies suggest that fecal coliform loadings are poorly correlated with turbidity. Sediments collected from the storm drain infrastructure had high concentrations of fecal coliform bacteria; however, surface eroded sediments had low concentrations. Overall, fecal coliform loading rates could be related to flow via a power function:

$$L \approx Q^n$$

where L is the loading rate [T^{-1}], Q is the volumetric flow rate [L^3/T] and n ranges from 1 to 1.5.

Subsequent work by Ahn et al. (2005) suggests that bacteria and viruses in stormwater runoff are either associated with particles smaller than 53 micrometers (µm) in diameter or are not associated with particles at all. This study assessed fecal coliform indicator bacteria concentrations in stormwater runoff from the Santa Ana River and filtered sediment through a 53 µm sieve. Measuring total organic carbon before and after this filtration exhibited virtually no change in total organic carbon.

Surbeck et al. (2006) support this finding by examining the load response of fecal coliform bacteria and sediment to changes in flow, otherwise known as flow fingerprinting. Sampling sites on the Santa Ana River mainstem (in arid Southern California) and several tributaries yielded data for several storm hydrographs in 2003 and 2004. The findings suggest that storm flow initially increases fecal coliform bacteria indicator concentrations and then remains more or less constant throughout the storm hydrograph. This differs from the flow/load relationship for sediments, which exhibits a power-law relationship with the storm hydrograph. The conclusion of the literature search is that while fecal coliform loads are related to storm flow, they do not appear to be strongly affected or influenced by sediment loadings.

Because the EMCs typically vary with storm depth, a statistical analysis was performed on local monitoring data to assess correlation between storm depth and pollutant concentration. TSS and *E. coli* concentration data were divided into bins by storm depth consistent with the monitoring summary presented in Figure 9. Then the average concentration was calculated for each bin. Figure 14 presents plots of this storm-associated concentration analysis for *E. coli* and TSS. Since the Sanchez Farms drainage basin is managed by a *bio swale*, water quality samples taken from that location were excluded from the figures below.

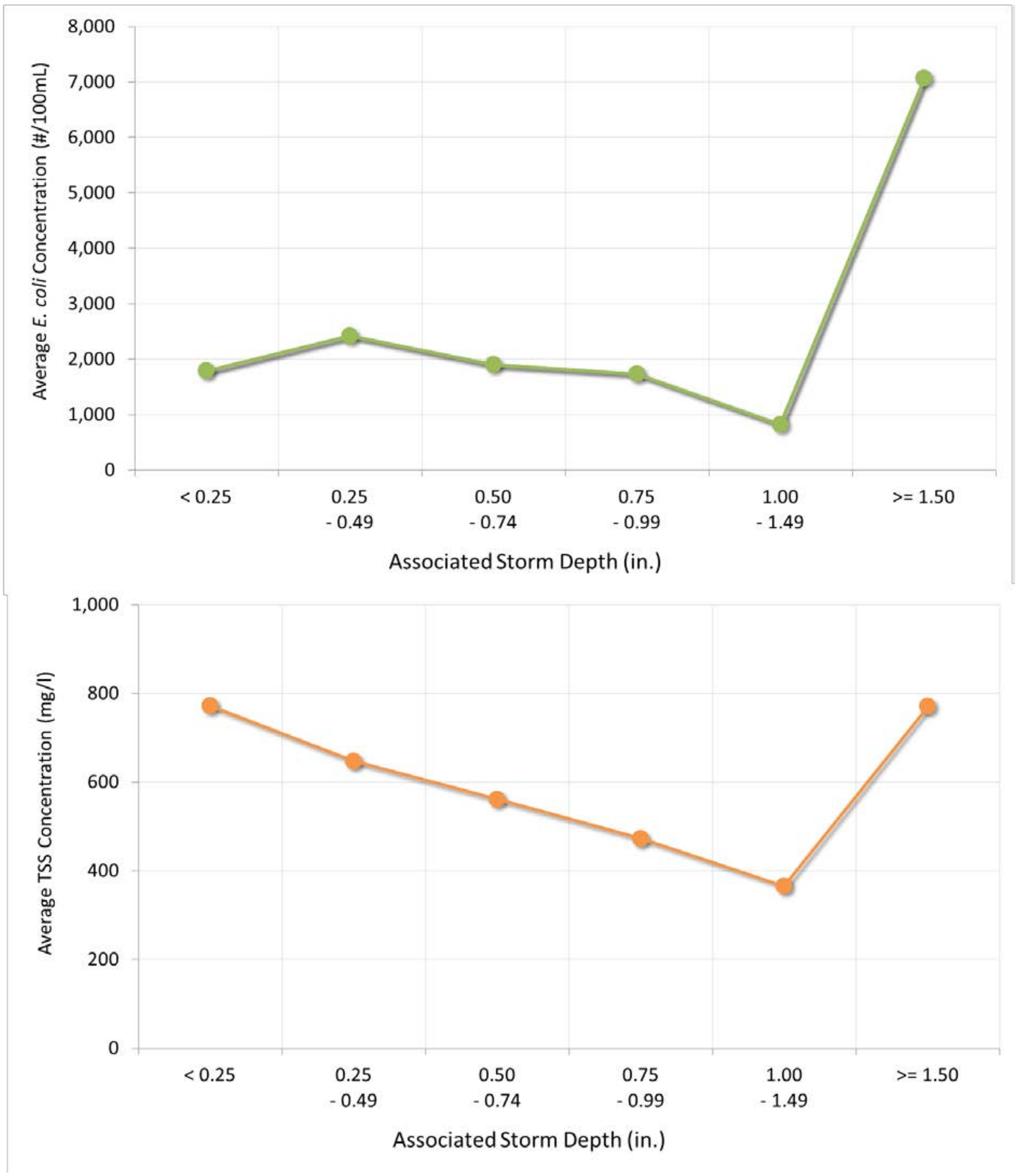


Figure 14. Statistical summary of Bernalillo County *E. coli* monitoring data.

Figure 14 highlights a relatively constant average *E. coli* concentration with increasing storm depth, with the exception of the largest storms where concentrations increase three to four-fold. Conversely, Figure 15 shows little evidence of a positive correlation between increasing TSS concentration and increasing storm depth on the basis of this monitoring data set; however, a basic understanding of the physical processes involved with sediment detachment and transport dictates that increasing energy (from rainfall and flow) will mobilize more sediment. Given the limited number of samples in the 0.75 in to 1.49 in. range relative to the others, it is difficult to draw a statistically definitive conclusion through simple data analysis about what is occurring; however, both *E. coli* and TSS concentrations appear to trend downward to a point as storm size increases (dilution effect), but then sharply increase for the largest events. Literature estimates of EMCs and export coefficients by land use were referenced to stratify the average concentration for each storm depth on the basis of the relative potential for contribution by each HRU (Lin, 2004). Table 6 and Table 7 present the baseline EMC values by HRU and storm depth for *E. coli* and TSS, respectively.

Table 6. EMC values for *E. coli* by HRU and storm depth

	***E. coli* concentration (#/100 mL)**		
HRU	**0.27-in. storm**	**0.47-in. storm**	**0.78-in. storm**
Parking Lot	188	750	1,500
Drainage Control	150	600	1,200
Transportation	188	750	1,500
Public-Institutional	56	225	450
Parks	63	250	500
Industrial	56	225	450
Vacant	94	375	750
Commercial	150	600	1,200
Single Family Residential	75	300	600
Multi-Family Residential	113	450	900
Agricultural	75	300	600

Table 7. EMC values for TSS by HRU and storm depth

	TSS concentration (mg/L)		
Land use	**0.27-in. storm**	**0.47-in. storm**	**0.78-in. storm**
Parking Lot	320	700	1,042
Drainage Control	120	262	469
Transportation	320	700	1,042
Public-Institutional	80	175	313
Parks	80	175	313
Industrial	280	613	911
Vacant	240	525	938
Commercial	280	613	911
Single Family Residential	160	350	625
Multi-Family Residential	280	613	911
Agricultural	256	560	834

EMC values for *E. coli* from Table 6 were compared against the median observation from the Adobe Acres drainage basin and a sample of literature values reported as part of the National Stormwater Quality Database v1.1 (Pitt, 2004). Figure 15 presents model EMC values by HRU against these literature and monitoring benchmarks as an additional check to ensure they fall within a reasonable range of values observed in the field. These EMC values will be used in conjunction with the previous presented storm hydrographs to validate the baseline representation.

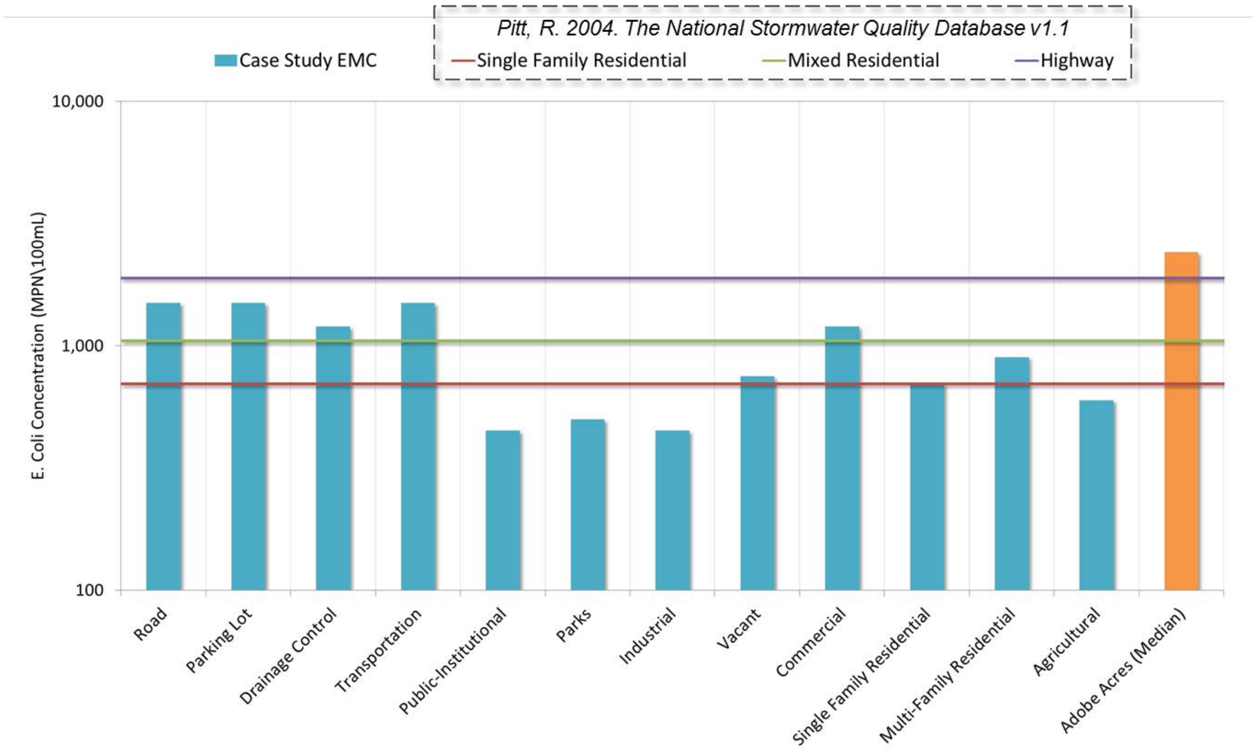


Figure 15. Comparison of model *E. coli* EMCs against monitoring and literature values.

The EMCs used to drive this *SUSTAIN* model application generally fall within the range of values reported in the National Stormwater Quality Database; however, they are quite lower than the median observed value at the Adobe Acres site. Discussions with the stakeholder group indicate that proximity to the river and seasonal groundwater conditions may make the Adobe Acres drainage basin prone to a denser population of waterfowl, which could influence the background bacteria concentrations at the site.

3.3. Baseline Validation: Adobe Acres

Baseline hydrographs and EMCs were used in a site-scale *SUSTAIN* validation model of the Adobe Acres drainage basin to assess the magnitude of the runoff and pollutant generation for each of the three storm depths. A map of the Adobe Acres baseline drainage area and HRU distribution is presented below in Figure 16. This model was configured using a single subwatershed. During simulation all flow and pollutant loads were routed to an assessment point where runoff and water quality were reported. Table 8 presents a summary of modeled peak flow, average TSS concentration, and average *E. coli* concentration for each of the three selected rainfall depths.

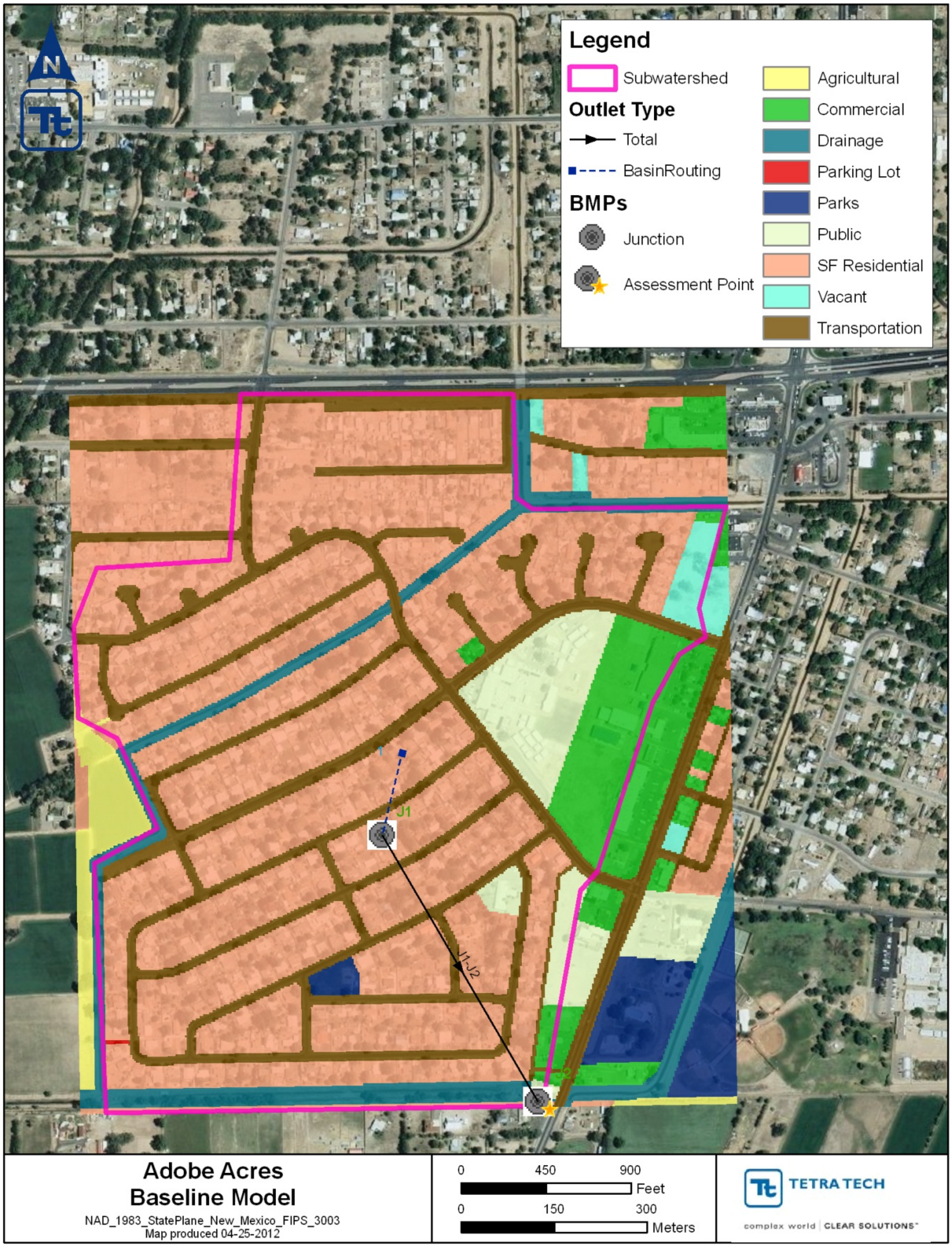


Figure 16. Adobe Acres *SUSTAIN* baseline hydrology and water quality validation model.

Table 8. Summary of modeled flow and pollutant concentrations for Adobe Acres

FDC zone	Rainfall depth (in.)	Peak flow (cfs)	Average *E. coli* concentration (#/100 mL)	Average TSS concentration (mg/L)
Mid-range Flows	0.27	3.4	150	133
Moist Conditions	0.47	15.7	641	455
High Flows	0.78	54.2	1,203	778

cfs = cubic feet per second; in. = inches; mg/L = milligrams per liter; mL = milliliters

Modeled *E. coli* and TSS concentrations presented in Table 8 were compared with observed data sampled from the Adobe Acres site. Observed data associated with all storms less than 1 inch were summarized and plotted against the modeled concentrations to assess the ability of the model baseline to reflect the range of observed water quality data. Figure 17 presents modeled concentration points against boxplots summarizing observed *E. coli* and TSS data. Modeled concentrations scatter about the observed median and are generally reflective of the inter-quartile range (25th to 75th percentile value) of the monitoring data.

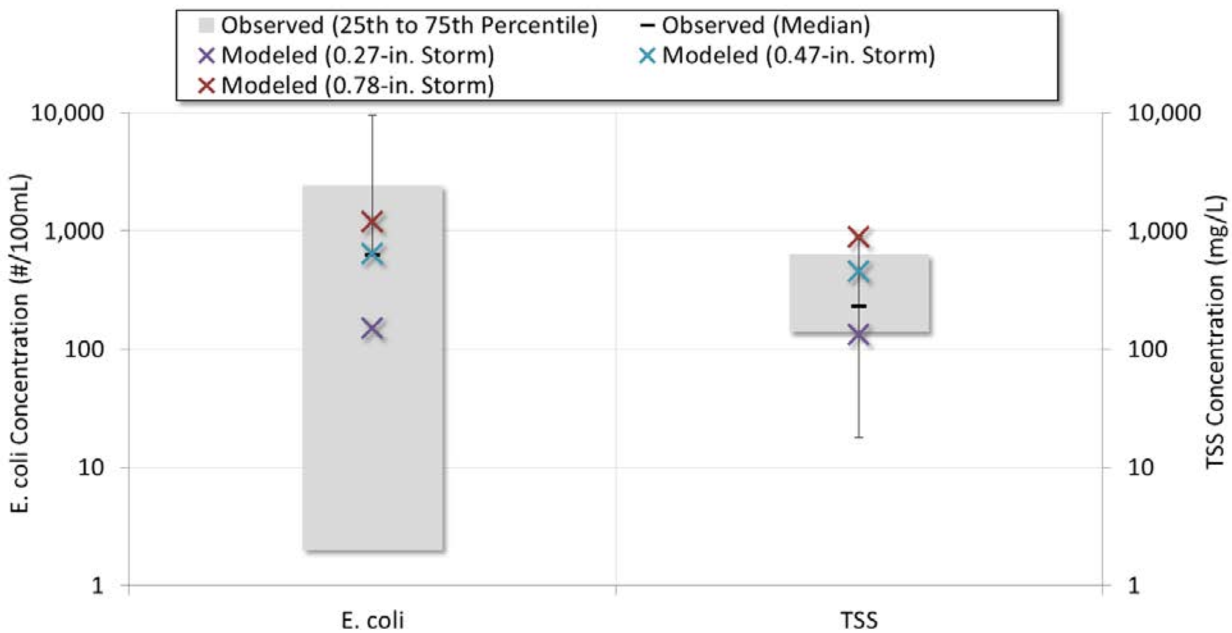


Figure 17. Plots of modeled *E. coli* and TSS concentrations versus observed data for Adobe Acres.

Figure 17 presents the modeled pollutant concentration for Adobe Acres against observed data for each of the three selected storm depths. Validation of this baseline representation is intended to (1) assess the range of water quality conditions associated with each storm, and (2) demonstrate that the modeled concentrations fall within the range of data observed at Adobe Acres.

Chapter 4. Proposed Management Activities

It is recognized that stormwater BMPs for the arid and semi-arid region are important tools for preserving and improving the water quality of the region's precious water resources. Those BMPs should be designed using the unique climate characteristics and to meet the special needs (water conservation, reuse, and sustainable land use management) of the region.

Gautam et al. (2010), among others, assert that nonstructural BMPs should play an important role in arid regions, where structural BMP options are often limited or expensive. Street sweeping was identified in the *Middle Rio Grande-Albuquerque Reach Watershed Restoration Action Strategy* as a viable practice for managing sediment and bacteria loading from urban land (MRGARWG, 2008). Pet waste management is another nonstructural BMP that is practical and effective in reducing bacteria pollution. Both Albuquerque and Bernalillo County have laws requiring pet waste to be picked up from any property other than that of the owners'.

Several references suggest that the best strategy for effective BMPs for the arid Southwest should focus on stormwater conservation and water reuse, for example rainwater harvesting, local groundwater infiltration when feasible, and minimizing evapotranspiration losses. LaBadie (2010) makes specific recommendations regarding the types of LID practices most favorable for the region's arid climate and identifies those practices deemed least favorable. A summary of favorable and unfavorable LID practices identified is presented below:

<u>Favorable practices</u>

- Harvesting parking lot runoff
- Extensive use of rain barrels
- Harvesting street runoff
- Detention facilities to capture *first flush* flows
- Increased urban tree cover

<u>Unfavorable practices</u>

- Swales
- Flow-through structures
- Rain gardens
- Green roofs

In addition to the BMPs listed above, a water conservation measure, xeriscaping or xerogardening, has gained popularity in arid and semi-arid regions in recent years. Xeriscaping is a practice that focuses on reducing water demand by using drought-tolerant plants, efficient irrigation, soil improvement, and mulching. When compared with traditional landscaping practices, xeriscaping requires lower soil moisture and can have a higher water retention capability. Therefore, xeriscaping serves as an effective measure for water conservation and reduces stormwater pollution during storm events by retaining more water on-site, resulting in less runoff. The Albuquerque Bernalillo County Water Utility Authority (ABCWUA) is implementing a rebate program to encourage homeowners to convert traditional landscape into xeriscape (ABCWUA, 2012). In addition to direct rainfall, harvested runoff from rooftops and impervious surfaces can be used to irrigate a xeriscaped area, which further reduces runoff pollution.

Of this and the other BMPs listed here, street sweeping and pet waste management were deemed suitable for the Albuquerque area with respect to nonstructural BMP selection. Additionally, rainwater harvesting, xeriscaping, and detention basins were deemed suitable and are considered in this *SUSTAIN* application study.

SUSTAIN requires BMP cost data as a key component of the optimization process. Data sets can be input either as individual components costs (i.e., length of pipe, volume of soil) or as an aggregate volumetric cost (i.e., $/ft^3). While national cost databases exist (such as those included in the *SUSTAIN* BMP cost database), up-to-date, local costs are always preferable to accurately reflect realistic materials and labor costs (for both construction and maintenance).

For comparison purposes, all costs are represented as an annual cost where applicable. Present value costs are assumed to be paid over the design lifetime in equal installments. These annualized costs are calculated using the following equation:

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$$

where *A* is the annualized cost, *P* is the present value of that cost, *i* is the assumed interest rate (5 percent), and *n* is the design life span in years.

4.1. Structural BMP Performance and Cost

Structural BMPs are physically represented in the *SUSTAIN* model with parameters that can be adjusted during optimization. The parameters used in *SUSTAIN* to represent structural BMPs are summarized in Table 9.

Table 9. BMP simulation parameters used in *SUSTAIN* for structural BMPs

Parameter	Xeriscaping	Rainwater collection	Detention basin
Initial condition			
Initial soil moisture	0.3	--	0.3
Initial water depth	0	0	0
Substrate			
Ponding depth (ft)	0.042	--	4
Substrate layer depth (ft)	2	--	1
Substrate layer porosity	0.4	--	0.3
Vegetative parameter, A	1	--	1
Background soil saturated infiltration rate* (inch/hr), fc	0.3	--	0.3
ET rate (in/day)	0.104	--	0.104
Water quality			
TSS 1st order decay rate (1/day), k	0.8	0.8	0.8
E. coli 1st order decay rate (1/day), k	0.5	0.5	0.5

* Soil map shows the majority background soil has hydrologic soil group of C; therefore, a 0.3 inch/hr background infiltration rate is assumed.

The BMP module in *SUSTAIN* was configured to represent the water retention and infiltration capacity provided by xeriscaping. It was recommended that the soil at the site be loosened and amended to a depth of 24 inches to prompt plant root development and moisture retention. In *SUSTAIN* a 24-inch substrate with 0.4 porosity was assumed with no underdrain. Additionally, a 0.5-inch ponding depth was used to represent depression storage. Also a conservative saturated background infiltration rate of 0.3 inch/hour (assuming Hydrologic Soil Group C) was applied.

The xeriscape rebate program conducted by ABCWUA pays property owners a credit of $1.00 for every square foot of qualifying landscape, with a minimum of 500 square feet to participate. While other maintenance costs would be expected with xeriscaping, because the case study was formulated from a municipal planning perspective, only the rebate cost was considered. Assuming a life span of 20 years and an interest rate of 5 percent yields a cost of $0.0802 for every square foot of xeriscape per year. Differing slightly from xeriscape representation, rainwater harvesting can be physically represented in *SUSTAIN* in the form of an arbitrary number of rain barrels. Rain barrels in *SUSTAIN* can be defined in volume, drainage area, drainage area soil and infiltration properties, and the like. Using a specified volume and a 2 dry-day release schedule (collected rainwater released to receiving landscape after 2 dry days), rainwater harvesting was modeled in *SUSTAIN*.

This involves two components: a rainwater collection and distribution system, and a landscape that consumes the collected rainwater. Both components have an initial capital cost and operation and maintenance (O&M) costs. It is important to note, however, that the water saved by rainwater harvesting results in cost savings. Additionally, most rainwater harvesting practices are implemented by private industry or individuals and are not a direct burden on MS4 permittees. Considering these factors, this study uses the cost information derived from the rainwater harvesting rebate program that ABCWUA implements. Rainwater collection system rebates are based on the amount of rain that can be stored on-site, with rebate level summarized in Table 10 below.

Table 10. Summary of rainwater harvesting rebates in Albuquerque

Rebate amount	Minimum volume (gallons/year)	Maximum volume (gallons/year)
$25	50	149
$50	150	299
$75	300	499
$100	500	999
$125	1,000	1,499
$150	> 1,499	

The cost numbers above were further converted into a unit volume cost in dollars per gallon, which are plotted in Figure 18 below. Using these data, a power function was generated to define a relationship between unit volume cost and storage volume, shown below:

$$P_{RWH,Unit} = 2.9019 V_b^{-0.472}$$

where $P_{RWH,Unit}$ is the present unit volume cost in dollars/gallon and V_b is the storage volume of the unit in gallons. The equivalent annual cost of this assuming a 20-year lifespan and 5 percent interest rate yields:

$$A_{RWH,Unit} = 0.2327 V_b^{-0.472}$$

The rebate amount for rainwater harvesting, similar to xeriscape conventions, was $1.50 per square foot. The minimum area was 500 square feet, while the maximum possible area was 2,000 square feet.

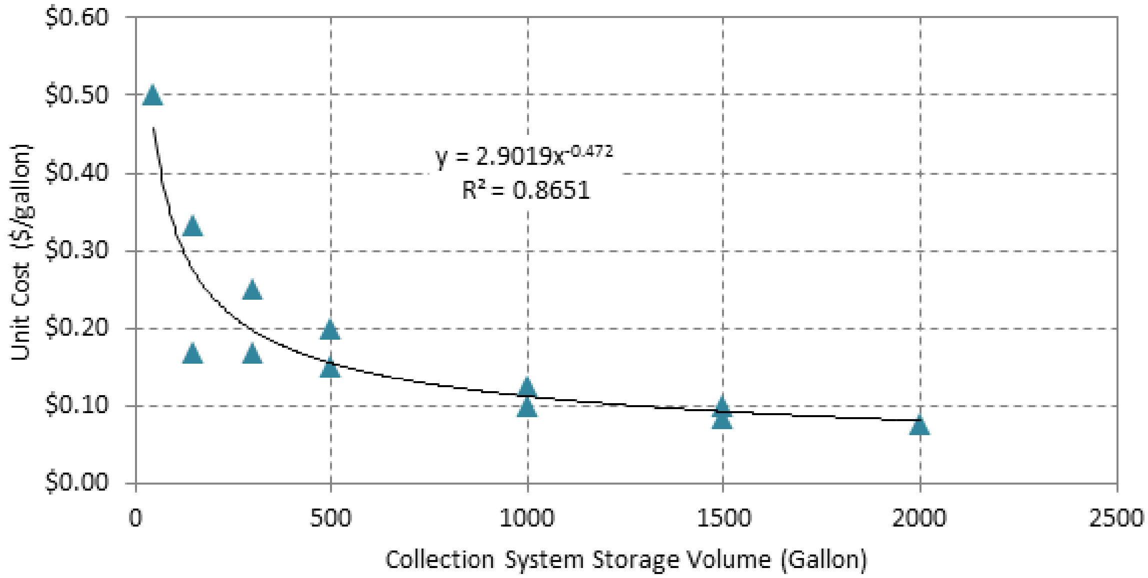


Figure 18. Unit cost per gallon of collection system storage.

Similar to rain barrels, detention basins can be physically represented in *SUSTAIN*. More specifically, a detention basin can be represented using the *SUSTAIN* dry pond template with specified surface area, ponding depth, and outlet orifice diameter sized to achieve 40-hour drain time.

The Bernalillo County BMP study, completed in November 2011, provides estimates of construction costs for four extended detention basin BMPs and detailed cost estimates for these facilities' annual O&M. The construction cost of a typical extended detention basin includes a unit volume cost of $0.67 per cubic foot of storage and a fixed cost of $29,000 for inlet, outlet structure, pipe, and riprap. With an additional 30 percent of the total base cost added as contingency cost, the overall construction cost can be expressed as

$$P_{DB,C} = 1.3 \times (\$0.67V + \$29{,}000)$$

where $P_{DB,C}$ is the present construction cost of a detention basin, and V is the volume of the detention basin in cubic feet.

The annual O&M cost consists of two components: per facility associated costs and BMP size associated costs. Per facility costs, not associated with the facility size, cover compliance inspection, inlet/outlet cleaning, nuisance control, and outlet maintenance. BMP size associated costs include sediment removal and vegetation/lawn care. Considering these two components, the annual O&M cost of each facility can be expressed as

$$A_{DB,O\&M} = \$0.0503V + \$1{,}458.81$$

where $A_{DB,O\&M}$ is the annual O&M costs of a detention basin, and V is the volume of the detention basin in cubic feet.

Annualizing construction costs at a 5 percent interest rate and assuming equal annual payments for the 35-year lifespan of a detention basin yields the following annual construction associated cost equation:

$$A_{DB,C} = 1.3 \times (\$0.67V + \$29{,}000) \times \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right]$$

$$\Rightarrow A_{DB,C} \approx \$0.0532V + \$2{,}303$$

where $A_{DB,C}$ is the annualized construction cost of the detention basin, and V is the volume of the detention basin in cubic feet. Combining this annualized construction cost with the annual O&M costs yields the following equation to calculate total annualized cost for a detention basin as a function of detention basin volume:

$$A_{DB,Total} = A_{DB,C} + A_{DB,O\&M} \approx \$0.1035V + \$3{,}762$$

where $A_{DB,Total}$ is the annualized total cost of a detention basin, and V is the volume of the detention basin in cubic feet.

4.2. Nonstructural BMP Performance and Cost

Nonstructural BMPs, i.e., street sweeping and pet waste management, are represented by modifying the corresponding HRU time series to reflect pollutant removal efficiencies (Table 11).

Table 11. Summary of nonstructural BMPs

Nonstructural BMPs	HRUs affected	Pollutants
Street sweeping	Roads	Sediment and Bacteria
Pet waste management	Multifamily, Single-family, Park and Recreation, Roads	Bacteria

Literature suggests that street sweeping can remove 5 to 70 percent of sediment depending on sweeping method and frequency (Radian, 2011). No literature values were found with regard to bacteria removal effectiveness of street sweeping. However, since bacteria naturally die off with sunlight exposure, their quantities tend to increase asymptotically to some limit and diminish over time with no additional inputs. The studies reviewed previously (Reeves et al., 2004; Ahn et al., 2005; Surbeck et al., 2006) all suggest that once bacteria are in the water, they tend not to be associated with particulate matter. However, *before* it reaches the water body, it is commonly recognized that trash and other debris on the land surface are places where bacteria are harbored. Street sweeping will remove the trash, sediment, and other debris from the road surface, and consequently, prevent those bacteria from being mobilized into the stormwater system. For this reason, the same percent removal rates for land-based sediment were also applied for bacteria.

The cost of street sweeping is a function of sweeping method and frequency. Cost data were compiled and compared from a number of sources. Some variation existed among the sources, as shown in Table 12. To better understand the impact of these cost assumptions on the recommended management strategies derived through BMP cost-benefit optimization, two sets of costs were applied. In addition to local Albuquerque cost data, published cost data from other regional municipalities with similar arid climate (i.e., Southern California) were also applied. Table 13 provides a breakdown of cost components for Albuquerque street sweeping costs, whereas Table 14 summarizes street sweeping costs from several cities in Southern California, according to a weekly sweeping schedule. For this study, two scenarios were considered using the most regionally relevant values: (1) the lower cost literature values from Southern California and (2) the higher cost local values from Albuquerque.

Table 12. Summary of literature values for street sweeping costs

Street sweeping cost ($ per curb mile swept)				
Original	**Present value†**	**Note**	**Locale**	**Source**
$25	$30	2009 dollars, total agency/ contractor cost for sweeping and disposal	Southern California	City of Costa Mesa City Council Report 2009
Vacuum: $25 Brush: $45	Vacuum: $36 Brush: $64	2005 dollars, include equipment, operation and maintenance costs	Minnesota	RMWMD 2005
$68	$156	1995 cost, Include labor, equipment, and material cost	Michigan	USEPA 1999
$164	$164	2012 dollars, includes owner, employee, equipment and operations and disposal costs	City of Albuquerque	City of Albuquerque 2012

† Present value assumes a 5% interest rate from original date of published costs, and rounded up to nearest dollar

Table 13. Albuquerque FY2012 street sweeping cost

Street sweeping cost components	Component cost ($ per curb mile swept)
Equipment replacement cost	$1.77
Fleet cost (including owner cost and operational cost)	$127.82
Employee wages cost	$29.80
Disposal cost	$4.14
Total	$163.54

Table 14. Street sweeping costs in California

	Cost components ($ per curb mile per week)		
Agency/contractor	**Sweeping**	**Disposal**	**Total**
City of Costa Mesa by city staff	$11.34	$2.89	$14.23
Clean Sweep (contractor)	$24.00	$4.66	$28.66
Nationwide (contractor)	$23.00	$4.88	$27.88
Dickson (contractor)	$26.00	$6.00	$32.00
City of Newport Beach by city staff	$14.00	$3.91	$17.91
City of Irvine by city staff	$20.00	$3.76	$23.76
City of Irvine by contract	$24.00	$3.76	$27.76
City of Huntington Beach by contract	$26.28	$3.47	$29.75
Average	**$21.08**	**$4.17**	**$25.11**

Source: City of Costa Mesa City Council Report 2009

To determine a reasonable annual cost estimate for street sweeping in Albuquerque, the length of road requiring sweeping needed to be estimated. Considering only roads in the Albuquerque jurisdiction, shown in Figure 19, approximately 2,400 miles of road were found. This results in an approximate road density of 0.02 mile/acre. Assuming that all roads have two curbs, the curb miles per acre are 0.04 mile/acre. Applying this density to a 100-acre area, costs were estimated on the basis of 4.1 curb miles per 100 acres.

Using street sweeping costs from Southern California, the present value cost of $25.11 in 2009 dollars is $29.07 in 2012 dollars. This value was previously rounded up to $30 in Table 12 for comparison purposes. Assuming 4.1 curb miles per 100 acres, this estimate of curb miles results in a street sweeping costs ranged from $119.19 per 100 acres per week swept (for the literature-based cost data scenario) to $670.51 (for local cost data scenario). These rates can then be annualized using the frequency of sweeping in a year (i.e., $119.19 × *n* weeks or $670.51 × *n* weeks). Table 15 shows the final sets of street sweeping costs and estimated removal rates by sweeping frequency for both scenarios that were applied for optimization.

Table 15. Street sweeping removal rates and cost estimates by sweeping frequency

Sweeping frequency	Sediment/bacteria removal efficiency	Sweeping cost ($/per curb mile per year)	
		California[a]	City of Albuquerque[b]
Monthly	5%	$348	$1,962.48
Biweekly	35%	$755	$4,252.04
Weekly	70%	$1,510	$8,504.08

[a] Derived from average cost values from the City of Costa Mesa City Council Report 2009, converted to 2012 dollars
[b] Derived from street sweeping cost provided by City of Albuquerque through EPA Region 6, in 2012 dollars

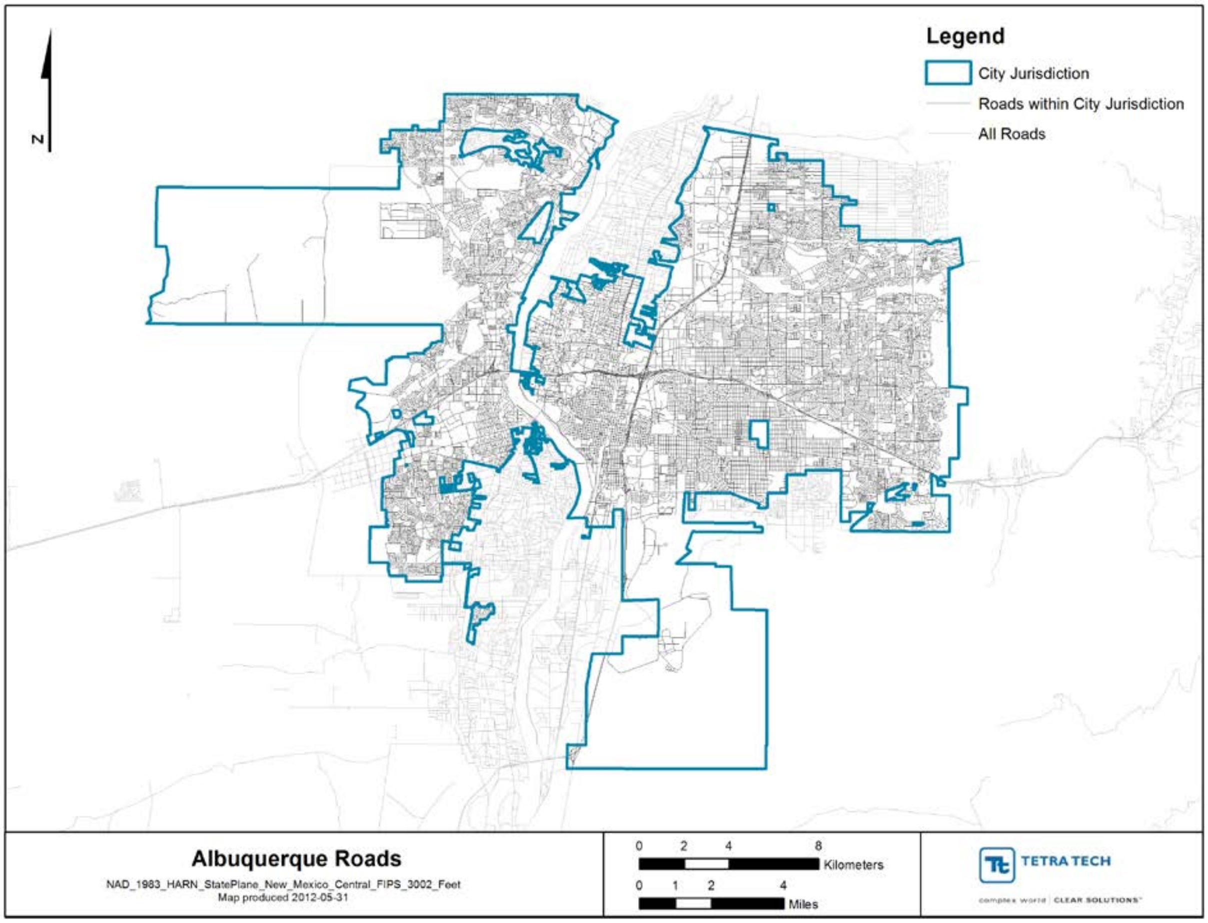
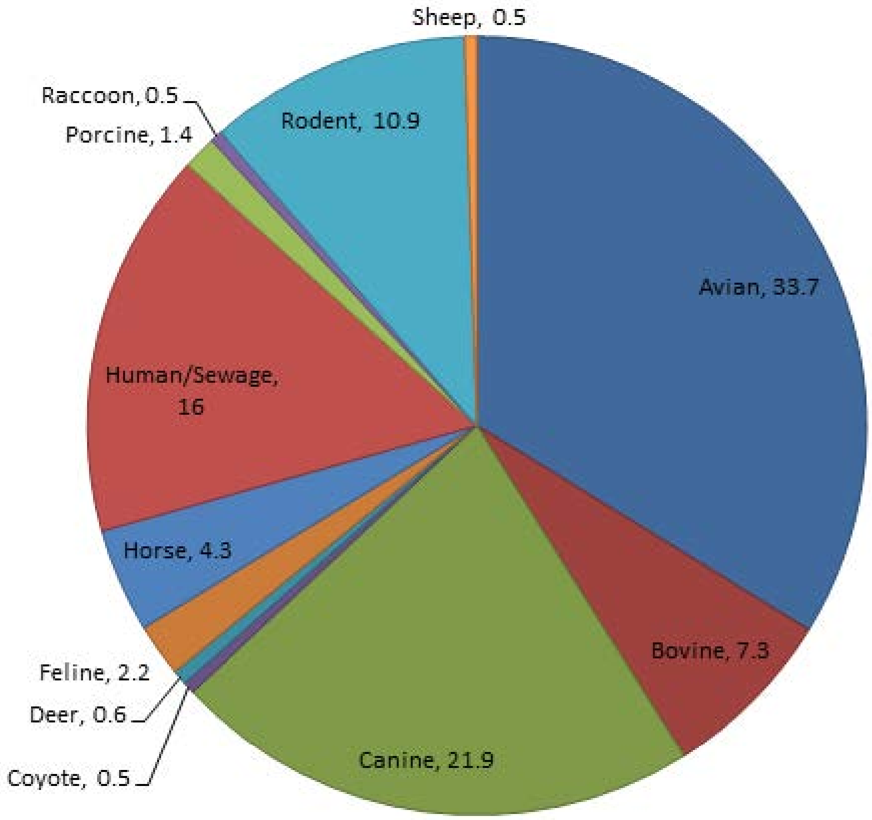


Figure 19. Roads in and outside the Albuquerque jurisdiction.

Less information was found regarding pet waste management programs. Although no literature values were discovered regarding the bacteria removal effectiveness of pet waste management, a bacteria source tracking study conducted in 2004 in Middle Rio Grande-Albuquerque watershed revealed that 21.9 percent of fecal coliform bacteria originate from dogs/canine (Figure 20). Therefore, for pet waste management, it was assumed that a combination of actions-based measures representing behavioral changes within the population could achieve a maximum bacterial removal efficiency of 20 percent. The scope of this study was limited to evaluating impact that such a program might have toward pollutant load reduction relative to other practices within the context of a cost-benefit optimization framework. A maximum efficiency of 20 percent is assumed because it was recognized that the benefit of pet waste management would only be applicable on a certain subset of land uses types within any given watershed. No specific implementations strategies or programs are being recommended.

While pet waste management programs are effective when implemented and followed, quantifying the associated costs are somewhat subjective and indirect. The cost of a pet waste management campaign varies depending on several factors, including the materials produced (signs, ads, cleanup stations) and if any funding mechanism can be established to offset the cost. For these and related factors, no local data were found. Considering the significant uncertainty associated with pet waste management costs, this study did not explicitly represent this cost component in the optimization analysis. Although to assess the impact of pet waste management programs, optimization scenarios with and without pet waste management were compared.



Source: NMED-SWQB 2010

Figure 20. Fecal coliform bacteria contribution distribution among sources.

Chapter 5. *SUSTAIN* Application for Representative Area

While this case study focuses on the proposed MS4 watershed-based permit area, the extent of this area spans 842.5 square miles (approximately 540,000 acres), which is beyond the practical application scale of a single *SUSTAIN* model. The MS4 watershed-based permit area also encompasses areas outside of Bernalillo County that are not fully represented in the datasets discussed in Chapter 2. As with any numerical construct, modeled *SUSTAIN* networks are simplifications of actual hydrologic and hydraulic networks. To minimize error associated with modeled time of concentration on an hourly time step, earlier *SUSTAIN* applications have shown that 100 acres is an appropriate spatial scale for subwatersheds (USEPA, 2012). In lieu of modeling the entire MS4 permit area, a representative subwatershed model was constructed for this analysis that (1) represents the urban land use distribution typically found in the MS4 permit area, and (2) satisfies the requirements of model spatial scale for use in *SUSTAIN*.

To develop this representative model of the MS4 permit area, the HRU distribution in available jurisdictional boundaries was tabulated. The distribution was then normalized down to a 100-acre size for modeling purposes. Two jurisdictional boundaries were used as the basis for summarizing HRU distributions for the representative model area. The first boundary was the intersection of the MS4 and Bernalillo County boundaries. The second was the Albuquerque jurisdictional boundary. Figure 21 is a map showing the extent of the various data layers.

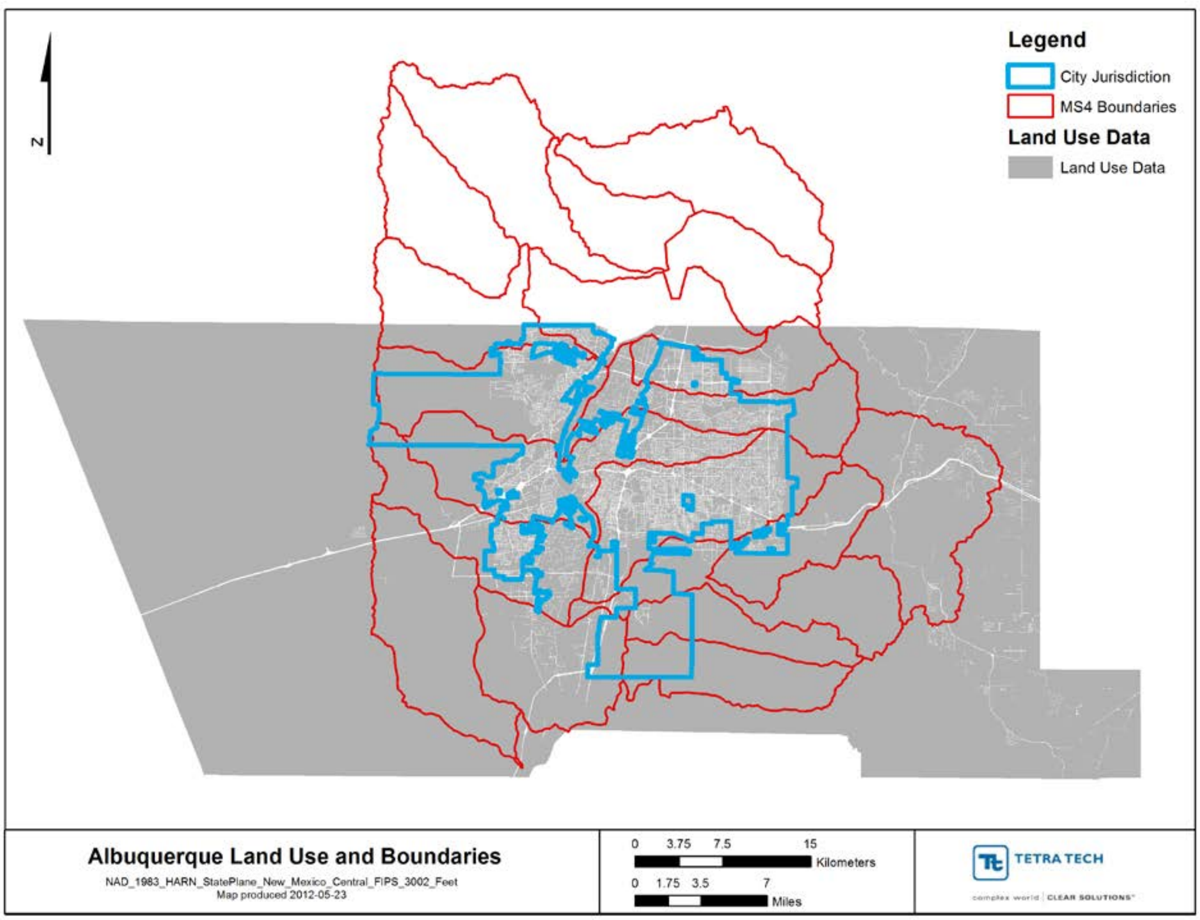


Figure 21. Map comparing the spatial extent of jurisdictional boundaries used for developing conceptual HRU distributions.

Figure 22 presents a comparison of each HRU distribution summarized using the boundaries from the MS4-Bernalillo County overlap and Albuquerque. Because the MS4 boundary extended well outside the urban core, it encompasses more of the vacant or undeveloped areas on the northern, eastern, and western perimeter of Albuquerque. Limiting the boundary to the intersection of the MS4 area and Bernalillo County helped emphasize the urban core; however, the overall HRU distribution was still dominated by vacant land. In contrast, the city's jurisdictional boundary by definition encompasses more urban areas. Table 16 presents a comparison of the HRU distributions in the two boundaries. Because the objective of this *SUSTAIN* case study is to assess placement of *urban* BMPs for a watershed-based permit, the HRU distribution developed using the city's jurisdictional boundary was chosen for the representative 100-acre model area.

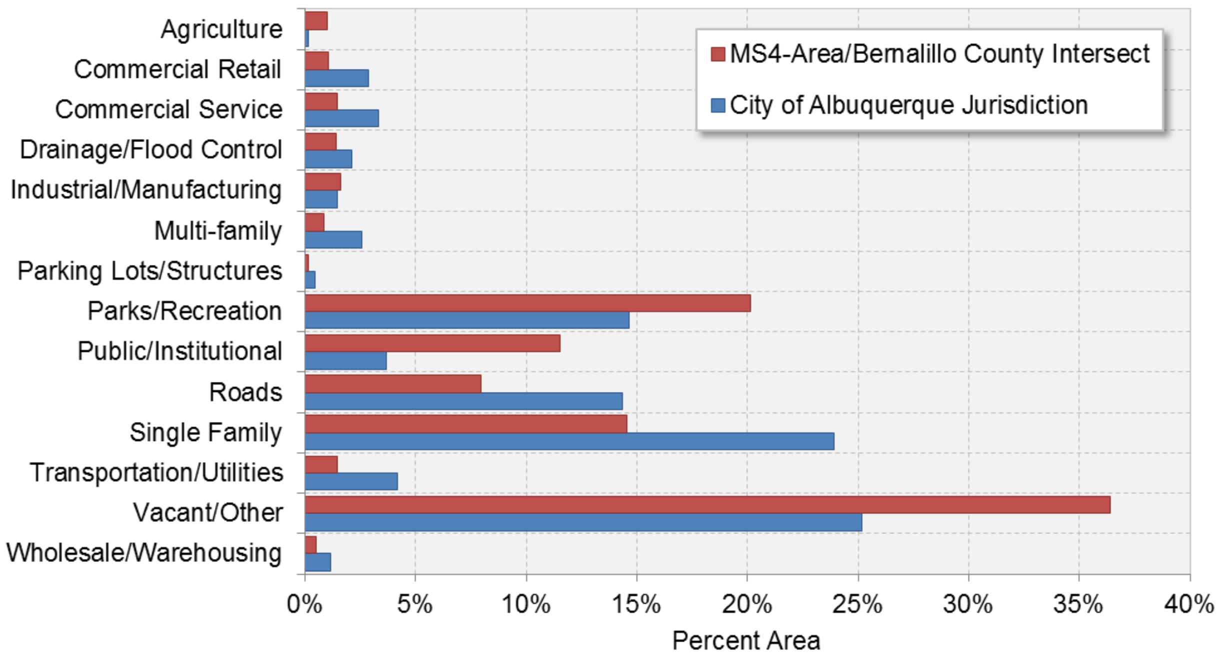


Figure 22. Comparison of HRU distributions summarized using the MS4 and Albuquerque's boundaries.

Table 16. HRU distribution for the 100-acre *SUSTAIN* conceptual model

Category	Name	HRU distribution		100-Acre model (acres)
		MS4 area Bernalillo County	City of Albuquerque	
1	Agriculture	1.00%	0.15%	0.15
2	Commercial Retail	1.06%	2.86%	2.86
3	Commercial Service	1.46%	3.33%	3.33
4	Drainage/Flood Control	1.40%	2.13%	2.13
5	Industrial/Manufacturing	1.60%	1.47%	1.47
6	Multifamily	0.86%	2.54%	2.54
7	Parking Lots/Structures	0.14%	0.42%	0.42
8	Parks/Recreation	20.12%	14.67%	14.67
9	Public/Institutional	11.51%	3.67%	3.67
10	Single Family	14.54%	23.92%	23.92
11	Transportation/Utilities	1.47%	4.19%	4.19
12	Vacant/Other	36.40%	25.16%	25.16
13	Wholesale/Warehousing	0.51%	1.15%	1.15
14	Roads	7.92%	14.35%	14.35

5.1. BMP Scenarios

Management practices in the 100-acre representative model included a combination of both non-structural and structural practices. The nonstructural BMPs were represented as changes in the modeled runoff boundary conditions while the structural practices were modeled explicitly using BMPs commonly available in *SUSTAIN*. The nonstructural BMPs scenarios included varying levels of street sweeping and/or pet waste management. Overall, 11 managed scenarios and one baseline scenario (no street sweeping and no pet waste management) were constructed as summarized in Table 17. The levels of the nonstructural BMPs are indicated by corresponding pollutant percent removals.

Table 17. Summary of nonstructural BMP scenarios

Scenario ID	Pollutant percent removal	
	Street sweeping	Pet waste management
Baseline	--	--
1	5%	--
2	35%	--
3	70%	--
4	--	10%
5	5%	10%
6	35%	10%
7	70%	10%
8	--	20%
9	5%	20%
10	35%	20%
11	70%	20%

These combinations of scenarios evaluate performance of the varying levels of both street sweeping and pet waste management also reflects the interactions between the two nonstructural practices considered here. For example, for the roads where both street sweeping and pet waste management applies, the combination of street sweeping with 35 percent pollutant removal and pet waste management with 10 percent pollutant removal will not result in an overall removal efficiency of 45 percent; instead the total removal efficiency is 41.5 percent, calculated as

$$41.5\% = 100\% - [(100\% - 10\%) \times (100\% - 35\%)]$$

As described previously in this section, three types of structural BMPs, i.e., rainwater collection system, xeriscape, and detention basin, are considered. Figure 23 illustrates the BMP routing configuration. Runoff from road, parking lot, commercial, industrial, public/institutional, multi-family residential, and single-family residential areas are collected by rainwater collection system, the overflow from the collection system during storm event drains to downstream xeriscape; during dry weather, the collected rainwater will be used to irrigate the downstream xeriscape. The maximum collection system storage volume is assumed to capture 0.5 inch runoff from the impervious area. Because the pollutant loading characteristics vary among the different land use categories, the performance of rainwater collection systems and xeriscape are expected to differ when treating runoff from different land uses. To compare performance of BMPs for various land use categories, each land use was assigned a unique representation of collection system and xeriscape. In addition to distributed BMPs, a regional detention basin designed to treat the entire 100-acre area was also included in the potential BMP network.

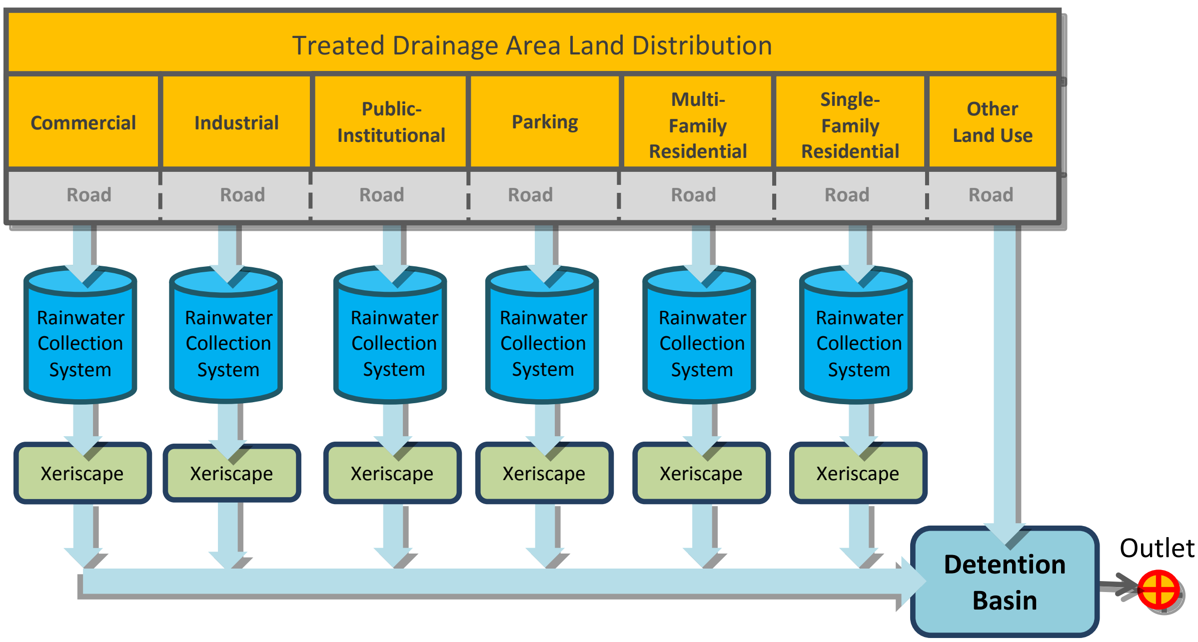


Figure 23. Structural BMP routing network configuration.

Xeriscape

The potential xeriscape area is estimated on the basis of GIS analysis. The first step is estimating the impervious surface area percentages of the selected land use categories. The city's land use raster geospatial layer was converted to a polygon file. An aerial image available from ESRI was used as a background to identify impervious surfaces. In each selected land use plot, polygons were drawn to represent the impervious surfaces (roofs, pavements, and the like). In developing impervious surface polygons, the focus was on the larger areas, and some of the smaller areas, such as sidewalks, might have been excluded for simplicity. These smaller areas, however, are believed to be a relatively minor area compared to the total impervious area and most likely would not significantly influence the overall calculation of average impervious areas.

For some areas, the aerial image is difficult to interpret because of resolution and other issues in the image. The resolution quality of the image is a factor for distinguishing smaller details and thus classifying them as impervious. For example, in housing land uses, smaller details such as porches/patios, sheds, and the like might have been difficult to distinguish. Because of the nature of the image, shadows from buildings and large trees could have interfered with classifying some areas as impervious or pervious. Another issue related to the nature of the image and image resolution is being able to distinguish between impervious surfaces, dead/dry grass, bare ground/dirt, or xeriscape in some areas. Figure 24 through Figure 29 show an example plot of each land use type with the impervious surface polygons. To calculate the percent impervious area, the area of impervious surface in a plot was compared to the total area of the plot. To generate the average impervious surface area by land use type, individual plot percentages were averaged by category. After the impervious area percentages were determined, the approximate percentages of pervious areas available for xeriscape were estimated. This was done by a visual inspection of an aerial image of the selected land use plots and their pervious areas. Table 18 summarizes the area percentages that could be converted to xeriscape.

Figure 24. Commercial retail land use (Category 2) example plot with impervious surfaces highlighted.

Figure 25. Commercial service land use (Category 3) example plot with impervious surfaces highlighted.

Figure 26. Industrial/manufacturing land use (Category 5) example plot with impervious surfaces highlighted.

Figure 27. Multifamily land use (category 6) example plot with impervious surfaces highlighted.

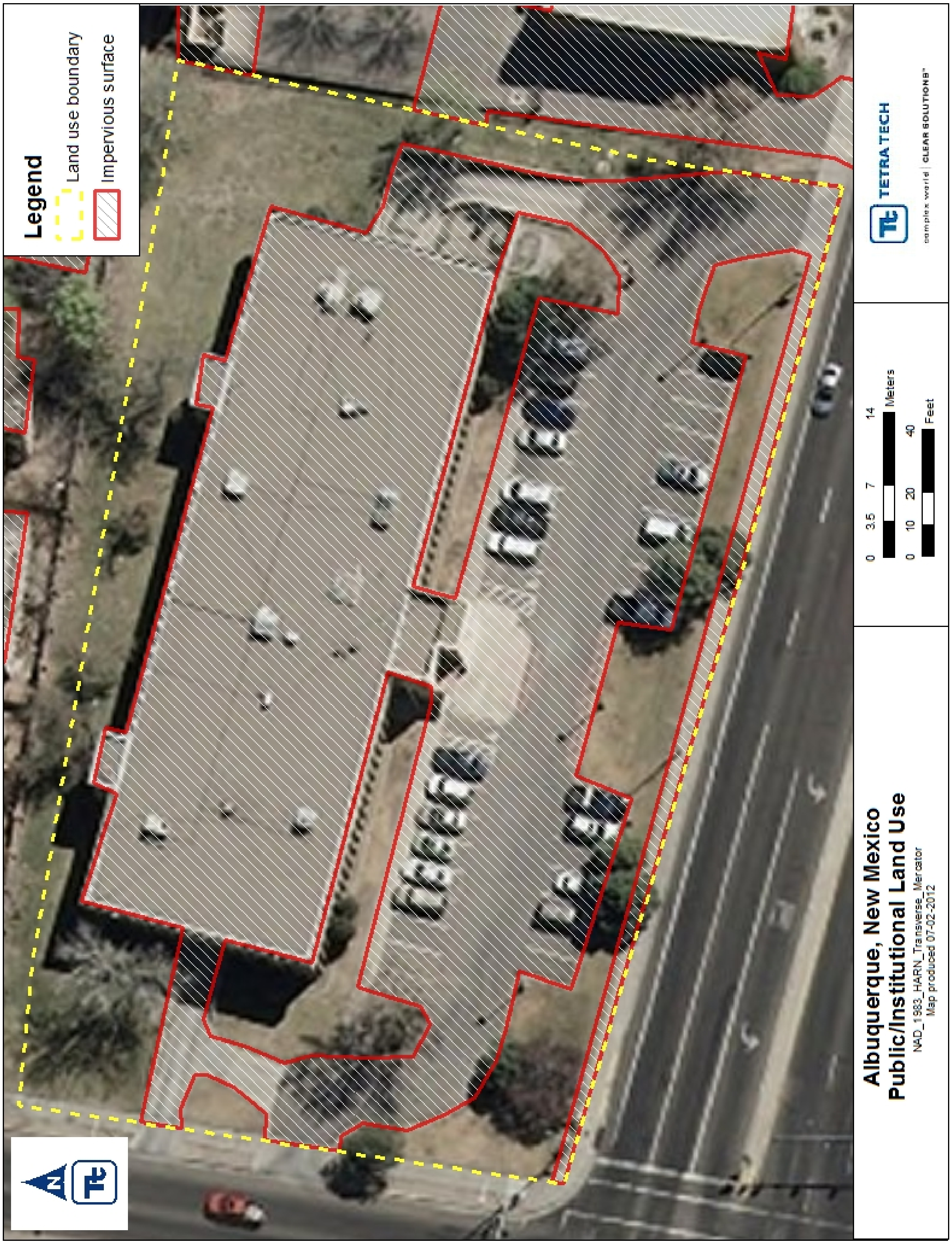


Figure 28. Public/institutional land use (category 9) example plot with impervious surfaces highlighted.

Figure 29. Single family land use (category 10) example plot with impervious surfaces highlighted.

Table 18. Estimated potential area that can be converted to xeriscape

Land use category	Impervious area including roads (acres)	Pervious area (acres)	Maximum potential xeriscape area		
			Potential xeriscape area (% of per. area)	Total area (acre)	Normalized area (ac. per ac. imp drainage area)
Commercial (including retail and service)	6.72	0.90	30%	0.27	0.04
Industrial	1.48	0.16	50%	0.08	0.05
Multi-family Residential	1.87	1.14	70%	0.80	0.43
Parking Lot	0.55	0.02	100%	0.02	0.04
Public/Institutional	3.65	0.44	60%	0.26	0.07
Single-family Residential	20.46	11.24	70%	7.87	0.38

Detention Basin

One detention basin facility is assumed for the 100-acre representative area. The detention basin is designed to retain the water quality capture volume (WQCV). This volume was calculated using the following relationship:

$$WQCV = a \times \left(0.91I^3 - 1.19I^2 + 0.78I\right)$$

where *WQCV* is the water quality capture volume in inches, *a* is a coefficient corresponding to WQCV drain time (defined in Table 19), and *I* is the percent imperviousness.

Table 19. Drain time coefficients for WQCV calculation

Drain time (hours)	Coefficient, a
12	0.8
24	0.9
40	1.0

Percent imperviousness *I* was estimated for each land use type in the Albuquerque watershed and tabulated in Table 20. From this information, an area-weighted average was calculated to get the average percent imperviousness in the watershed.

Table 20. Summary of percent imperviousness in Albuquerque by land use category

Category	Name	Percentage	Area (acres)	Imperviousness
1	Agriculture	0.15%	0.15	15%
2	Commercial Retail	2.86%	2.86	85%
3	Commercial Service	3.33%	3.33	86%
4	Drainage/Flood Control	2.13%	2.13	100%
5	Industrial/Manufacturing	1.47%	1.47	89%
6	Multifamily	2.54%	2.54	55%
7	Parking Lots/Structures	0.42%	0.42	100%
8	Parks/Recreation	14.67%	14.67	20%

Category	Name	Percentage	Area (acres)	Imperviousness
9	Public/Institutional	3.67%	3.67	88%
10	Single Family	23.92%	23.92	53%
11	Transportation/Utilities	4.19%	4.19	90%
12	Vacant/Other	25.16%	25.16	20%
13	Wholesale/Warehousing	1.15%	1.15	85%
14	Roads	14.35%	14.35	90%
			Area weighted % imperviousness	52.1%

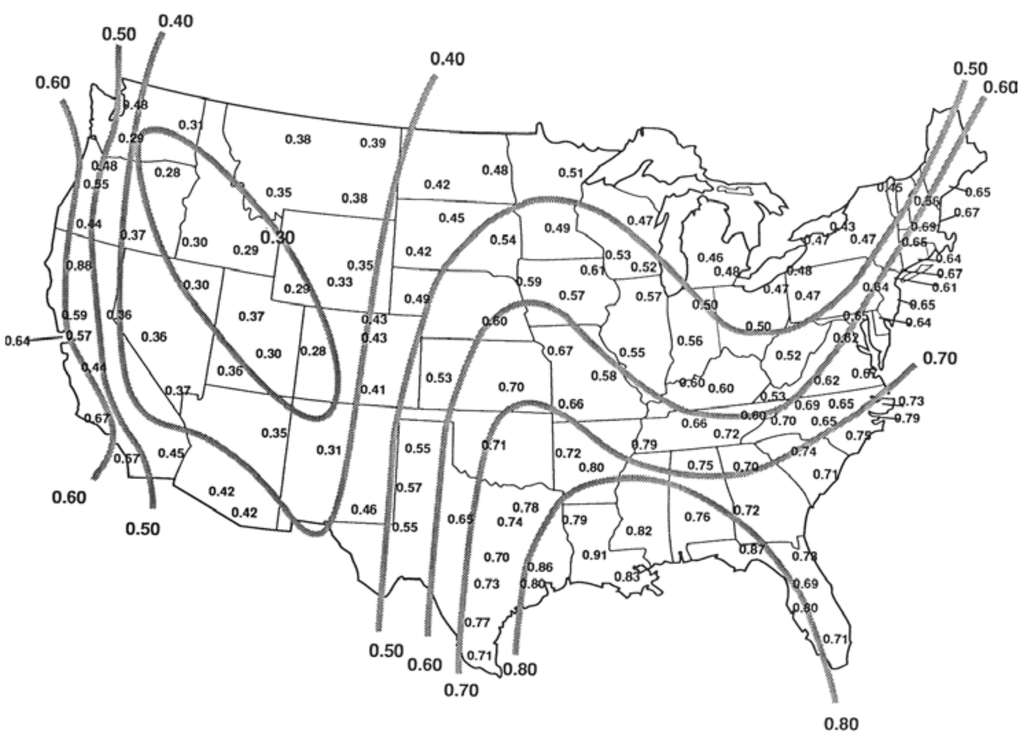
Using an average imperviousness of 52 percent and assuming a drainage time of 40 hours, WQCV was calculated to be 0.21 inch.

$$WQCV = 1.0 \cdot \left[0.91(0.52)^3 - 1.19(0.52)^2 + 0.78(0.52)\right] = 0.21$$

WQCV outside Albuquerque can be estimated using the following relationship:

$$WQCV_{Other} = d_6\left(\frac{WQCV}{0.43}\right)$$

where $WQCV_{Other}$ is the WQCV outside the watershed in inches and d_6 is the average depth of runoff-producing storms from Figure 30.



Source: Guo and Urbonas 1996

Figure 30. Distribution of mean precipitation, *d_6*, in inches for the United States.

Using the $WQCV_{Other}$ equation and assuming a d_6 of 0.41 inch yields a $WQCV_{Other}$ of 0.202 inch, or 1.68 acre-feet. Considering the implementation of rainwater harvest and xeriscape throughout the drainage area, the WQCV calculated on the basis of the existing condition might be over designed. The smaller volume of 25, 50, and 75 percent of the calculated WQCV are also included as options.

Chapter 6. Evaluation of BMP Performance

Evaluation of BMP performance provides valuable information regarding the magnitude and trend of pollutant removal efficiencies under various conditions and helps determine the achievable pollutant removal effectiveness.

Nonstructural BMPs

Pollutant removal rates of nonstructural BMPs were estimated for each scenario given in Table 17. Comparing nonstructural BMP reductions to the baseline scenario shows both the importance of nonstructural BMPs in reducing TSS loads (Figure 31) and *E. coli* loads (Figure 32).

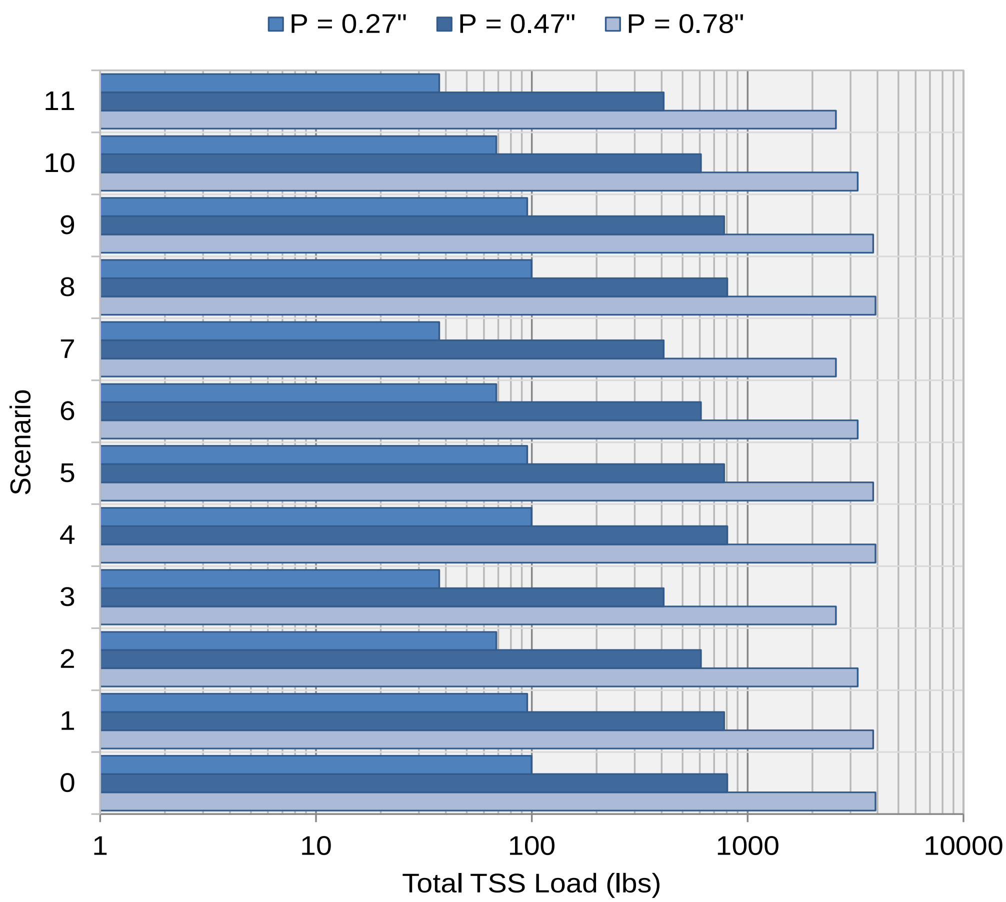


Figure 31. Comparison of nonstructural BMP scenarios and their effect on TSS load reductions for various storm event sizes.

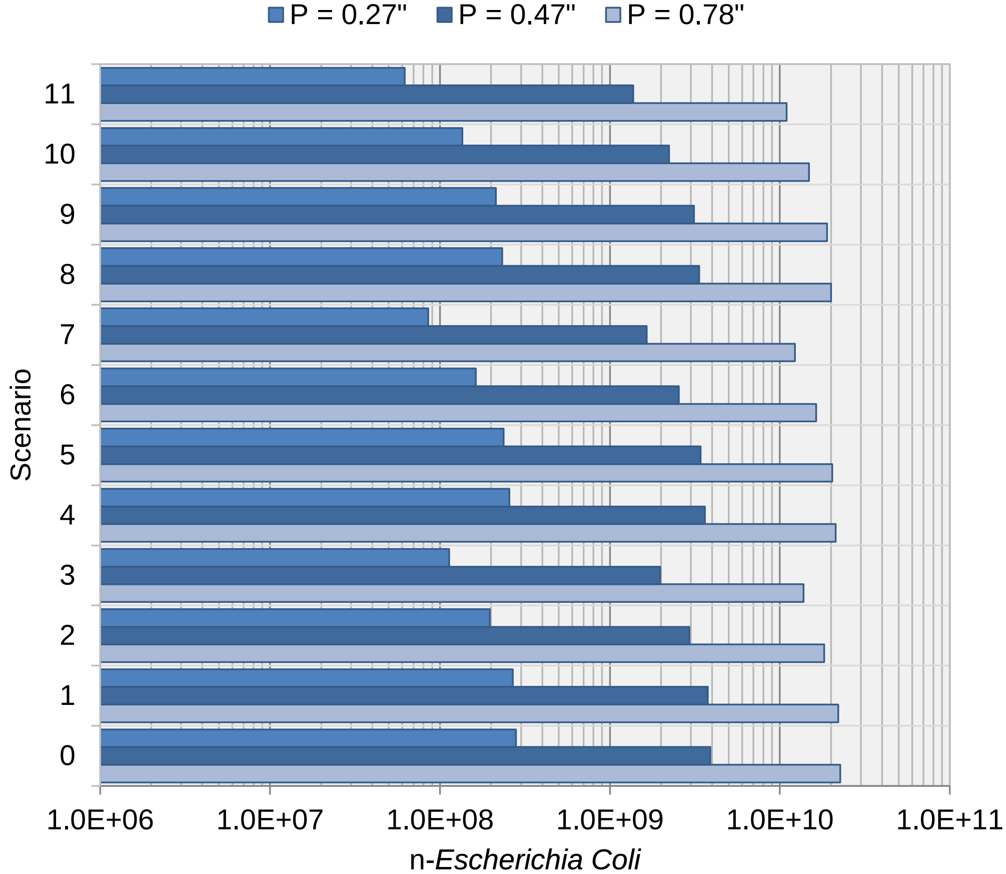


Figure 32. Comparison of nonstructural BMP scenarios and their effect on *E. coli* load reductions for various storm event sizes.

While cost estimates for street sweeping were made, costs for pet waste management programs were difficult to estimate. For the purposes of comparing scenarios, reduction and associated costs, a cost was assumed for pet waste management programs. For the case of 10 percent *E. coli* removal by the programs, an annual cost of $1,000 was assumed for a 100-acre area. Doubling this estimate for the 20 percent case yields $2,000. It is important to note these assumptions and the current limitations of cost estimates for pet waste management programs.

Cost versus performance was examined for both TSS and *E. coli* loads for the three storm scenarios. Because pet waste management programs would not reduce TSS loads, Figure 33 shows discrete levels of cost versus reduction as street sweeping frequency increases and pet waste management programs are considered. Figure 34 shows an almost linear cost to reduction relationship for *E. coli*, even for larger storm events. Note, however, that there is a high degree of uncertainty in the cost estimates for pet waste management programs.

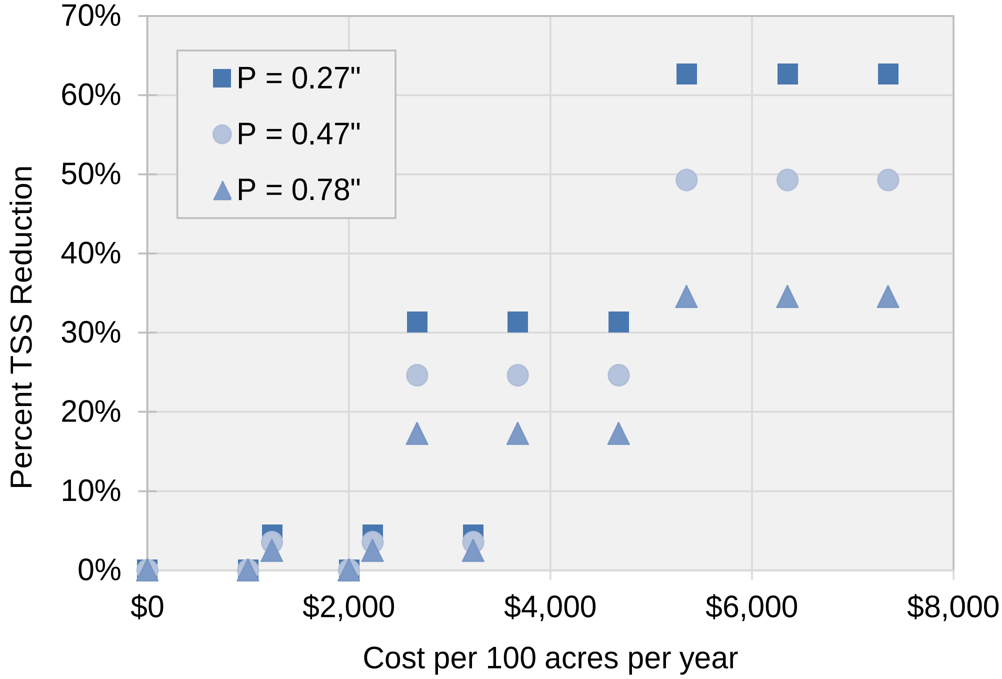


Figure 33. Comparison of nonstructural BMP scenario costs and their reduction of TSS loads for various storm event sizes.

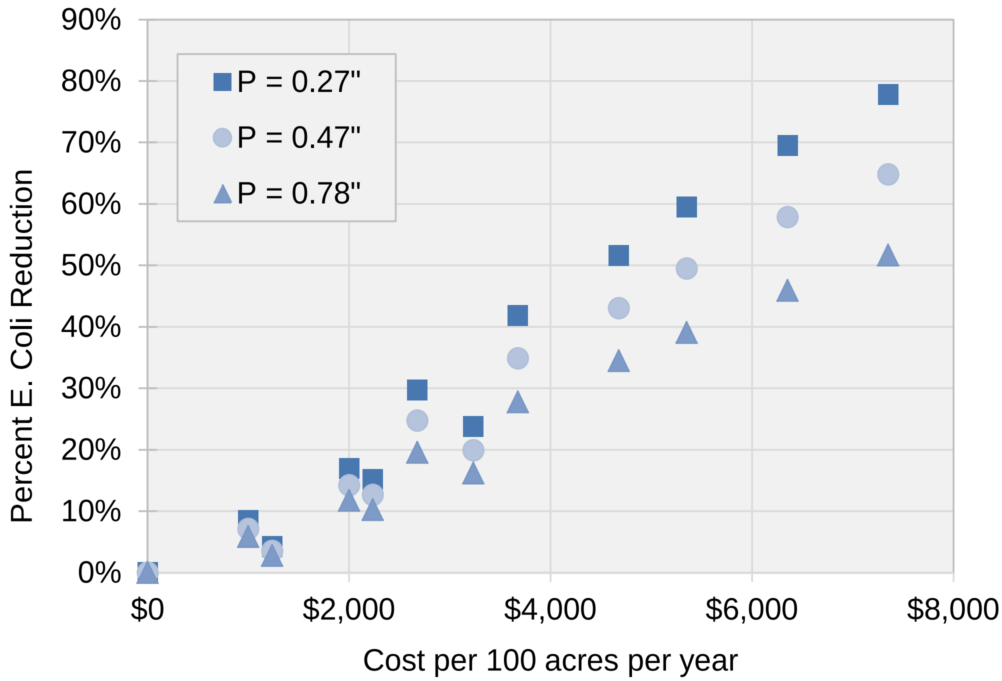


Figure 34. Comparison of nonstructural BMP scenario costs and their reduction of *E. coli* loads for various storm event sizes.

Structural BMPs

The pollutant removal performance of structural BMPs is affected by several factors, including hydrology and water quality characteristics of the drainage area, storm size, and size of the BMP relative to its drainage area. In this section, performance of the selected structural BMPs, including the distributed BMPs (i.e., the combination of rainwater collection system and xeriscape), and regional extended detention basin, are evaluated. With BMP performance measured as the pollutant load reduction percentages decrease with the increasing storm size, the evaluation of the BMPs was focused on the largest design storm (0.78-inches), which has the lowest load reduction percentage.

The performance of the rainwater collection system and xeriscape on *E. coli* removal was presented in Figure 35 through Figure 40 for each land use category. For these figures, the charts on left show load reduction versus dollar spent per acre impervious drainage area while the charts on right plot show the *E. coli* load reduction percentage with the near-optimal (i.e., least cost) combination of rainwater capture storage depth and xeriscape area as square feet per acre impervious area. It can be seen that within the maximum potential xeriscape area and 0.5-inch maximum rainwater collection storage capture depth, all land uses, with the exception of parking lots, can achieve 100 percent load reduction for the 0.78-inch storm; while parking lots have a maximum load reduction of 95 percent.

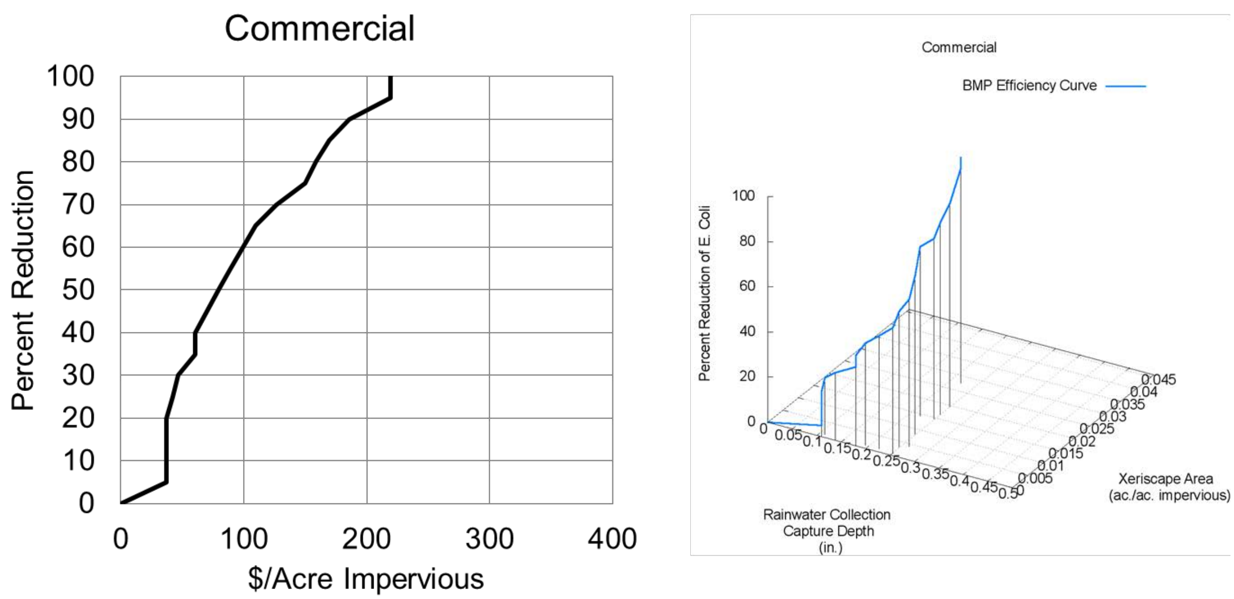


Figure 35. Commercial land use—rainwater collection system and xeriscape performance and cost-effectiveness curve.

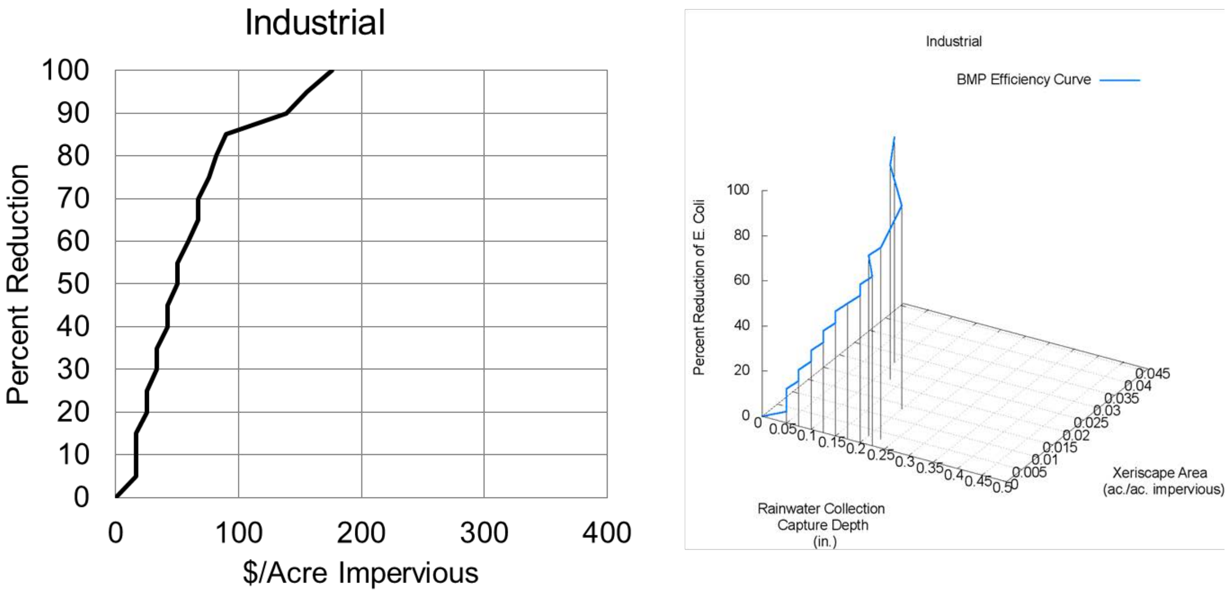


Figure 36. Industrial land use—rainwater collection system and xeriscape performance and cost-effectiveness curve.

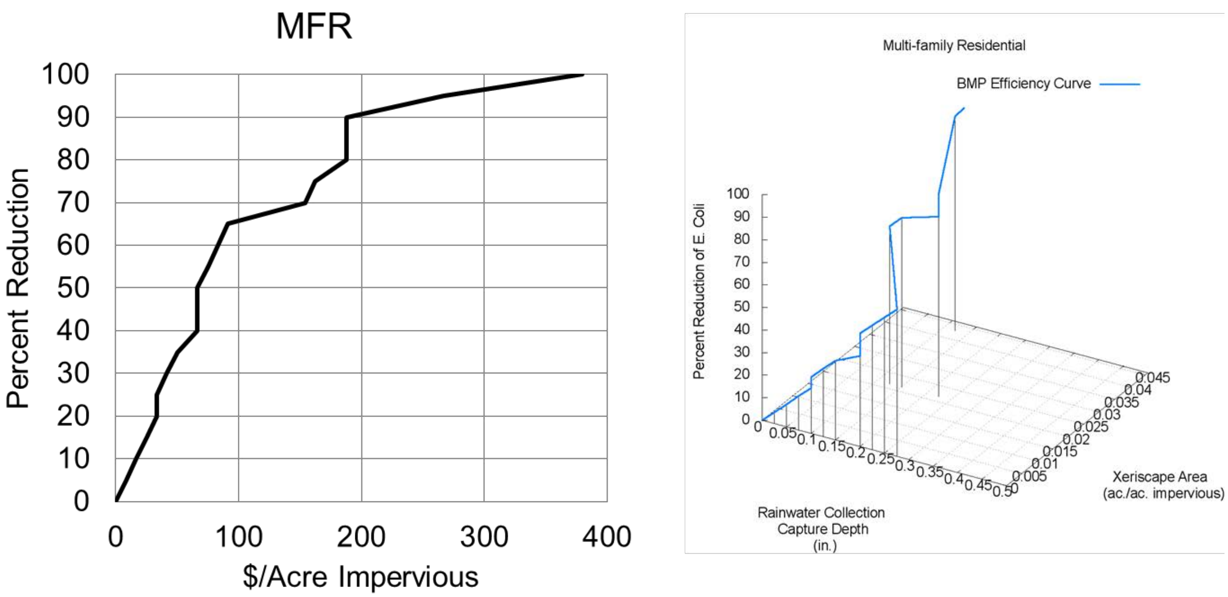


Figure 37. Multi-family residential land use—rainwater collection system and xeriscape performance and cost-effectiveness curve.

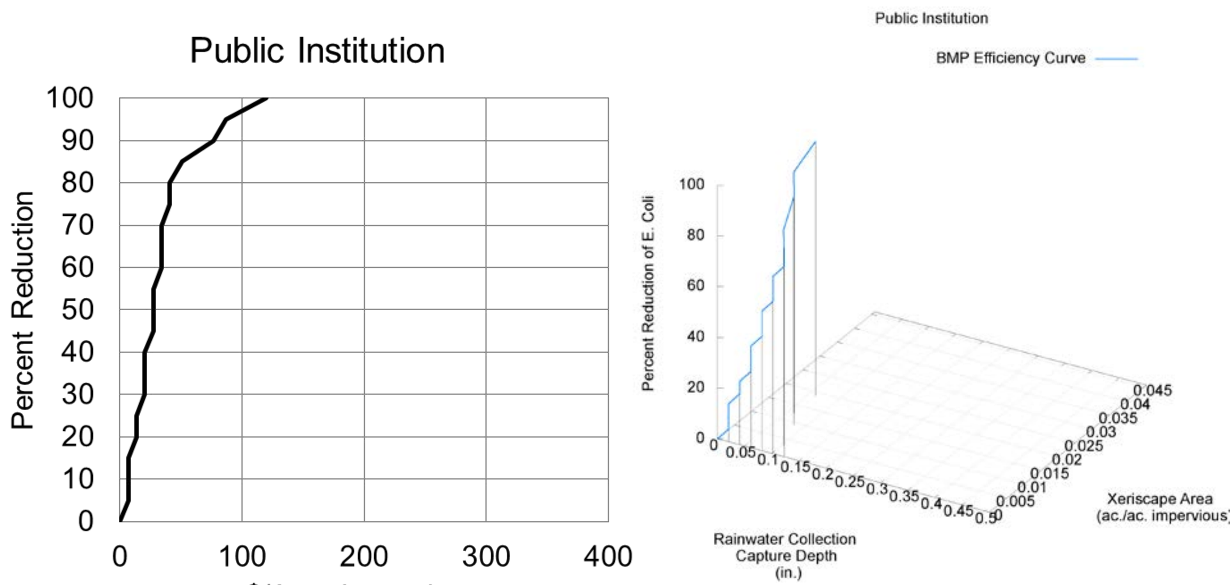


Figure 38. Public/Institutional land use—rainwater collection system and xeriscape performance and cost-effectiveness curve.

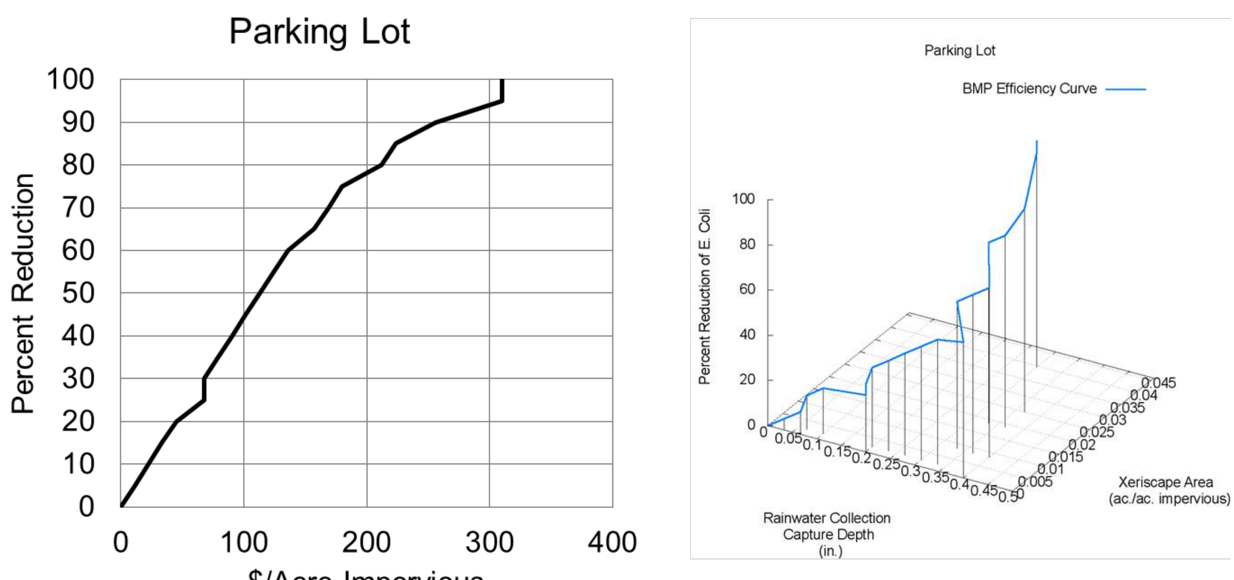


Figure 39. Parking lot land use—rainwater collection system and xeriscape performance and cost-effectiveness curve.

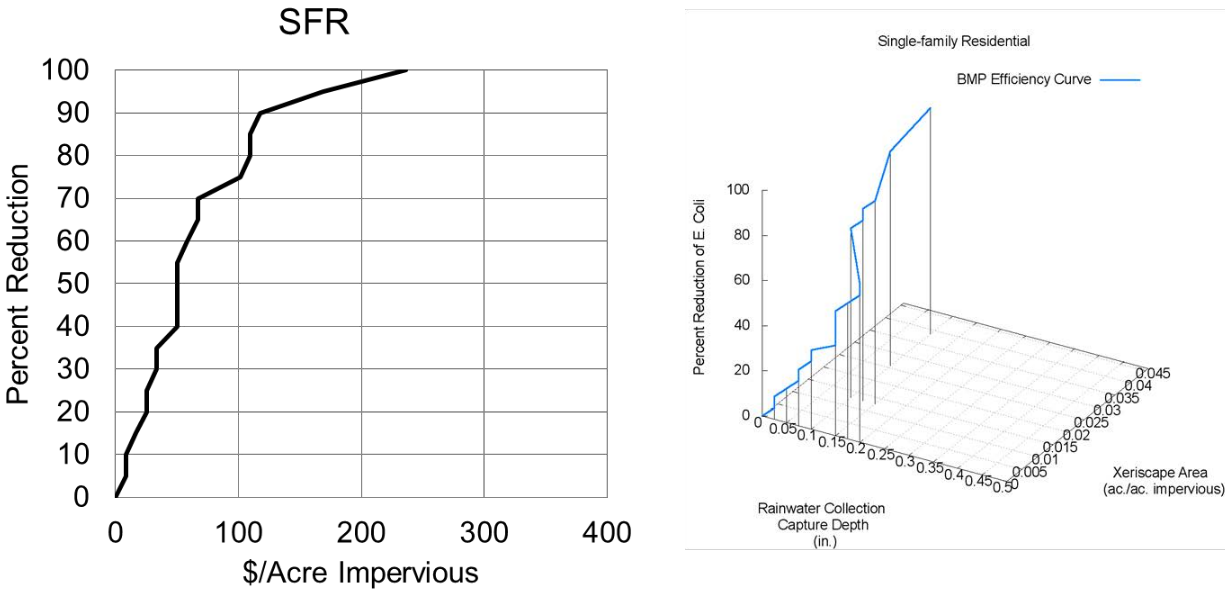


Figure 40. Single-family residential land use—rainwater collection system and xeriscape performance and cost-effectiveness curve.

BMP performance variations among different land uses are dependent upon hydrology and pollutant concentration. Table 21 lists the CN and *E. coli* EMC of each land use category, and summarizes the maximum BMP performances, unit impervious drainage area cost, and the BMP configurations achieving maximum *E. coli* load reduction for the 0.78-inch storm. It was observed that parking lot is the land use category with the highest CN and *E. coli* EMC, and it has the highest unit impervious drainage area annual treatment cost ($310 per acre impervious drainage area); while public/institutional has the lowest CN and *E. coli* EMC and, consequently, the lowest unit area annual treatment cost at $103 per acre impervious drainage area.

Table 21. Maximum distributed BMP performances and composition by land use categories

Land use category	CN	*E. coli* EMC (#/100 mL)	Max. *E. coli* load reduction (%)	BMP configurations	
				Rainwater storage (in.)	Xeriscape (ac./ac. Imp DA)
Commercial (including retail and service)	94	1,200	99%	0.18	0.040
Industrial	91	450	100%	0.10	0.024
Multi-family Residential	90	900	100%	0.13	0.043
Parking Lot	98	1,500	96%	0.30	0.040
Public/Institutional	86	450	100%	0.06	0.016
Single-family Residential	87	600	100%	0.10	0.039

A detention basin treating the 100-acre composite area is evaluated. The detention basin is sized with the WQCV, as calculated in the previous section, and has a drain time of 40 hours. Figure 41 plots the TSS and *E. coli* load removal efficiencies for the various storm sizes. With the 0.27-inch storm, both TSS and *E. coli* have 100 percent removal because of the complete runoff volume reduction through infiltration at the site. With the 0.47-inch storm, TSS has a 74 percent removal and *E. coli* a 73 percent removal. With the 0.78-inch storm, percent removal of TSS is 43 percent and that of *E. coli* is 38 percent. These percent removal estimates are comparable with pollutant removal rates based on the Sanchez Farm monitoring data (Radian 2011), which suggested 81 percent removal of TSS, and between 60 percent (under high-flow conditions) and 73 percent (under low-flow condition) removal of *E. coli*.

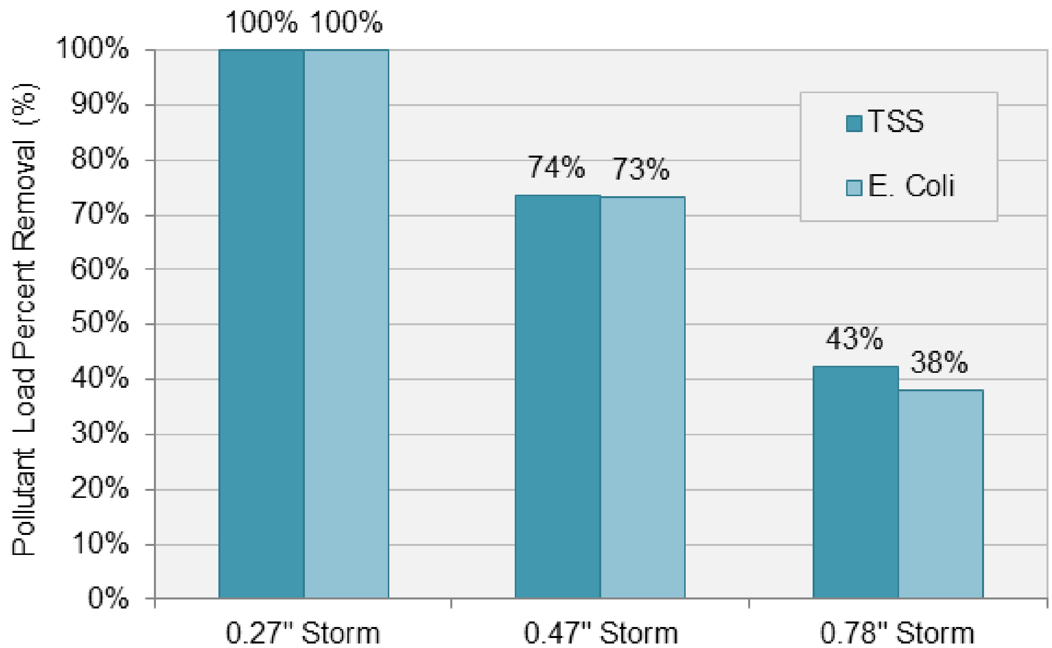


Figure 41. Detention basin pollutant removal efficiency (100-acre composite drainage area).

This section presents the BMP performance evaluation results. It provides valuable information on the maximum achievable *E. coli* load reduction by land use categories, and the optimal distributed BMP compositions at various treatment levels, and corresponding costs. The information derived on the maximum effective distributed BMP sizes are used to define the optimization search boundaries as described in the next section.

Chapter 7. BMP Optimization

This section discusses selection of a numeric management target for optimization and outlines a series of 11 scenarios which evaluate management strategies using the previously discussed structural and nonstructural BMPs. The cost-effectiveness curves from each of the 11 scenarios are discussed independently to show the progression of costs and percent reduction resulting from increased management. Different management practices may perform better at various points along the spectrum. To capture the variability of all 11 scenarios, a composite cost-effectiveness curve is developed to highlight the optimal management “frontier” along the boundary of all curves.

7.1. Optimization Target

The Middle Rio Grande *E. coli* TMDL calculates bacteria load targets as a function of flow and proposed *E. coli* water quality standards. A conversion is also applied to express bacteria loads in colony forming units per day (cfu/day) (NMED-SWQB, 2010). New Mexico regulates *E. coli* using two standards on the basis of a (1) maximum concentration for single samples of 410 cfu/100 mL, and (2) a maximum concentration of the 30-day geometric mean of 126 cfu/100 mL. These regulatory criteria were used to develop *E. coli* load targets for each of the three selected precipitation depths modeled in *SUSTAIN*. Table 22 presents load targets and the load reduction required according to *SUSTAIN* model output.

Table 22. *E. coli* Load targets by storm scenario depth for single sample and geometric mean

Rainfall (in.)	Storm event flow volume (ft^3/event)	Storm event *E. coli* load (#/event)	Geometric mean target (#/event)	Single sample target (#/event)	Geometric mean required reduction	Single sample required reduction
0.27	5,435	2.8E+08	1.9E+08	6.3E+08	31%	0%
0.47	20,581	3.9E+09	7.3E+08	2.4E+09	81%	39%
0.78	66,850	2.3E+10	2.4E+09	7.8E+09	89%	66%

On the basis of Table 22, the 0.78-inch storm represents the limiting event for meeting any percent reduction target calculated using the TMDL criteria. Management of this storm event is inclusive of managing the 0.27- and 0.47-inch storm events. Therefore, the 0.78-inch storm will be used as the critical condition for running the optimization scenarios targeting *E. coli* load reduction.

7.2. Optimization Scenarios and Results

The ultimate optimization objective is to identify the most cost effective stormwater management solutions that meet the TMDL target. The overall optimization problem formulation can be expressed as:

Objective: *Minimize* Cost (BMP options, BMP size);
Minimize E. coli load generated from 0.78 inch storm

Subject to: Nonstructural BMP scenarios;
Extent of structural BMP types & sizes

As presented in Chapter 6, both nonstructural and structural BMPs are effective means to reduce *E. coli* loading. When they are implemented simultaneously, because the nonstructural BMPs change the inflow pollutant loading to the structural BMPs, the effectiveness of structural BMPs will be different from that under the condition without nonstructural BMPs. To test the impact of the street sweeping cost values on recommended management strategies, two independent optimization scenarios were formulated and ran using (1) literature values from Southern California, and (2) local values from Albuquerque. Considering the interaction between nonstructural and structural BMPs, 12 independent optimization runs were performed for each cost scenario (24 total runs) to derive cost-effectiveness curves for various nonstructural base conditions, i.e., various combination of pet waste management and street sweeping, as documented in Section 5.1. The decision variables of the optimization runs were the sizes of structural BMPs, including rainwater collection storage, xeriscape, and regional detention basin. Nonstructural BMPs controls were applied as part of the boundary condition for each run, with their respective costs added afterwards to the resulting cost-effectiveness curves. Upper bounds of the decision variables were set at the maximum values determined on the basis of the land use based BMP performance evaluation results. Table 23 summarizes the 12 optimization run scenarios.

Table 23. Optimization run scenarios

ID	Nonstructural BMPs		Structural BMPs
	Street sweeping	Pet waste management	
0	None	None	BMP Types: Rainwater collection system Xeriscape Detention basin Maximum BMP Sizes: See Table 21 for the sizes of rainwater collection system and xeriscape. See Section 4.1 for the sizes of detention basin
1	Monthly	None	
2	Biweekly	None	
3	Weekly	None	
4	None	10%	
5	Monthly	10%	
6	Biweekly	10%	
7	Weekly	10%	
8	None	20%	
9	Monthly	20%	
10	Biweekly	20%	
11	Weekly	20%	

The cost-effectiveness curves for the 12 optimization runs are plotted in Figure 42 to Figure 48. Figure 42 shows the optimization scenarios without street sweeping. The curves in this figure are common to both cost scenarios because street sweeping is not considered. Figure 43 shows the scenarios with monthly street sweeping for literature-based costs, whereas Figure 44 uses local street sweeping costs. Figure 45 shows the scenarios with biweekly sweeping for literature-based costs, whereas Figure 46 uses local street sweeping costs. Finally, Figure 47 shows the scenarios with weekly sweeping for literature-based costs, whereas Figure 48 uses local street sweeping costs. In each figure, three scenarios with various levels of pet waste management are plotted. As described previously, there is uncertainty associated with the cost of pet waste management. The costs for implementing and enforcing the program might be offset by tax revenues or fines from violating pet owners, resulting in a negative cost in certain cases. For this analysis, pet waste management cost was not represented in the optimization analysis. The three lines in each plot show the total cost and *E. coli* load reduction generated with the 0.78-inch storm under three levels of pet waste management options.

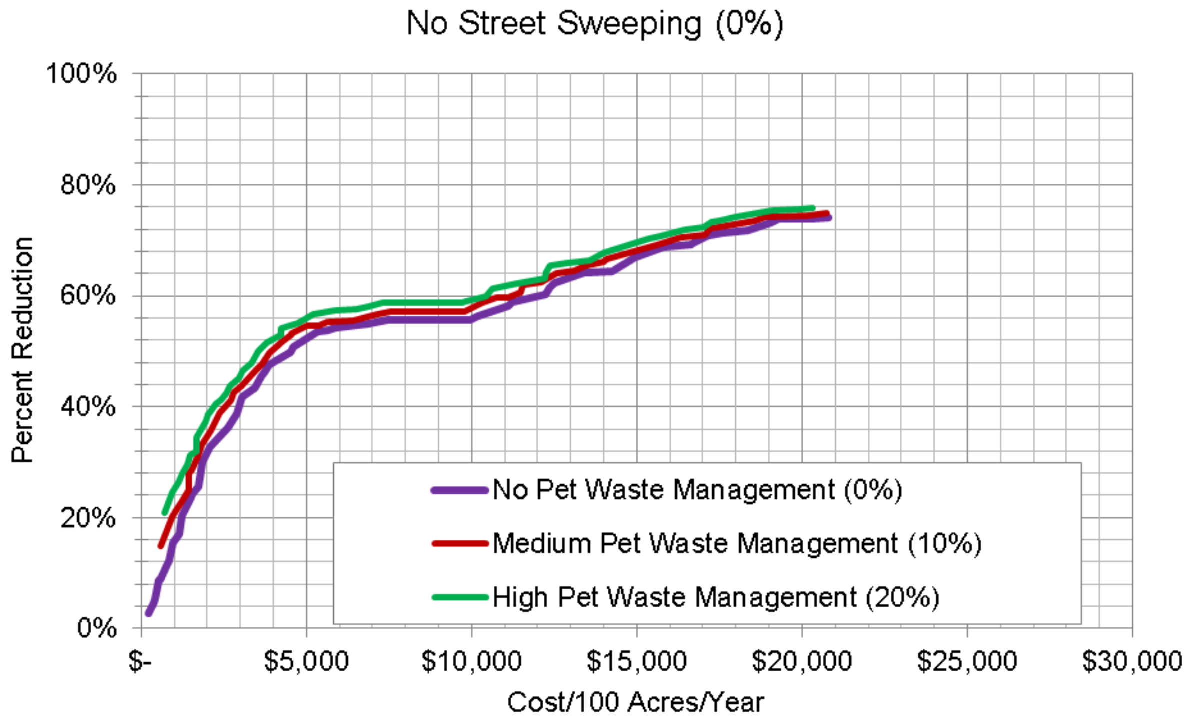


Figure 42. Cost-effectiveness curves of optimization scenarios without street sweeping.

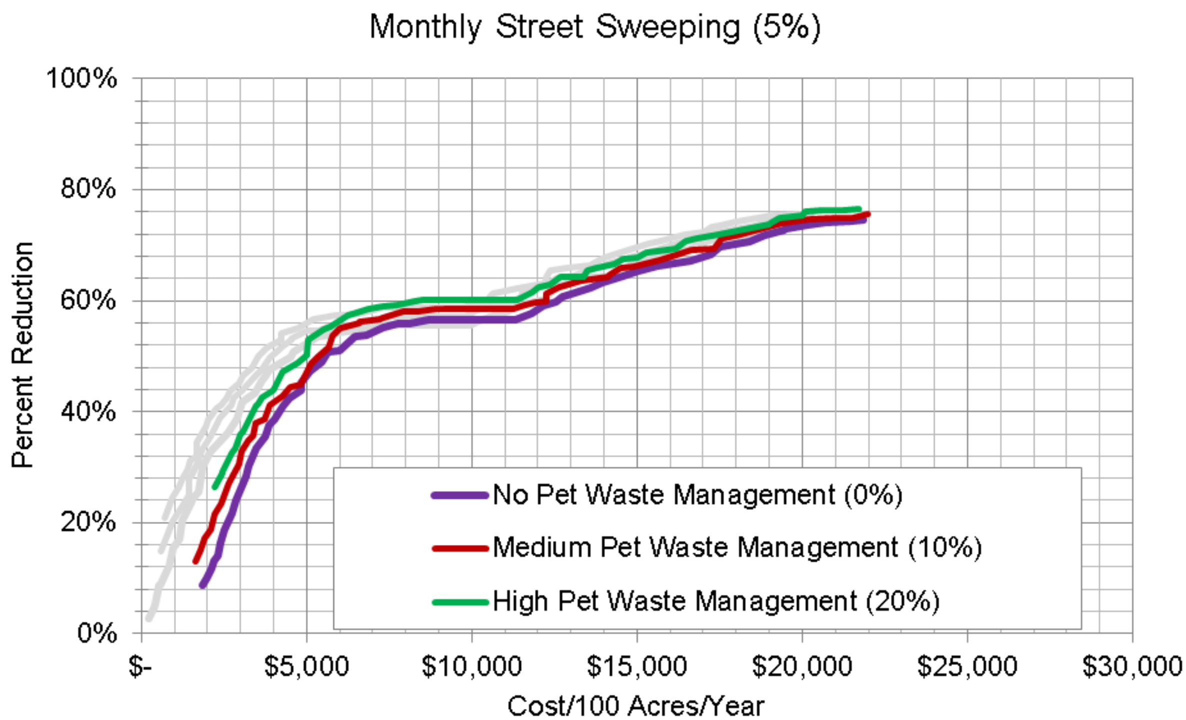


Figure 43. Literature-based cost optimization with monthly street sweeping (5% load removal).

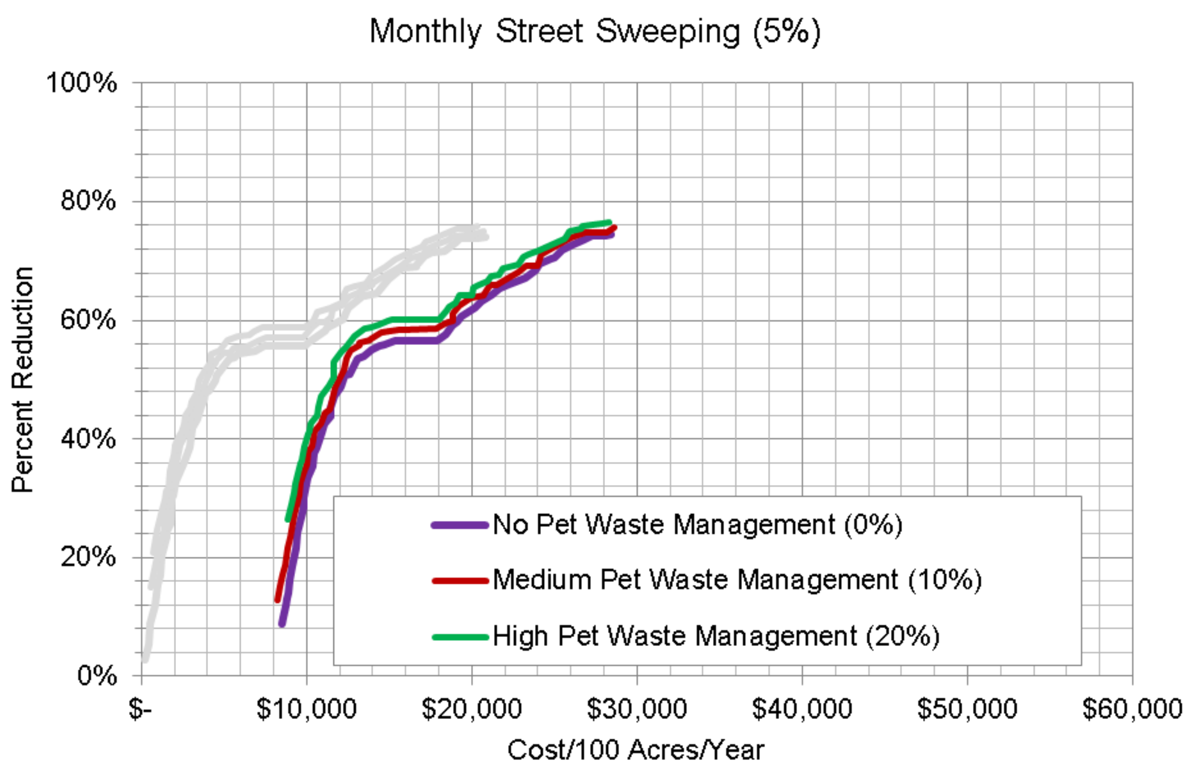


Figure 44. Local-cost based optimization with monthly street sweeping (5% load removal).

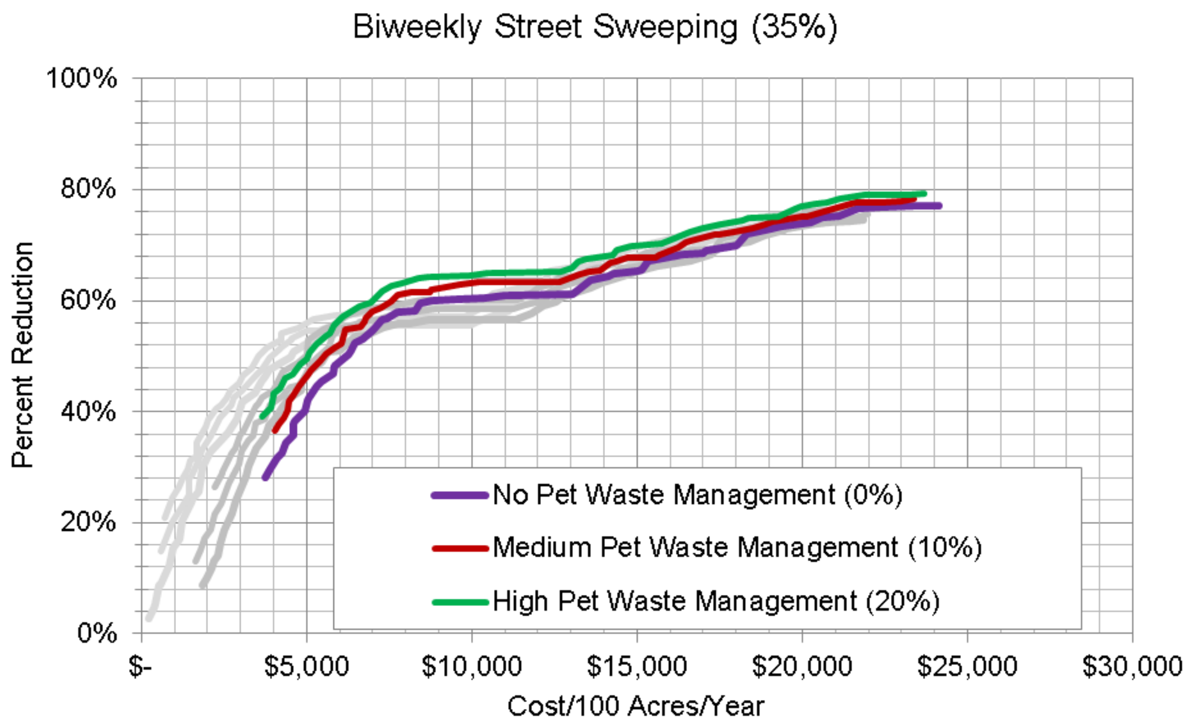


Figure 45. Literature-based cost optimization with biweekly street sweeping (35% load removal).

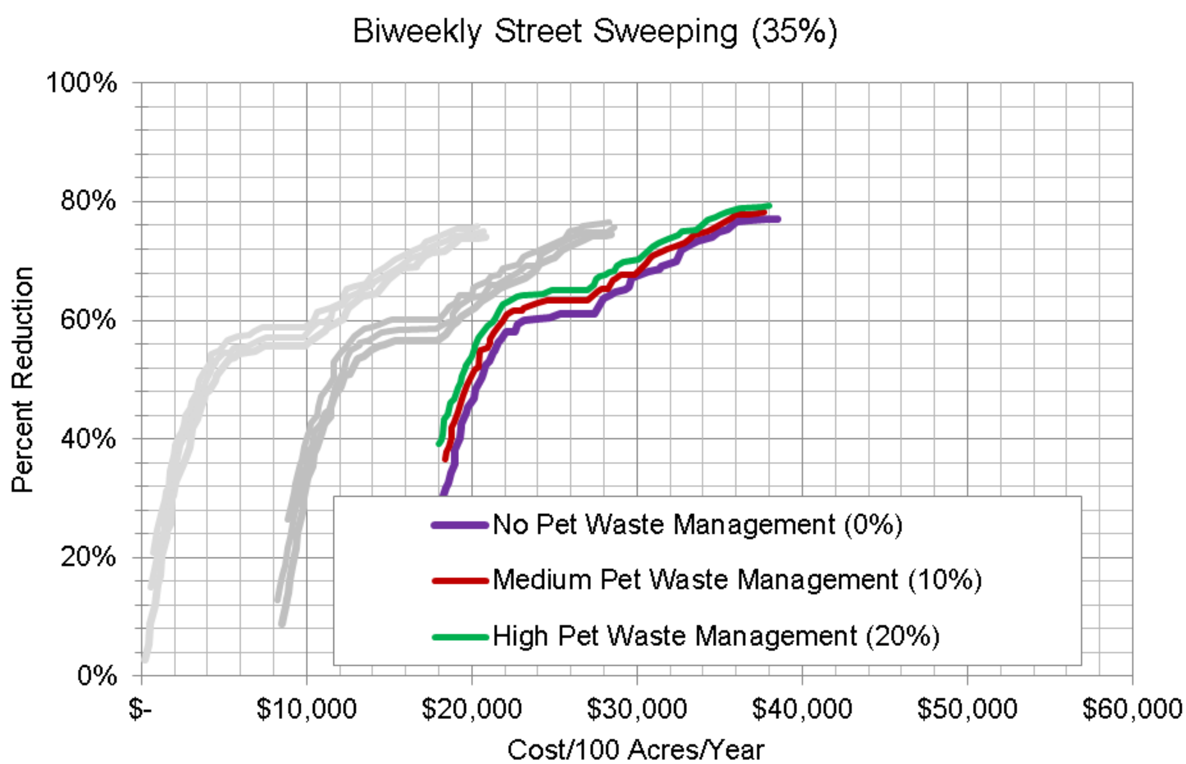


Figure 46. Local cost based optimization with biweekly street sweeping (35% load removal).

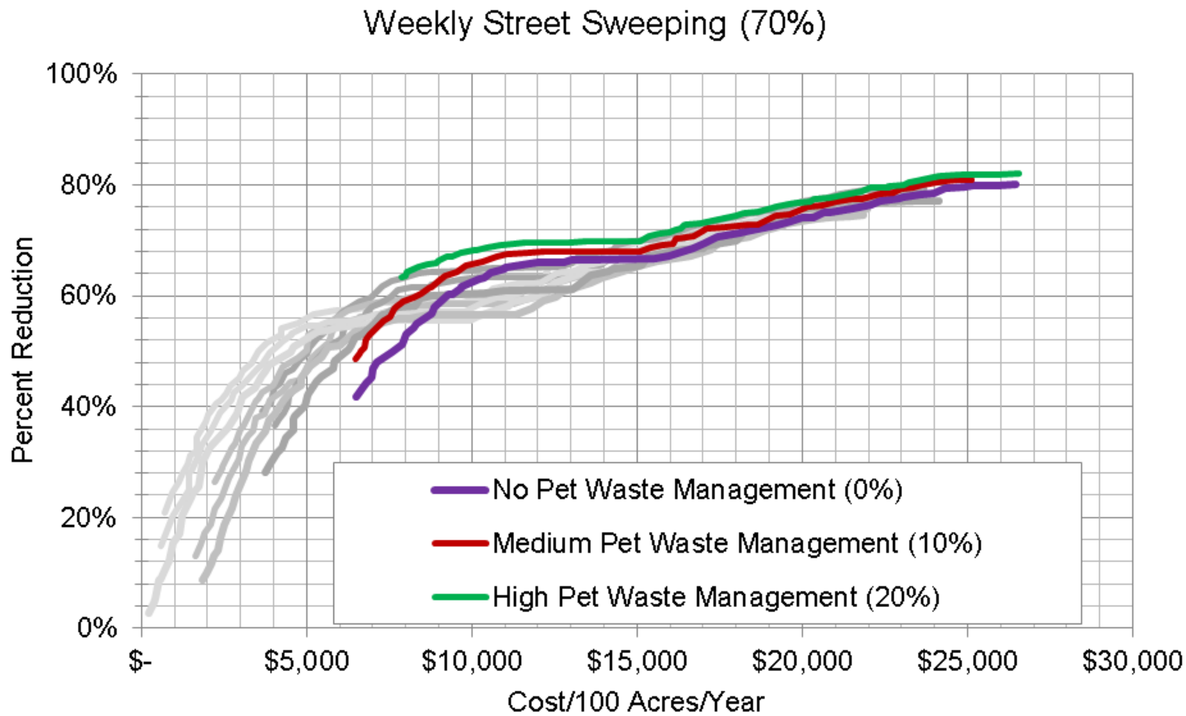


Figure 47. Literature-based cost optimization with weekly street sweeping (70% load removal).

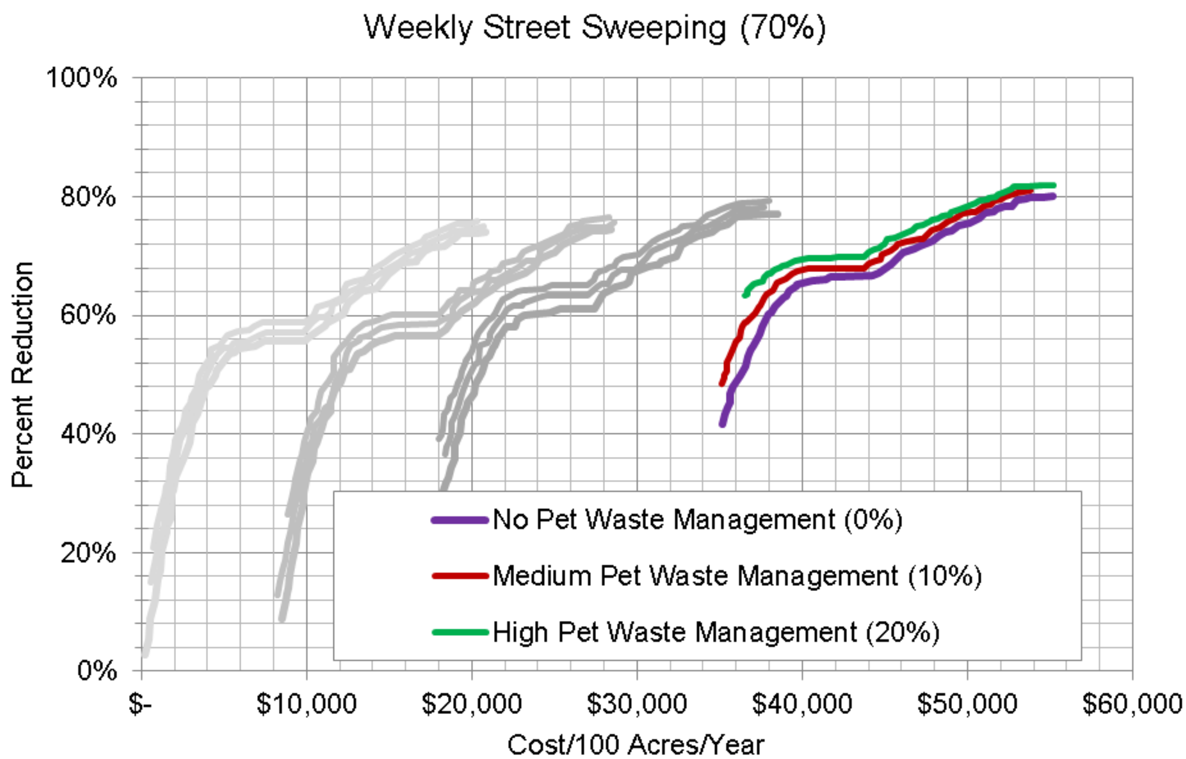


Figure 48. Literature-based cost optimization with weekly street sweeping (70% load removal).

The composite optimal cost-effectiveness curve shown in Figure 49 was developed by identifying the most cost-effective solutions from among all model runs for the various sets of cost assumptions. Figure 50 and Figure 51 plot the cost distributions for the literature and local composite curves, respectively, shown in Figure 49. The lower panel of the figure zooms into the region associated with the TMDL target and highlights the required 66 percent solutions.

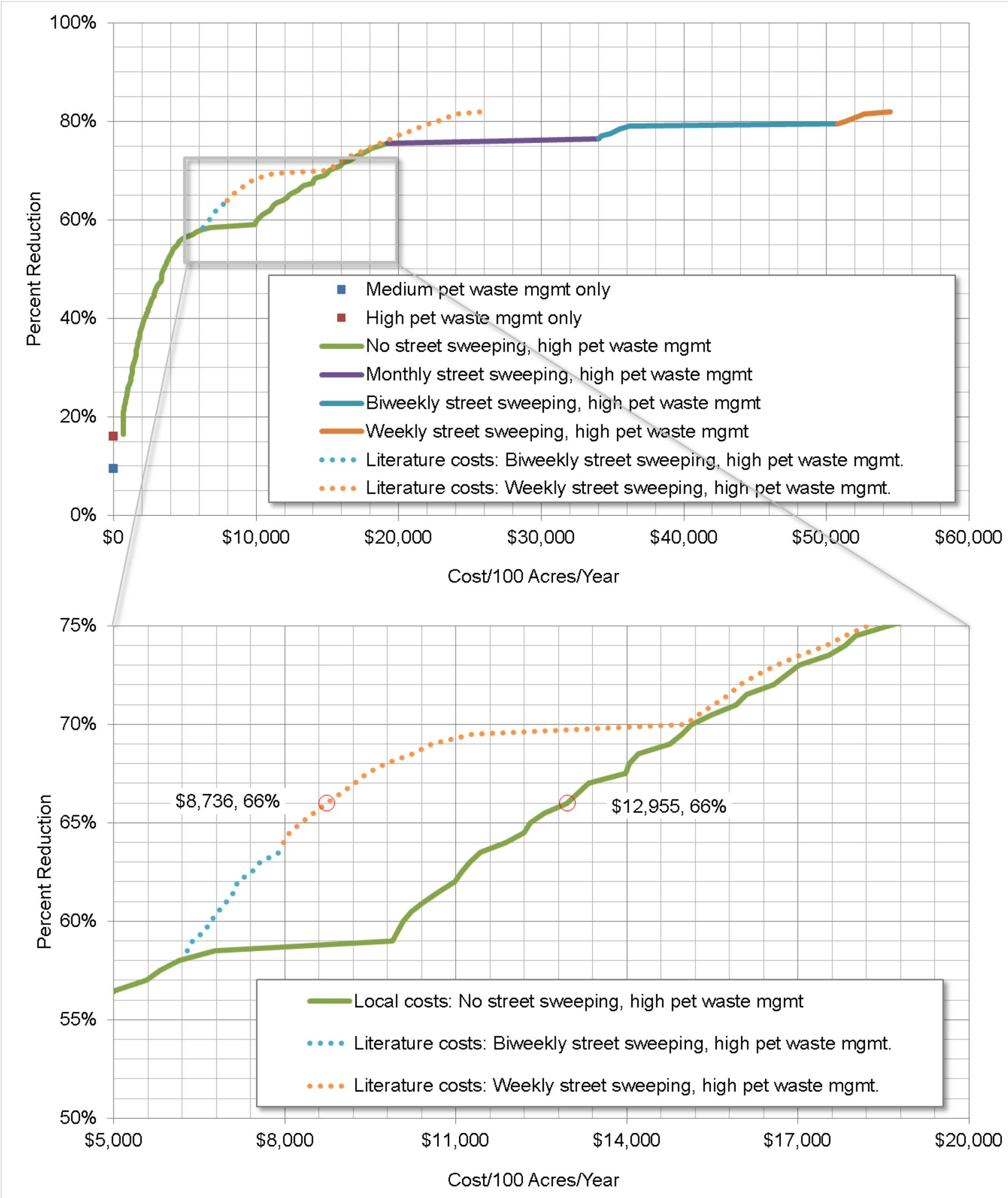


Figure 49. Composite optimal cost-effectiveness curve and selected solution meeting target.

Figure 49 illustrates the sensitivity of street sweeping costs for influencing the recommended management strategies. Note that because they have no assigned cost, medium and high pet waste management are shown as discrete points at $0. Their respective performance values reflect the net benefit of each level in the representative 100-acre watershed. Two notable inflection points are in the lower panel of Figure 49—one at 59 percent along the green curve, and another at 70 percent along the orange dotted curve. A look at the BMP cost distributions for both curves (Figure 50 and Figure 51) reveals the preferred selection order for the various BMPs.

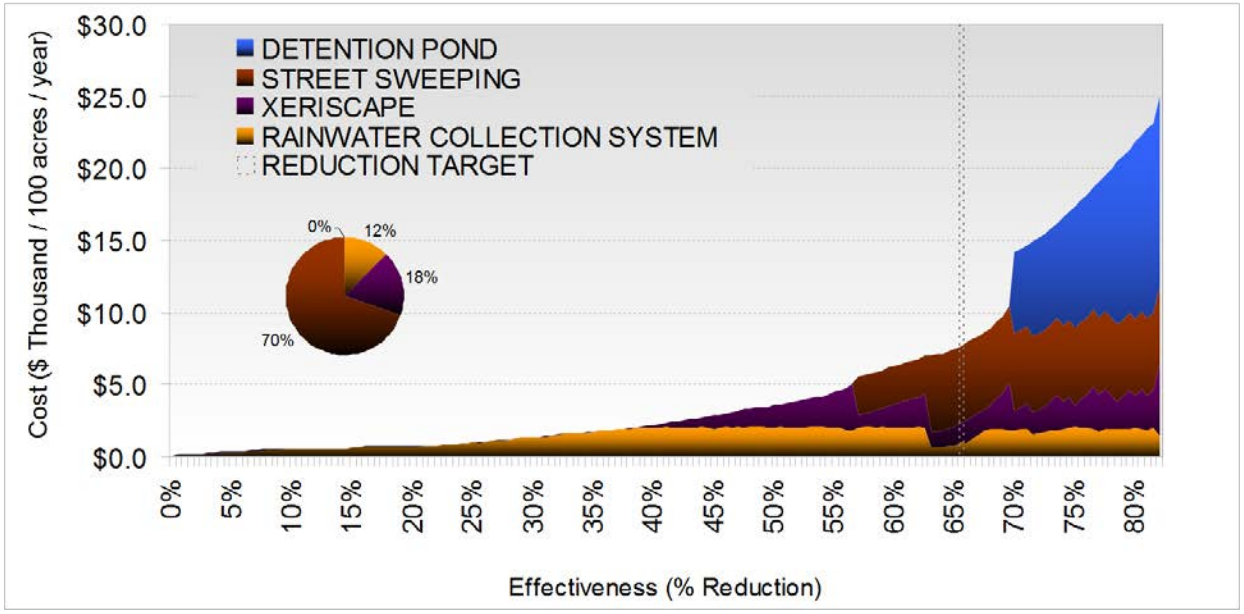


Figure 50. Literature-based street sweeping cost data: BMP cost composition of the optimal solutions.

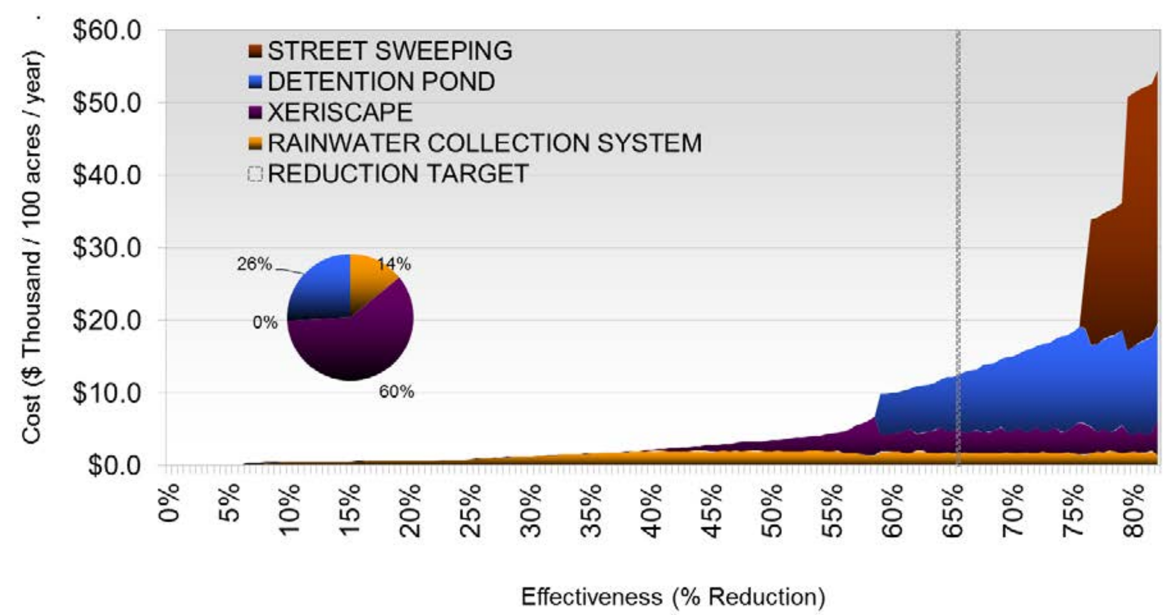


Figure 51. Local street sweeping cost data: BMP cost composition of the optimal solutions.

Note that at the lower reduction range from 0 to approximately 57 percent, structural practices like rainwater collection and xeriscaping are more cost-effective for controlling runoff and bacteria mobilization than street sweeping. At the reduction range between 57 to about 63 percent (on the basis of literature street sweeping costs), biweekly sweeping is optimal, and weekly sweeping becomes optimal when the reduction requirement exceeds 63 percent. Figure 51 shows that 59 percent is the point where using xeriscaping comes into play. Without street sweeping, xeriscaping is able to yield a higher percent removal because runoff carries more pollutants. When the detention pond enters the picture, there is an initial mobilization cost with the benefit it provides, which when optimized, reduces the overall need for xeriscaping. Beyond that point, the required size of the detention pond gradually increases. From 57 percent reduction upward in the lower cost scenario, those cost assumptions begin to have a more notable influence on the results; biweekly street sweeping is chosen next, followed by weekly street sweeping at 63 percent and beyond. Similar to what occurred in Figure 51, Figure 50 also shows a brief dip in the use of rainwater collection systems and xeriscaping because of the added benefit of pollutant removal that more frequent street sweeping provides; however, as the reduction requirement increases, using those distributed BMPs recovers. Under the literature-based street sweeping cost scenario, the detention basin is never selected until the reduction requirement reaches 71 percent, suggesting that regional detention basin is not preferred over those other practices until a high load reduction is required.

Another very interesting finding between these comparisons is the order in which the detention pond is preferred as a function of street sweeping cost. In Figure 50, which assumes the lower literature-based street sweeping costs, the detention pond is chosen after all other options have been exhausted. On the other hand, Figure 51 shows that when street sweeping is more expensive, the detention pond is chosen before street sweeping. It is interesting to note that monthly street sweeping was never selected among the optimal solutions under the literature-based costs scenario, implying that waiting such a long time between street sweeping events is not cost-effective for managing bacteria load in runoff. The use of xeriscaping also moves from third second place to third as street sweeping cost increases, suggesting that when biweekly street sweeping is cheaper, it initially reduces the demand for xeriscaping as a means of controlling bacteria loading in runoff. Also, when street sweeping is more expensive, xeriscaping supplements detention ponds and on-site rainwater collection as means for controlling bacteria loads associated with runoff.

The TMDL target established in Section 7.1 can be translated into a 66 percent *E. coli* load reduction during the 0.78-inch storm. As indicated in Figure 49, Figure 50, and Figure 51, the optimal solutions that achieve a 66 percent *E. coli* load reduction have total costs ranging between $8,736 and $12,955 per year for the 100-acre representative study area, depending on the assumed costs for street sweeping. For the literature-based scenario, the solution selected high pet waste management, rainwater collection systems, weekly street sweeping, and xeriscaping. Assuming literature-based street sweeping values, Table 24 lists component costs of the nonstructural and structural BMPs, and the corresponding load reduction of both *E. coli* and TSS. The table shows that the nonstructural BMP components (pet waste management and street sweeping) cost $6,197 per year and achieve 51.7 percent *E. coli* and 34.5 percent TSS loading reduction, but the structural BMP components (rainwater collection and xeriscaping) cost $2,539 per year and generate an additional 14.3 percent load reduction of *E. coli* and 18.0 percent load reduction of TSS. With literature-based street sweeping costs, on a unit cost per percent *E. coli* load reduction, nonstructural BMP (about $120/percent reduction) is more cost-effective than structural BMPs ($177.5/percent reduction).

Table 24. Optimal literature-based costs solution achieving 66% *E. coli* load reduction (0.78-inch storm)

Solution component	BMPs		
	High pet waste mgmt., weekly street sweeping	**Rainwater collection and xeriscape**	**Total**
Cost ($/year per 100 ac.)	$6,197	$2,539	$8,736
E. coli load reduction (0.78-inch storm)	51.7%	14.3%	66.0%
TSS load reduction (0.78-inch storm)	34.5%	18.0%	52.6%

On the other hand, Table 25 lists component costs of the nonstructural, distributed, and centralized BMPs, and the corresponding load reduction of both *E. coli* and TSS assuming local street sweeping costs. The table shows that the nonstructural BMP component (high pet waste management) cost $0 per year and achieves 12 percent *E. coli* (TSS loading reduction is not applicable), while distributed BMP components (rainwater collection and xeriscaping) cost $4,477 per year and generate an additional 43.5 percent load reduction of *E. coli* and 50.0 percent load reduction of TSS. The centralized BMP (wet pond) cost is $8,478 per year and generates an additional 22.6 percent reduction of *E. coli* and 13.6 percent load reduction of TSS. Using local street sweeping costs, the unit cost per percent *E. coli* load reduction for distributed BMPs ($103/percent reduction) is more cost-effective than the wet pond ($375/percent reduction).

Table 25. Optimal local costs solution achieving 66% *E. coli* load reduction (0.78-inch storm)

Solution component	BMPs			
	High pet waste management and no street sweeping	**Rainwater collection and xeriscape**	**Extended detention pond**	**Total**
Cost ($/year per 100 ac.)	--	$4,477	$8,478	$12,955
E. coli load reduction (0.78-inch storm)	12.0%	43.5%	22.6%	66.1%
TSS load reduction (0.78-inch storm)	--	50.0%	13.6%	63.6%

Table 26 shows structural BMP composition for the selected optimal solution with the literature-based cost solution. Table 27 shows similar information for the local cost solution. They suggests that parking lots should have the highest treatment level (0.3-inch collection depth, and 0.03-acre xeriscape per acre impervious drainage area), followed by commercial and multi-family residential (0.2-inch collection depth, and 0.03-acre xeriscape per acre impervious drainage area). The literature cost solution then adds industrial area (0.2-inch collection depth, and 0.01-acre xeriscape per acre impervious drainage area), and public/institutional area (0.1-inch rainwater storage depth), but does not use treatment for single-family residential.

Table 26. Distributed BMP composition of the optimal solution achieving 66 percent *E. coli* load reduction for the 0.78-inch storm

Land use category	BMP configurations	
	Rainwater storage (in.)	**Xeriscape (ac./ac. impervious drainage area)**
Commercial (including retail and service)	0.2	0.03
Industrial	0.2	0.01
Multi-family Residential	0.2	0.03
Parking Lot	0.3	0.03

Land use category	BMP configurations	
	Rainwater storage (in.)	Xeriscape (ac./ac. impervious drainage area)
Public/Institutional	0.1	--
Single-family Residential	--	--

On the other hand, the local cost solution uses single-family residential treatments (0.2-inch rainwater storage depth) and reduces industrial treatment. This solution also uses 50 percent of the maximum possible design size for the wet pond. For both of these solutions, the treatment prioritization was dependent on the runoff and pollutant loading characteristics of the various land use categories, as previously discussed in Section 5.1.

Table 27. BMP composition of the optimal local cost solution achieving 66 percent *E. coli* load reduction for the 0.78 inch storm

Land use category	BMP configurations		
	Rainwater storage (in.)	Xeriscape (ac./ac. impervious drainage area)	Extended detention pond (% of WQCV)
Commercial (including retail and service)	0.2	0.03	--
Industrial	0.1	--	--
Multi-family Residential	0.2	0.03	--
Parking Lot	0.3	0.03	--
Public/Institutional	0.1	--	--
Single-family Residential	0.2	--	--
100-acre drainage area	n/a	n/a	50%

Chapter 8. Summary and Conclusions

This case study presented an approach to identify cost-effective stormwater management strategies with the objective of reducing *E. coli* loading based on a target consistent with the Middle Rio Grande *E. coli* TMDL. The report documents the various steps in developing a *SUSTAIN* application, including establishing baseline hydrology and water quality representation, identifying the critical condition for management, formulating management objectives, and synthesizing model outputs with a focus on the *E. coli* TMDL and pending WBP. Through this study, a framework was established that can be applied to support the development of implementation strategies for meeting water quality targets associated with both the *E. coli* TMDL and pending WBP. The study concludes by reflecting on key insights gained in relation to the original study objectives, which are as follows:

- Develop a boundary condition using a simple hydrology method (such as TR-20/55 or Rational Method), in conjunction with event-mean concentrations
- Evaluate the trade-offs in cost and management performance of both structural and nonstructural BMPs during the optimization process
- Estimate water quality performance of proposed management practices based on critical conditions identified in the Middle Rio Grande *E. coli* TMDL to support a pilot MS4 watershed-based permit under development by EPA Region 6.

Before dissecting these three objectives, it is important to reassess the role of models in general and *SUSTAIN* specifically in the planning process. The optimization approach used in *SUSTAIN* offers a unique evaluation platform for evaluating complex, spatially heterogeneous urban system and associated cost benefit implications of management decisions. In a classic text on numeric methods and modeling, Hamming suggests that “the purpose of computing is insight, not numbers” (Hamming 1973). The utility of this approach lies not in the ability to compute and a single number but to uncover patterns and trends that provide important insights that would not have otherwise been gained. *SUSTAIN* is a comprehensive decision support system meant to enhance the stormwater management planning and implementation process by allowing stakeholders to evaluate and visualize the tradeoffs between management and cost. As the planning process moves forward and implementation begins, the framework developed through this case study offers a methodology that can be used for developing future modeling studies. The following sections describe lessons learned for each case study objective.

8.1. Baseline Representation

While previous *SUSTAIN* case studies focused on evaluating management practices intended for specific locations (sewersheds) in support of narrowly focused management objectives, this study in Albuquerque focused on broader management strategies at a bigger spatial scale. Even though no existing continuous simulation model was available as a basis for developing input boundary conditions, it is unlikely that such a model would have offered *plug and play* integration into the *SUSTAIN* system as this study was spatially broader than the scope of many detailed models. Moreover, the arid climate setting for this analysis (about 9.5 inches of rainfall per year) explains why continuous simulation models are not widely applied or available. These challenges presented an opportunity to demonstrate alternative approaches to model development. The study began by first identifying locally acceptable methods for representing key spatial and temporal characteristics of the system, specifically as follows:

- Temporal representation of boundary conditions
    - Selection of design storms

- Development of baseline runoff hydrographs
- Development of baseline water quality load time series

- Spatial representation of the study area

Considering the arid climate and frequency of rainfall events, this study explored an alternative approach for developing the baseline rainfall/runoff response. Three design storms were selected and linked to instream conditions using the FDC zones established during *E. coli* TMDL development. A simple hydrology method, TR-55, in conjunction with event-mean concentrations, was used to develop the boundary conditions for each HRU. The method TR-55 approach offered a flexible alternative to a true continuous simulation boundary condition that was easy to configure and integrated seamlessly with *SUSTAIN* via external ASCII time series files. As TR-55 is probably the most widely used representation of hydrology, its use in a *SUSTAIN* application creates an opportunity for expansion of the software user community.

Although the Rio Grande watershed drainage area encompasses approximately 14,000 square miles at the pour point where the river reaches Albuquerque, New Mexico; the scope of this case study was limited strictly to stormwater contributions originating from local urban areas in Albuquerque and Bernalillo County. While this case study also considered the proposed MS4 watershed-based permit area, the entire extent of this boundary is beyond the practical scale for a *SUSTAIN* model application. The watershed-based permit area spans 842.5 square miles (approximately 540,000 acres) and encompasses areas outside the Bernalillo County land use spatial data set used to develop the *SUSTAIN* HRUs and baseline condition. As with any numerical construct, networks modeled in *SUSTAIN* are simplifications of reality.

In lieu of modeling the entire MS4 permit area, a representative watershed model was constructed for this analysis that (1) represents the urban land use distribution typically found in the MS4 permit area, and (2) satisfies the requirements of model spatial scale for use in *SUSTAIN*. This study modeled a representative 100-acre area that had the same relative land use distribution as the entire MS4 permit area. Building the *SUSTAIN* analysis on the 100-acre representative site yields model results without the overhead of simulating the full spatial extent of the MS4 permit area.

8.2. Evaluation of Structural and Nonstructural BMPs

Stormwater BMPs for the arid and semi-arid region are an important tool for preserving and improving the water quality of the region's precious water resources, and those BMPs should be designed using the unique climate characteristics to meet the special needs (water conservation, reuse, and sustainable land use management) of the region. Several references suggest that the most effective BMPs for the arid Southwest are those that focus on stormwater conservation and water reuse, for example rainwater harvesting, local groundwater infiltration when feasible, and minimizing evapotranspiration losses. In this study, rainwater harvesting and xeriscape were selected as site-scale practices because (1) they conserve water, and (2) they contribute to runoff source control. In addition, regional detention basins were also modeled because they not only provide water quality management (sediment settling), but also flood control. In addition to those structural practices two nonstructural practices, street sweeping and pet waste management, were modeled.

Before the optimization analysis, each individual BMP was evaluated for its effectiveness in reducing pollutant loading. The evaluation was based on the largest design storm, which represented the limiting boundary condition. BMP performance evaluation results revealed valuable information on the maximum achievable *E. coli* load reduction by land use category and the optimal distributed BMP composition and cost at various treatment levels. The maximum distributed BMP sizes associated with the largest design storm were used to define the upper bounds for optimization. On the basis of the assumptions outlined in this study, the following insights were gained with respect to the cost-effectiveness of management practices:

- The incentive-based rebate programs designed to encourage the use of xeriscape and rainwater harvesting features were the first to be maximized during optimization because they represented the most cost-effective component for achieving the management target. Opportunity for those types of features focused primarily on residential land uses that shared the burden of capital and O&M costs with the homeowners (through the rebate incentive program) rather than entirely on the public entity. However, this introduces some added uncertainty on BMP performance in cases where homeowners do not maintain the practices at designed conditions.
- Nonstructural BMPs are effective and economical measures for reducing nonpoint source pollution. Because pet waste management had no assigned cost (except for possible public education costs), it was maximized in every optimized solution—this type of source control directly addresses the *E. coli* pollutant problem. When the lower literature costs were used for street sweeping, it was selected early in the trajectory of near-optimal solutions; however, when the higher local costs were used, it was not selected as part of the required treatment level. Street sweeping cost assumptions also affected the order in which structural practices were selected. When street sweeping costs are lower, the practice reduces the overall need for structural practices by controlling loading at the source. The results also suggested that more infrequent sweeping (i.e., monthly) was not cost-effective compared to what can be achieved with distributed practices. When street sweeping costs are higher, centralized wet ponds become an attractive and necessary supplement to rainwater conservation practices. Street sweeping was considered only after all structural practices were exhausted. Those outcomes should be interpreted with the following caveat:
    - The large range of street sweeping costs (literature versus local sources) suggests cost estimates might not be directly comparable. For example, if the higher cost estimates include equipment purchase, storage, and maintenance, a more cost-effective solution might be to contract the street sweeping work to a private entity that is able to reduce overhead costs through economies of scale. For instance, a street sweeping contractor will share overhead costs among its clients through work scheduling, because their equipment will not be sitting idle during off weeks.
- For the scenarios where street sweeping costs were low, regional detention basins were not selected for achieving a management target of a 66 percent *E. coli* reduction. That outcome should be interpreted with the following caveat:
    - The study did not consider flood control as a management objective. The objective function and constraints that guide the optimization process were focused solely on minimizing cost to achieve reductions in *E. coli* load during a 0.78-inch design storm. Flood control is a critical component of stormwater management in Albuquerque and must be properly evaluated against an independent set of management objectives and constraints. The results of this study were not intended to evaluate BMPs against flood control criteria.
- The most cost-effective solution is dependent on the selected management (load reduction) target. As shown in Figure 49, the composition of any best solution (cost and practices) is dependent on the management target selected on the y-axis. In this case study, a load percent reduction target of 66 percent was calculated using the runoff volume of the limiting design storm and *E. coli* concentration specified in the TMDL. Selecting a different load reduction target would result in a different mixture of BMPs.

It should be emphasized that the conclusions of this study are highly sensitive to the cost assumed for the various management practices and programs. BMP costs are critical to the optimization goals of meeting management objectives while minimizing the total solution cost. The cost of the site-scale, distributed BMPs were determined using information about the local rebate program(s) that promote xeriscape and rainwater harvesting features. Regional detention basin costs in this study were based on capital and maintenance costs estimated by Bernalillo County. This study also does not explicitly consider costs associated with a comprehensive pet waste management initiative. It is reasonable to assume that in practice, this type of program would incur some costs associated with administration, public outreach and education, and production costs associated with literature, signage, or other outreach materials. Some of those costs might be offset by the institution and enforcement of fines collected from pet waste violators.

Although it appears that the rebate program cost is significantly less than that of the capital costs, rebates were considered a reasonable way to reflect the economic value of rainwater harvesting and water conservation. Implementation of those distributed BMPs is inherently more complex than that of centralized practices and subject to a higher degree of uncertainty because these practices are generally distributed throughout a catchment area. The costs of O&M, while more focused and predictable for centralized practices, could become more burdensome and unpredictable when BMPs are scattered throughout a watershed.

8.3. Applicability to Watershed Based MS4 Permit

The Middle Rio Grande watershed, and specifically Albuquerque, was selected for this case study because of the recent *E. coli* TMDL and ongoing development of an MS4 WBP. According to EPA Region 6, this permit will identify a number of implementation options for regulated MS4 operators. The *SUSTAIN* application framework established in this study serves as a quantitative tool to evaluate and select management practices for fulfillment of the WBP. Specifically, the findings related to (1) the cost-effectiveness of specific BMPs, (2) conditions under which BMPs are and are not effective, and (3) tradeoffs between structural and nonstructural BMPs provide meaningful guidance to stakeholders (both implementers and regulators) for selecting cost-effective measures.

While it was not practically feasible to model the full permit area or contributing TMDL boundaries in detail, relevance was maintained by using a locally representative land use distribution scaled to a manageable size (approximately 100 acres) for use as a single subwatershed in *SUSTAIN*. The configuration of this scaled-down model accounted for the spatial distribution and relative magnitude of runoff and pollutant loadings from individual land uses in the Albuquerque metropolitan area. Nevertheless, specific implementation strategies for compliance under the MS4 permit will need to be further tailored to conditions and constraints at specific locations. It is recognized that any location in a watershed will have unique characteristics that will influence what can and cannot be done there. For this reason, no model can replace the need for on-the-ground engineering and planning. Nevertheless, given the range of conditions and constraints reflected in this modeling study, it is likely that a cost-effective solution for achieving a 66 percent *E. coli* reduction would cost between $8,736 and $12,955 per 100 acres per year (assuming a 20-year BMP life cycle). These outcomes offer a scalable benchmark on which to compare future monitoring, modeling, and implementation outcomes for proposed management strategies in the Albuquerque metropolitan region.

Chapter 9. References

ABCWUA (Albuquerque Bernalillo County Water Utility Authority). 2012. Xeriscape and Rainwater Harvesting Landscape Rebate Program. <http://www.abcwua.org/content/view/132/222/>. Accessed May, 2012

Ahn, J.H., S.B. Grant, C.Q. Surbeck, P.M. DiGiacomo, N.P Nezlin, and S. Jiang. 2005. Coastal water quality impact of stormwater runoff from an urban watershed in Southern California. *Environmental Science & Technology* 39(16):5940-5953

Albuquerque GIS (Albuquerque geographic information systems). 2012. Data downloads. <http://www.cabq.gov/gis/download.html>. Accessed January 14, 2012.

City of Costa Mesa. 2009. *Evaluation of Current and Proposed Street Sweeping Service Levels*. City Council Study Session Agenda Report. Prepared by Public Services Department – Maintenance Services Division for City of Costa Mesa, California. October 13, 2009.

Gautam, M., K. Acharya., and M. Stone. 2010. Best management practices for stormwater management in the Desert Southwest. *Journal of Contemporary Water Research & Education* 146:39–49.

Glass, S. 2012, January 6. Email from Steve Glass, Bernalillo County, to Ryan Murphy, Tetra Tech, Inc., regarding Bernalillo County water quality monitoring data.

Guo, J.C.Y., and B. Urbonas. 1996. Maximized Detention Volume Determined by Runoff Capture Ratio, *Journal of Water Resource Planning and Management* 122(1):33. doi:10.1061/(ASCE)0733-9496(1996)122:1(33)

Hamming, R.W. 1973. *Numerical Methods for Scientists and Engineers*. Dover Publications, Inc: New York, NY.

LaBadie, K.T. 2010. *Identifying Barriers to LID and GI in the Albuquerque Area*. <http://docs.google.com/fileview?id=0B8IAgdT8Da3tZDE5NDQ4NDUtN2M5My00ZTIwLTkyNGItMDgwMWVlZTUwNjY4&hl=en>. Accessed August 23, 2011.

Lin, J.P. 2004. *Review of Published Export Coefficient and Event Mean Concentration Data*. U.S. Army Corps of Engineers, Wetlands Regulatory Assistance Program, Vicksburg, MS.

MRGARWG (Middle Rio Grande-Albuquerque Reach Watershed Group). 2008. *Middle Rio Grande-Albuquerque Reach Watershed Restoration Action Strategy*. Prepared for the New Mexico Environmental Department, Santa Fe, NM.

NMED-SWQB (New Mexico Environment Department–Surface Water Quality Bureau). 2010. *Total Maximum Daily Load (TMDL) for the Middle Rio Grande Watershed*. New Mexico Environment Department, Santa Fe, NM.

NRC (National Research Council). 2008. *Urban Stormwater Management in the United States*. The National Academic Press, Washington, DC.

NRCS (Natural Resources Conservation Service). 2012. Win TR-55 Watershed Hydrology. <http://nitcnrcsbase-www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/quality/?&cid=stelprdb1042901>. Accessed April 23, 2012.

Penttila, R. 2011. Albuquerque's Move Toward a Low Impact Development Future. Presentation to the 2011 MS4 Region 6 Conference. <http://www.scieca.org/2011ms4/ms4lidpresentation-penttila.pdf>. Accessed August 23, 2011.

Pitt, R., M.A., and R.M. 2004. *The National Stormwater Quality Database (NSQD, version 1.1)*. Dept. of Civil and Envionrmental Engineering, University of Alabama. Tuscaloosa, AL

Radian (Radian Engineering, LLC). 2011. *Best Management Practices Study*. Prepared for Bernalillo County Public Works, by Radian Engineering, LLC, in association with CHM2 Hill.

Reeves, R.L., S.B. Grant, R.D. Mrse, C.M. Copil Oancea, B.F. Sanders, and A.B. Boehm. 2004. Scaling and Management of Fecal Indicator Bacteria in Runoff from a Coastal Urban Watershed in Southern California. *Environmental Science & Technology* 38(9):2637-2648

RMWMD (Ramsey-Washington Metro Watershed District). 2005. Street Sweeping – Report No. 1 State of the Practice, St. Paul, Minnesota 55109. <http://www.rwmwd.org/vertical/Sites/%7BAB493DE7-F6CB-4A58-AFE0-56D80D38CD24%7D/uploads/%7B9EE2CF53-44F6-4614-BE01-F80EE0C151E1%7D.PDF>. Accessed October 2012.

Surbeck, C.Q., S.C. Jiang, J.H. Ahn, and S.B. Grant. 2006. Flow Fingerprinting Fecal Pollution and Suspended Solids in Stormwater Runoff from an Urban Coastal Watershed. *Environmental Science & Technology* 40(14):4435-4441

USEPA (U.S. Environmental Protection Agency). 1999. *Preliminary Data Summary of Urban Storm Water Best Management Practices*. EPA-821-R-99-012. Office of Water, Washington, DC 20460. <http://water.epa.gov/scitech/wastetech/guide/stormwater/>. Accessed October 2012.

USEPA (U.S. Environmental Protection Agency). 2009. *SUSTAIN—A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality*. EPA/600/R-09/095. U.S. Environmental Protection Agency, Water Supply and Water Resources Division, National Risk Management Research Laboratory, Cincinnati, OH. <http://www.epa.gov/nrmrl/pubs/600r09095/600r09095.pdf>. Accessed August 13, 2011.

USEPA (U.S. Environmental Protection Agency). 2012. *Report on Enhanced Framework (SUSTAIN) and Field Applications to Placement of BMPs in Urban Watersheds*. EPA/600/R-11/144. U.S. Environmental Protection Agency, Water Supply and Water Resources Division, National Risk Management Research Laboratory, Cincinnati, OH.

USGS (U.S. Geological Survey). 1996. *HYSEP: A Computer Program for Streamflow Hydrograph Separation and Analysis.* Water Resources Investigation Report 96-4040. U.S. Geological Survey, Reston, VA.

Appendix: HRU Runoff Hydrographs

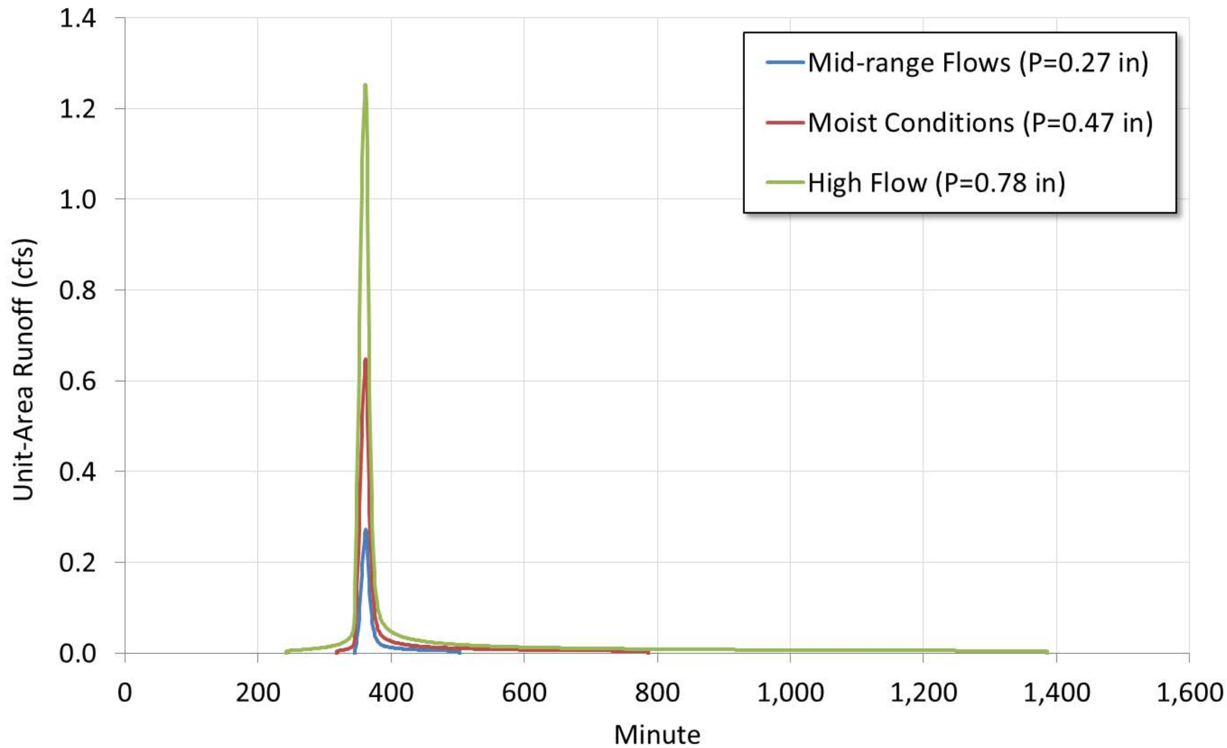


Figure 52. Unit-area (1 acre) runoff hydrographs representing the Parking Lot.

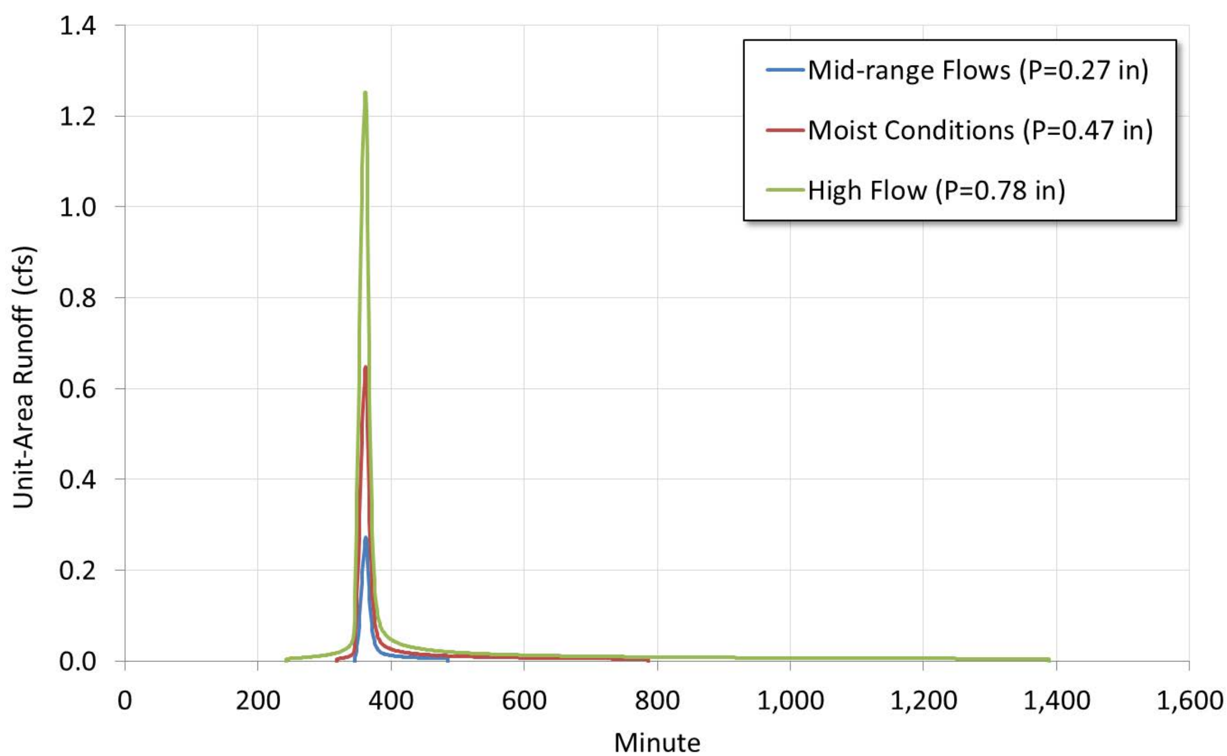


Figure 53. Unit-area (1 acre) runoff hydrographs representing the Drainage/Flood Control.

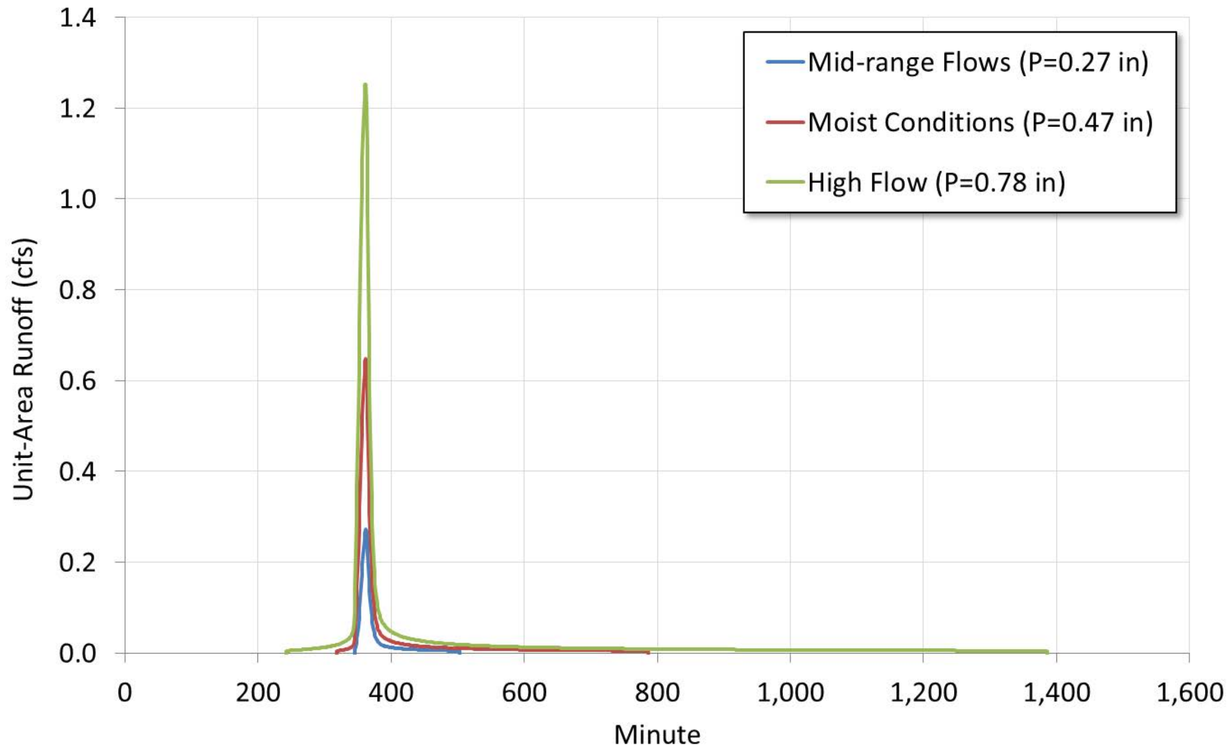


Figure 54. Unit-area (1 acre) runoff hydrographs representing the Road.

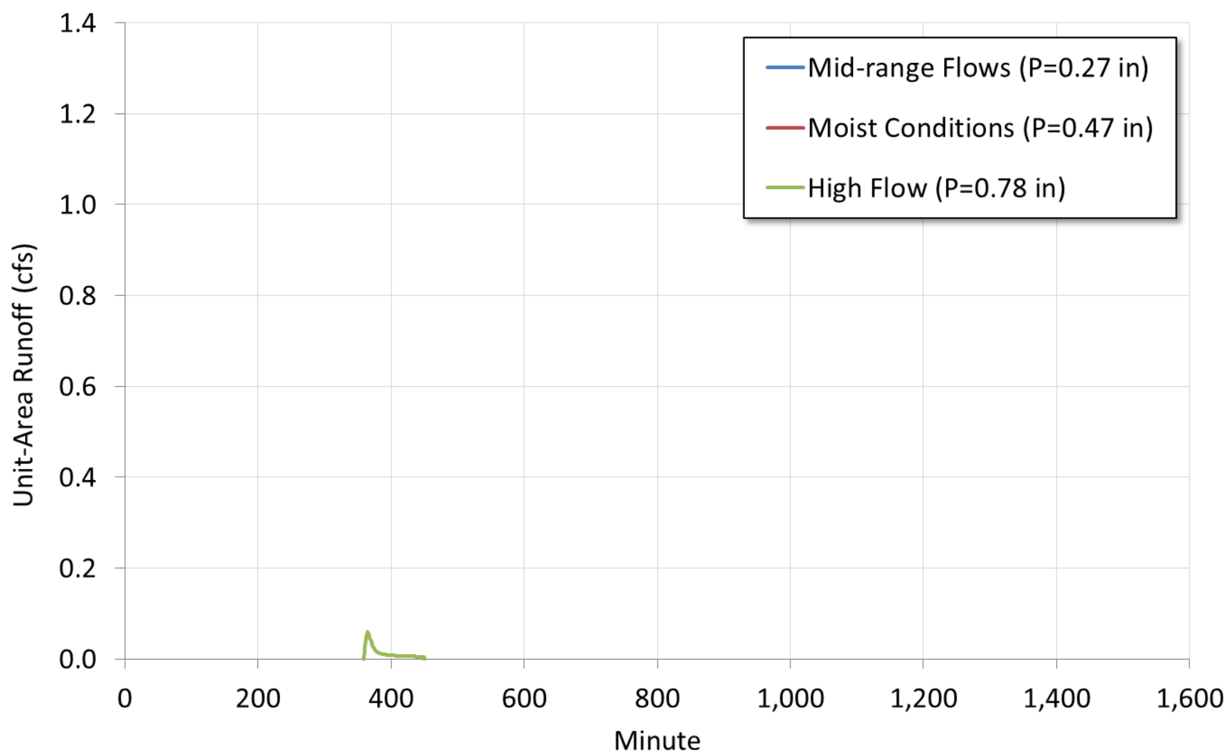


Figure 55. Unit-area (1 acre) runoff hydrographs representing the Single Family Residential.

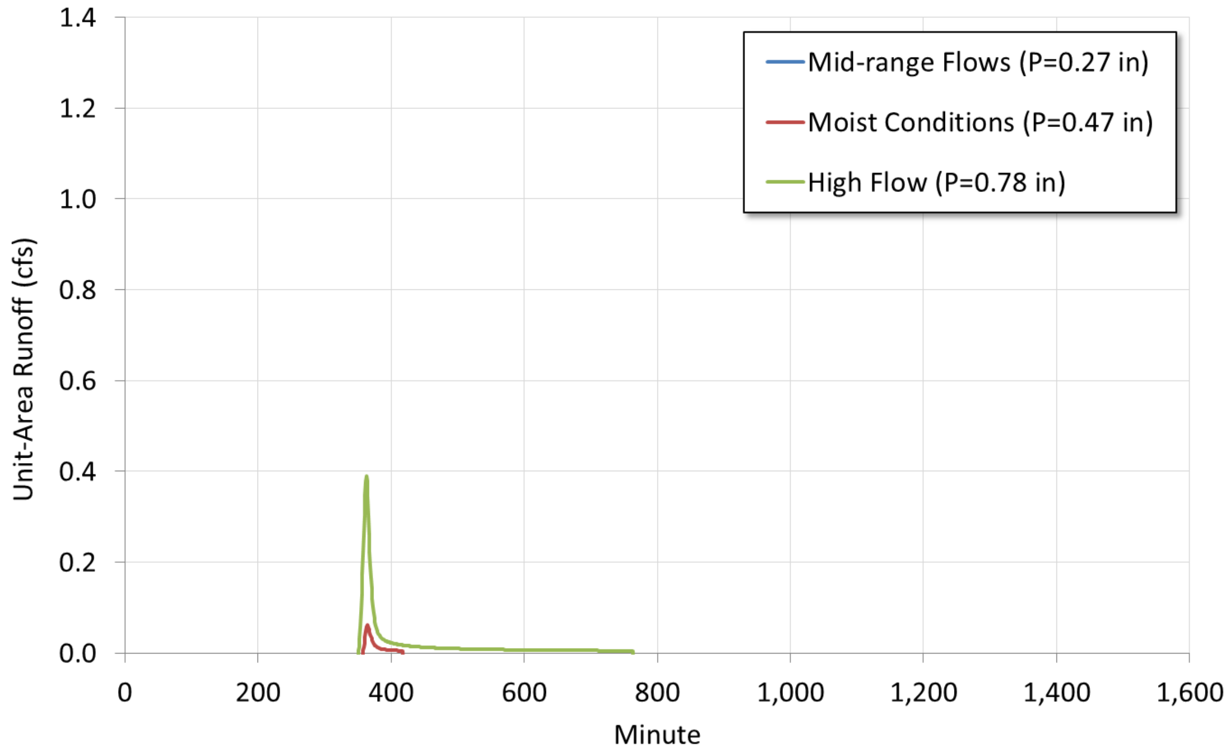


Figure 56. Unit-area (1 acre) runoff hydrographs representing the Multi-Family Residential.

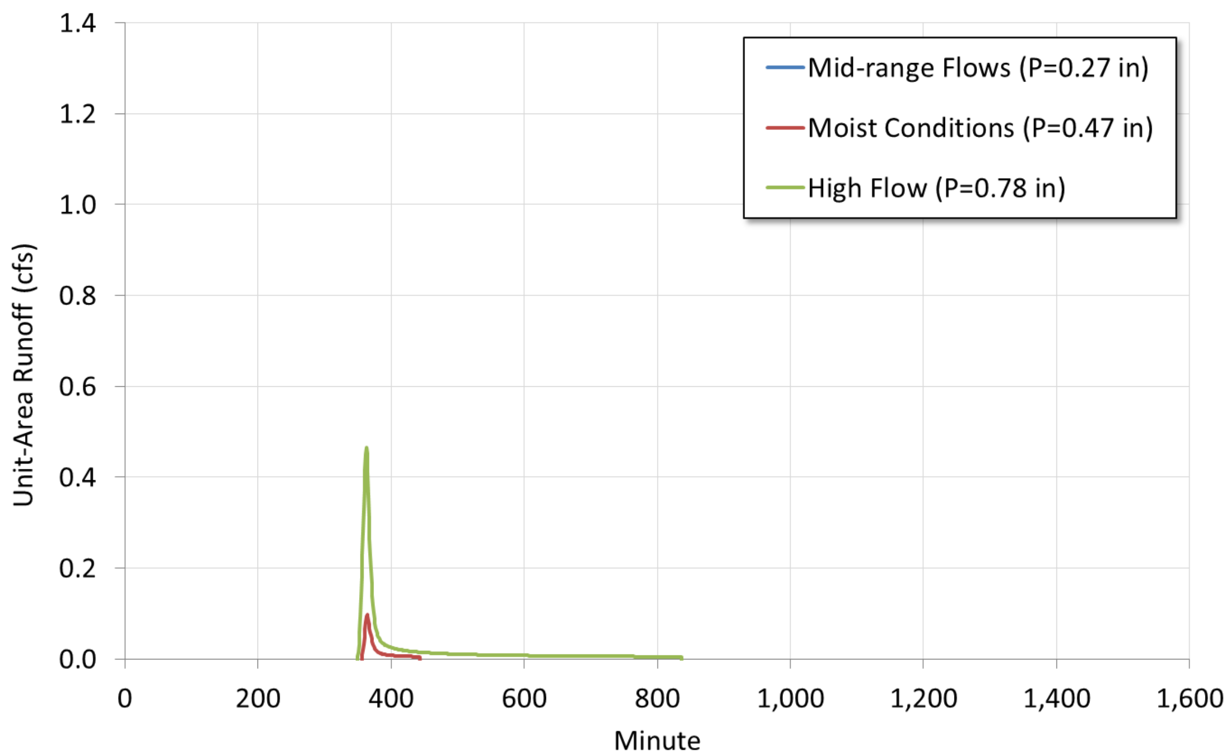


Figure 57. Unit-area (1 acre) runoff hydrographs representing the Industrial.

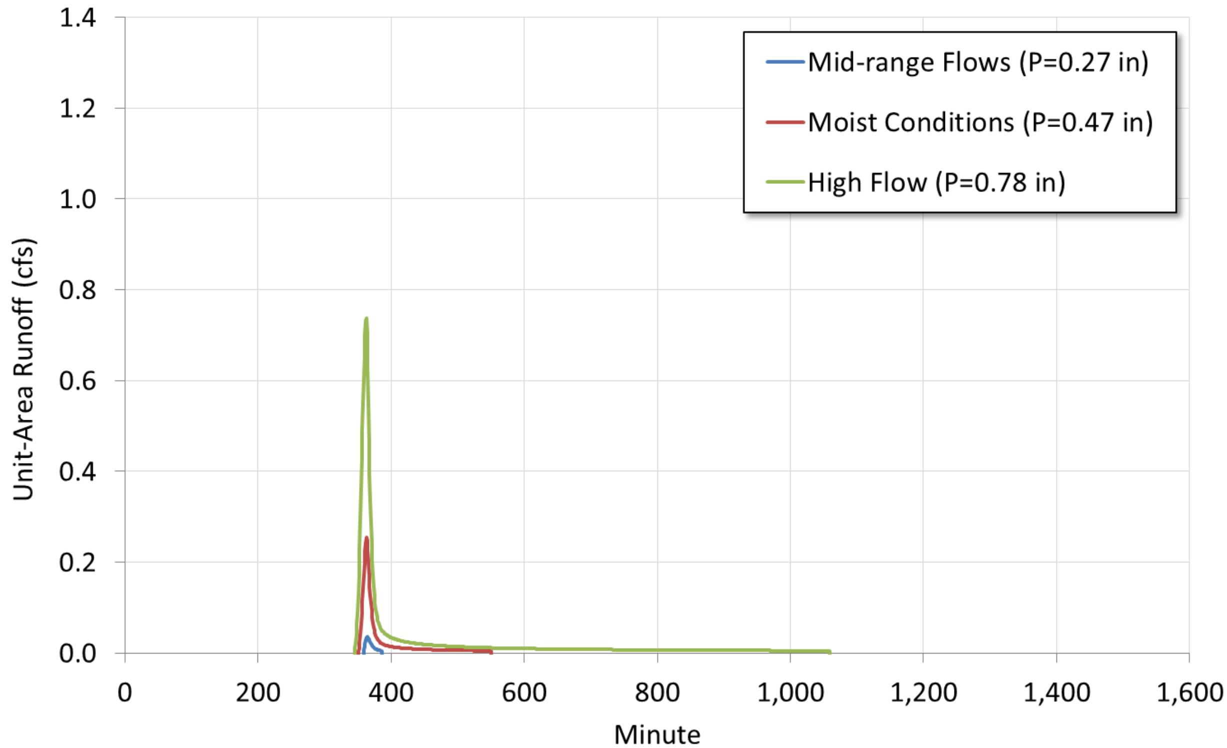


Figure 58. Unit-area (1 acre) runoff hydrographs representing the Commercial.

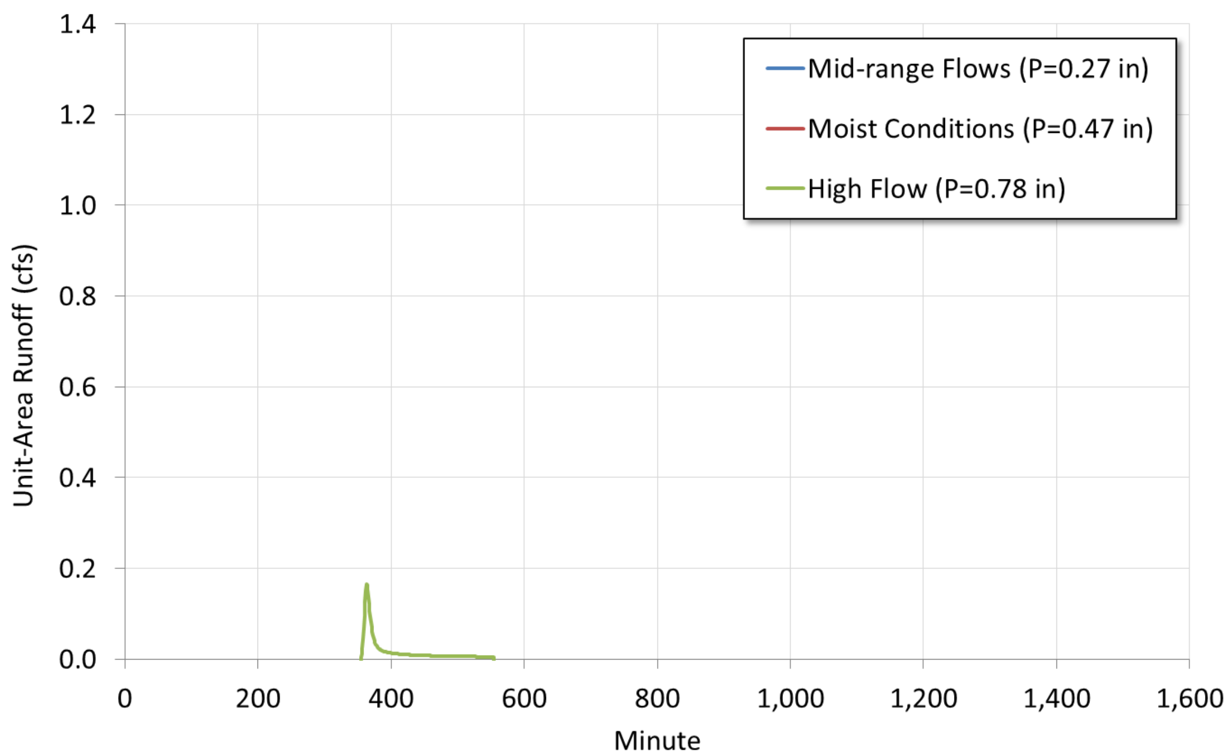


Figure 59. Unit-area (1 acre) runoff hydrographs representing the Public-Institutional.

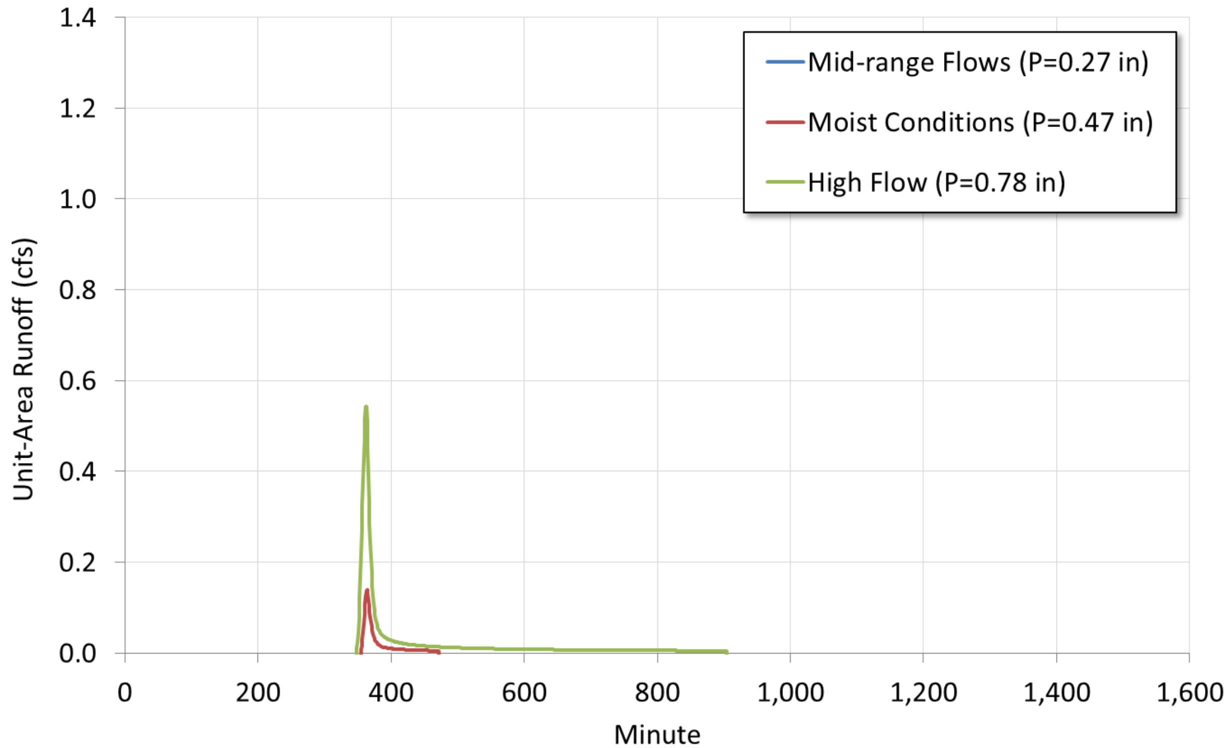


Figure 60. Unit-area (1 acre) runoff hydrographs representing the Transportation.

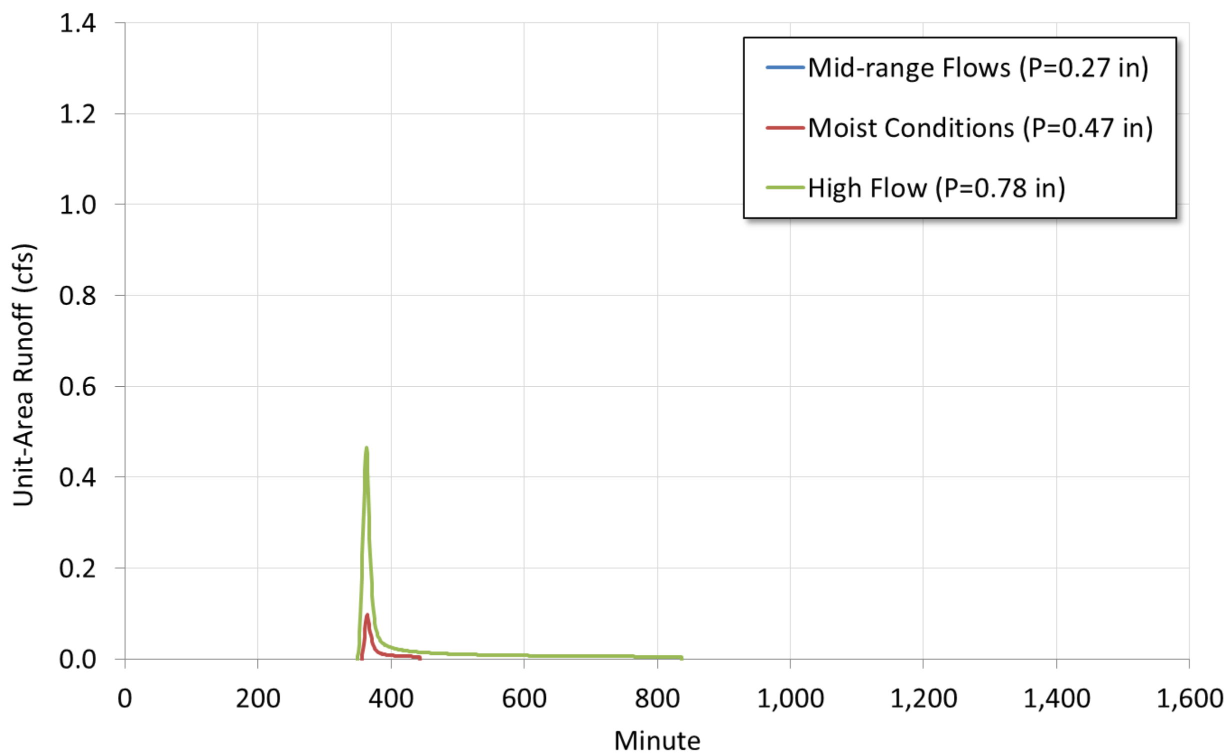


Figure 61. Unit-area (1 acre) runoff hydrographs representing the Vacant.

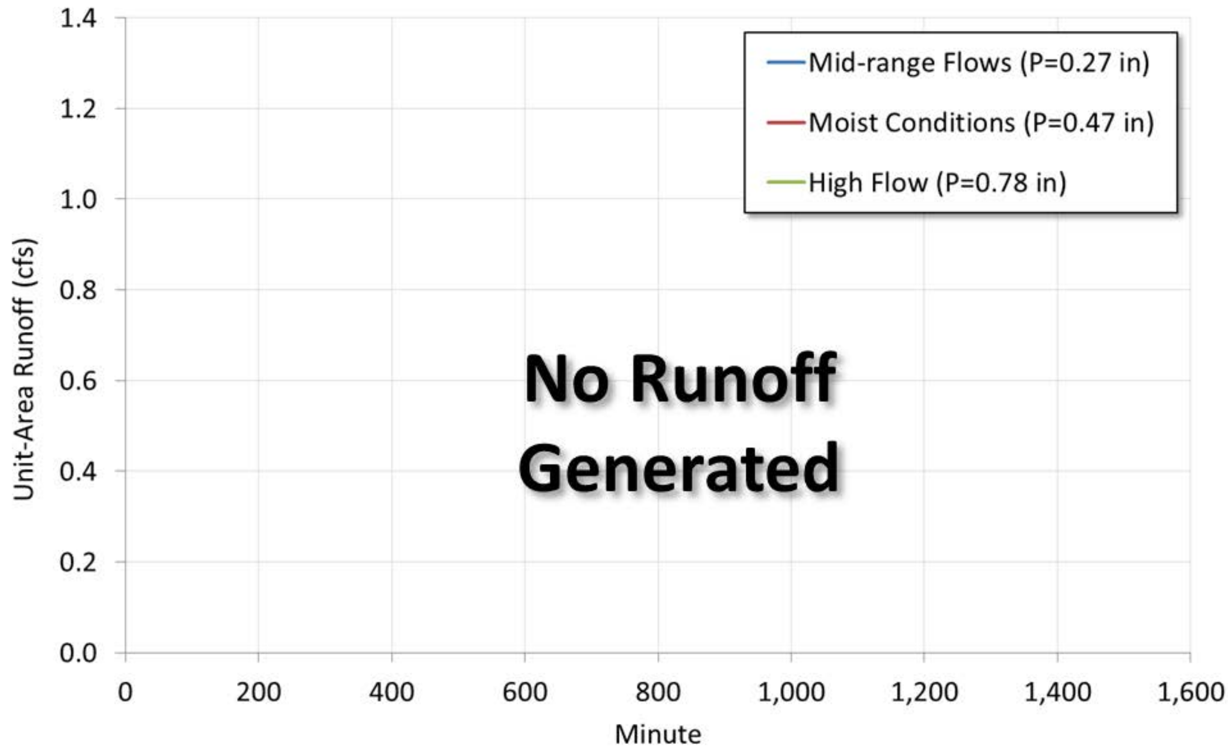


Figure 62. Unit-area (1 acre) runoff hydrographs representing the Parks.

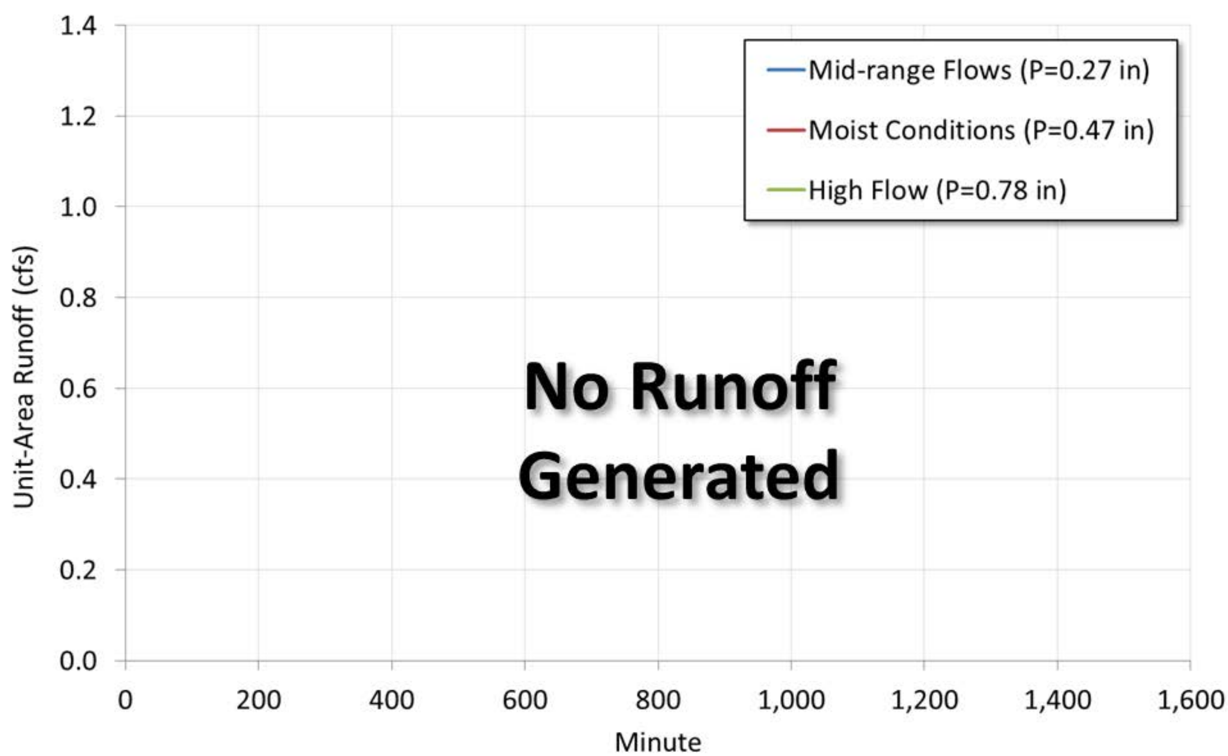


Figure 63. Unit-area (1 acre) runoff hydrographs representing the Agricultural.

Table 28. Summary of rainfall events at the Albuquerque International Airport (2000–2009)

Interval	Start Time	End Time	Total Rainfall (in.)	Wet Count (hr)	Peak Intensity (in./hr)	Average Peak (in./hr)
1	1/1/00 4:00	1/4/00 10:00	0.16	5	0.08	0.03
2	1/31/00 6:00	2/4/00 6:00	0.22	8	0.07	0.03
3	2/22/00 7:00	2/25/00 8:00	0.20	2	0.18	0.10
4	3/7/00 9:00	3/10/00 14:00	0.24	3	0.16	0.08
5	3/21/00 4:00	3/26/00 3:00	0.83	31	0.07	0.03
6	3/28/00 11:00	4/3/00 17:00	0.20	6	0.07	0.03
7	6/2/00 16:00	6/5/00 17:00	0.16	2	0.10	0.08
8	6/28/00 15:00	7/3/00 23:00	0.48	6	0.22	0.08
9	7/11/00 17:00	7/16/00 23:00	0.30	7	0.14	0.04
10	7/21/00 16:00	7/24/00 17:00	0.42	2	0.38	0.21
11	8/17/00 23:00	8/21/00 21:00	0.42	10	0.17	0.04
12	9/21/00 21:00	9/24/00 21:00	0.27	1	0.27	0.27
13	10/4/00 15:00	10/16/00 4:00	1.42	38	0.15	0.04
14	10/21/00 11:00	10/27/00 21:00	0.88	13	0.42	0.07
15	10/28/00 0:00	10/31/00 14:00	0.34	9	0.15	0.04
16	11/3/00 6:00	11/10/00 0:00	0.37	9	0.11	0.04
17	11/23/00 1:00	11/26/00 9:00	0.49	9	0.13	0.05
18	12/26/00 8:00	12/29/00 17:00	0.16	8	0.04	0.02
19	1/27/01 10:00	2/2/01 16:00	0.16	7	0.05	0.02
20	2/26/01 2:00	3/3/01 11:00	0.20	13	0.05	0.02
21	3/7/01 14:00	3/11/01 14:00	0.21	6	0.12	0.04
22	4/5/01 18:00	4/9/01 11:00	0.22	9	0.10	0.02
23	4/27/01 15:00	4/30/01 23:00	0.29	4	0.12	0.07
24	5/13/01 5:00	5/17/01 14:00	0.18	4	0.09	0.05
25	5/19/01 8:00	5/22/01 15:00	0.17	4	0.13	0.04
26	6/29/01 21:00	7/5/01 22:00	0.48	7	0.20	0.07
27	7/17/01 6:00	7/24/01 1:00	0.36	9	0.13	0.04
28	7/26/01 0:00	7/29/01 18:00	0.46	5	0.37	0.09
29	7/31/01 17:00	8/5/01 9:00	0.21	3	0.12	0.07
30	8/5/01 15:00	8/19/01 21:00	1.27	16	0.24	0.08
31	8/29/01 19:00	9/1/01 20:00	0.11	2	0.09	0.05
32	9/12/01 18:00	9/19/01 16:00	0.51	10	0.19	0.05
33	10/8/01 13:00	10/13/01 14:00	0.14	4	0.06	0.03
34	11/14/01 13:00	11/19/01 13:00	0.50	16	0.07	0.03
35	11/23/01 3:00	11/26/01 4:00	0.18	2	0.09	0.09
36	12/29/01 20:00	1/2/02 4:00	0.17	7	0.05	0.02
37	1/30/02 13:00	2/3/02 0:00	0.26	7	0.07	0.04
38	4/6/02 17:00	4/10/02 19:00	0.39	11	0.15	0.04
39	6/22/02 16:00	6/25/02 16:00	0.11	1	0.11	0.11
40	7/7/02 5:00	7/13/02 17:00	0.45	7	0.33	0.06
41	7/17/02 14:00	7/25/02 0:00	0.43	6	0.19	0.07
42	8/2/02 20:00	8/10/02 7:00	0.93	10	0.32	0.09
43	8/19/02 15:00	8/23/02 18:00	0.64	3	0.61	0.21
44	9/7/02 23:00	9/16/02 12:00	1.18	21	0.20	0.06
45	9/18/02 12:00	9/21/02 15:00	0.26	4	0.17	0.07
46	10/23/02 13:00	10/30/02 7:00	0.49	9	0.22	0.05
47	11/4/02 6:00	11/7/02 7:00	0.11	2	0.06	0.05
48	11/9/02 21:00	11/13/02 1:00	0.38	5	0.16	0.08
49	12/3/02 0:00	12/6/02 18:00	0.36	14	0.07	0.03

Interval	Start Time	End Time	Total Rainfall (in.)	Wet Count (hr)	Peak Intensity (in./hr)	Average Peak (in./hr)
50	2/8/03 19:00	2/11/03 23:00	0.25	5	0.13	0.05
51	2/13/03 1:00	2/16/03 16:00	0.39	8	0.26	0.05
52	2/18/03 12:00	2/23/03 12:00	0.17	5	0.07	0.03
53	2/24/03 17:00	3/3/03 21:00	0.21	10	0.04	0.02
54	3/16/03 19:00	3/24/03 11:00	1.44	28	0.23	0.05
55	6/1/03 14:00	6/4/03 17:00	0.15	3	0.11	0.05
56	7/20/03 17:00	7/25/03 15:00	0.41	4	0.32	0.10
57	8/9/03 0:00	8/12/03 1:00	0.13	2	0.07	0.06
58	8/24/03 20:00	8/28/03 10:00	0.20	5	0.10	0.04
59	8/28/03 17:00	9/2/03 18:00	0.37	7	0.14	0.05
60	9/7/03 14:00	9/13/03 18:00	0.29	8	0.19	0.04
61	10/7/03 10:00	10/13/03 22:00	1.50	19	0.41	0.08
62	11/12/03 15:00	11/16/03 8:00	0.48	15	0.09	0.03
63	12/12/03 3:00	12/15/03 9:00	0.11	5	0.04	0.02
64	2/21/04 11:00	2/27/04 2:00	1.08	14	0.20	0.08
65	3/2/04 13:00	3/8/04 8:00	0.63	16	0.18	0.04
66	4/2/04 8:00	4/7/04 15:00	2.47	24	0.57	0.10
67	4/8/04 0:00	4/13/04 19:00	0.53	11	0.12	0.05
68	6/29/04 1:00	7/2/04 19:00	0.60	9	0.15	0.07
69	7/11/04 16:00	7/30/04 19:00	2.25	24	0.55	0.09
70	8/10/04 15:00	8/14/04 16:00	0.12	3	0.08	0.04
71	9/18/04 21:00	9/23/04 0:00	0.88	14	0.21	0.06
72	10/5/04 4:00	10/9/04 19:00	0.34	5	0.22	0.07
73	10/11/04 4:00	10/16/04 15:00	0.39	8	0.17	0.05
74	10/17/04 14:00	10/20/04 15:00	0.11	2	0.09	0.05
75	10/26/04 20:00	10/30/04 5:00	0.23	6	0.06	0.04
76	11/19/04 0:00	11/26/04 10:00	1.26	18	0.29	0.07
77	11/28/04 13:00	12/2/04 10:00	0.11	3	0.07	0.04
78	12/29/04 21:00	1/1/05 23:00	0.25	3	0.12	0.08
79	1/2/05 12:00	1/7/05 21:00	0.76	17	0.21	0.04
80	1/26/05 23:00	2/2/05 7:00	0.62	17	0.17	0.04
81	2/11/05 3:00	2/15/05 17:00	0.81	26	0.08	0.03
82	2/15/05 21:00	2/26/05 23:00	0.94	24	0.11	0.04
83	3/5/05 9:00	3/9/05 12:00	0.31	8	0.15	0.04
84	3/13/05 21:00	3/18/05 1:00	0.69	16	0.10	0.04
85	3/25/05 4:00	3/29/05 15:00	0.11	6	0.03	0.02
86	4/10/05 5:00	4/13/05 19:00	0.16	6	0.07	0.03
87	4/16/05 14:00	4/19/05 17:00	0.61	4	0.24	0.15
88	4/24/05 4:00	4/28/05 20:00	0.40	10	0.10	0.04
89	5/3/05 15:00	5/6/05 20:00	0.29	3	0.20	0.10
90	7/17/05 18:00	7/20/05 18:00	0.30	1	0.30	0.30
91	7/22/05 14:00	7/25/05 14:00	0.57	1	0.57	0.57
92	7/28/05 17:00	7/31/05 17:00	0.16	1	0.16	0.16
93	8/6/05 21:00	8/10/05 0:00	0.15	4	0.12	0.04
94	8/12/05 2:00	8/18/05 16:00	0.33	6	0.12	0.05
95	9/2/05 19:00	9/14/05 13:00	1.27	11	0.52	0.12
96	9/28/05 4:00	10/2/05 17:00	1.56	17	0.32	0.09
97	10/9/05 5:00	10/13/05 21:00	0.39	12	0.10	0.03
98	10/15/05 11:00	10/21/05 16:00	0.55	8	0.17	0.07
99	4/29/06 2:00	5/2/06 5:00	0.13	4	0.06	0.03
100	6/7/06 22:00	6/12/06 15:00	0.11	4	0.07	0.03

Interval	Start Time	End Time	Total Rainfall (in.)	Wet Count (hr)	Peak Intensity (in./hr)	Average Peak (in./hr)
101	6/26/06 19:00	7/2/06 18:00	1.03	5	0.67	0.21
102	7/6/06 0:00	7/11/06 18:00	1.68	10	0.51	0.17
103	7/18/06 6:00	7/21/06 23:00	0.15	4	0.06	0.04
104	7/24/06 19:00	8/4/06 21:00	2.06	25	0.52	0.08
105	8/5/06 3:00	8/27/06 22:00	3.40	30	0.49	0.11
106	9/1/06 8:00	9/4/06 22:00	0.25	4	0.12	0.06
107	9/6/06 15:00	9/12/06 16:00	0.54	10	0.14	0.05
108	9/20/06 13:00	9/23/06 21:00	0.31	3	0.20	0.10
109	10/8/06 0:00	10/12/06 21:00	1.60	17	0.42	0.09
110	12/19/06 10:00	12/23/06 1:00	0.37	10	0.10	0.04
111	12/28/06 14:00	1/2/07 13:00	1.13	28	0.08	0.04
112	1/30/07 19:00	2/2/07 22:00	0.12	4	0.05	0.03
113	2/11/07 5:00	2/17/07 8:00	0.70	24	0.09	0.03
114	3/21/07 19:00	3/27/07 7:00	0.64	15	0.15	0.04
115	4/6/07 20:00	4/12/07 11:00	0.27	6	0.10	0.05
116	4/12/07 14:00	4/16/07 17:00	0.68	10	0.28	0.07
117	4/23/07 20:00	4/26/07 21:00	0.11	2	0.10	0.05
118	5/1/07 13:00	5/5/07 18:00	0.74	9	0.23	0.08
119	5/6/07 11:00	5/11/07 19:00	0.13	3	0.09	0.04
120	5/14/07 16:00	5/21/07 21:00	0.81	6	0.69	0.13
121	5/25/07 14:00	5/28/07 14:00	0.32	1	0.32	0.32
122	6/9/07 16:00	6/14/07 19:00	0.66	5	0.43	0.13
123	7/4/07 17:00	7/7/07 17:00	0.33	1	0.33	0.33
124	7/19/07 17:00	7/27/07 14:00	0.93	7	0.77	0.13
125	7/29/07 14:00	8/3/07 22:00	0.32	7	0.15	0.05
126	8/4/07 19:00	8/10/07 17:00	0.92	4	0.85	0.23
127	8/23/07 19:00	9/1/07 19:00	0.13	5	0.07	0.03
128	9/17/07 15:00	9/26/07 12:00	0.72	7	0.47	0.10
129	10/1/07 19:00	10/7/07 21:00	0.17	4	0.13	0.04
130	11/22/07 21:00	11/26/07 17:00	0.11	4	0.06	0.03
131	11/29/07 13:00	12/4/07 4:00	0.48	6	0.34	0.08
132	12/8/07 15:00	12/14/07 15:00	0.76	19	0.11	0.04
133	1/6/08 12:00	1/10/08 16:00	0.19	7	0.06	0.03
134	1/27/08 20:00	2/1/08 0:00	0.20	3	0.17	0.07
135	2/21/08 3:00	2/26/08 4:00	0.24	9	0.09	0.03
136	4/9/08 15:00	4/12/08 16:00	0.11	2	0.07	0.05
137	6/29/08 16:00	7/2/08 17:00	0.50	2	0.42	0.25
138	7/3/08 16:00	7/25/08 19:00	3.27	23	1.18	0.14
139	7/26/08 14:00	7/31/08 14:00	0.11	3	0.05	0.04
140	8/3/08 19:00	8/12/08 13:00	0.40	10	0.18	0.04
141	8/15/08 15:00	8/19/08 23:00	0.38	7	0.13	0.05
142	8/30/08 13:00	9/3/08 10:00	0.26	4	0.14	0.06
143	10/4/08 18:00	10/8/08 6:00	1.25	13	0.19	0.10
144	10/14/08 5:00	10/17/08 9:00	0.13	5	0.05	0.03
145	11/27/08 8:00	11/30/08 15:00	0.21	5	0.14	0.04
146	12/13/08 0:00	12/21/08 11:00	0.39	15	0.10	0.03
147	12/26/08 10:00	12/29/08 14:00	0.17	4	0.09	0.04
148	3/9/09 4:00	3/12/09 10:00	0.24	7	0.08	0.03
149	4/11/09 3:00	4/15/09 3:00	0.20	6	0.08	0.03
150	4/17/09 17:00	4/21/09 1:00	0.14	6	0.07	0.02
151	5/18/09 20:00	5/28/09 12:00	0.31	12	0.08	0.03

Interval	Start Time	End Time	Total Rainfall (in.)	Wet Count (hr)	Peak Intensity (in./hr)	Average Peak (in./hr)
152	6/10/09 1:00	6/13/09 6:00	0.23	6	0.06	0.04
153	6/24/09 15:00	6/29/09 18:00	0.47	9	0.17	0.05
154	7/3/09 4:00	7/6/09 7:00	0.51	4	0.18	0.13
155	7/21/09 18:00	7/24/09 20:00	0.19	3	0.11	0.06
156	8/13/09 19:00	8/17/09 7:00	0.33	8	0.10	0.04
157	8/22/09 21:00	8/28/09 13:00	0.60	11	0.27	0.05
158	9/9/09 17:00	9/14/09 17:00	0.16	7	0.05	0.02
159	9/16/09 0:00	9/20/09 15:00	1.25	17	0.17	0.07
160	10/7/09 4:00	10/11/09 11:00	0.21	5	0.10	0.04
161	10/20/09 14:00	10/24/09 10:00	1.00	14	0.28	0.07
162	10/28/09 4:00	11/1/09 13:00	0.30	6	0.11	0.05