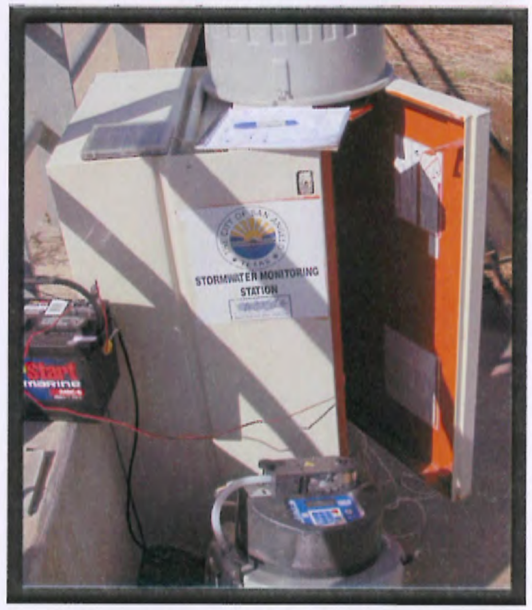

UCRA Storm Water Management Plan for the City of San Angelo

Development of Best Management Practices
Structural & Non-Structural Controls

Completed February 2013

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Upper Colorado River Authority
San Angelo, Texas

&

Texas Institute for Applied Environmental Research
Tarleton State University

Completed February 2013

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1.0 Executive Summary

This project was undertaken to provide a valuable tool for the City of San Angelo Storm Water Department as the staff manages a program to comply with the Phase II small Municipal Separate Storm Sewer Systems (MS4s) general permit rules promulgated by the US Environmental Protection Agency (USEPA) and administered in Texas by the Texas Commission on Environmental Quality (TCEQ). In addition, the Storm Water Department is charged with administering the comprehensive storm water ordinance adopted by the City. The primary objectives of the project included a detailed description of the San Angelo urban watershed, definition of the water quality and hydraulic characteristics of urban storm water, development of a predictive water quality and hydraulic model for use by the City, and identification of a non-structural and structural control plan for use by the Storm Water Department to mitigate storm water problems.

Phase 1 of the project included the detailed mapping of the urban watershed including the identification of the boundaries of the multiple watershed basins and sub-basins located within the city. The City's GIS system, other mapping sources and extensive ground truthing were utilized to ensure that all areas that effect storm water production within the city were included. This effort resulted in the identification of 35 sub-basins encompassing 33,377 acres. Land uses were detailed within the sub-basins and the areal extent and type of impervious cover reported. This work enabled the selection of potential storm water monitoring sites and assisted in the selection of the appropriate urban storm water model to be utilized in the project. This phase also included the preparation of specifications for permanent storm water monitoring stations and the purchase and installation of the equipment at these ten sites.

Phase 2 involved implementation of the storm water monitoring program to collect data resulting from rainfall events within the City. The monitoring stations automatically measured runoff flows and rainfall amounts and collect samples for analysis. After retrieval by the UCRA staff, the samples were shipped to the Lower Colorado River Authority Environmental Laboratory and tested for Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), and nutrients such as nitrogen and phosphorus. Through October 2012, 20 storm events have been monitored. The collected data was utilized to calculate storm event pollutant loadings at each site and to calibrate the water quality and hydraulic model being concurrently developed.

The data collections, observations and investigations resulted in the identification of 23 potential sites for consideration for the construction of structural controls that can serve as a "ready list" for the Storm Water Department. In addition, the Department protocols, procedures and programs were examined as to the development of a comprehensive non-structural and low structural storm water control program. Utilizing an appropriate set of criteria, the 23 potential structural control sites were evaluated and seven sites were selected as "critical sites and situations". These sites were then submitted to the project engineer for preparation of design development for each site including construction cost estimates. These sites serve as a list of "shovel ready" projects for the Department and should be considered as the highest priority for implementation.

The data analysis and investigations also resulted in the identification of two potential projects that were clearly outside the parameters of this study, but were judged to have considerable merit in innovation and beneficial uses of storm water. During Phase 2 monitoring, extremely large storm water flows were measured from the Red Arroyo watershed. This prompted the project staff to investigate these yields as a potential public supply source. As a result, Red Arroyo was determined to be a viable prospect for the development of a public water supply source that could reliably produce in excess of 50% of the San

Angelo's water needs. The second project envisioned is the pumping of water from the North Concho River near Bryant Boulevard to a pond on the Santa Fe Golf Course. This pond would be designed as a wetland treatment system and would discharge water down a series of streams and small ponds through the golf course to ultimately discharge back to the river. The intent of the project is to greatly improve the aesthetic environment of the golf course and provide significant improvement to the water quality of the river.

Phase 3 of the project involved modeling by the now calibrated hydraulic and water quality model developed by the Texas Institute for Environmental Research (TIAER). Initially, the hydraulics (i.e., storm water hydrograph) of each site selected for design development were modeled for both a one-year, 12-hour storm and a five-year, 12-hour storm. These storm events were selected as typical for this area and represent a normal flow event and a normal high flow event. Following this, a design storm was selected as one of these two design storms for each site based on the objectives for the control structure. Utilizing the design flows for each site and the hydraulic modeling results, the typical designs reported in design development were modified if necessary to fit the design flow selected. After design modifications, each structural control recommended was modeled to determine the water quality and hydraulic effects of implementation of the structural control. This included the reporting of the reduction of storm event pollutants and mitigation of peak flows. Evaluation of the modeling output will allow the Storm Water Department to prioritize structural control projects and perform cost/benefit analysis.

Phase 4 of the project included the preparation of the Storm Water Master Plan document including this summary. Report sections 3.0 and 4.0 include a description of the watershed and the data collections and investigations. Report sections 5.0 and 6.0 describe the non-structural and structural controls developed and recommended for implementation. Report section 7.0 outlines several overriding conclusions reached by the investigators as a result of the data collections, investigations and watershed modeling performed in preparing this document. These conclusions and any recommendations resulting from the conclusions are presented below:

1. The City of San Angelo has adopted a comprehensive storm water ordinance and established a Storm Water Department and program. These form the basis for a non-structural and low structural program to mitigate storm water problems. These are identified and reviewed within this report and it is obvious that implementation of the ordinance and Department programs will have a positive impact on existing and future storm water issues. Adoption of this master plan will provide a comprehensive guide to mitigating existing and future critical storm water problems. In addition to the minor recommendations stated in report section 6.1, the following recommendations are suggested to improve the storm water program.

- The Master Plan should be updated based on a five year schedule.
- The storm water monitoring and watershed modeling inputs should continue for an additional three years. This will insure program continuity and provide for further calibration of the model and additional data for Master Plan updates.
- During the next three years, the UCRA and the City of San Angelo should seek funding for structural control construction from the Texas non-point source program (319-h) and any other funding sources. Several of the recommended best management practices (BMPs) have multiple uses such as recreational, water conservation and beneficial use, and as such may qualify for other grant programs in addition to providing water quality benefits.

- Report section 3.66 identifies two potential beneficial use projects that were judged to be beyond the scope of this project. Both of these projects appear to have considerable merit and should be further evaluated.

2. Because of financial, engineering and public acceptability constraints, structural controls are largely site driven. This is particularly true of large projects. This report identifies 23 potential projects that will mitigate storm water urban flooding and/or water quality issues.

- It is recommended that these potential projects be recognized by the Storm Water Department as a "ready" list of potential future structural controls.
- Seven of the above projects have been subject to design development and efficiency modeling, and six of those projects are presented in this report for implementation. As these projects are implemented, it is recommended that the City Storm Water Department continue to provide design development and modeling for additional projects on the list to provide for an on-going program.

3. Serious and widespread water quality and urban flooding problems exists within the City. These problems have been identified in the report as critical sites and situations. Several other sites appear to be approaching critical status and will become problems with growth and development in their sub-basins. It is apparent that non-structural and low structural control strategies alone will not adequately mitigate these critical sites. As stated above, six projects have been subject to design development, efficiency modeling and cost determination.

- It is recommended that the City Storm Water Department prioritize the design development projects and proceed to seeking the means to implement the highest rated projects. In prioritizing the projects, the criteria should consider funding opportunities, impact on water quality and urban flooding, water conservation and beneficial use, public acceptability, and O&M costs.

4. From an impact only criteria the most urgent sites regarding water quality and urban flooding within the City of San Angelo are as follows:

Urban Flooding – Southwest Boulevard near Loop 306. Severely inadequate storm water conduit under street causes back-up and impoundment of storm water above crossing and frequent overtopping of roadway. Intense storm events often result in life threatening situations and potential damage to nearby commercial establishments.

Water Quality Impact- There is a tremendous annual loading of sediment, BOD and nutrients being discharged to the South Concho River near the City Water Treatment Plant and Lone Wolf Bridge from Red Arroyo. These contaminates are effecting water quality in Bell Street Reservoir, downstream water quality, the storage capacity of the in-stream reservoir and San Angelo's water supply system.

5. From an impact only criteria the most urgent developing problem with water quality or urban flooding appears to be Red Arroyo at Knickerbocker Road. With growth and development in this watershed, there appears to be a danger of overloading the storm water conduits under the road, damming of storm flows and eventual overtopping of the roadway.

- Development within this watershed should be carefully considered by the Storm Water Department.

- Appropriate entities should begin planning for possible improvements to the storm water conduits across this roadway.
- Upstream structural controls should be seriously considered by the Storm Water Department.

6. Water quality and loading data collected during this study indicates that there is a correlation between residential development and higher nitrogen values and loadings.

- It is recommended that existing public education programs, as a non-structural control, place a higher value on educating home owners and others as to the proper usage of fertilizers.
- Public education planners should determine optimum methods and instructions to help homeowners and others to better ensure proper fertilizer usage.

2.0 Introduction

In recent years, the City of San Angelo has fallen under the purview of the Phase II small Municipal Separate Storm Sewer Systems (MS4s) general permit rules promulgated by the US Environmental Protection Agency (USEPA) and administered in Texas by the Texas Commission on Environmental Quality (TCEQ). In essence, these rules classify the City's many storm water outfalls that discharge to waters of the US and require the City to obtain a National Pollutant Discharge Elimination System (NPDES) permit for these outfalls. Within its jurisdiction, the City of San Angelo is now responsible for the quality of the storm water that enters these waters. In 2009 & 2010 the City prepared and adopted a comprehensive storm water ordinance which included a storm water fee system that would pay for the actions necessary to administer and implement the ordinance. Following many months of stakeholder input, the City adopted new construction and development rules and specifications, and initiated a comprehensive public education program.

Historically, the City's urban streams, decorative ponds and lakes have been heavily impacted by non-point source pollution from urban runoff. The urban segment of the North Concho River has experienced numerous fish kills, deteriorated water quality and poor aesthetic conditions. Since the river corridor serves as the backbone of the City's park and recreation development, inferior water quality has been a major issue with City staff and administration in recent years. In the mid 1990's, the City and the Upper Colorado River Authority (UCRA) utilized a combination of USEPA grant funds and local contributions to construct facilities to treat major outfalls of storm water in the downtown area. As a result, the frequency and duration of fish kills has been substantially reduced and water quality conditions have improved. However, the North Concho River from Bell Street Lake to O.C. Fisher Dam remains on the 303d list as an impaired water body for depressed dissolved oxygen levels and exceedance of e-coli bacteria standards. Some segments downstream of San Angelo have also been placed on a concern list for excessive nitrogen, phosphorus and algae content.

San Angelo has a limited storm sewer system and storm water channels. Most storm water runoff is conveyed by city streets, alleys and natural drainage features. As the city has grown, urban flooding has become increasingly problematic. This is particularly true where upstream development has impacted downstream areas with inadequate hydraulic capacity to handle the increased storm flow. The City's storm water ordinance and development requirements address many of the future concerns for existing urban flooding problems. Unfortunately, the requirements tend to be local in scope and do little to define the existing problems or the larger area and city wide impacts.

The City of San Angelo and UCRA entered into a cooperative agreement to develop a storm water monitoring and modeling program as a tool for the City's storm water management system. The entire urban watershed has been mapped with all sub-basins identified, including detailed land use within the sub-basins. The mapping has been accompanied by ground verification to ensure accuracy. Automatic storm water monitoring stations have been installed at ten critical watershed locations. At each station during rainfall events, the volume of precipitation, its intensity, duration of rainfall and storm water flows are recorded. Storm water samples are also automatically collected.

The UCRA retained the services of the Texas Institute of Applied Environmental Research (TIAER) at Tarleton State University to provide hydraulic and water quality modeling for the entire urban watershed. Using default values, the models are continually calibrated with real time monitoring data. At the conclusion of the project, the City will possess a highly accurate model that displays existing conditions and can predict consequent hydrologic and water quality conditions by changing parameters such as storm intensity/duration, changes in land use, or future development within the urban area.

The cooperative agreement between the City and UCRA also requires that the UCRA develop a Master Plan to examine and identify structural and non-structural control strategies to address both water quality and urban flooding. The goal of the plan is to assist the City Storm Water Department in planning and implementing control strategies to mitigate the problems identified during the monitoring and modeling phase of the program. This document will detail the results of the monitoring, modeling and investigative work performed during this project, identify and describe available structural and non-structural control strategies, identify and prioritize hydraulic and water quality sites and provide design development for seven high priority projects.

3.0 Watershed Identification and Characterization

3.1 Criteria and Rationale for Inclusion

In preparing the overall and sub-basin watershed maps, an attempt was made to include all of the corporate limits of the City and storm water contributing areas located outside the corporate limits. This would account for all of the storm water contributed downstream and would allow planners to manipulate various land uses within the model as changes occur. Sub-basin boundaries within the map were generally derived from one-meter resolution aerial surveys. It was discovered early in the project that recent physical alterations or obscure structures could sometimes alter runoff patterns. These were ground verified with corrections made to the map. Soil maps, land use maps and impervious cover layers were also added to the watershed maps.

3.2 Watershed and Sub-basin Boundaries

Figure 1 is a map of the San Angelo urban watershed and the 45 sub-basins identified within the greater San Angelo area. Ten sub-basins were not selected for modeling due to the lack of impact on the hydraulic or water quality characteristics of the urban watershed. The modeled areas include 35 sub-basins with a watershed area of 33,377 acres.

San Angelo Watershed

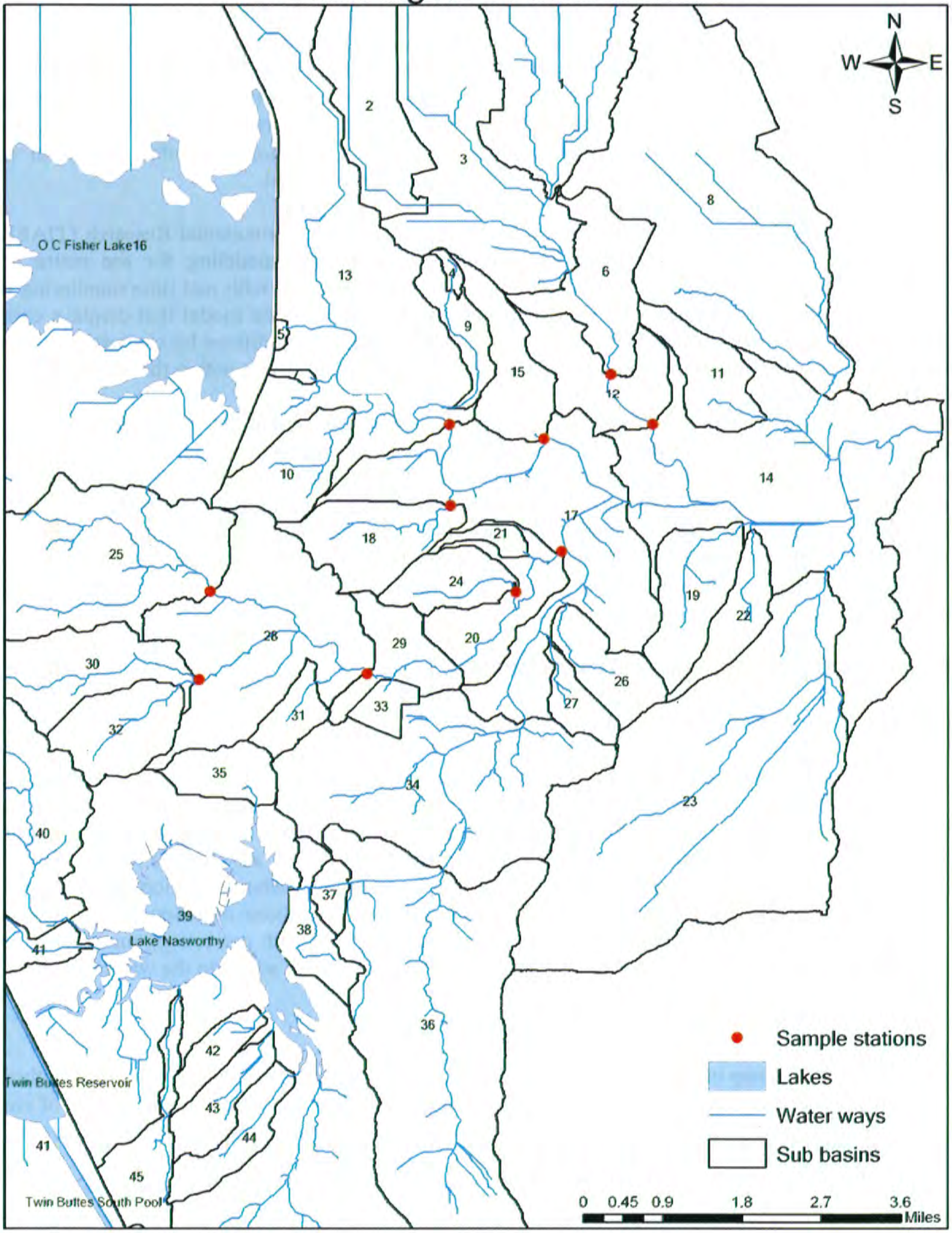


FIGURE 1

3.3 Sub-basin Land Use

The land use and impervious area categories in the San Angelo watershed delineated in this study are listed in Tables 1 and 2, along with the total area. Appendix B and C contain the detailed land use and impervious area information of the 35 sub-basins selected for detailed modeling.

Table 1: Summary of Land Use Categories for 35 Sub-Basins

Land Use Categories	Area (acres)
Agriculture (Cultivated Land)	5,624.14
Agriculture (Commercial, Dairies)	36.95
Agriculture (Residential, 3-10 acres with house)	1,591.66
Commercial	912.4
Industry, Heavy	704.52
Industry, Light	395.8
Mobile Home (individual)	139.37
Mobile Home Park	49.12
Office	158.55
Parking Lot Offsite	74.16
Parks, Recreation	2,042.04
Public, Semi Public	2,846.44
Residential High Density (Apartments)	338.09
Residential Low Density	5,928.10
Residential Medium Density (Townhouses, Duplex)	250.98
Retail Personal Services	898.34
Two Single-Family on One Lot	18.55
Vacant (Undeveloped)	11,367.79
Total	**33,377.01**

Source: Land Use GIS Data from City of San Angelo (2010)

Table 2: Summary of Impervious Cover Categories for 35 Sub-Basins

Impervious Area Categories	Area (acres)
Building Footprints	2,736.72
Non-residential	2,540.72
Pavement	3,189.14
Total	**8,466.63**

Source: Impervious Cover GIS Data from City Of San Angelo (2010)

3.4 Methods and Location of Data Collections and Observations

The location of storm water data collection stations are shown on Figure 1. These sites were selected based on their locations in reference to the sub-basin configuration, spatial distribution within the City, infrastructure to facilitate installation and suitable control points for flow determination. The sites were equipped with ISCO Model 6712 automatic samplers and tipping bucket rain gauges. The flow monitor/recorder utilizes a bubbler system to measure the height of water at the control point above the zero flow elevation. The open channel or other structure cross section area or dimensions and upstream slope was measured at and above the control point and programmed into the flow recorder. With channel roughness and other engineering factors programmed, the flow recorders are able to accurately measure flows on a continuous basis during a storm event. The automated samplers come pre-programmed with flow calculations for configurations from open channels to every type of weir, pipe, culvert or flume. Following a storm event, personnel are able to download a hydrograph of the event from the equipment.

The automatic samplers can be programmed to collect a volume of sample from the storm water stream at a timed frequency or on a flow-weighted basis. The programmed settings were determined based on an assessment of the likely maximum event length. All of the stations are equipped with 24 separate one-liter sample bottles and programmed to collect sub-samples at a fixed time interval. This protocol allowed the collection of a discrete first flush sample as well as a time-weighted composite of the remainder of the storm event. Uniform time based samples are collected for these events. Following this baseline data, samplers can programmed to collect sub-samples based on a specific volume of storm water passing the sample site. Sub-samples collected can also be composited into a single flow weighed sample. The laboratory analyzes samples for the following parameters: BOD, TSS, Total Organic Carbon (TOC), Total Kjeldahl Nitrogen (TKN), Nitrate-Nitrite (NO_3-NO_2), Total Phosphorus (TP). The completed laboratory data combined with the storm water flows allows the calculation of the total pollutant loadings for each of the parameters tested (see Appendix G for laboratory data and loadings). Note that Total Nitrogen is calculated at TKN plus NO_2+NO_3.

In addition to the specific data and observations collected under this project, measurements and observations have been on-going for an extended period of time. The Texas Clean Rivers Program, preparation of a Concho River Watershed Protection Plan and previous storm water projects and investigations have accumulated a large data base of analytical data, observations and UCRA staff experience related to storm water problems in urban San Angelo.

3.5 Watershed Modeling

The EPA Storm Water Management Model (SWMM) was selected for application on this City of San Angelo project. SWMM is a dynamic rainfall-runoff model with capabilities to simulate single event or long-term (continuous) runoff quantity and quality from urban areas. SWMM simulates runoff by considering sub-catchment areas that receive precipitation and produce runoff and pollutant loads, and then transports this runoff through pipes, channels, and storage/treatment units. SWMM, which was first developed in 1971, has undergone several major upgrades, and has been widely applied throughout the world for urban storm water planning. The latest version of the model, SWMM Version 5, was produced by the U.S. Environmental Protection Agency's National Risk Management Research Laboratory with assistance from the consulting firm of CDN, Inc. This latest version of SWMM is being used on this project.

3.6 Summary of Data Collections and Observations

3.61 Recognized Water Quality and Urban Flooding Concerns

There are several areas in which urban flooding occurs within the City. Many are a nuisance or minor inconvenience to motorists during storm events. However, some are potentially life threatening or a threat to property. Major concerns are listed below:

- Southwest Blvd. near Loop 306 – Southwest Blvd. is a major feeder artery and the area is often closed due to high water. Several businesses in the area have been affected by storm water and/or are currently threatened. Numerous vehicles have been washed off the crossing during intense events.

- College Hills Blvd. @ Red Arroyo – this street is another major artery and is frequently closed during storm events.

- Knickerbocker Rd. @ Red Arroyo – this point has not been subject to flooding in the past, but the capacity of the channel and the existing flood marks and flow measurements indicate that the bridge structure could be breached in the future.

- Bell Street @ East Angelo Draw and multiple points downstream – a major traffic artery often closed due to high water at East Angelo Draw. Multiple street crossings and residences downstream are also threatened.

- East Angelo Draw - has an extremely large and diverse watershed. Numerous street crossings, structures, residences and businesses are at risk.

- Howard Street @ Brentwood Park – this conveyance in part utilizes and crosses Howard Street and serves as the main channel for a drainage system. It is often closed during storm events.

- Sulfur Draw– several street crossings including S. Monroe and Paseo de Vaca are seriously impacted by this waterway and are often closed.

- Drainage Way area including Avenue R & Hill Street – numerous street intersections and crossings are seriously impacted by this waterway. Historically, vehicles and homes have been flooded in this area and streets closed.

- Area Upstream of Parkview Lake – several street intersections including Sul Ross & Lindenwood are seriously impacted following significant storm events.

- Live Oak Street @ Evans – Live Oak Street is a major traffic artery and is impacted by storm water.

- North Concho River Low Water Crossings @ Irving, 1st and 14^{th} Street.

The State of Texas Clean Rivers Program water quality network has identified the downtown segment of the North Concho River as being water quality impaired. The stream has been listed for low dissolved oxygen levels and for excessive *E. coli* bacteria. The impairment listings come from a statistically valid number of samples over a specific period of time failing to meet stream samples. The stream segment is also the location of numerous historical fish kills and poor aesthetic conditions due to excessive algae growth.

There are several decorative ponds constructed throughout the City to collect urban runoff. These generally take advantage of natural terrain and urban runoff for their configuration and contents. As they age they accumulate sludge and serve as nutrient beds, then water quality deteriorates and they become a liability to adjacent homeowners and neighborhoods. Fish kills occur often and residents file complaints with City and State regulatory agencies. These structures can serve as structural controls to allow settling of particulate matter and improve downstream water quality. The current problem is that they have not had maintenance methods designed into their construction.

The recently completed Concho River Basin Watershed Protection Plan (CRBWPP) identifies several urban water quality concerns in addition to those identified above. These include an excessive sediment load to the South Concho River from Red Arroyo and organic and nutrient load to the Main Concho River below Bell Street from East Angelo Draw. Because of the watershed's land use characteristics, a potential concern was cited on East Angelo Draw for metals and hydrocarbons.

In the mid 1990's a Non-Point Source/Urban Runoff BMP Master Plan was prepared for the urban North Concho watershed utilizing USEPA grant funds. This study served as a guide for the UCRA and City of San Angelo in developing the BMPs constructed utilizing grant funds and local match. While this study did not generate additional storm water quality data, it did cite numerous previous comprehensive studies that quantified contaminant loadings within the watershed's sub-basins.

A list of geographic locations and pollutants of concern identified prior to beginning the project follows:

- Downtown Segment of North Concho River – dissolved oxygen, *E. coli* bacteria.
- Main Concho Segment immediately below Bell Street – biological integrity.
- South Concho River @ Red Arroyo – sediment loads.
- East Angelo Draw @ Main Concho – nutrient loading, possible metals, hydrocarbons.
- Sub-basin outfalls to North Concho urban watershed - dissolved oxygen, nutrients, *E. coli*.
- Sub-basin outfalls to Red Arroyo - sediment, nutrients.

3.62 Summary of Storm Water Loadings

Appendix G contains the water quality data and calculated loadings measured by the storm water monitoring system. Monitoring began on June 28, 2010 with a storm event on that date. Data presented in Appendix G is the actual laboratory analytical results for the parameters tested and the loadings are the analytical results as applied to the volume of storm water measured and expressed as pounds of the pollutant tested. This number is the approximate weight in pounds of the pollutant that passed the site during the storm. Primarily due to the large volumes of storm water created, Red Arroyo and its tributaries are the greatest contributors of pollutant loadings in the urban San Angelo watershed. Red Arroyo gets its name from the red colored soils that outcrop most noticeably in the upper watershed. This soil is in reality an outcrop of a geologic feature, the San Angelo Formation. While published soil maps and descriptions do not list the soil type as being highly erodible, observations indicate the opposite. The red clay present in the soil is obvious in the red color in any runoff from the watershed and is primarily responsible for the high TSS measured.

TSS is a good parameter to indicate total pollutant loadings since high levels of TSS are often indicative of high organic loadings and nutrient loadings. Sample station #2 analytical results are indicative of pollutant loadings to the South Concho River, and sample station #3 results are indicative of upstream pollutant loadings to the North Concho River through downtown San Angelo where the water quality impairments have been identified.

Examination of the water quality and loading data in Appendix G allows the formulation of some important conclusions regarding storm water quality, generally and specifically, for the urban San Angelo watershed. A review of the water quality data indicates that several "first flush" samples were collected for a number of sites. These are the samples collected within the first 15 minutes of a storm event, and the literature indicates that these may contain the highest concentration of pollutants. Appendix G data substantiates that this is indeed the case in the San Angelo watershed. Further, in smaller storms the first flush sample will contain a higher percentage of the total BOD load than in more intense storms. During the storm event monitored in November 2011, the total rainfall measured was approximately 0.3 inches with a rapid onset and abrupt termination. In realty, the entire event was all a "first flush" due to its brevity. It also followed a significant period without rainfall. All of these factors combined to produce some exceptionally high BOD concentrations measured in the samples collected and is a spectacular indication of the first flush phenomena.

Continuing a review of the BOD data, several other conclusions can be made. There appears to be remarkable continuity between sample sites in BOD values measured during a single event, particularly if the rainfall amount and intensity is similar. Also, BOD values appear to be higher from sub-basins with more residential development and average BOD values are higher for events of lower total rainfall and lower intensity of rainfall. Total loadings are, however, generally higher from the storms with larger total rainfall amounts and of greater intensity. For reference, most wastewater discharge permits issued by the State normally require BOD and TSS concentrations to be 20 mg/l or less. However, the BOD and TSS values contained in Appendix G are characteristic and typical of urban runoff generally, and are confirmations of previously collected data within the City.

Examination of the nutrient data also reveals some interesting conclusions. Seasonal storms will result in the discharge of 500 to 1000 pounds of nitrogen to the South Concho River from Red Arroyo. Assuming that a commercial fertilizer contains 10% nitrogen, the nitrogen loading to the river would be the equivalent of between 5000 pounds (100 50lb. bags) and 10,000 pounds (200 50lb. bags) of fertilizer being dumped into the river. These high loading numbers are reflective of the large volume of storm water discharged at this site. Other sample sites also display high nitrogen values and loadings. Comparative analysis of nitrogen loading data and land use indicates a strong correlation between high nitrogen values and residential land use and development. Sub-basins with low density residential development display the lowest nitrogen numbers. This relationship holds true across watersheds and sub-basins.

3.63 Summary of Hydraulic Characteristics

As stated above, the largest event monitored was a 25-50 year return interval event that occurred on August 13, 2011. This event resulted in widespread and numerous incidents of urban flooding. Some of the incidents could be categorized as life threatening and required emergency rescue of motorists. As stated above, the Red Arroyo watershed and its numerous sub-basins are the largest contributors to storm water in the City.

The measured hydrographs shown in Appendix A, as expected, are very reflective of the storm characteristics and watershed development. A sudden onset, short-duration storm produces a typical hydrograph where there is a rapid increase of storm flow to the peak flow measured and a longer duration decline in flow to the termination point. Storms where there were two distinct periods of intense rainfall normally produced a two peak flow curve. The two peak curve was more distinct in the smaller watersheds than in larger watersheds. Watersheds with more impervious cover produce greater yields of storm water per unit of rainfall and the yields to total rainfall are generally accurately predictive from one storm event to another. Other factors, such as rainfall intensity, will also determine total watershed yield, but, generally, yields are reflective of and predictable based on total rainfall.

3.64 Identification of Critical Locations and Situations

The data collections and observations obtained to date have generally confirmed the water quality and hydraulic concerns identified in report section 3.62. Identification of these locations and situations of concern is important since they will largely dictate the selection and prioritization of best management practices recommended by this project. The reduction of pollutant loadings and reduction of urban flooding are of highest priority in identification of sites. In addition to the on-site water quality, hydraulic, and pollutant loading data collected, other situations may also influence selection of sites. These include the current available funding for implementation of controls, beneficial use of storm water opportunities, water conservation, recreational opportunities, topographic suitability and public acceptability.

Utilizing the screening criteria identified above, seven sites have been identified as critical locations or situations. These sites have been subject to further evaluation and design development which are fully developed in report section 6. The identification of these sites and the reasons for inclusion are as follows:

Red Arroyo Downstream of Sherwood Way (U.S. Hwy 67) – This site is prone to urban flooding problems and offers potential funding opportunities through an existing grant to construct a series of dry pond/wet pond facilities that would reduce urban flooding, reduce pollutant loadings and provide recreational opportunities.

Storm Water Drainage Upstream of Southwest Blvd. Near Loop 306 - This site frequently experiences serious urban flooding and analytical data indicate a very heavy pollutant load. Topographic realities dictate the need for a series of dry pond facilities that not only reduce hydraulic peaks for flood mitigation, but also decrease pollutant loads.

Red Arroyo Near South Chadbourne Street Bridge – This site offers a suitable topographic area for development of a large dry pond/wet pond facility that will substantively reduce the sediment and pollutant loading to the South Concho River. This site also offers opportunities for beneficial use of storm water, water conservation and recreational opportunities.

North Concho River Near 14th Street Bridge - This site potentially offers a suitable area for development of control facilities to mitigate downstream flooding and reduce pollutant loadings to this stream segment, which is listed for water quality impairments. Moreover, such facilities could aesthetically improve the existing stream channel, providing additional recreational opportunities.

Downtown North Concho River - This general area offers the potential of multiple sites for installation of package storm water treatment units. It is assumed that these units would be similar to the existing package unit located near the Celebration Bridge which is extremely efficient in reducing pollutant loads. Since this stream segment is listed for water quality concerns, this proposal is advantageous to the goals of the project.

TXDOT Property Near Baptist Memorial – This site lies below Baptist Memorial Drainage on a tributary to East Angelo Draw. There is a possibility of additional funding for this project. An irrigation pond with pre-sedimentation could provide water conservation and beneficial use opportunities and reduce both pollutant loading and hydraulic peaks on East Angelo Draw. Baptist Memorial has indicated that it is interested in utilizing storm water for irrigation of its complex. This would be a beneficial use of storm water by conserving a significant quantity of potable water and providing considerable cost savings to the complex.

East Angelo Draw Near Concho River and Sports Complex – A large wet pond located at this site could provide significant reduction in the pollutant loads discharged to the Concho River below San Angelo. In addition, the facility could provide water conservation and beneficial use opportunities as the impounded water could be utilized to irrigate the Rio Concho Sports Complex. Also, the pond could enhance aesthetic and recreational use of the much used complex.

3.65 Initial Modeling Outputs

The Master Plan is required to identify several potential sites for structural control design development. The seven critical locations/situations identified in report section 3.64 were submitted to the engineering consultant for design development and to TIAER for initial modeling of storm hydrographs. The engineer was instructed to develop example or typical designs for the sites in order that the design capacities could be increased or decreased dependent upon hydrologic conditions, project objectives and "best fit" determinations. TIAER was instructed to hydraulically model each site for both 1 year/12 hour and 5 year/12 hour storms. These storm frequencies are typical of both "normal" and high intensity storm water events in this area. In refining designs for control strategies, one of these storms would be selected as the "design storm" for that facility dependent upon the objectives of the control strategy. The total rainfall for the 1 year/12 hour storm is 1.66 inches and the 5 year/12 hour storm is 3.06 inches. Most of the proposed control strategies will utilize the 1 year storm for design, but the critical urban flooding locations will utilize the 5 year storm for design. Report section 6.6 includes the hydraulic characteristics obtained in the initial modeling for each critical location and the recommended design flows and control strategy final design.

3.66 Additional Storm Water Beneficial Use Opportunities

Based on the watershed investigations, data collections, and observations, a number of specific sites were identified as being potential critical locations or situations and potential sites for control strategy construction. All of these are identified in report section 6.2. Several of these would be very visible, high profile projects that offer beneficial use of storm water, but project costs or other ramifications prevented selection of these as initial design development projects. Two of the highest profile projects are described and further developed as follows:

Site No. 17 – Red Arroyo Near S. Chadbourne Street, Municipal Water Supply – This site was selected for design development of a conventional control structure. Data collections of large storm water volumes, however, beg strongly that an additional opportunity exists to utilize this site for the development of a large storm water storage lake to be used as a municipal water supply. This site recorded in excess of 9,700 acre feet of storm water during a period of record drought from August 2010 to July 2012. During this time period only 18.94 inches of rainfall occurred. It is obvious that the site could potentially provide up to 10,000 acre feet of water annually in an average precipitation year, which would be 65% of San Angelo's annual municipal water need. The size of the watershed with its high runoff potential makes this site an extremely reliable water supply and could also serve as a significant storm water treatment system. Construction of this facility would also mitigate the water quality impacts of the Red Arroyo on the South Concho River. This project would require a significant capital cost and permitting effort, therefore it was removed from consideration as a normal storm water control strategy for the purposes of this project (see Appendix H).

Site No. 2 – Santa Fe Golf Course, Pond System and Artificial Stream – This site was selected and concept developed to improve the aesthetics at the existing golf course and provide treatment to the North Concho River through the segment identified as being water quality impaired. The project would entail the development of a high volume circulation system to pump from the river to a pond on the golf course. The pond would be designed and constructed as a wetland treatment system with abundant aquatic plants and morphology to maximize water treatment. Following adequate detention time, the water would traverse the golf course through a series of artificial streams and small ponds that ultimately discharge back to the river. Small decorative bridges would be constructed over the streams at appropriate locations to facilitate use of the golf course.

Properly designed wetland systems are very effective in reducing nutrients, suspended solids and oxygen demanding substances. The affected stream segment by this proposed facility is currently listed by the TCEQ as an impaired water body and often displays poor aesthetic conditions including prolific algae blooms. The treatment system could reduce algae blooms, eliminate oxygen depletion by reducing diurnal oxygen minimums, and improve water clarity. In addition, the beneficial treatment effects would be extended downstream due to the normal stream flow.

4.0 Quality Assurance

Sampling, sample handling, laboratory methods and data screening have been conducted based on the TCEQ Surface Water Quality Monitoring (SWQM) Procedures, Volume 1, RG –415, 2008. Although this data has been used as a screening tool and will not be entered into the State Water Quality Database, it was deemed appropriate to utilize this source as a guide for proper sampling and analytical protocols where applicable.

5.0 Types of Structural & Non-Structural Control Strategies Considered

By definition, Best Management Practices (BMPs) are non-structural and low-structural management alternatives. Watershed controls that reduce water pollution and hydraulic impacts include BMPs and storage/treatment. For ease of discussion, all of these shall be referred to as structural and non-structural control strategies.

Structural control strategies include, berms, earthwork and outlet devices or modifications to land surface features that facilitate on-site storage and /or flow attenuation. Storage attenuates peak runoff flows, treats runoff by physical settling or totally contains the flow through percolation/retention. Storage/treatment options can be designed and operated as dry or wet ponds to provide sufficient detention time to allow settling as a physical treatment method. Settling reduces suspended matter and BOD, nutrients, heavy metals and hydrocarbons.

Other structural controls include vortex separators and biological controls. In recent years the separators were developed to accelerate storm water settling characteristics and improve floatable debris and litter removal. These units are very efficient, but are limited by flow capacity to small and moderate sized storm water outfalls. In addition to treatment, suspended solid prevention options are also available and include erosion control stabilization, runoff control and re-vegetation. In recent years, biological controls have been developed and successfully utilized at numerous locations. These include artificial wetlands and use of specific plants to remove nutrients and other contaminates. These systems often require large spaces and may not be compatible with most potential sites included in this study.

Non-structural controls include institutional planning and legislative measures, modification of maintenance practices and control of development and natural land conditions. Public education is also an extremely effective control strategy because it can alter private and public policy and behavior. The City of San Angelo has a comprehensive non-structural control program in place. Storm water ordinance and development policies established a department specifically devoted to storm water, along with a comprehensive public education program. In considering non-structural control strategies in this study, the existing procedures shall be examined with additional new or modified strategies recommended.

6.0 Development of the BMP Master Plan

6.1 Non- Structural Control Strategies

Nonstructural controls focus on prevention and include any action with the specific intent to reduce contaminates at the source or to reduce surface water runoff. A multi-faceted approach toward prevention will be needed to achieve a reduction in contaminate generation and/or to treat potential pollutants before they reach local surface waters and to prevent urban flooding. The UCRA developed the North Concho River Urban Runoff/Non-Point Source Abatement Master Plan in 1996 with funds from TCEQ 319(h) project dollars. This Master Plan was given to the City of San Angelo to serve as a guide in the development and construction of several structural control projects. The plan also presented recommendations for non-structural controls with seven categories of suggested controls. A list of suggested categories with status updates for each category and recommendations for improvement follows:

Public Information – The City of San Angelo has a dedicated, comprehensive public information/education program in place based on the BMPs identified in the TCEQ storm water permit requirements. After three years experience with the existing BMPs, the following recommendations to enhance the existing program are being suggested:

-- Media Campaign: The media campaign with the existing program has included educational billboards placed in prominent locations, bookmarks distributed as inserts into monthly water bills (reaching 36,000 households), and radio and newspaper coverage. It is suggested that at least four billboards continue to be on display for two months twice a year. It has been determined that bookmarks are a cost effective way to distribute information to the public. Other recommendations include printed magnets and bumper stickers. Continued focus on the media is essential and should include regular interviews on local TV and radio stations and event coverage in the newspaper.

-- Training for City Officials & Employees: Training was held for the nine city departments most directly related to storm water issues. It is recommended that additional training for other city employees be conducted. All city employees and council members could benefit from general education on storm water components with common language and an understanding of where to begin improvements. At the department trainings it was discovered that there is interest in implementing improvements. After training, it is recommended that each city department report on current practices that are in line with storm water goals and make suggestions with methods for implementing the improvements.

-- Educational Materials: An informational brochure was printed as well as the aforementioned book marks. Materials were distributed by hand and via mail. It was discovered that smaller printed materials with less information are easier to keep up with and more effective. Additionally, both the City of San Angelo and the UCRA have websites with educational information and links available. A more focused look at the websites and use of social media in terms of storm water would be beneficial to the programs to connect those interested in local environmental issues with ways to contribute.

-- School Programming: The UCRA has an extensive partnership with the San Angelo Independent School District (SAISD) and the San Angelo Museum of Fine Arts (SAMFA). This has provided many educational opportunities with students. As a result of these partnerships, thousands of students come through the Water Education Center each year with scheduled field trips and via programs like the Texas Research Institute for Young Scholars and Camp Odyssey. It is recommended that these types of programs and partnerships not only continue, but be expanded for the education of future generations to come.

-- Community Outreach & Involvement: Storm drain marking is currently being implemented using a group of middle school students (Aqua Squad). It is suggested that future marking programs incorporate other community groups. A community wide river clean up was held this past year and as a result it was suggested that two cleanup projects be held annually, focusing on different sections of the river through town. This not only provides aesthetic improvements but gives ownership to the community and builds partnerships with other organizations. Outreach to local homeowners groups, churches and others is also suggested to provide a venue for the education of other adult populations.

-- Partnerships: The UCRA believes that strong partnerships, both in the public and private sector, are vital. It is suggested that partnerships with SAMFA, SAISD and other environmental organizations be continued. It is also suggested that partnerships with local landscaping companies and nurseries be formed to educate these entities as to best practices.

Establishment of an Urban Runoff Control Coordinating Agency – The City of San Angelo currently has a functioning Storm Water Department that serves in this capacity.

City Ordinance Review/Revision - The City has adopted a storm water ordinance that includes a fee schedule to fund the Storm Water Department. Construction and development standards and specifications related to storm water issues are included in the ordinance It is assumed that City staff and administration will continuously evaluate these programs and recommend changes if required.

Enforcement of Existing Ordinances- The Storm Water Department duties include ordinance enforcement.

City Operation and Maintenance Procedure Review- The Storm Water Department currently has the equipment and staff to address this category. There are some initial problems with policy and procedure. The following are improvements to the existing program:

- -- Mowing of grassy waterways should include a protocol that includes a maximum mowing height.
- -- Unless an absolute necessity to increase the capacity of a waterway is warranted, disturbance of the existing soil cover should be avoided. Loose fill should never be left in waterways.
- -- Changes or modifications to waterway channels at/or upstream of the existing storm water sample and monitoring stations should be avoided because of unintended influences on the storm water monitoring program. If changes or modifications cannot be avoided, the UCRA office should be contacted so that adjustments can be made to the monitoring program and, if necessary, automated sampling equipment can be re-programmed.
- -- Street sweeping schedules should be adaptive rather than fixed. Scheduling should be responsive to existent conditions and machinery should be deployed in a timely manner to areas with greatest need.

Material Stockpile and Construction Site Management – City policy has changed considerably in regards to municipal projects and the State has enforced construction site storm water management. The City Storm Water requirements also address this potential problem.

Review of Building Permits and New Subdivision Plans – Current City ordinances and regulations address this control. In addition, the tools provided by this project will assist the Storm Water Department in evaluating additions and changes to the urban watershed.

6.2 Structural Control Alternatives

Structural controls normally require capital outlay, alteration of existing topography or structure, or involve the construction of new structures and devices. There is one characteristic in common, however, structures must be placed in an appropriate location and often require large spaces. Structural controls are usually site driven and must be appropriate to the surroundings. The most likely locations for structural controls are at or near storm water paths and on publically owned land or land that could be publically owned. Potential site selection must also consider the project goals to reduce pollutant loadings and urban flooding. A list of structural control sites has been identified and appropriate alternatives proposed. From the list of potential sites, seven sites have been selected for design development. The list of structural alternatives identified provides a working list of as follows:

Site No. 1 – Sunken Garden Park, south and adjacent to the N. Concho River and west of Bryant Boulevard.

Alternatives: (a) Native water plants treatment system, pump water from river to basin and discharge through existing small waterway. (b) Same except use basin for biological rock filter treatment system.

Site No. 2 – Santa Fe Park and Golf course

Alternatives: Develop wetland pond treatment system. Install high volume pump to circulate water from N. Concho River through a series of wetland ponds and artificial streams, and discharge it back to the river. The ponds and artificial streams would be integrated into the existing golf course and feature an extensively developed aquatic plant system.

Site No. 3 – North Concho River immediately below 14th Street

Alternatives: Construction of in-channel gabion structure to create dry pond impoundment for suspended solid removal.

Site No. 4 – Downtown North Concho River storm water inlets

Alternatives: Size and install package (Vortex Separator) treatment units to treat numerous small volume storm water outfalls.

Site No. 5 – North Concho River, 2100 feet upstream of 14th Street

Alternatives: Construction of concrete dam for controlled release. This alternative would provide an enhanced water environment for the adjacent park including fishing, etc. The controlled release would provide and extend additional normal stream flow and attenuate flood flows downstream. It is estimated that 15 to 20 acre feet of storm water temporary storage could be provided in addition to the normal impoundment.

Site No. 6 – North Concho River, at low dams @ 29th Street, 6th Street and 1st Street

Alternatives: Retrofit these low dams to provide storm water storage (increase elevation) and provide controlled release structures. This will provide and extend normal stream flow and attenuate flood flows downstream by providing temporary storage.

Site No. 7 – Pecan Street, south of Railroad, north of 4th street. Vacant lot

Alternatives: (a) Dry pond with gabion (b) First flush sedimentation and filter bed (c) Wet pond with dry storage capacity

Site No. 8 – 11th Street and Pecan, Vacant lot

Alternatives: (a) First flush dry pond with low gabion (b) Package treatment unit.

Site No. 9 – Two decorative impoundments (Lake A, upstream and B, downstream) located south of the intersection of Van Buren & Greenwood

Alternatives: (a) Retrofit Lake A to include sediment storage area in upper end. (b) Install large package treatment unit or series of smaller units above Lake A.

Site No. 10 – City owned Brentwood Park control structure
Alternatives: (a) To preserve and extend life of existing structure, construct low gabion dry pond on park land above reservoir. (b) Install large package treatment unit upstream of reservoir.

Site No. 11 – Classen Blvd. from North Street to Abilene Street

Alternatives: (a) Construct 20 ft. wide island down center of street, within island construct storm water channel with multiple gabion structures to attenuate flow peaks through storage and discharge (b) Construct 20 ft. wide island down center of street, within island devise underground storm water storage and dewatering system.

Site No. 12 – Santa Rita Park from South Monroe to Madison Street

Alternatives: Substantially increase elevation on existing dam and install controlled release structure to utilize grassy park area adjacent to channel as sedimentation area.

Site No. 13 – West Washington Drive @ Sulfur Draw

Alternatives: Eliminate existing low dam upstream and construct gabion dry pond immediately south of Washington.

Site No. 14- TXDOT property adjacent and North of East-West Throughway immediately downstream of Baptist Memorial complex.

Alternatives: Construct large wet pond with controlled release structure to allow temporary storage of excess storm water. Impounded water would be utilized by Baptist Memorial for irrigation of grounds.

Site No. 15 – East Angelo Draw near the Rio Concho Sports Complex

Alternatives: Construct large wet pond with controlled release structure to allow temporary storage of excess storm water. Impounded water to be utilized as decorative and recreational opportunity for the public.

Site No. 16 – East Angelo Draw between East-West Throughway and Pulliam Street

Alternatives: Within wide floodway at suitable location, construct gabion dam dry pond structure to entrap contaminates and attenuate peak flood flows.

Site No. 17 – Red Arroyo @ South Chadbourne

Alternatives: Immediately below South Chadbourne Bridge, construct large wet pond with controlled release feature to allow temporary storage of excess flood flows. Impounded water could be released downstream or utilized on-site. As an additional alternative, the large volume of storm water passing this site annually could provide potential water supply opportunities for San Angelo.

Site No. 18 – Storm water channels upstream of Southwest Blvd.

Alternatives: Construct series of low gabion structures to entrap contaminates and attenuate peak flood flows.

Site No. 19 – Red Arroyo @ College Hills Blvd.

Alternatives: (a) Construct large gabion dry pond structure above bridge to entrap contaminates and attenuate peak flood flows. (b) Construct large wet pond with controlled release features that allow storage of excess flood flows. Impounded water to be utilized as decorative/recreational feature.

Site No. 20 – Red Arroyo @ numerous points to accentuate and improve planned trail system

Alternatives: Series of small decorative impoundments designed to have no impact on flood elevation with controlled release features and pre-sedimentation structure. The structures will entrap contaminates and mitigate peak flood flows.

Site No. 21 – Red Arroyo @ Knickerbocker Road

Alternatives: (a) Construct large gabion dry pond structure at suitable location upstream of bridge that encompasses all of the floodway. This structure will reduce contaminate loading and help mitigate peak flood flows.

Site No. 22 – Parkview Lake.

Alternatives: Retrofit existing upper portion of lake to provide pre-sedimentation of suspended solids. This provision will improve water quality within lake and allow continued use of the structure as storm water wet pond control feature. Dredging sediment currently in the lake could increase storage by 50%.

Site No. 23 – Sunset Lake

Alternatives: Remove accumulated slit and retrofit existing upper portion of lake to provide a pre-sedimentation basin. This provision will improve water quality within lake and allow continued use of the structure as storm water wet pond control feature. Dredging sediment currently in the lake could increase storage by 75%.

6.3 Alternative Screening

The alternative structural control strategies or methods identified at each site are based on available technologies and obvious site restrictions. In some cases a single alternative has been identified. A list of structural control projects have been developed from the site list and alternatives identified. The screening criterion included the following elements:

- Assumed effectiveness of method to reduce pollutants and urban flooding.
- Probable construction cost.
- Cost of O&M.
- Public acceptability.
- General environmental effects.
- Negative impacts on existing flood elevation.
- Potential beneficial use of storm water.
- Existing or potential funding opportunities for alternative.

6.4 Site Selection for Design Development

During the planning phase of this project it was determined that structural control strategies impacting critical areas experiencing urban flooding or those with critical water quality problems should be explored from a design standpoint. This approach provides the City of San Angelo Storm Water Department with a ready list of projects that identify cost, location, layout, elevation and other engineering factors. The initial proposal included five projects with design development. As result of this study, a total of seven projects were developed and are found in Appendix F. In addition these sites are identified in report section 3.64 Critical locations and situations. It is highly recommended that these projects be considered for priority construction. In addition to the critical elements of the projects selected, other factors have been considered. This includes the likely possibility of grant funding for the project or third party participation in construction.

6.5 Project Design Development

The following sites were selected for design development. Sites are identified with a control strategy and a short summary explaining the reason(s) for inclusion. As these sites were selected for design development and identified by the Engineer, they were assigned storm water structural control numbers (SWSCN) 1-7. These identifications, as used by the engineer, are also identified. In addition to providing design development, the engineer also provided cost estimates for the typical design submitted. Following initial hydraulic modeling of these sites and selection of appropriate design flows for each site, the recommended facilities were updated as to size and project costs. These numbers are provided below and specific redesign data for modeling use is presented in the next report section.

Site No. 3, SWSCN #4 – North Concho River immediately below 14th Street. Construction of an in-channel gabion structure to create a dry pond impoundment for suspended solid removal. This project was included because of its low probable cost, effectiveness and proximity upstream of the stream segment listed as impaired by the TCEQ. Hydraulic modeling indicates that the proposed facility in design development is unfeasible to construct at this site and has therefore been eliminated for consideration.

Site No. 4, SWSCN #5 – Downtown North Concho River storm water inlets. Size and install package (Vortex Separator) treatment units to treat numerous small volume storm water outfalls. This project was also selected because of its probable low cost. In addition, implementation could be accomplished in a staged fashion and would have an immediate water quality effect within the listed stream segment. Final design entails the construction of eight treatment units capable of handling storm water peak flows up to 25 cfs at a cost of $70,000 each. Total cost for this control strategy is estimated at $560,000. It should be recognized that this strategy could be implemented through time.

Site No. 14, SWSCN #6- TXDOT property adjacent and North of East-West Throughway immediately downstream of Baptist Memorial complex. Construct a large wet pond with controlled release structure to allow temporary storage of excess storm water. Impounded water to be utilized by Baptist Memorial for irrigation of grounds and the project could mitigate a portion of the municipal storm water charges. This project was selected due to its potential to reduce Pulliam Draw urban flooding and improve water quality. This project could also be funded with assistance from Baptist Memorial. Staff and management at the facility have recognized the potential for the project and some pre-planning has been done. Cost estimates for this facility are $370, 000.

Site No. 15, SWSCN #7 – East Angelo Draw near the Rio Concho Sports Complex. Construct large wet pond with controlled release structure to allow temporary storage of excess storm water. Impounded water could be utilized as decorative impoundment, recreational opportunity for the public and offers the potential for irrigation of the sports complex. Because of the City owned space available, this site offers the best opportunity to address potential downstream water quality implications with a major project. The project would also be a likely candidate for grant funding. Cost estimates for this facility is $3,163,000

Site No. 17, SWSCN #3 – Red Arroyo @ South Chadbourne. Immediately below South Chadbourne Bridge construct large wet pond with controlled release feature to allow temporary storage of excess flood flows. Impounded water could be released downstream or utilized on-site. This site is privately owned and the owner wishes to participate with the City in developing this facility. It offers a large undeveloped area and suitable typography to provide a large structure to control the sediment load to the South Concho River. Report section 3.66 also describes an alternative beneficial use for this site that falls outside of the parameters of this study. The recommended structural control facility for this site would be sized to control the total flow from a one year frequency storm and store 190 acre feet of water. The cost of the facility is estimated at $ 4,919,000.

Site No. 18, SWSCN #2 – Storm water channels upstream of Southwest Blvd. Construct a series of low gabion structures to entrap contaminates and attenuate peak flood flows. This site has long experienced serious urban flooding problems which are likely to worsen as additional development occurs within the existing sub-divisions and commercial areas. Water quality monitoring at this site indicates excessive contaminant loadings. The proposed control strategy is a cost effective and efficient method of mitigating both problems. The typical design for these structures has been recommended to increase storage by a factor of 1.4. Total cost for the project is estimated at $191,000.

Site No. 20, SWSCN # 1 – Red Arroyo @ numerous points to accentuate and improve planned trail system. Series of small decorative impoundments designed to have no impact on flood elevation with controlled release features and pre-sedimentation structure. The structures will entrap contaminates and mitigate peak flood flows. This ideal strategy can be constructed at several points and will collectively impact both urban flooding and contaminate loadings while providing aesthetic improvements to the flood channel and planned walking trails. These impoundments may also be included in a proposed grant program to develop the trails. It is recommended to construct four of the typical structures down the waterway and it is estimated that the total cost would be $241,000.

6.6 Summary of Design Development Project Modeling

In the previous section, it was stated that the typical designs created during the design development by the engineer are included in Appendix F. Following the initial hydraulic modeling completed by TIAER, each of the sites and typical designs were examined based on the selected design storms. As a result, recommendations were formulated that would be applied to the typical designs and to the water quality and hydraulic modeling of each control strategy. These recommendations included the following, which are also summarized in Appendix A:

Site No. 20, SWSCN # 1 – Use 1 yr. 12 hr. frequency storm. Total rainfall = 1.66 inches, Flow peak = 361 cfs, Total discharge = 83 ac.ft. Utilizing existing typical design, double existing storage pool capacity from 1.045 ac.ft. to 2.09 ac.ft. Assume four (4) units constructed that total 8.36 ac.ft. pool capacity. Modeled as single unit under two conditions: Dry with 24 minute detention time (D.T.) and ½ full with 12 minute D.T.

Site No. 18, SWSCN #2 – Due to existing urban flooding problems use 5 yr. 12 hour storm with total rainfall of 3.06 inches.
South Tributary: Peak flow= 220 CFS, Total flow = 22 ac.ft.
North Tributary: Peak flow= 588 CFS, Total flow = 120 ac.ft.
Combined watershed: Peak flow= 559 CFS, Total flow = 142 ac.ft.
Design: Based on peak flow distribution and growth potential, construct 7 units on North tributary and 5 units on South tributary. Size total dry pond storage capacity to 30% of total storm discharge or 262.918 X 0.3 = 79 ac.ft. This design capacity will result in each single unit having a dry pond capacity of 6.58 ac. ft.
Modeled as single unit on combined watershed. Also assume dry pond dike allows a discharge of approximately 30% of inflow before top of dike breached at pond capacity.

Site No. 17, SWSCN #3 – Use 1 yr. 12 hr. storm event. Total rainfall = 1.66 in., Flow peak = 471 cfs, Total runoff = 282 ac.ft. Structure Design: Wet pond with controlled release weir and spillway. At spillway elevation total storage= 290 ac.ft. At bottom of controlled release weir total storage = 190 ac.ft. Modeled under four conditions: at dry, 25% capacity, 50% capacity and storage pond full capacity.

Site No. 3, SWSCN #4 – Delete this BMP due to excessive flows and existing topography.

Site No. 4, SWSCN #5 – Use 1 yr. 12 hr. storm. Total rainfall = 1.66 in., Flow peak= 440 cfs. Assume 8 Aqua-Swirl units controlling 25% of watershed. Then: 440X.25/8= 13.75 CFS (6,171 gpm) at peak flow. Use 12 ft. diameter unit = 113 sq. ft. then: 6,171/113= 54 gpm/sq.ft. at peak flow. Use removal efficiency/ loading rate curve for modeling of entire storm.

Site No. 14, SWSCN #6 – Use 1 yr. 12 hr. storm. Total rainfall = 1.66 in., Peak flow = 96.64 cfs, Total runoff = 11.1 ac. ft. Utilize existing design of 11.613 ac.ft storage pond with sediment bay. Use hydraulic data from sub-basin 12-A and water quality data from sample station #3.

Site No. 15, SWSCN #7 – Use 1 yr. 12 hr. storm. Total rainfall = 1.58 in., Storm, flow peak = 194 cfs, Total runoff = 77 ac.ft.; utilize design as proposed. Modeled under four conditions: at dry, 25% capacity, 50% capacity and full. (Note that because the drainage area above this site exceeds 10 square miles, which is the maximum area to use point rainfall, the total rainfall was diminished using the relationship in Technical Paper # 40 by the U.S. Department of Commerce.)

7.0 Recommendations and Conclusions

This report describes the on-going data collection and storm water modeling program that the UCRA is currently providing to the City of San Angelo Storm Water Department. In addition, it reports the findings to date and displays the data, observations and modeling results in detail. It also includes a review of the non-structural Storm Water Department organization, protocols and programs with recommendations for implementation. A list of 23 potential sites for structural controls is provided and detailed design development provided for six high priority projects contained within that list.

As a result of the project elements described above, the following overriding conclusions regarding the Storm Water System that presently serves the City of San Angelo have been determined. In addition, appropriate recommendations related to the conclusions are provided.

1. The City of San Angelo has adopted a comprehensive storm water ordinance and established a Storm Water Department and program. These form the basis for a non-structural and low structural program to mitigate storm water problems. These are identified and reviewed within this report and it is obvious that implementation of the ordinance and Department programs will have a positive impact on existing and future problems. In addition, adoption of this Master Plan will provide a comprehensive guide to mitigating existing and future critical storm water problems. In addition to the minor recommendations stated in report section 6.1, the following recommendations are suggested to improve the storm water program.

- The Master Plan should be updated based on a five-year schedule.
- The storm water monitoring and watershed modeling inputs should continue for an additional three years under the supervision of the UCRA. This will insure program continuity and provide for further calibration of the model and additional data for Master Plan updates.
- During the next three years, the UCRA and the City of San Angelo should seek funding for structural control construction from the Texas non-point source program (319-h) and any other funding sources. Several of the recommended BMP's have multiple uses such as recreational, water conservation and beneficial use and as such may qualify for other grant programs in addition to providing water quality benefits.
- Report section 3.66 identifies two potential beneficial use projects that were judged to be beyond the scope of this project. Both of these projects appear to have considerable merit and should be further evaluated.

2. Because of financial, engineering and public acceptability constraints, structural controls are largely site driven. This is particularly true of large projects. This report identifies 23 potential projects that will mitigate storm water urban flooding and/or water quality issues.

- It is recommended that these potential projects be recognized by the Storm Water Department as a "ready" list of future structural controls.
- Seven of the above projects have been subject to design development and efficiency modeling and six of these projects are presented in this report for implementation. As these projects are implemented, it is recommended that the City Storm Water Department continue to provide design development and modeling for additional projects on the list to provide for an on-going program.

3. Serious and widespread water quality and urban flooding problems exists within the City. These problems have been identified in the report as critical sites and situations. Several other sites appear to be approaching critical status and will become problems with increasing development within the City's watershed. It is apparent that non-structural and low structural control strategies alone will not adequately mitigate these critical sites. As stated above, six projects have been subject to design development, efficiency modeling and cost determination.

- It is recommended that the City Storm Water Department prioritize the design development projects and seek the means to implement the highest rated projects. Prioritization criteria should consider funding opportunities, impacts on water quality and urban flooding, water conservation and beneficial use, public acceptability, and O&M costs.

4. From an impact only criteria, the most urgent sites as to water quality and urban flooding within the City of San Angelo are as follows:

Urban Flooding – Southwest Boulevard near Loop 306. Severely inadequate storm water conduit under street causes back-up and impoundment of storm water above crossing and frequent overtopping of roadway. Intense storm events often result in life threatening situations and potential damage to nearby commercial establishments.

Water Quality Impact- There is a tremendous annual loading of sediment, BOD and nutrients being discharged to the South Concho River near the City Water Treatment Plant and Lone Wolf Bridge from Red Arroyo. These contaminates are effecting water quality in Bell Street Reservoir, downstream water quality, the storage capacity of the in-stream reservoir and San Angelo's water supply system.

5. From an impact only criteria, the most urgent developing problem with water quality or urban flooding appears to be Red Arroyo at Knickerbocker Road. With increasing development in this watershed, there appears to be a danger of overloading the storm water conduits under the road, damming of storm flows and eventual overtopping of the roadway.

- Development within this watershed should be carefully considered by the Storm Water Department.
- Appropriate entities should begin planning for possible improvements to the storm water conduits across this roadway.
- Upstream structural controls should be seriously considered by the Storm Water Department.

6. Water quality and loading data collected during this study indicates that there is a correlation between residential development and higher nitrogen values and loadings.

- It is recommended that public education, as a non-structural control, place a higher value on educating home owners and others regarding the proper use of fertilizers.
- Public education planners should determine optimum methods and instructions to help homeowners and others in proper fertilizer use.

APPENDIX A

URBAN MODELING OF SAN ANGELO

SECTION A-1
INTRODUCTION

The primary object of the overall project is to assist City of San Angelo (COSA) in the implementation of a storm water management plan, which includes water quality characterization and hydrologic and water quality modeling of the urban watershed of the city. The desired model is to be an accurate and predictive tool for evaluating water quality and storm flows throughout the city. Also, the model is to allow the assessment of existing conditions throughout the watershed, evaluation of best management practices (BMPs), prediction of stream flow and water quality changes resulting from land use changes in the watershed.

The modeling tasks consist of 1) selection of the appropriate model for predicting storm water flows and water quality, 2) verification of the selected model to storm water flows obtained at monitoring locations operated by the Upper Colorado River Authority (UCRA), 3) development of a water quality modeling component using storm water quality data collected by UCRA, and 4) application of the urban water quantity/quality model to assess various urban BMPs. Each of these four tasks is discussed separately within this appendix.

SECTION A-2
MODEL SELECTION

Selection of the appropriate computer model for urban watershed management depends on the number of factor: 1) answers needed, 2) application of information, 3) physical situation, 4) special considerations required of the model (e.g., such as pressure flow in pipes), 5) available data, and 6) capabilities of the modeler and of the final user (Debo and Reese 2002).

For the project purposes there are four simulation capabilities desired of the watershed model. Some models contain only two or three of these capabilities, though it is highly desirable for this project that the selected model contains all four characteristics. Each characteristic is discussed briefly below:

1. Hydraulics – Hydraulic models are normally used to predict flow elevation, velocities, distribution, and pressures, given flow rates and boundary characteristics as input. Typical hydraulic models include:
   - Typical hydraulic models include: A) Backward models – HEC-RAS and WSPRO and B) Unsteady Models – UNET, SWMM, DAMBRK, AD-ICPR, or DWOPER
2. Hydrology – Hydrologic models are normally used to predict flow rates at various points throughout a watershed or basin, given the typical inputs of rainfall, basin characteristics, and basin structure.
   - Pertinent hydrologic models include: HEC-HMS, HYDROS, SWAT, HSPF, TR-20, PSRM, HYMO, TR-55, ILLUDAS
3. Water Quality – Water quality models, as needed for this project, involve prediction of nutrient and sediment concentrations in storm water runoff. There are a number of

water-quality models, each with specific capabilities and draw backs. Pertinent water quality models include: SWMM, DR3M, SWAT, STORM, HSPF

4. Best Management Practices (BMP) – BMP models are normally used to assess sediment and nutrient load and to predict flows and load reduction under selected BMP scenarios in rural and urban areas.
   - Pertinent models that can assess water quality and hydrology implications of BMPs include: SWAT, HSPF, SWMM.

The first model characteristic, hydraulics, is not a critical requirement for the immediate project needs. A model that includes hydraulics, however, provides future utility and capabilities should the desire or need arise to be able to estimate flow elevations during storm water events. (Note: Operation of the hydraulic characteristic of a model necessitates accurate cross sectional information of along the entire length of waterways and conveyances systems as well as streambed slopes, and this information was not obtained in sufficient detail for this purpose in this project.)

The federal, state and regional water agencies, other institutes, and private firms have developed numerous watershed simulation models. Some models are public domain while others are proprietary. For this project application a public domain model that can be obtained without cost is a requirement. The following three models, HSPF, SWAT, and SWMM, each contain the capabilities for hydrologic, water quality, and BMP simulations, meeting the minimum requirements for the project (Tables A-1 and A-2). SWMM is much better adapted than either HSPF or SWAT for inclusion of information to allow hydraulic predictions should such a need be desired in the future.

Table A-1 Basic information on alternative watershed models

Short ame	Descriptive Name	Model Development Organization & Website
HSPF	Hydrological Simulation Program-Fortran	U.S. Geological Survey (USGS) http://water.usgs.gov/software/HSPF/
SWAT	Soil and Water Assessment Tool	Agriculture Research Services (ARS) http://swatmodel.tamu.edu/
SWMM	Storm Water Management Model	Environmental Protection Agency (EPA) http://www.epa.gov/ednnrmrl/models/swmm/index.htm

Table A-2 Main characteristics of the alternative watershed models

Model	Precipitation Event	Typical Simulation Period	Capability (Water)	Application
HSPF	Continuous	Day to Years	Quality/Quantity	Urban/Rural
SWAT	Continuous	Day to Years	Quality/ Quantity	Agricultural/Rural/Urban
SWMM	Single or continuous	Day to Year	Quality/ Quantity	Urban /Rural

Hydrological Simulation Program - FORTRAN (HSPF) is a comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. HSPF incorporates watershed-scale ARM and NPS models into a basin-scale analysis framework that includes fate and transport in one-dimensional stream channels. It is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The results of a model simulation are a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at any point in a watershed. HSPF simulates three sediment types (sand, silt, and clay) in addition to a single organic chemical and transformation products of that chemical (EPA 2012).

The Agriculture Research Service (ARS) of the U.S. Department of Agriculture (USDA) has developed several watershed models that share certain computational methods. The Simulator for Water Resources in Rural Basins (SWRRB) was developed by modifying and expanding the Chemicals, Runoff, and Erosion from Agricultural Management System (CREAMS) model that simulates hydrology, erosion, nutrients, and pesticides from field-size areas. SWRRB expands CREAMS for applicability to larger more complex watersheds. The SWAT model was developed during the 1990s based largely on expanding SWRRB. SWAT is supported by the USDA ARS Grassland, Soil, and Water Research Laboratory in Temple, Texas (Arnolds et al. 1998; Neitsch et al., 2002a; Neitsch et al., 2002b). SWAT is a river basin or watershed scale model developed to predict the impact of land management practices on water, sediment and agricultural chemical yield in large complex watershed with varying soil, land use and management conditions over long periods (continuous-time) of time (Arnold et al., 1999). SWAT can predict the effect of different management scenarios on water quality, sediment yields, and pollution loading in rural watersheds, though it does also contain an urban component.

The EPA's Storm Water Management Model (SWMM) has been widely applied through the U.S. and Canada, and elsewhere as well. SWMM is a comprehensive hydrologic, hydraulic, and water quality simulation model developed primarily for urban areas (Huber and Dickinson, 1988). Application includes various aspects of planning and design of urban drainage and storm water management facilities and studies addressing nonpoint pollution and related issues. The model was originally developed in 1969-1972 and continues to be periodically updated and expanded (Wurbs and James, 2001).

Among these three candidate watershed simulation models, SWMM was selected because it best meets all four desired characteristics that were listed above. SWMM has capabilities for dynamic rainfall-runoff simulation of single events or long-term (continuous) simulation of multiple events with an emphasis on urban areas, but capabilities for rural areas also. Further, SWMM is a public domain model, with capabilities to simulate typical wet or dry pond BMPs, and it uses a time step of less than one day, which is critical to capturing the dynamics of storm flows for small urban catchments such as needed in the applications of this project.

SECTION A-3
BACKGROUND INFORMATION

To successfully develop separate SWMM models for key areas of the COSA watershed, various types of area-specific information were required. SWMM should be verified through a two-step calibrated and validated process against storm water quantity data collected specifically in the COSA area, which was a major task undertaken by UCRA and explained in the main body of this report. An initial step of the project was to delineate the COSA watershed into sub-basins that included the drainage area above key locations, such as the UCRA operated storm water monitoring locations that were designated as permanent stations. Separate SWMM models were developed for the drainage area of each permanent station. Geographic information system (GIS) soil-type and COSA generated land use/land cover data for sub-basin(s) comprising the drainage areas above permanent monitoring stations became data input to the SWMM model. Storm water quantity and quality data collected by UCRA at the project's permanent stations were used to verify the SWMM model predictions of rainfall runoff at the location of each permanent station

Within this section of Appendix A, the various model input data are discussed, including watershed delineation at the sub-basin level for developing the drainage area above each permanent monitoring station, land use and soils data at the sub-basin level, and rainfall data available at most permanent monitoring stations. Also, the storm water quality and quantity data used for verification of SWMM models are provided in summary.

A-3.1 Watershed Delineation

An initial step for the project was to delineate the COSA area into appropriate sub-basins. Watershed delineation into sub-basins was implemented using ArcSWAT based on Digital Elevation Models (DEMs). The characteristics of the Tom Green County DEMs used for the delineation were 30-meter resolution in the format of Spatial Data Transfer Standard (SDTS), produced by the National Mapping Program of the U.S. Geological Survey (USGS) and obtained from Geo Community (2012). Through defining outlets and inlets, a detailed stream network within the watershed was developed. A sub-basin outlet is the point where streamflow exits the sub-basin area (i.e., the most downstream location of the sub-basin). The sub-basin delineation for the COSA watershed was based on defining outlets that included the 10 permanent monitoring stations, 12 temporary monitoring stations, and 23 other points of interests (Figure A-1). Also included on Figure A-1 is the location of seven potential BMP sites. The detailed information of 10 permanent sites, 12 temporary sites, and 7 BMPs are shown in Table A-3.

A-3.2 Land Use Categories for Modeled Sub-Basins

The land use categories provided by the City of San Angelo for the 35 sub-basins selected for detailed modeling are summarized in Table A-4 (COSA, 2010). Excluding the vacant area category, residential (low density and single-family detached; 17.8%), agriculture (cultivated land; 16.9%), and public and semi-public (8.5%) have the first, second, and third highest percent value, respectively. Impervious cover categories also provided by the City of San Angelo are provided in Table A-5. The land use data for each sub-basin are used as input to SWMM. Also, these land use data were aggregated into low, medium, and high categories for developing the multiple regression equations to define water quality input to SWAT. The impervious area data were used for to define percent of impervious area and percent of runoff routed between sub-areas as inputs in SWMM model. The pavement areas in Table A-5 were delineated by lines, and areas were computed using the proximity function of Analysis Tools in ArcToolbox. Appendices B and C contain the detailed land use and impervious area information of the entire project area.

Table A-3 Basic information on permanent and temporary monitoring sites and BMP sites

Sites	Description	Coordinates Latitude (deg min. sec.)	Longitude (deg min sec)	Comments
1	East Angelo Draw at Preusser St	31 27 59.5	100 24 32.00	Permanent
2	Red Arroyo at COSA WTP	31 26 45.73	100 25 37.75	Permanent
3	North Concho at Houston Harte (US 67)	31 27 57.76	100 26 52.68	Permanent
4	Sulphur Draw at Washington St	31 27 9.78	100 26 52.14	Permanent
5	Police HQ Drainage at E. Beauregard	31 27 51.84	100 25 46.5	Permanent
6	Avenue R Drainage	31 26 14.40	100 26 7.50	Permanent
7	Red Arroyo at Knickerbocker Rd	31 25 30.40	100 27 48.52	Permanent
8	SW Blvd Drainage	31 25 23.46	100 29 41.40	Permanent
9	Red Arroyo at Sherwood Way (US 67 S)	31 26 16.23	100 29 36.76	Permanent
10	East Angelo Draw at Upton St.	31 28 30.33	100 25 3.93	Permanent
A	Van Buren Ponds Inlet	31 28 23.71	100 28 26.01	Temporary
B	Brentwood Pond Inlet	31 28 4.87	100 27 58.82	Temporary
C	11th street BMP Inlet	31 28 6.52	100 26 54.68	Temporary
D	Oakes & Avenue N Drainage	31 26 40.67	100 25 56.86	Temporary
E	Foster Road Drainage	31 25 10.78	100 27 24.62	Temporary
F	Parkview Lakes Inlet	31 25 22.69	100 28 23.85	Temporary
G	Green Meadow Dr Drainage	31 25 19.28	100 29 58.65	Temporary
H	GAFB Drainage	31 27 0.26	100 23 29.29	Temporary
I	Concho River at Bell St	31 27 13.88	100 24 48.71	Temporary
J	Lakeview Park Pond Inlet	31 29 18.48	100 26 53.29	Temporary
K	East Angelo Draw at 28th St	31 29 31.14	100 25 31.09	Temporary
L	Red Arroyo at Jackson St	31 25 33.49	100 26 45.76	Temporary
1	Red Arroyo below Sherwood Way	31 26 10.68	100 29 6.60	BMP
2	South West Draw	31 25 20.94	100 30 1.32	BMP
3	Red Arroyo Immediately below Chadbourne Street	31 26 16.92	100 25 53.82	BMP
4	Concho River below 14th Street	31 27 53.94	100 27 23.64	BMP
5	Proposed for 8 Locations in Downtown Watershed	31 27 28.92	100 26 4.14	BMP
6	Proposed below Baptist Memorial on TxDot Property	31 28 35.70	100 25 29.28	BMP
7	Pulliam Draw @ Sports Complex	31 27 16.44	100 24 3.54	BMP

Table A-4 Summary of land use categories for 35 modeled sub-basins (Source: COSA, 2010)

Land Use Categories	Area(acres)	Percentage of Area (%)
Agriculture (cultivated land)	5,656	16.49%
Agriculture_Commercial (ranches, dairies)	37	0.11%
Agriculture_Residential (3-10 acre lot with house)	1,606	4.68%
Commercial	957	2.79%
Industrial, Heavy	753	2.20%
Industrial, Light	428	1.25%
Mobile Home (individual)	150	0.44%
Mobile Home Park	52	0.15%
Office	159	0.46%
Parking Lot Offsite	74	0.22%
Parks_Recreation	2,049	5.97%
Public_Semi-Public	2,886	8.41%
Residential, High Density (apartments)	343	1.00%
Residential, Low Density (single-family detached)	6,310	18.39%
Residential, Medium Density (townhouse, duplex)	301	0.88%
Retail_Personal Services	920	2.68%
Two Single-Family on One Lot	20	0.06%
Vacant	11,604	33.83%
Total	34,305	100.00%

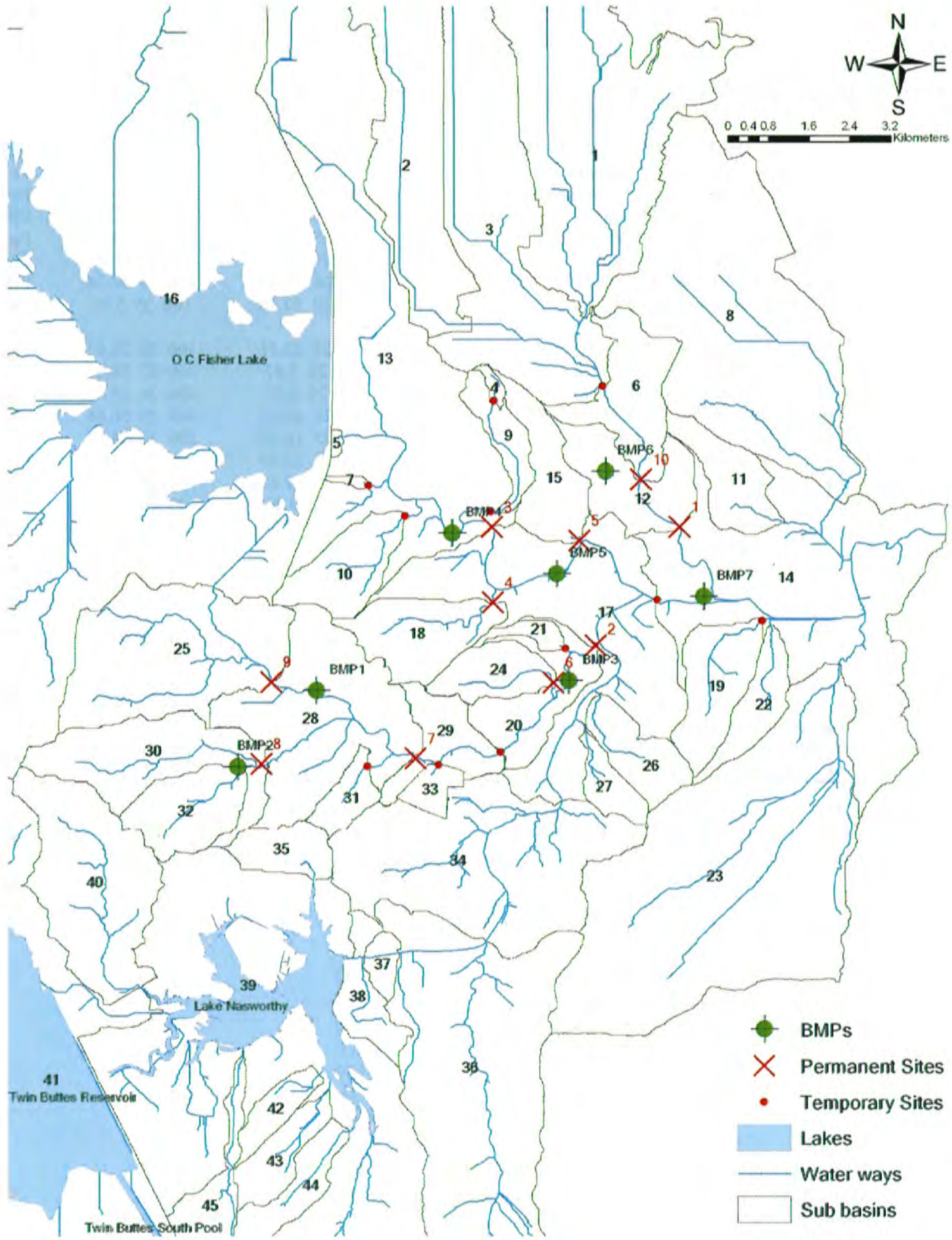


Figure A-1. Sub-basin delineation of City of San Angelo and adjacent watershed areas

Table A-5 Summary of impervious categories for modeled sub-basins

Impervious Area Categories	Area(acre)
Building Footprints	2,736.77
Non residential	2,540.72
Pavement	3,189.14
Total	8,466.63

Source: Impervious GIS Data from City of San Angelo (2010)

A-3.3 Soil Type Area Categories for Modeled Sub-basins

The soil type categories for the 35 modeled sub-basins along with area and hydrologic soil group information are summarized in Table A-6. The soils data were obtained from the U.S. Department of Agriculture - Natural Resources Conservation Service (NRCS) detailed soil survey information, Soil Survey Geographic (SSURGO). The soil information (e.g., sandy loam, clay loam, silt clay) and the associated hydrologic soil group are used to define the suction head, conductivity, and initial deficit values in Green-Ampt infiltration method in SWMM model. An (Angelo clay loam), Km (undulating cho association), and Me (mereta clay loam) have the first (27.95%), second (9.98%), and third (9.43%) highest percent values of all soil types, respectively. Appendix D contains the detailed soil type information of the thirty-five sub-basins selected for detailed modeling.

Table A-6 Summary of soil type categories in San Angelo area

Symbol	Unit Name	Area (acres)	Hydrologic Soil Group
AmC	Miles fine sandy loam, 3 to 5 percent slopes	62.4	B
AnA	Angelo clay loam, 0 to 1 percent slopes	14583.2	C
AnB	Angelo clay loam, 1 to 3 percent slopes	896.3	C
AoA	Angelo silty clay, 0 to 1 percent slopes	0.0	C
AoB	Angelo silty clay, 1 to 3 percent slopes	0.0	C
AuB	Angelo-Urban land complex, 0 to 3 percent slopes	2447.8	C
BeD	Berda loam, 3 to 8 percent slopes	67.0	B
CF	Cut and fill,	75.1	-
CLP	Pits, caliche	423.0	-
CoB	Cobb fine sandy loam, 1 to 3 percent slopes	170.7	B
CsD	Oben-Latom complex, 1 to 8 percent slopes	129.3	C/D
DAM	Dams	85.8	-
Dr	Dev and Rioconcho soils	0.0	A/C
EcC	Ector association, undulating	0.0	D
EcE	Ector association, hilly	25.8	D
EsA	Estacado loam, 0 to 1 percent slopes	0.0	B
EsB	Estacado loam, 1 to 3 percent slopes	0.0	B
KaA	Kavett clay, 0 to 1 percent slopes	0.0	D
KaB	Kavett clay, 1 to 3 percent slopes	0.0	D
KmC	Cho association, undulating	5528.4	C
KoD	Cho-Vernon complex, 1 to 8 percent slopes	840.4	C/D
KuD	Cho-Urban land complex, 1 to 8 percent slopes	2940.9	C/D
Lc	Lipan clay	431.0	D

Symbol	Unit Name	Area (acres)	Hydrologic Soil Group
MeA	Mereta clay loam, 0 to 1 percent slopes	3730.0	C
MeB	Mereta clay loam, 1 to 3 percent slopes	1490.7	C
MuB	Mereta-Urban land complex, 0 to 3 percent slopes	1381.6	C/D
OlA	Sagerton clay loam, 0 to 1 percent slopes	4106.0	C
OlB	Sagerton clay loam, 1 to 3 percent slopes	83.7	C
OuB	Sagerton-Urban land complex, 0 to 3 percent slopes	210.2	C/D
Rn	Rioconcho clay loam	0.0	C
Rs	Rioconcho and Spur soils	4038.0	B/C
RtA	Rotan clay loam, 0 to 1 percent slopes	440.9	C
ShB	Slaughter clay loam, 1 to 3 percent slopes	0.0	C
SkA	Slaughter-Cho complex, 0 to 1 percent slopes	4525.7	C
SLF	Sanitary landfill 267 *	236.9	-
SuA	Slaughter-Urban land complex, 0 to 1 percent slopes	685.0	C/D
TaC	Tarrant association, undulating	39.4	D
TaE	Tarrant association, hilly	414.0	D
ToA	Tobosa clay, 0 to 1 percent slopes	535.2	D
ToB	Tobosa clay, 1 to 3 percent slopes	49.6	D
TuA	Tulia loam, 0 to 1 percent slopes	472.7	B
TuB	Tulia loam, 1 to 3 percent slopes	2594.9	B
TuC	Tulia loam, 3 to 5 percent slopes	140.7	B
TvC	Tulia-Urban land Complex, 0 to 5 percent slopes	941.2	B/D
Ur	Urban land	227.2	D
W	Water	326.4	-

Source: NRCS Soil Survey Geographic (SSURGO) Data (2012)

A-3.4 Measured Rainfall at Permanent Monitoring Sites

Rainfall is the driving input data to the SWMM model as those data are processed by the model to simulate the time-history of storm water flow and quality. Measured rainfall data collected by UCRA at 1- or 15-minutes time intervals was used as model input for the model calibration and validation process and for evaluation of potential BMPs. The measured rainfall data were collected using a tipping bucket gage located with the automated storm water monitoring instrumentation all but two of the permanent stations (Table A-7). While the rainfall gage density is very good with this project, the rainfall input data to SWMM can only be considered as estimations of the average rainfall in the drainage area above permanent stations because of the pronounced spatial variability of rainfall within a storm event.

Table A-7 Basic statistics for total cumulative rainfall by event at each permanent station for June 2010-March 2012

Site	No. of Events	Total Cumulative Event Rainfall(in) Min.	Max.	Median	Mean
1	22	ND	ND	ND	ND
2	22	0.01	3.73	0.84	1.01
3	18	0.03	3.18	0.40	0.71
4	29	0.08	4.01	0.44	0.82
5	18	0.09	5.01	0.80	1.20
6	24	0.05	3.51	0.40	0.64
7	19	ND	ND	ND	ND
8	29	0.04	4.19	0.35	0.67
9	15	0.05	3.87	0.53	1.0
10	11	0.43	4.27	1.43	1.66

ND – No Data; due to obstructions and interferences, a rain gage was not installed at the site.

Rainfall data at site 9 is available after May 2011.

A-3.5 Channel Characteristics and Measured Runoff

The channel geometry, Manning's n coefficient and slope were used with Manning's Equation to compute the runoff based on measured depth. The channel characteristic information used for computing the runoff at each site is shown in Table A-8. Basic statistics analysis at all sites is performed as shown in Table A-9. The detailed runoff information is provided in Appendix E.

Table A-8 Channel characteristics at 10 permanent monitoring sites

Site	Slope (ft./ft.)	Manning's n value	Dimension (ft.)	Shape
1	0.02	0.045	40 top (T), 8.5bottom (B), 4.5 height (H)	Trapezoidal
2	0.01	0.05	22width (W)	Rectangular
3	0.01	0.04	130W	Broad Crest
4	0.01	0.03	18W	Rectangular
5	0.01	0.02	12W(2 square)	Rectangular
6	0.015	0.05	66T, 23B, 4.5H	Trapezoidal
7	0.01	0.07	55T, 10B, 4.5H	Trapezoidal
8	0.005	0.05	128.69T, 37.06B, 9.053H	Rectangular (H<2)+Trapezoidal (H>2)
9	0.01	0.10	55W	Rectangular
10	0.005	0.045	125W	Rectangular

1. Due to the modification of channel geometry at site 6 after April 2011, the initial channel geometry (44T, 6B, 5.5H) was changed into 66T, 23B, 4.5H.
2. Channel geometry at site 8 that was surveyed by the city of San Angelo is used.

Table A-9 Basic runoff event statistics for permanent monitoring sites (Estimated using water depth and channel characteristic information for June 25, 2010 to March 08, 2012 storm events)

		Total Runoff (10^3 ft^3)			
Sites	Events	Min.	Max.	Median	Mean
1	22	4.09	5,489	600	1,046
2	22	0.05	45,231	7,226	12,323
3	18	173.09	42,269	4,935	9,084
4	29	0.08	5,890	712	1,436
5	18	22.23	2,805	254	630
6	24	45.41	6,093	323	745
7	19	82.73	53267	8339	14,388
8	29	0.84	6,117	388	957
9	15	29.62	50,656	3,830	11,436
10	11	11.64	3,603	1,231	1,345

SECTION A-4
SWMM MODEL WATER QUANTITY VERIFICATION

A-4.1 Verification Approach

Separate SWMM models were developed for the drainage areas above most permanent sites with an emphasis given to those sites near or collocated with potential BMPs that were to be evaluated as part of this project. Each SWMM model was verified against storm water hydrograph data collected at each site. For the purposes of this study, the small rainfall events were excluded from use in the verification process, and the focus was on the larger sized runoff events. The reason for this decision was to focus efforts on those events most meaningful to the project objective of evaluating BMPs for design storms of 1-year or 5-year return frequency.

SWMM operates on a smallest unit of area called a subcatchment, and subcatchments are connected from upstream to downstream by a network of conveyance channels and conduits. For the SWMM application to the San Angelo area, the delineated sub-basins were made equivalent to SWMM's subcatchments, and these areas were connected by approximating in the model the actual drainage and conveyance systems.

Model verification consists of determining the accuracy and robustness of the model through a two-step process of calibration followed by validation. During the calibration step the SWMM model for each site's drainage area was operated to simulate storm water runoff for a predetermined set of the monitoring events captured at the site for which there was also rainfall data. During the calibration process the simulated SWMM results, especially peak flow and storm volume, were compared to the measured data. Adjustments to the SWMM input parameters that describe the landscape were made to improve the visual comparison of model results to measured data. While measured rainfall data undoubtedly contained inaccuracies regarding representativeness for the drainage area above each site, these data were not adjusted; mainly because there was not a framework for evaluating possible non-representativeness of those data. During both the calibration and verification process, it was understood that the measured rainfall data most likely underrepresented the true average rainfall over each drainage area in some instances, overrepresented the true average in other instances, and for some events reasonably represented the true average. Therefore during the calibration process, it was anticipated that the model should both over-predict and under-predict storm water peaks and volume on some events. A consistent pattern of over- or under-prediction was justification for adjusting input landscape parameters in SWMM.

Once an acceptable calibration was obtained, the SWMM model was operated for the storm events reserved for the validation step, and a comparison of simulated and measured data are made for these events. If the SWMM model is sufficiently robust, then the validation results should be comparable in accuracy to those results from the calibration step. In many instances, the validation results were, however, not as accurate as the calibration results. Such occurrences of poorer validation results indicate that the calibration step may have departed into a curve fitting exercise and did not capture the true mechanisms and physical processes sufficiently to allow the model to accurately predict storm hydrographs over a wide range of storm conditions.

In this common situation of unacceptably poor validation-step results, the model was then "calibrated" to the validation storm data and "validated" to the calibration step data. At this point, a model with sufficient accuracy and robustness was obtained. For the SWMM verification process, TIAER had to resort to this final step to obtain an appropriately robust model of each desired permanent site. This first verification used measured storm events from June 25, 2010 through January 10, 2011.

Finally, in the last months of the project, the models were re-verified using additional storm events captured by UCRA from January 11, 2011 to March 10, 2012 (Table A-10). It was at this juncture in the model verification process that a sufficient number of storm events existed at the permanent monitoring stations to allow the smaller runoff events to be excluded from consideration. By excluding the smaller events, this enabled the process to focus on optimizing model performance for the size events most meaningful to the objective of evaluating BMPS with design storm events of either 1-year or 5-year return frequency.

A-4.2 Model Verification Results

Visual inspection of peak flows and total storm volumes was used to optimize SWMM model results providing the models as they presently exist for the drainage areas of permanent monitoring sites 1-10. The model results and measured hydrograph data for the larger runoff events used in the verification process are summarized in Table A-10 and presented graphically in Figures A-2 through A-20. The approach taken in verifying model predictions at each of the 10 permanent monitoring stations was to give somewhat greater emphasis to matching predictions to measured flows for the largest event, which occurred August 13 and 14, 2011 and had rainfall amounts ranging from 3 to 5 inches. In the final verification the simulated August 2011 peak flows were over predicted whereas the simulated peak flow for the other selected events was under predicted more times than not. As discussed above under the Verification Approach (Section A-4.1), because of the actual rainfall in the drainage area above each site was not precisely known, the expectation of the verification process was that some events would be over predicted and others under predicted. Permanent site 5 provided the greatest difficulties to successful verification with the large August 2011 event predicted peak flows and volumes much larger than the measured (Table A-10 and Figure A-10). At all other sites except site 5 the measured peak flow of the August 2011 event was by far the greatest, but at site 5 of the four large events used in verification the July 2010 event had a higher measured peak and the October 2010 had a peak of similar value. While there is no indication of failed measurements for August 2011 event, perhaps an undetected equipment malfunction occurred. Predicted and measured storm flow peaks were in good agreement at site 8 (Table A-10 and Figures A-15 and A-16). Other sites had SWMM predictions that fell between the extremes of the poor results and site 5 and the good results at site 8. Given the complexities of stormwater runoff and variability of the true rainfall over a drainage area, the SWMM simulations at all but site 5 were visually graded as being fair to good.

Table A-10 Median and Large Storm Events Used for SWMM Verification

Site	Events	Verification Event Periods	Peak Flow		Total Volume	
			Measured	Simulated	Measured	Simulated
1	1	8/24/10 9:45 AM to 08/26/10 00:00 AM	108	143	26	46
	2	10/23/10 6:00 AM to 10/24/10 12:00 PM	98	69	22	30
	3	6/21/11 16:30 PM to 06/22/11 19:00 PM	70	120	18	16
	4	8/13/11 9:15 AM to 8/14/11 8:30 AM	807	1,000	127	252
	5	10/08/11 10:00 AM to 10/09/11 23:00 PM	157	256	59	80
	6	01/24/12 20:00 PM to 01/26/12 23:00 PM	52	81	39	41
	7	02/12/12 23:00 to 02/20/12 2:00 AM	92	68	55	64
2	1	08/13/1106:00 AM to 08/17/11 19:00 PM	1,254	1,800	1,129	1,045
	2	10/08/11 08:00 AM to 10/11/11 17:00 PM	833	401	894	431
	3	01/24/12 14:30 PM to 01/30/12 02:00 AM	411	169	604	296
	4	03/08/12 22:00 to 03/10/12 09:15 AM	256	108	175	117
3	1	6/25/10 12:30 PM to 7/7/10 12:00 AM [ξ]	169	158	245	188
	2	7/9/10 7:30 AM to 7/11/10 12:00 AM	292	451	157	70
	3	8/24/10 11:30 AM to 8/25/10 12:00 PM	561	496	273	108
	4	9/24/10 00:00 AM to 9/27/10 12:00 AM	339	452	117	90
	5	10/23/10 12:00 AM to 10/25/10 12:00 AM	615	263	228	48
	6	08/13/11 09:15 AM to 08/14/11 13:00 PM	2,355	2,614	914	520
4	1	6/25/10 13:30 PM to 7/12/10 12:00 PM	145	40	121	62
	2	8/24/10 17:00 PM to 8/25/10 12:00 PM	301	249	63	31
	3	09/24/10 12:00 AM to 09/27/10 06:00 AM	324	264	65	37
	4	10/23/10 00:00 AM to 10/24/10 12:00 PM	388	380	70	39
	5	05/20/11 00:00 AM to 05/20/11 14:00 PM	195	48	16	6
	6	06/21/11 14:00 PM to 06/22/11/ 05:00 AM	112	114	9	15
	7	08/13/11 09:30 AM to 08/13/11 22:00 PM	1,085	1,264	135	158
	8	10/08/11 06:00 AM to 10/09/11 18:00 PM	167	202	81	50
	9	01/24/12 16:00 AM to 01/26/12 13:00 PM	121	58	67	32

Site	Events	Verification Event Periods	Peak Flow Measured	Peak Flow Simulated	Total Volume Measured	Total Volume Simulated
	10	02/12/12 12:00 PM to 02/19/2012 12:00 PM	145	109	86	51
	11	03/08/12 18:00 PM to 03/10/21 15:30 PM	136	25	41	15
5	1	6/25/10 12:00 PM to 7/7/10 8:30 PM [ξ]	94	37	68	47
5	2	7/8/10 10:00 AM to 7/12/10 12:00 PM	321	281	64	46
5	3	10/23/10 06:00 AM to 10/23/10 18:00 PM	185	191	16	30
5	4	08/13/11 01:00 AM to 08/15/11 09:45 AM	256	1,423	64	165
6	1	7/7/10 10:06 AM to 7/11/10 06:00 AM	116	113	43	8
6	2	8/24/10 15:45 PM to 08/25/10 07:00 AM	115	152	25	12
6	3	09/24/10 16:00 PM to 09/26/10 01:00 AM	105	70	22	6
6	4	10/23/10 06:15 AM to 10/23/10 23:45 PM	178	170	29	14
6	5	08/13/11 00:00 AM to 08/14/11 18:00	560	620	140	51
6	6	11/08/11 00:00 AM to 11/08/11 12:00 PM	62	114	6	2
6	7	01/09/12 00:00 AM to 01/09/12 14:00 PM	40	51	7	4
6	8	01/24/12 14:15 PM to 01/26/2012 06:00 AM	23	39	9	13
7	1	05/20/11 01:00 AM to 05/22/11 10:00 AM	284	28	221	43
7	2	06/21/11 15:00 PM to 06/22/11 17:15 PM	282	26	90	28
7	3	08/11/11 22:00 PM to 08/16/11 05:00 AM	1,121	1,826	1,132	785
7	4	01/24/12 12:15 PM to 01/29/12 00:00 AM	410	141	761	245
7	5	03/08/12 22:00 PM to 03/10/12 10:30 AM	336	90	371	96
8	1	8/24/10 10:45 AM to 8/28/10 00:00 AM	101	98	25	27
8	2	9/24/10 16:00 PM to 9/26/10 06:00 AM	312	252	50	57
8	3	10/23/10 00:00 AM to 10/25/10 10:30 AM	268	287	52	55
8	4	08/12/11 00:00 AM to 08/15/11 11:45 AM	1,111	1,203	140	256
8	5	10/08/11 06:00 AM to 10/12/11 23:45 PM	124	78	75	58
8	6	01/08/12 23:00 PM to 01/09/12 12:30 PM	64	30	15	8
8	7	01/24/2012 12:00 PM to 01/28/12 11:00 AM	103	62	71	38
8	8	03/08/12 12:00 PM to 03/10/12 10:45 AM	71	36	20	19
9	1	05/19/11 12:00 PM to 05/21/11 00:00 AM	126	91	22	41
9	2	06/21/11 04:30 AM to 06/22/11 19:00 PM	131	43	19	16
9	3	08/13/11 08:30 AM to 08/15/11 12:00 PM	767	871	280	195
9	4	10/08/11 08:00 AM to 10/10/11 10:00 AM	346	270	231	134
9	5	02/12/12 20:00 PM to 02/19/12 22:00 PM	75	148	33	107
9	6	03/08/12 19:00 PM to 03/11/12 11:00 AM	108	88	44	44
10	1	8/24/10 9:45 AM to 08/26/10 00:00 AM	165	72	28	18
10	2	10/23/10 6:00 AM to 10/24/10 12:00 PM	235	22	65	8
10	3	8/13/11 9:15 AM to 8/14/11 16:00 PM	636	636	95	147
10	4	10/08/11 10:00 AM to 10/09/11 23:00 PM	176	55	47	31
10	5	02/16/12 20:00 PM to 02/19/12 03:45 AM	116	19	61	11

[ξ] This June-July 2010 period contained several storm events used for SWMM calibration.

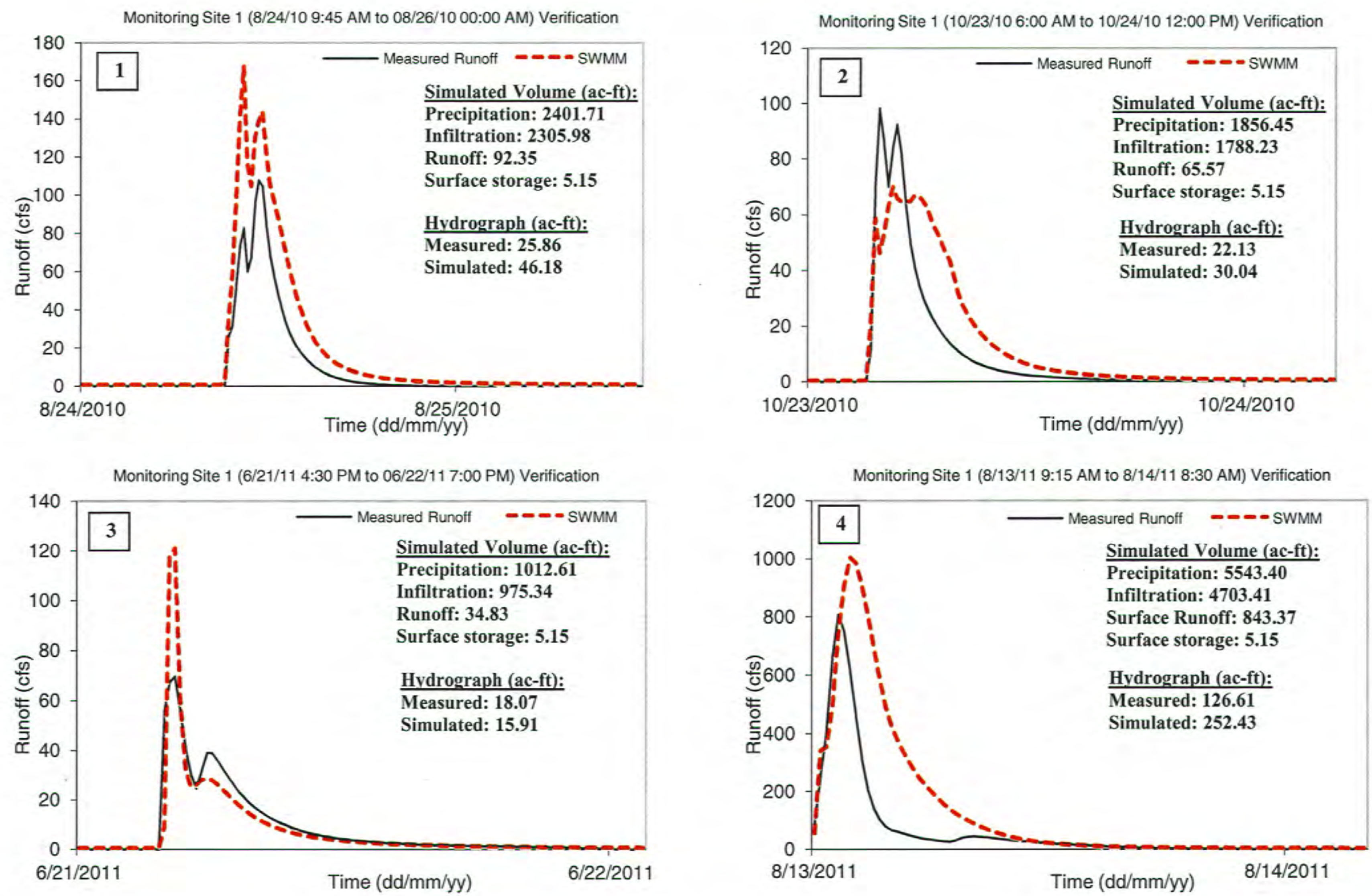


Figure A-2. Comparison of measured and predicted storm hydrographs at Site 1 (Events 1-4)

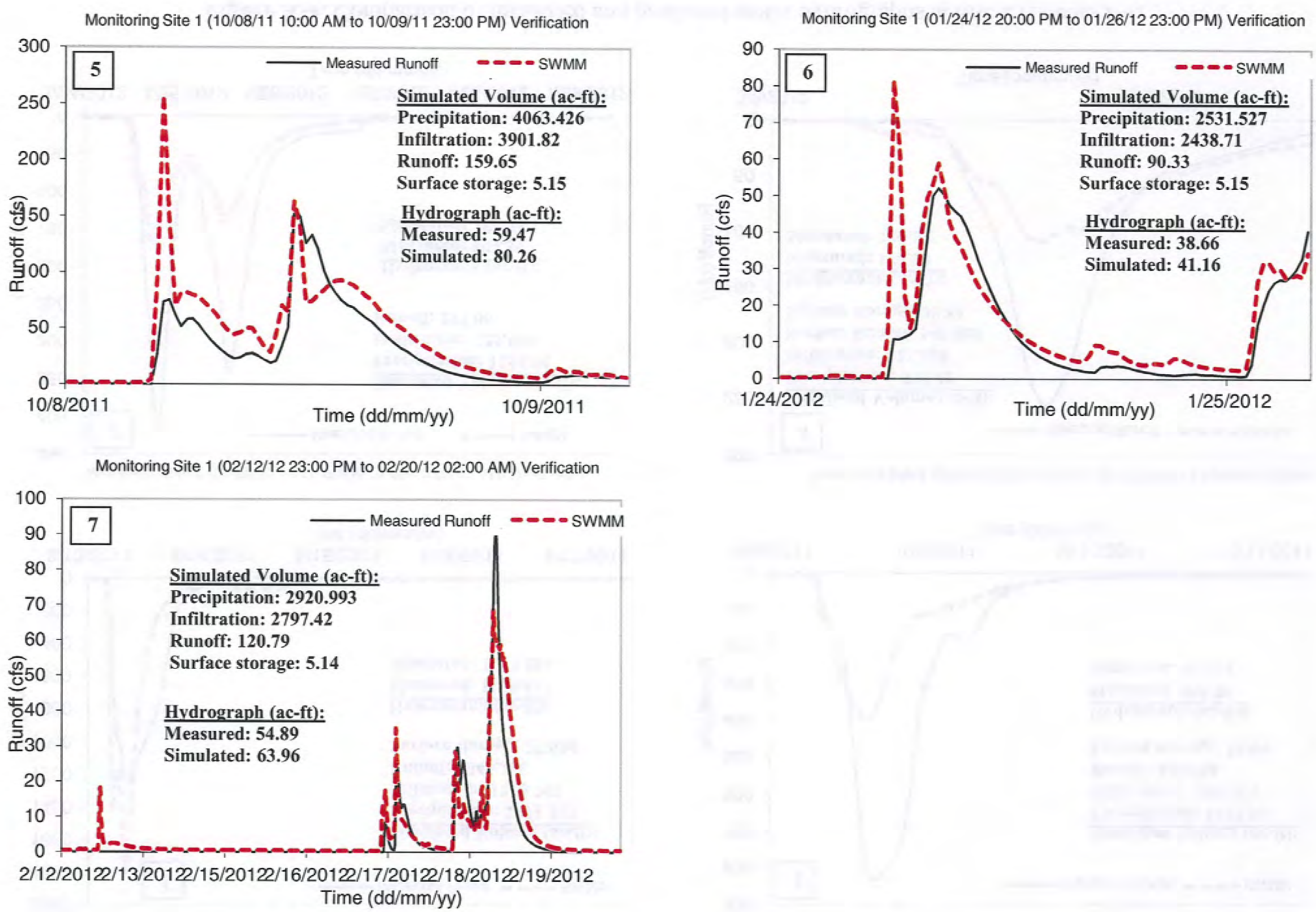


Figure A-3. Comparison of measured and predicted storm hydrographs at Site 1 (Events 5-7)

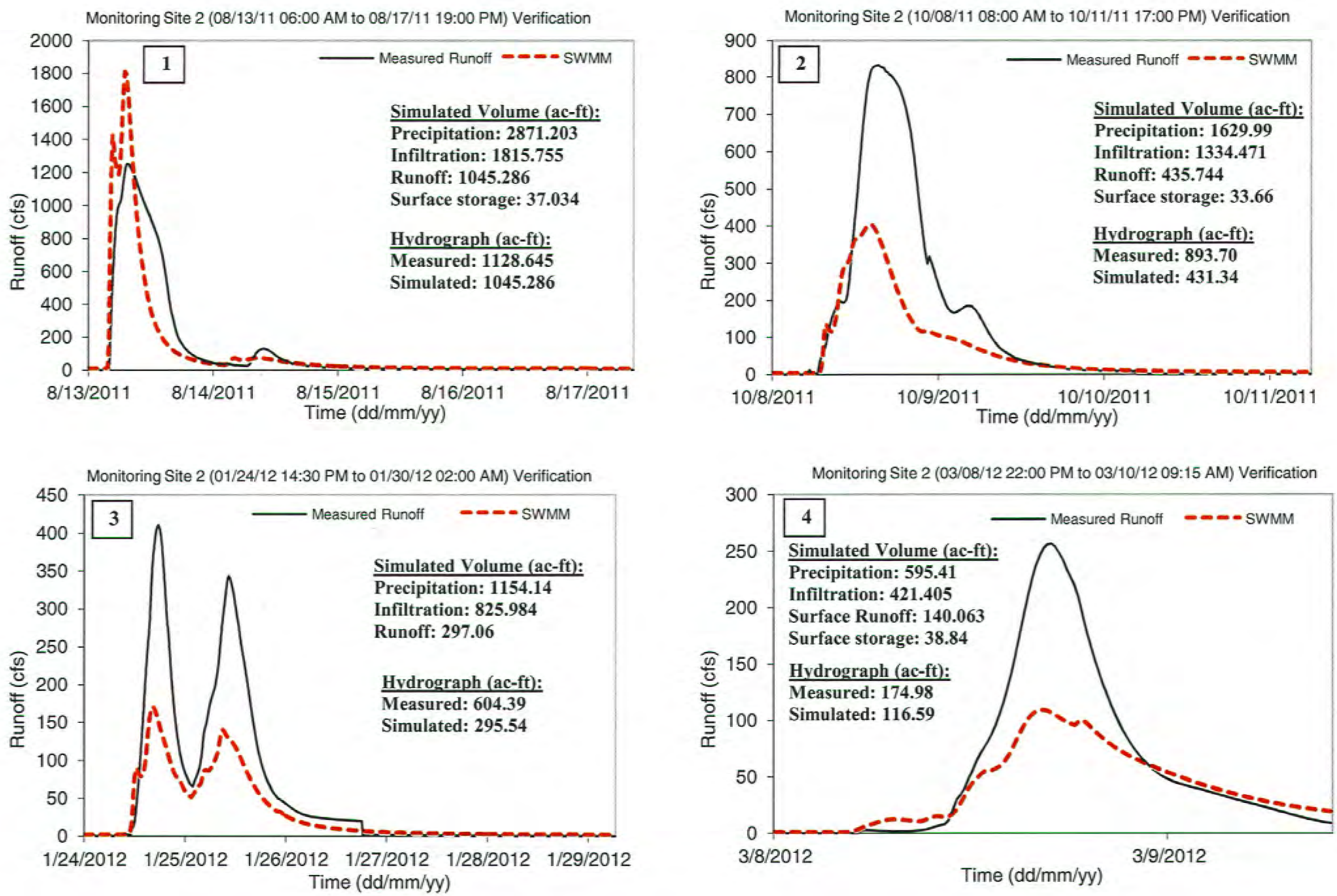


Figure A-4. Comparison of measured and predicted storm hydrographs at Site 2 (Events 1-4)

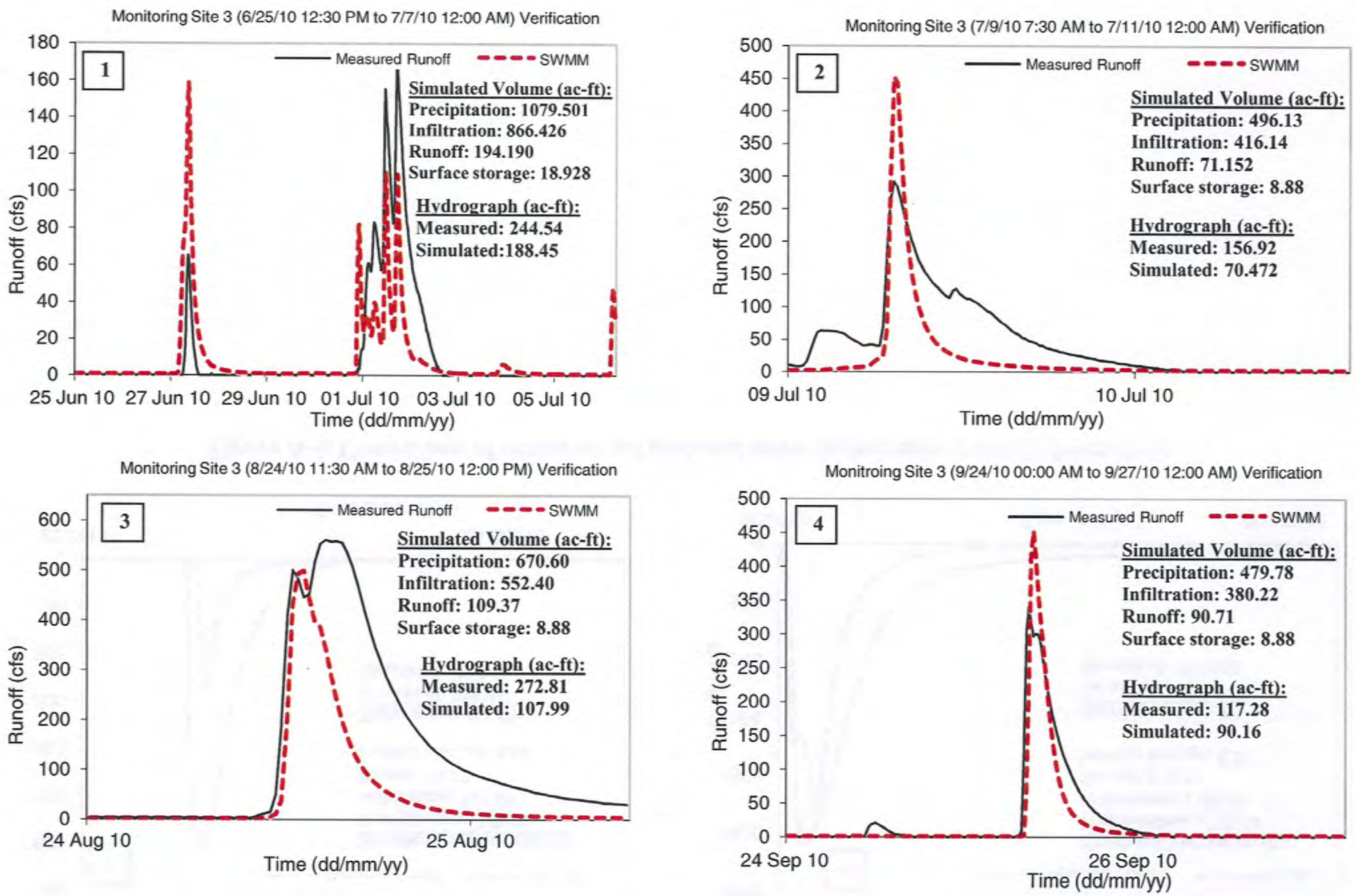
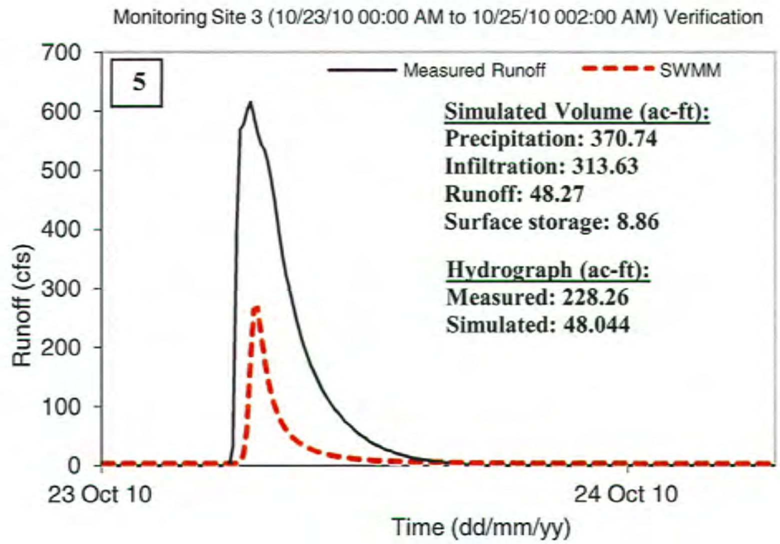


Figure A-5. Comparison of measured and predicted storm hydrographs at Site 3 (Events 1-4)



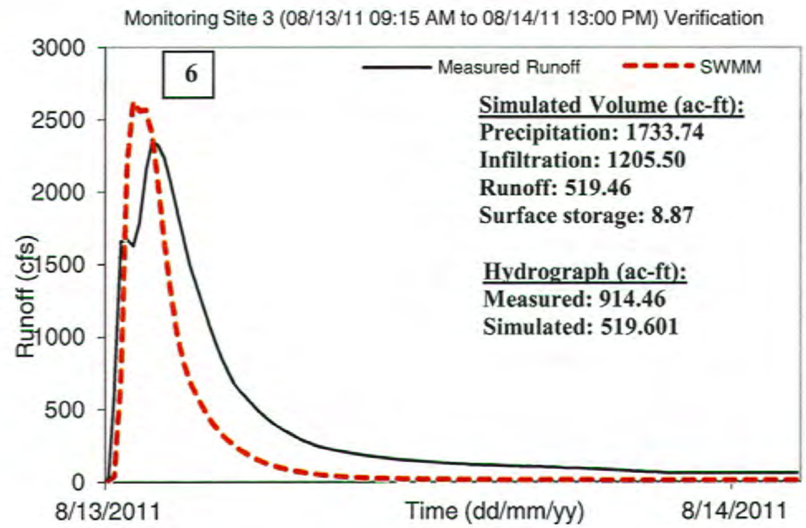


Figure A-6. Comparison of measured and predicted storm hydrographs at Site 3 (Events 5-6)

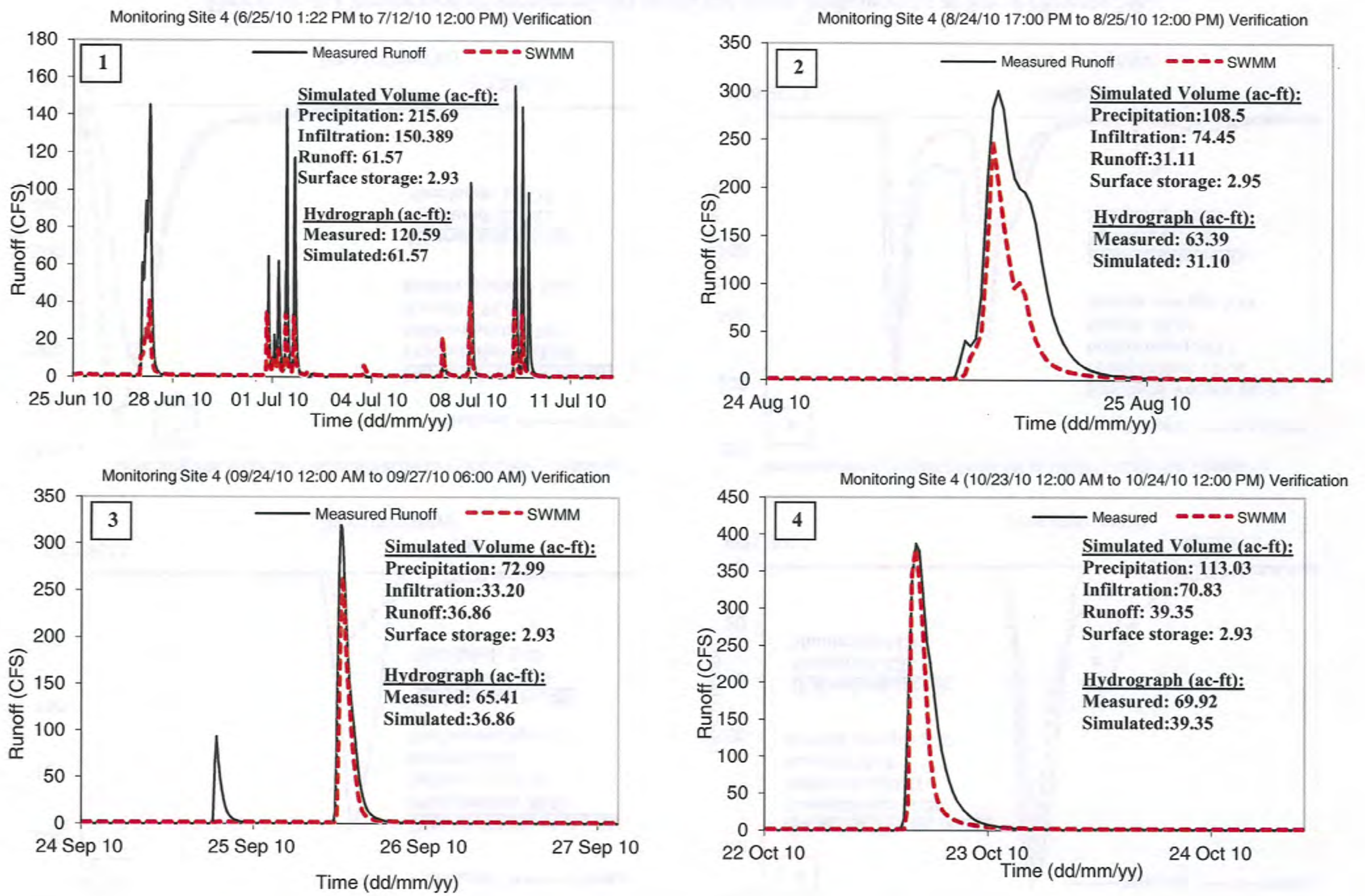


Figure A-7. Comparison of measured and predicted storm hydrographs at Site 4 (Events 1-4)

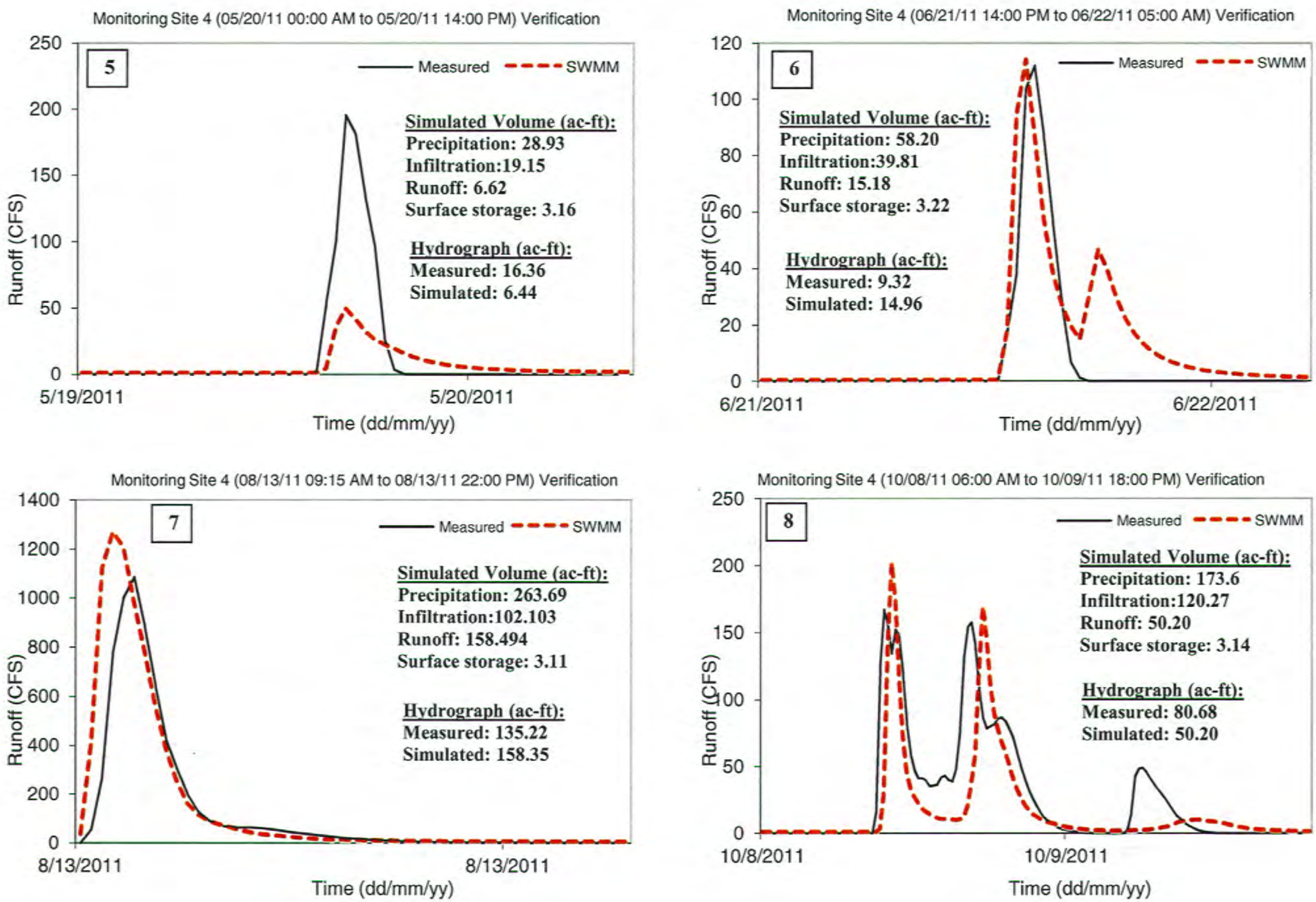
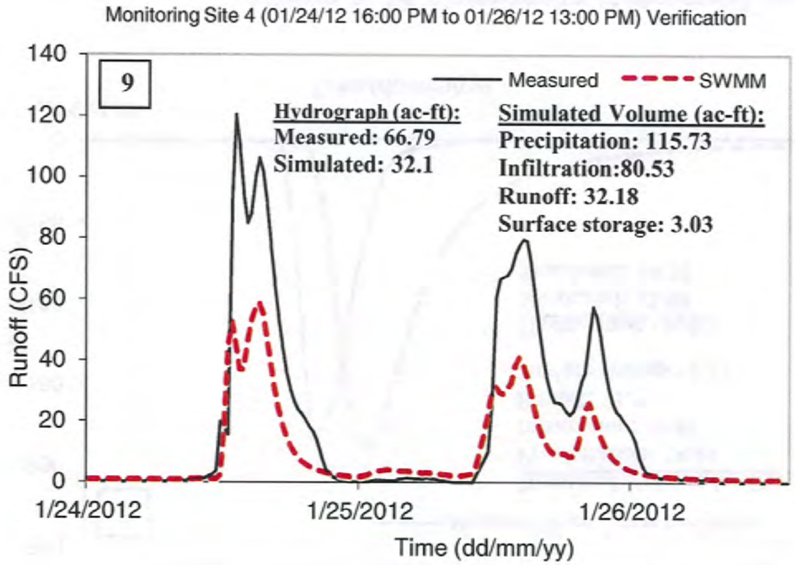
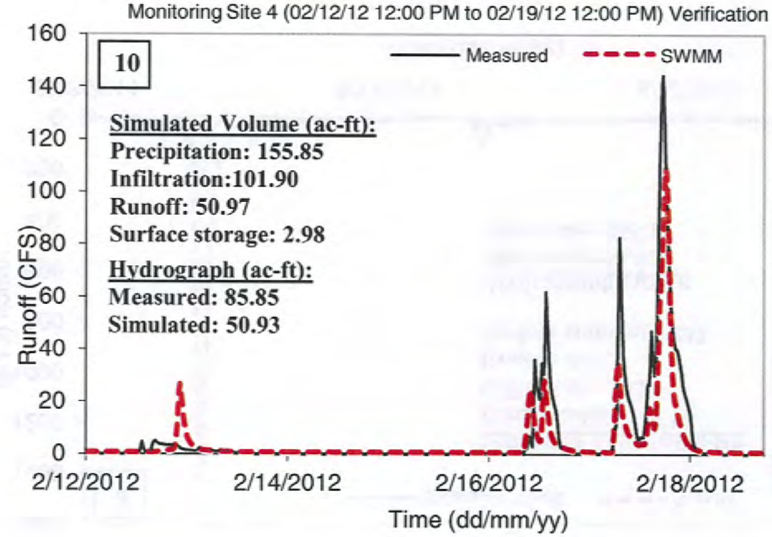


Figure A-8. Comparison of measured and predicted storm hydrographs at Site 4 (Events 5-8)





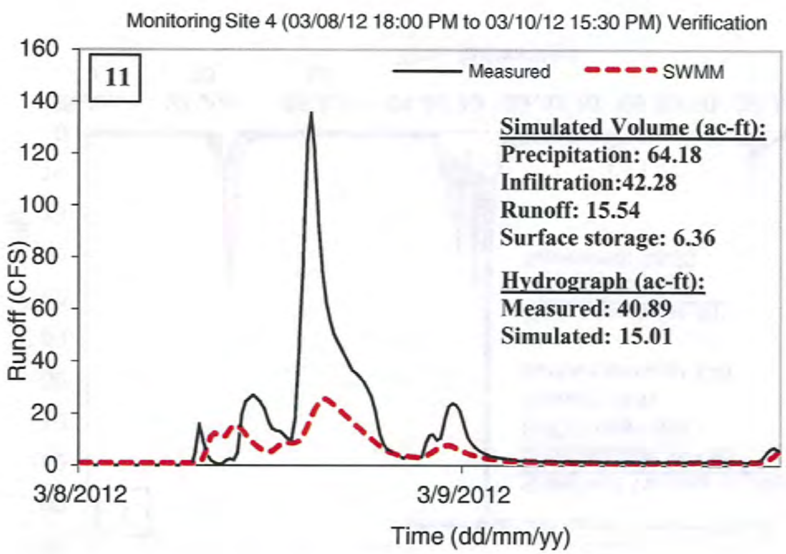


Figure A-9. Comparison of measured and predicted storm hydrographs at Site 4 (Events 9-11)

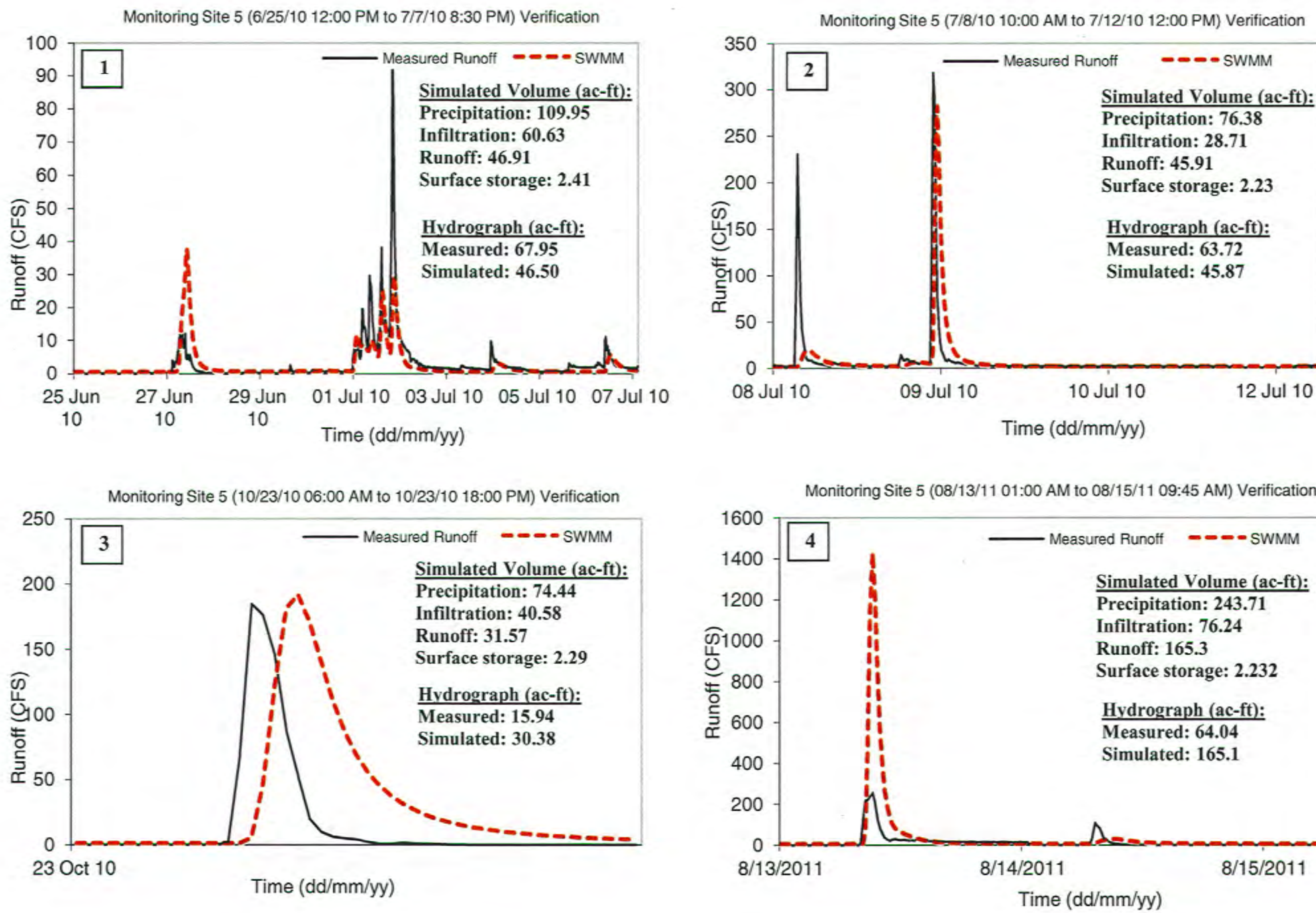


Figure A-10. Comparison of measured and predicted storm hydrographs at Site 5 (Events 1-4)

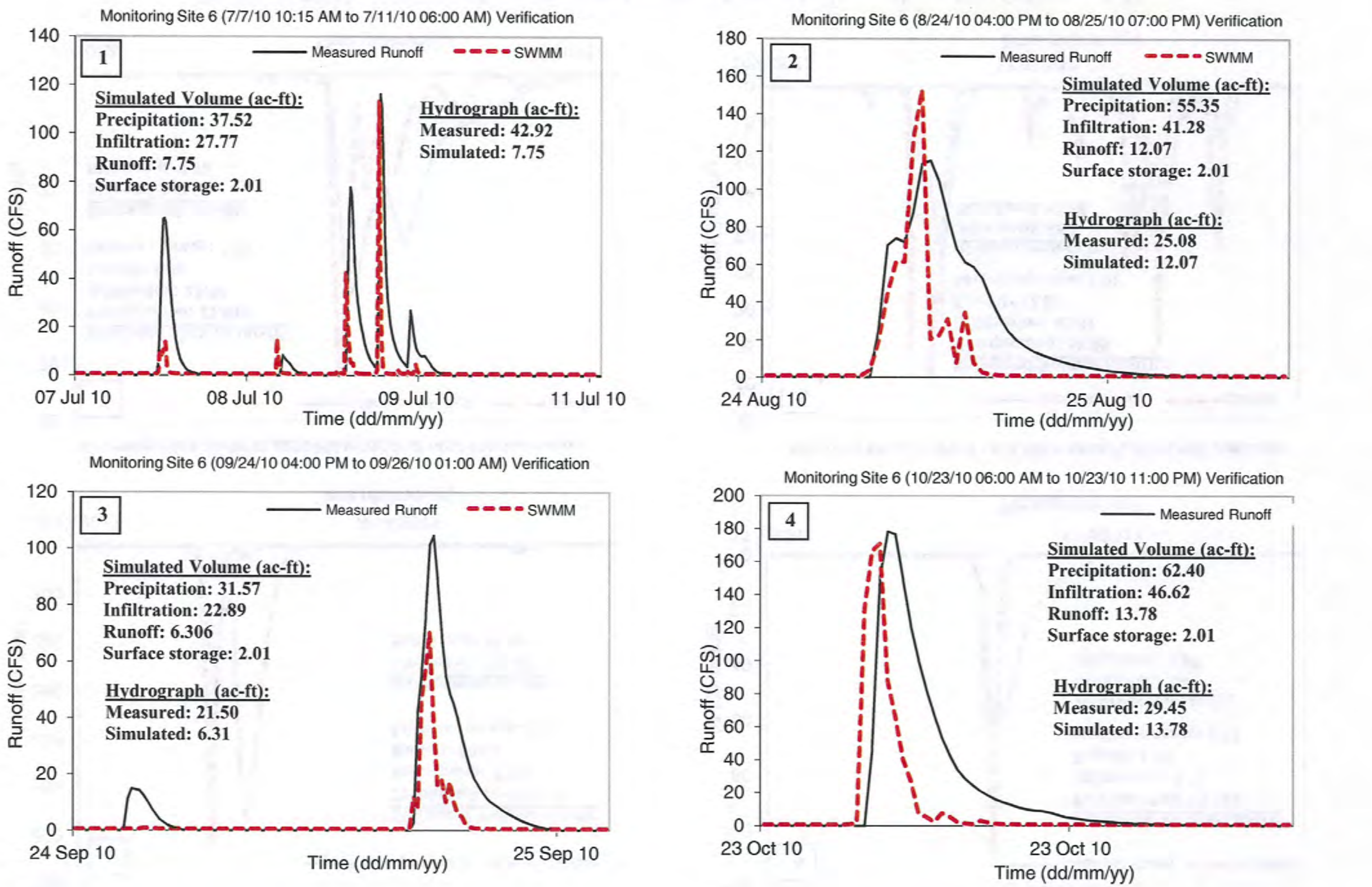


Figure A-11. Comparison of measured and predicted storm hydrographs at Site 6 (Events 1-4)

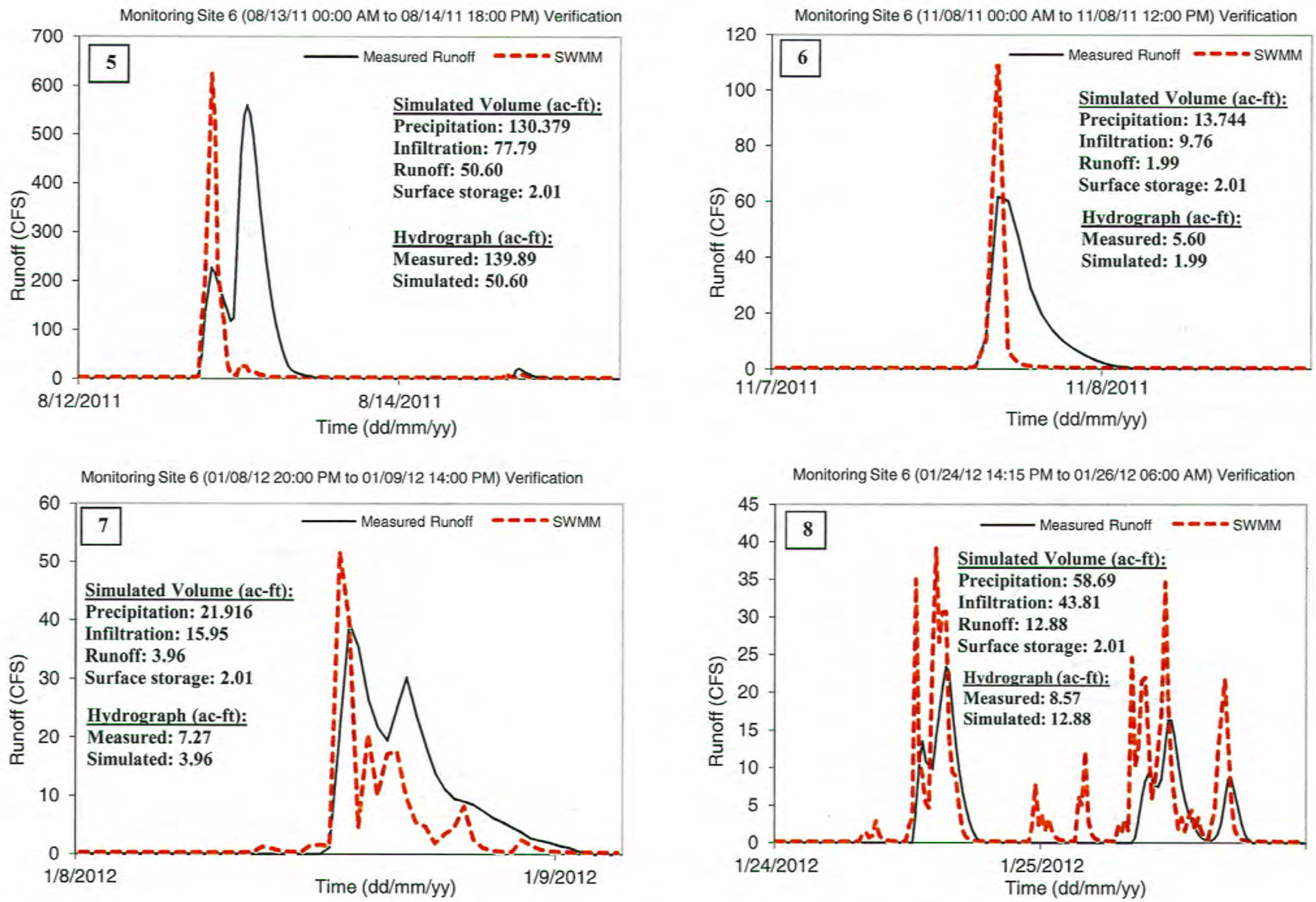


Figure A-12. Comparison of measured and predicted storm hydrographs at Site 6 (Events 5-8)

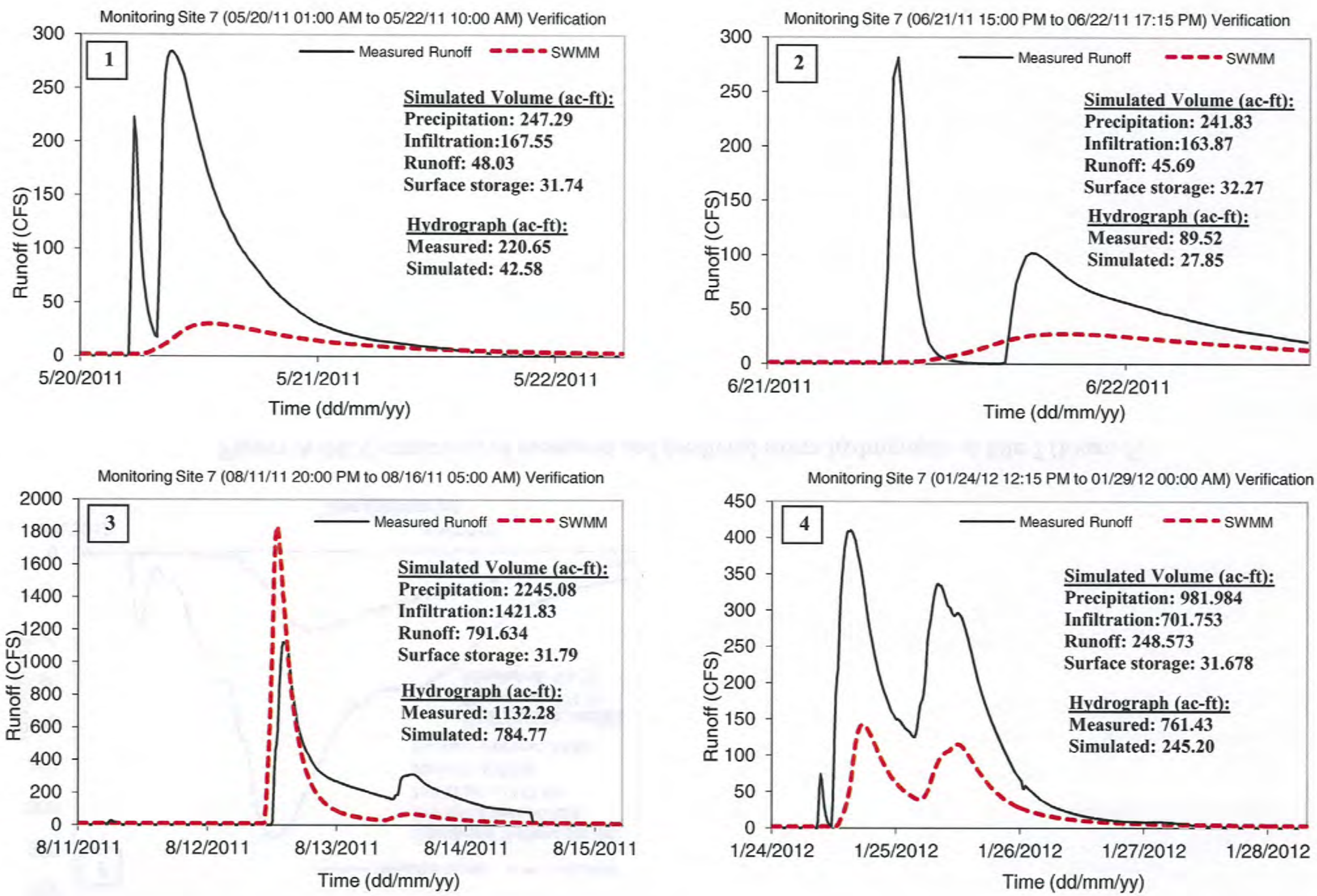


Figure A-13. Comparison of measured and predicted storm hydrographs at Site 7 (Events 1-4)

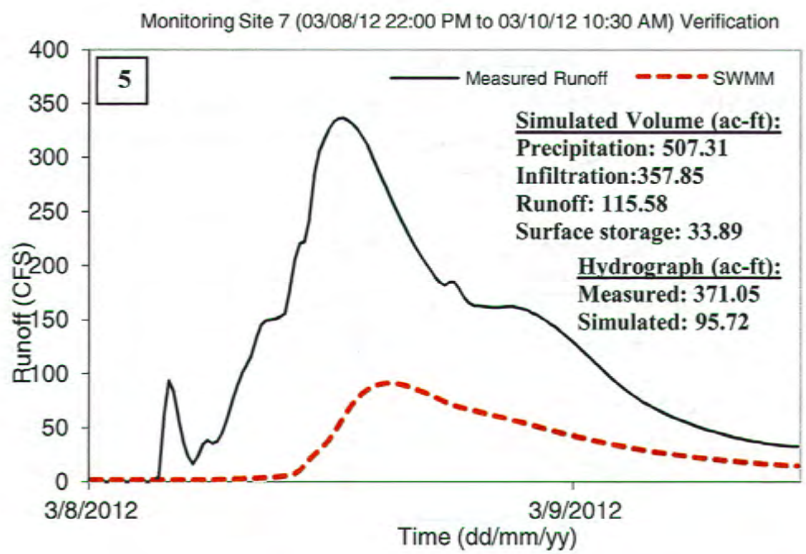


Figure A-14. Comparison of measured and predicted storm hydrographs at Site 7 (Event 5)

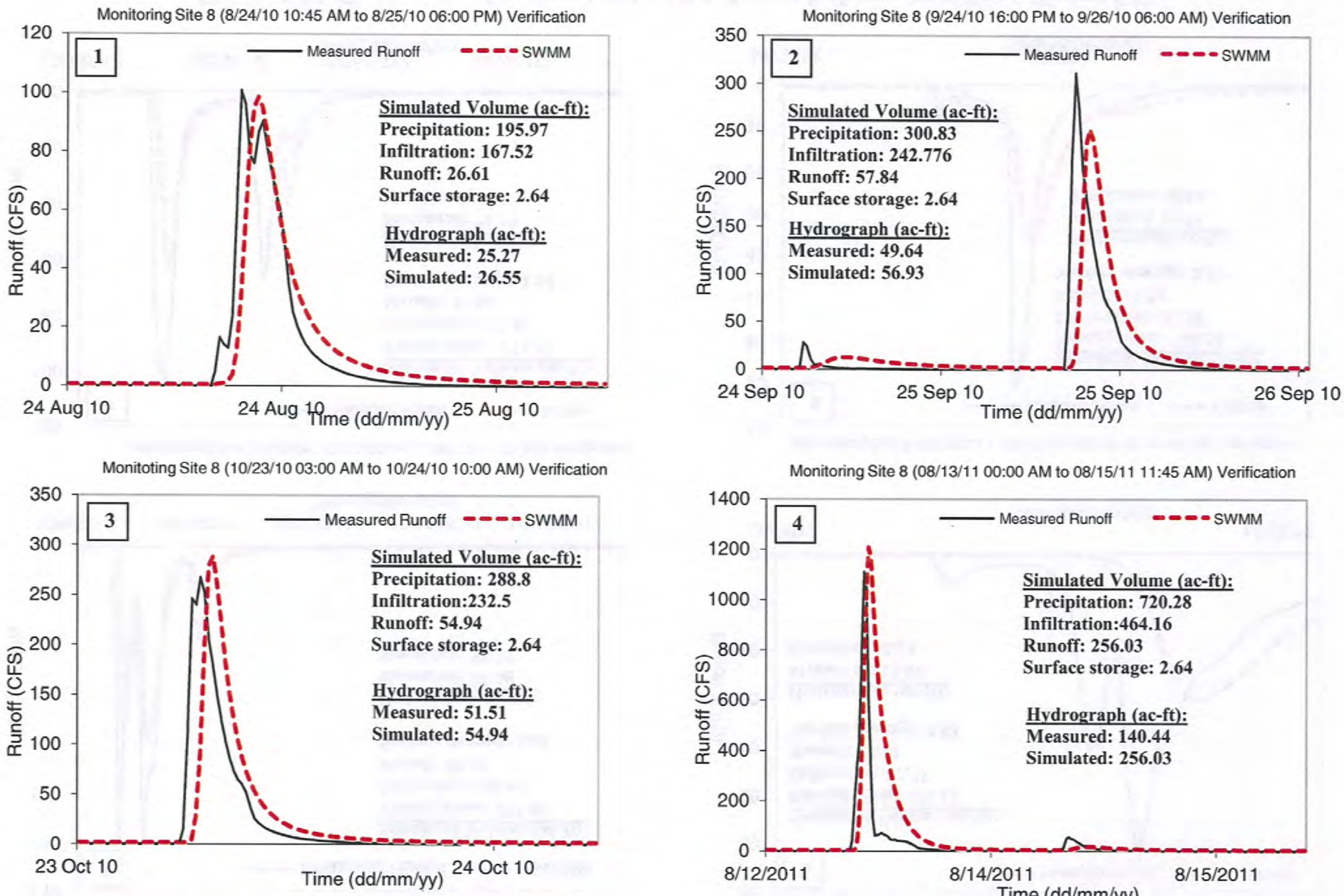


Figure A-15. Comparison of measured and predicted storm hydrographs at Site 8 (Events 1-4)

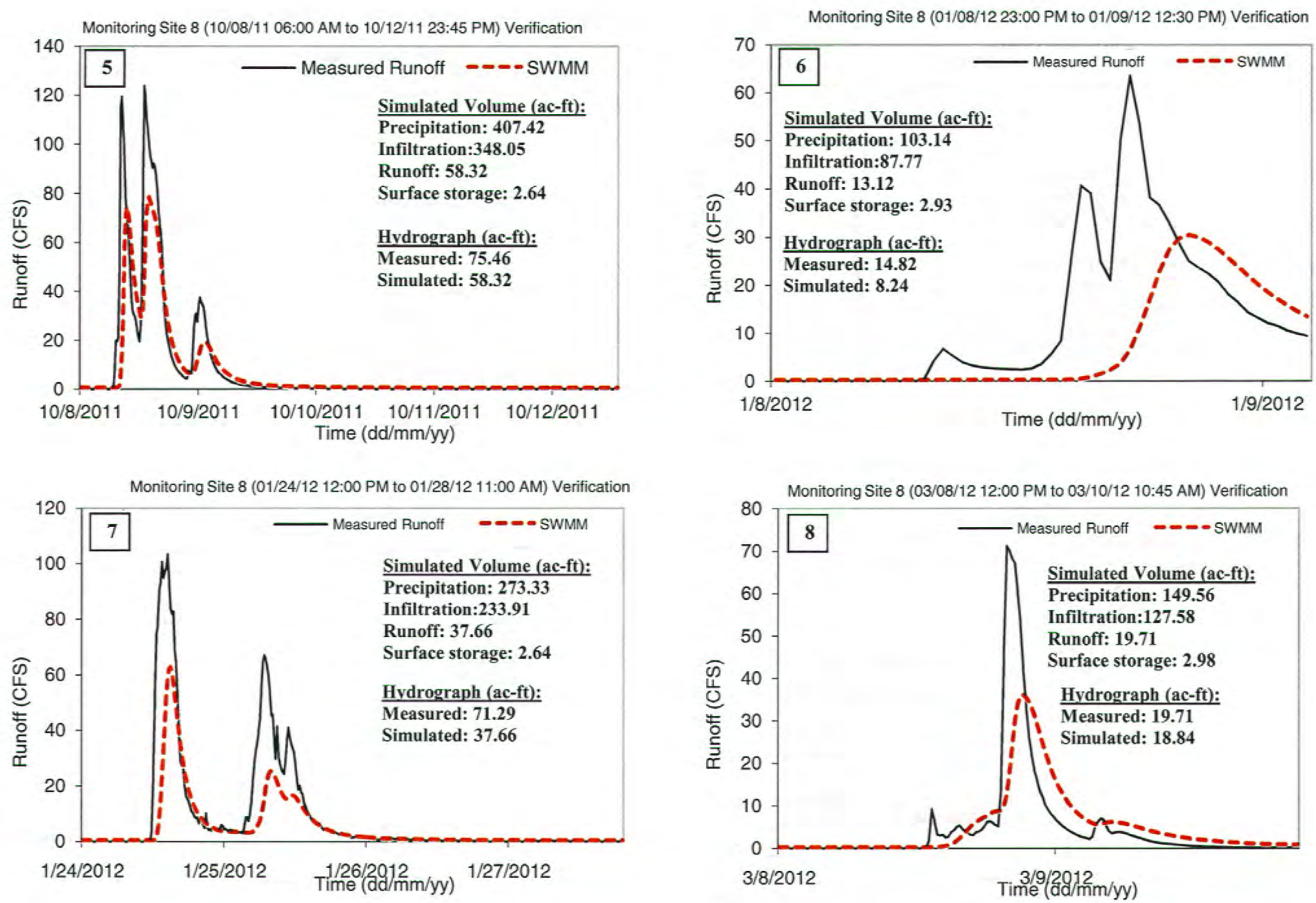


Figure A-16. Comparison of measured and predicted storm hydrographs at Site 8 (Events 5-8)

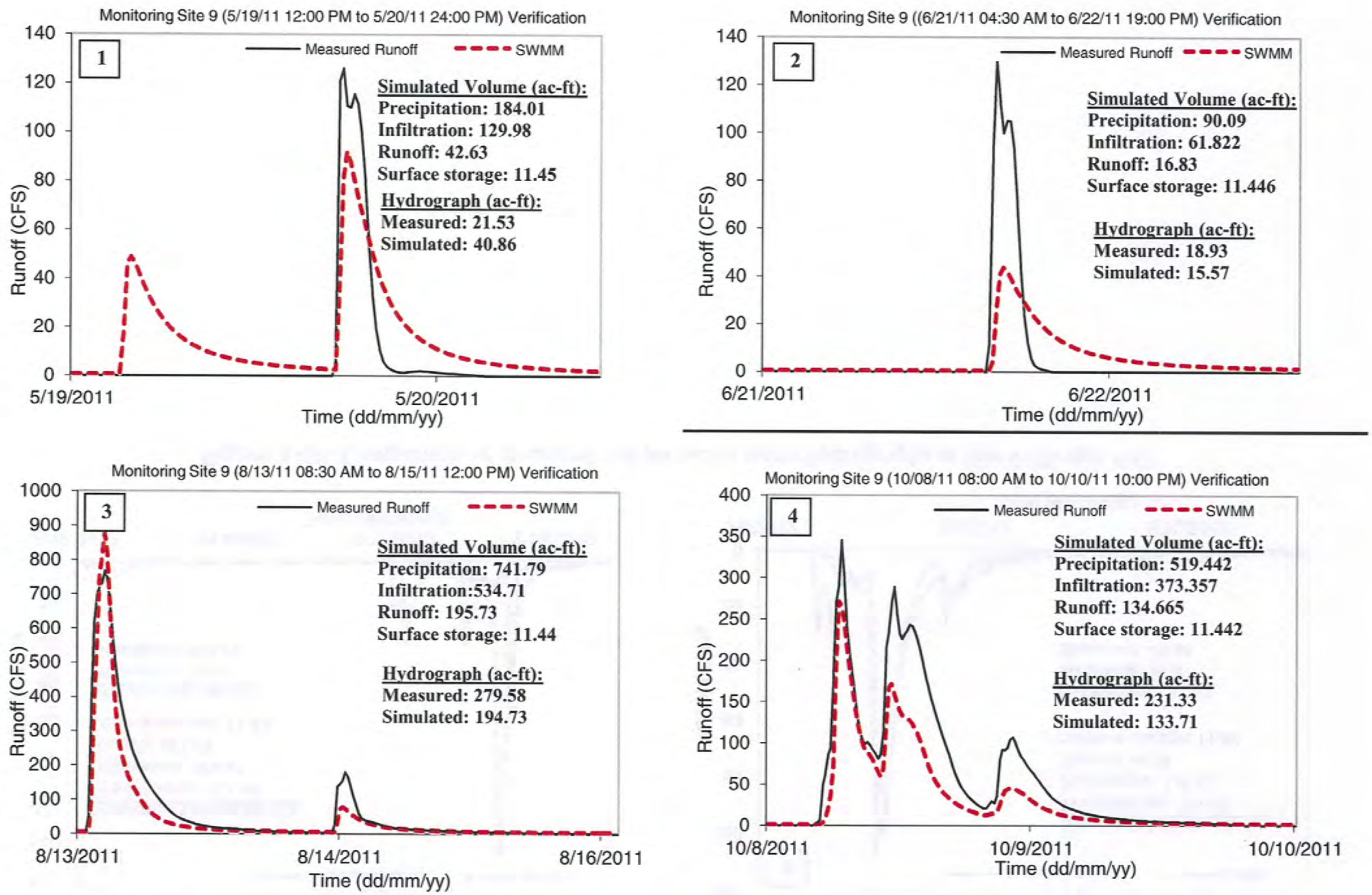


Figure A-17. Comparison of measured and predicted storm hydrographs at Site 9 (Events 1-4)

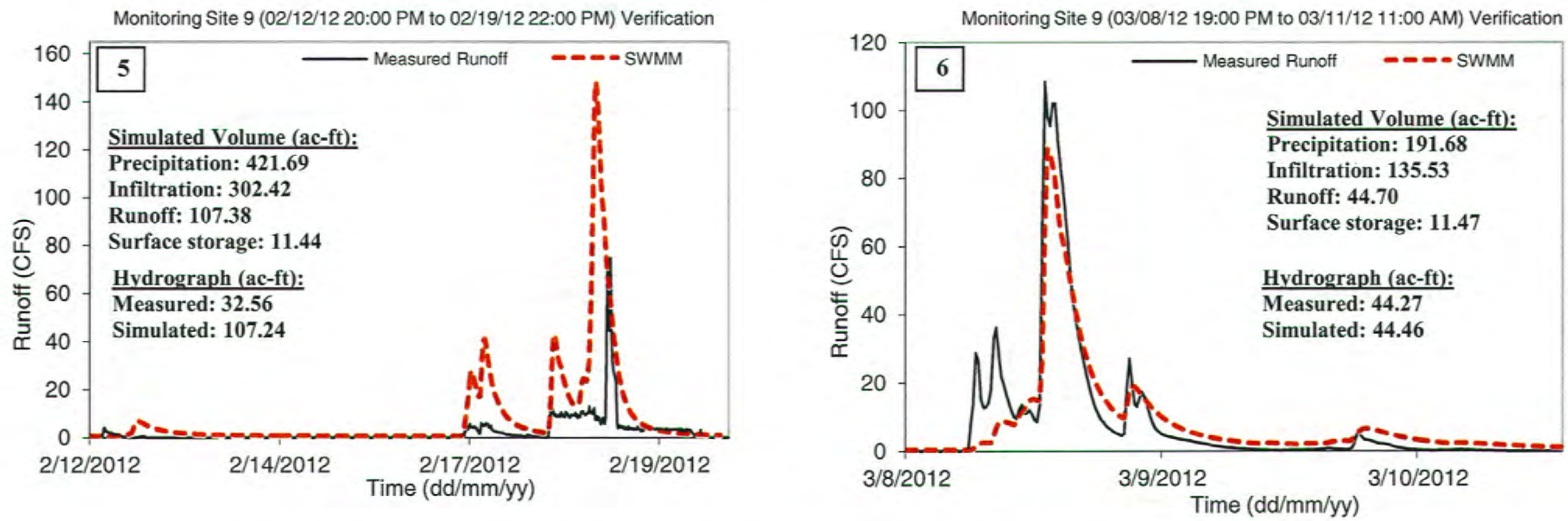


Figure A-18. Comparison of measured and predicted storm hydrographs at Site 9 (Events 5-6)

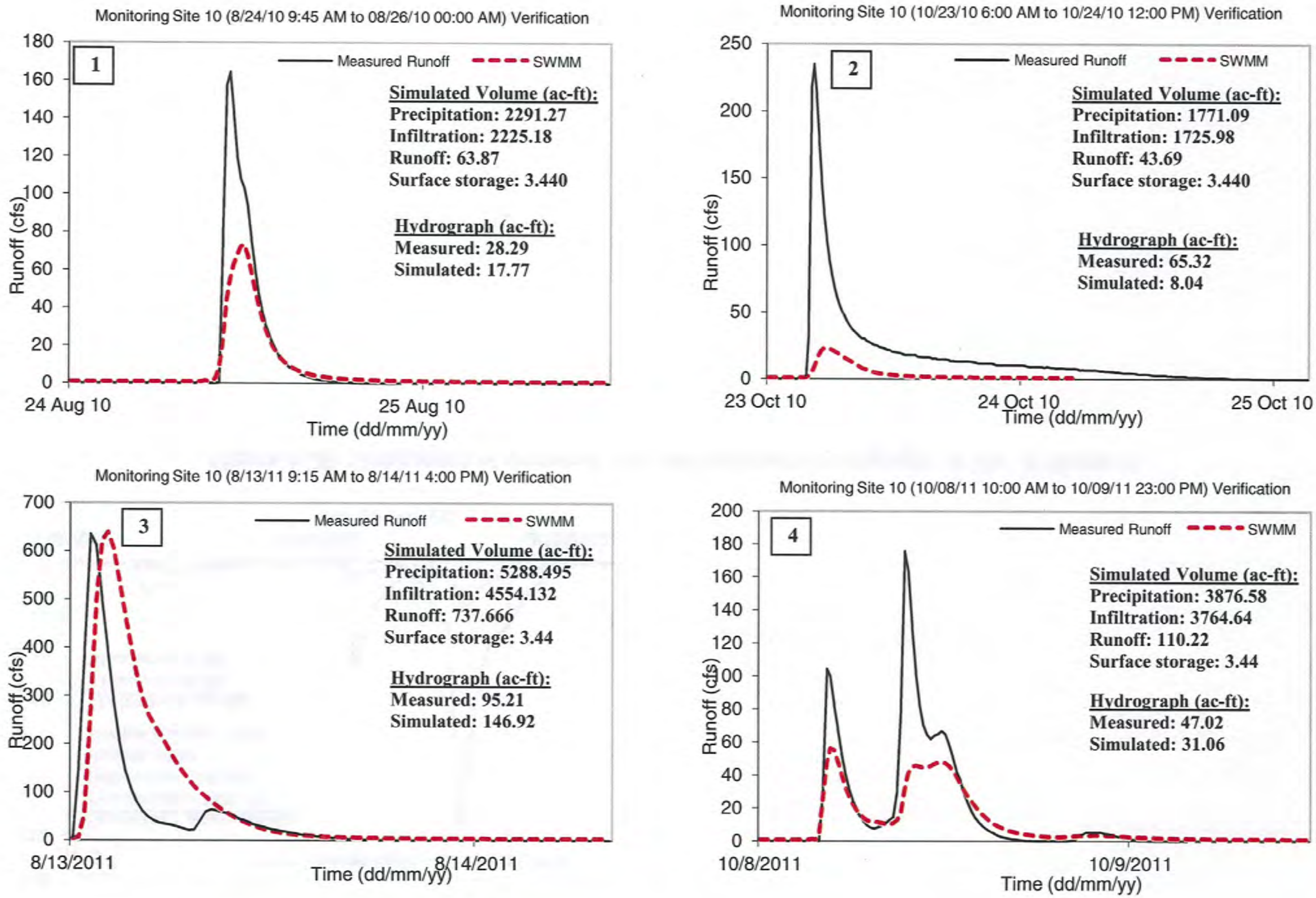


Figure A-19. Comparison of measured and predicted storm hydrographs at Site 10 (Events 1-4)

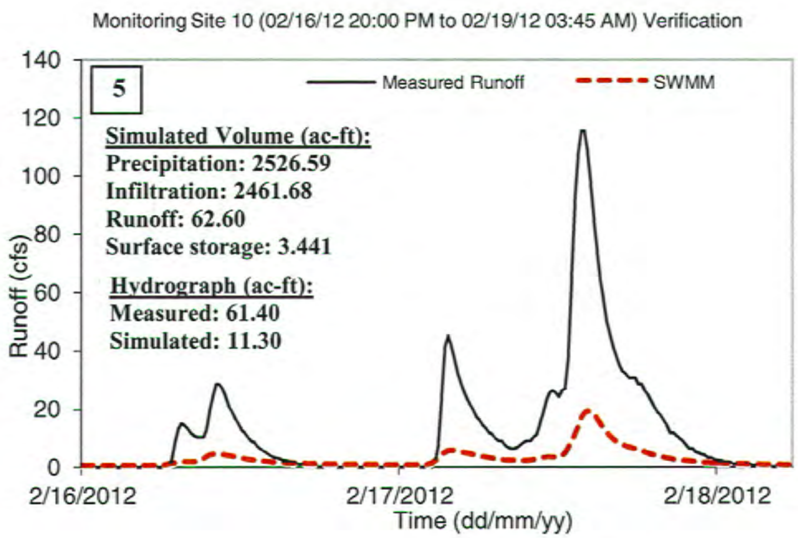


Figure A-20. Comparison of measured and predicted storm hydrographs at Site 10 (Event 5)

SECTION A-5
SWMM MODEL WATER QUALITY REPRESENTATION

After the hydrology verification portion of the SWMM model for each site was completed, the next step was to develop the water quality portion. Because the monitoring data was collected to represent event mean concentrations (EMCs) of total suspended solids (TSS), total phosphorus (TP), 5-day biochemical oxygen demand (BOD), and total nitrogen (TN) as determined from nitrite-nitrate nitrogen plus total Kjeldahl nitrogen, the EMC option of SWMM was employed for the water quality modeling. The EMC option in SWMM requires that the user specify as input a concentration. In the absence of BMPs that reduce pollutant loadings (e.g., through removal processes of a dry or wet pond), the model predicted concentrations will be similar to or the same as the input concentrations.

To develop EMCs for model input that reflect the mixture of land uses in the drainage area above each site and the influence of rainfall intensity, equations for TSS, TN, TP, and BOD were developed using multiple regression techniques with the independent variables of a) antecedent days prior to runoff event without rainfall (antecedent days), b) rainfall-runoff storm erosivity (EI) factor, and c) three aggregated land uses (i.e., low intensity land use, moderate land use and high intensity, Table A-11). Therefore the general multiple regression equations developed from the measured data have this general form:

Water Quality Parameter = A* (Antecedent days) + B * (EI) + C * (Low) +
D * (Moderate) + E * (High) (3)

Where A, B, C, D and E are constants determined from the multiple regression approach and Low, Moderate, and High are percent of the drainage area above a site using the aggregated land uses provided in Table A-11. Rainfall-runoff storm erosivity factor (EI) was calculated as follows:

$$EI_{30} = (E)(I_{30}) = \left(\sum_{r=1}^{n} e_r \Delta V_r\right) I_{30} \quad (4)$$

Where, EI_{30} is storm erosivity (hundred of ft·tonf·acre^{-1}·in^{-1}); tonf is tons-force; E is storm kinetic energy (ft·tonf·acre^{-1}); I_{30} is maximum 30-min rainfall intensity (in· h^{-1}); e_r is rainfall kinetic energy $(1{,}099 \times [1 - 0.72 \times \exp(-1.27 i_r)])$; i_r is rainfall intensity; ΔV_r is depth of rainfall $(i_r \times \Delta t_r)$; Δt_r is duration of the increment used in the rainfall data collection (15 minutes for most data collected on this project); and r is the r^{th} increment out of a total of n increments.

The multiple regression equations for TSS, TN, TP, and BOD developed using this approach are provided in Table A-12.

The equation for each pollutant was used to develop the EMCs for each site and each storm event that was measured at that site using the unique land use of the drainage area above the site, the antecedent days without rain prior to the storm event, and the value of EI for the measured rainfall associated with the event. A comparison of the measured EMCs to EMCs determined from the regression equations is provided in Figure A-21 for TSS and TP and Figure A-22 for TN and BOD. Also provided on each graph is the 1:1 line which would represent the perfect fit of predicted and measured EMCs. From these four graphs it is apparent that the regression equations and predicted concentrations, while capturing the general trend of the measured data, are only fair representations of the measured data. Generally the regression equation results capture the median concentration well but do not provide results that have the range of concentrations found in the measured data. This weakness of underestimating the variability in the data is most obvious for TN and BOD, whereas TSS and TP prediction more closely reflect the range of the observed data. It appears some important factors driving EMC concentrations are absent from the present equations; perhaps a seasonality component which was not explored in this analysis. Despite the apparent weaknesses the regression equations for each water quality parameters do provide a fair prediction of EMCs that are sensitive to changes in rainfall intensity, antecedent days without rainfall, and land use intensity.

Table A-11 Detailed Information for Land Use Categories Used in Developing EMC Multiple Regression Equations

Land Use	Detailed Land Use Categories
Low Intensity	Agriculture (cultivated land) Agriculture Commercial (ranches, dairies) Agriculture Residential (3-10 acre lot with house) Public Semi-Public Vacant
Moderate Intensity	Parks Recreation Others
High Intensity	Commercial Industrial, Heavy Industrial, Light Mobile Home (individual) Mobile Home Park Office Parking Lot Offsite Residential, High Density (apartments) Residential, Low Density (single-family detached) Residential, Medium Density (townhouse, duplex) Retail_Personal Services Two Single-Family on One Lot Roads_Pavement

Table A-12 Multiple Regression Equation Coefficients Developed from Measured EMCs for the Period (June 28, August 24, September 24, and October 23, 2010)

Pollutant	Antecedent Days	EI	Land Use Intensity		
			Low	Moderate	High
TSS	4.3255	1.92534	2.03857	-2.3316	1.02494
TP	0.00677	0.00283	0.00298	-0.0019	0.00224
TN	0.02193	0.00403	0.01686	0.02268	0.02701
BOD	0.07979	-0.14819	0.19683	0.11767	0.2531

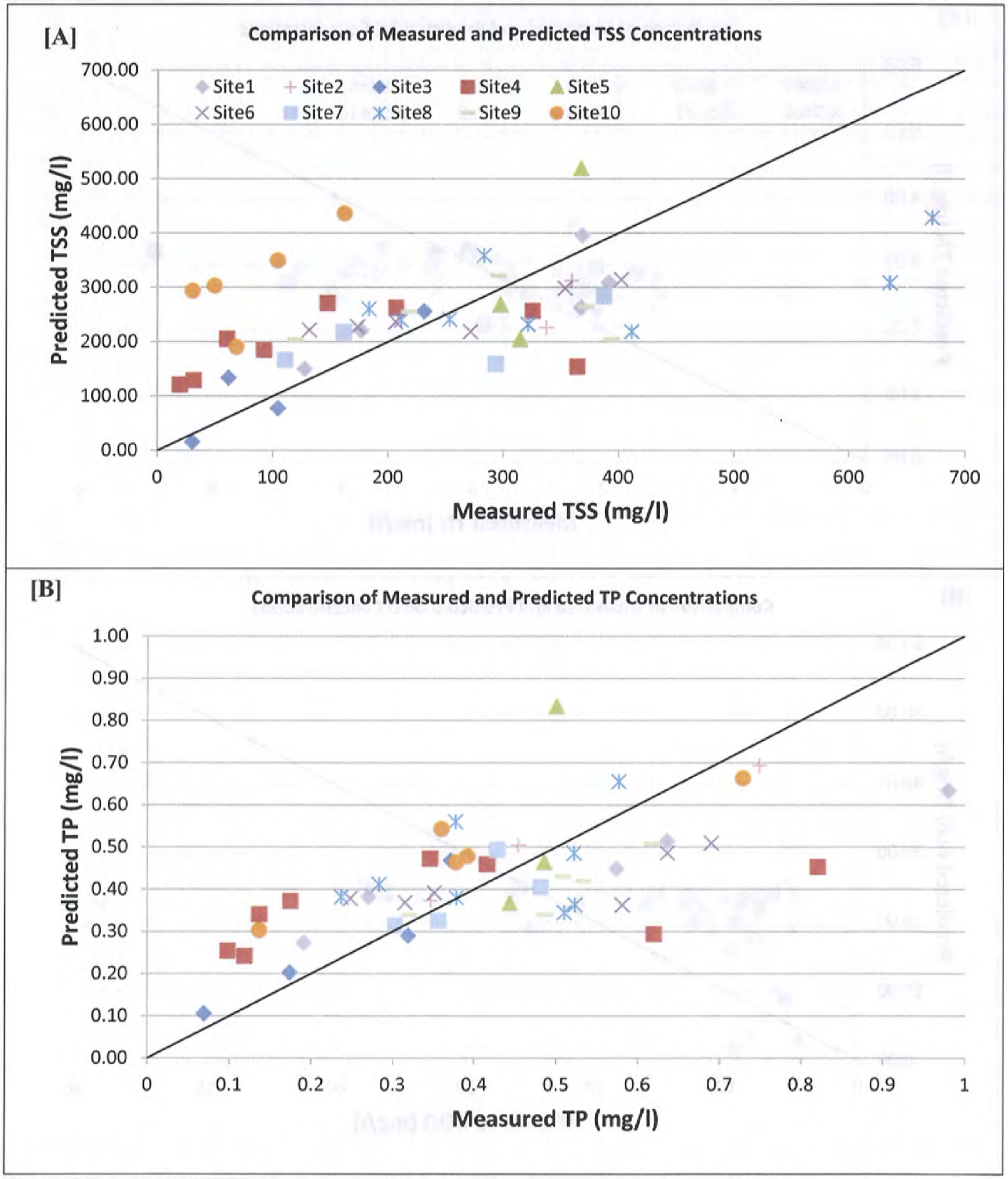


Figure A-21. Comparison of the measured EMCs to EMCs determined from the regression equations for [A] TSS and [B] TP

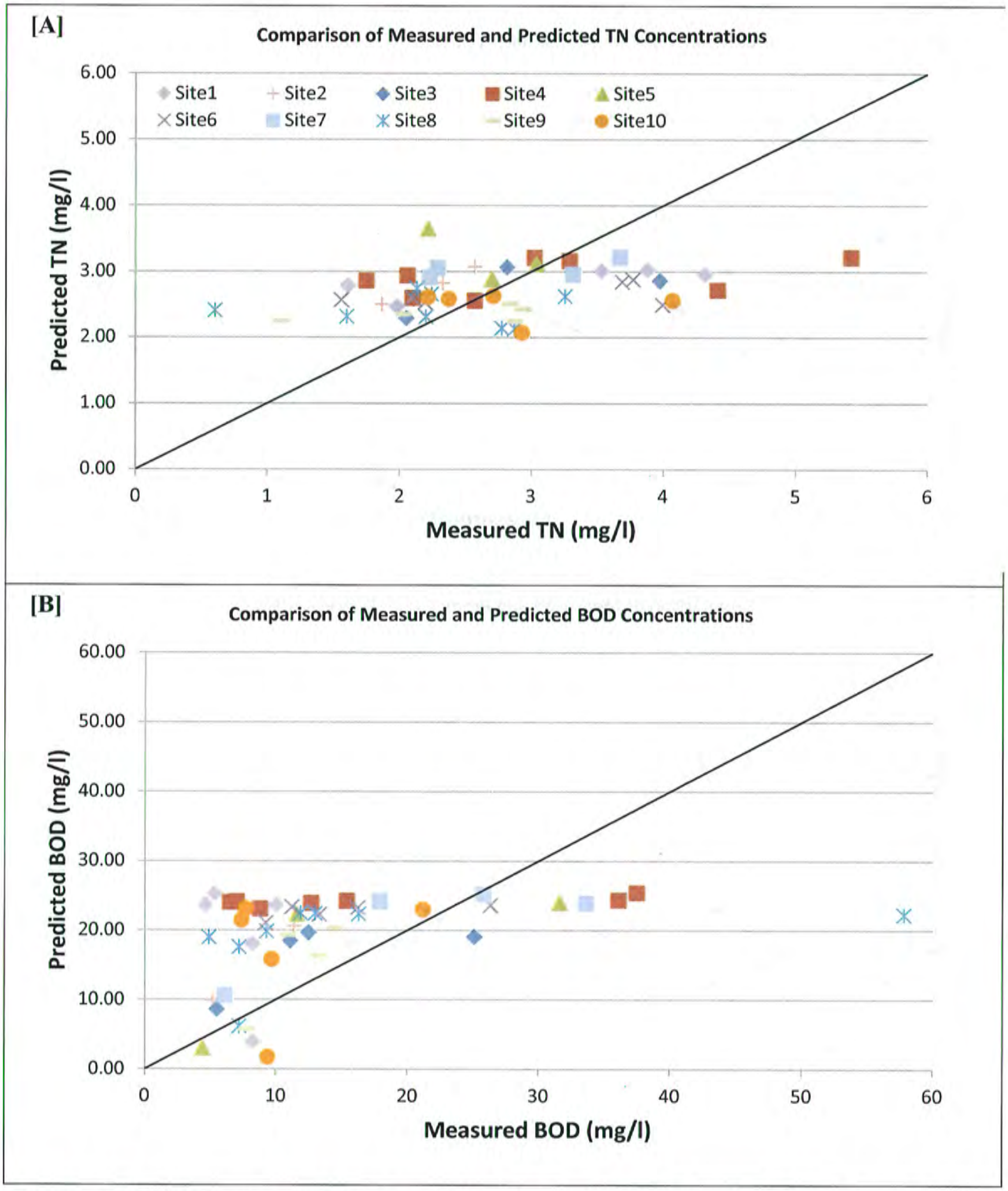


Figure A-22. Comparison of the measured EMCs to EMCs determined from the regression equations for [A] TN and [B] BOD

SECTION A-6
BEST MANAGEMENT PRACTICES

The validated SWMM models for the City of San Angelo area were used to evaluate BMPs that are being considered for flood control, water storage, and/or storm water pollution reduction. To evaluate these potential BMPs, first two design rainfall events were developed, the needed SWMM models were run with the two design rainfall events, UCRA staff evaluated the SWMM results deciding upon which rainfall event to use in the SWMM simulation of the BMP, and each SWMM model was run with the BMP added to the model using the UCRA selected rainfall event with results provided back to UCRA.

A-6.1 Design Rainfall Events and BMP Location

The design rainfall events were determined for a Type-II design rainfall (Hershfield, 1961; Frederick et al., 1977) at 15-minute intervals for a 12-hour duration storm for return intervals of 1 and 5 years as shown in Figure A-23. The selected design rainfall events were used for determining the BMP size corresponding to storm water issue needing to be addressed at each monitoring site. Total rainfall for the 1-year return interval 12-hour event was 1.66 inches and for the 5-year event the rainfall was 3.06 inches.

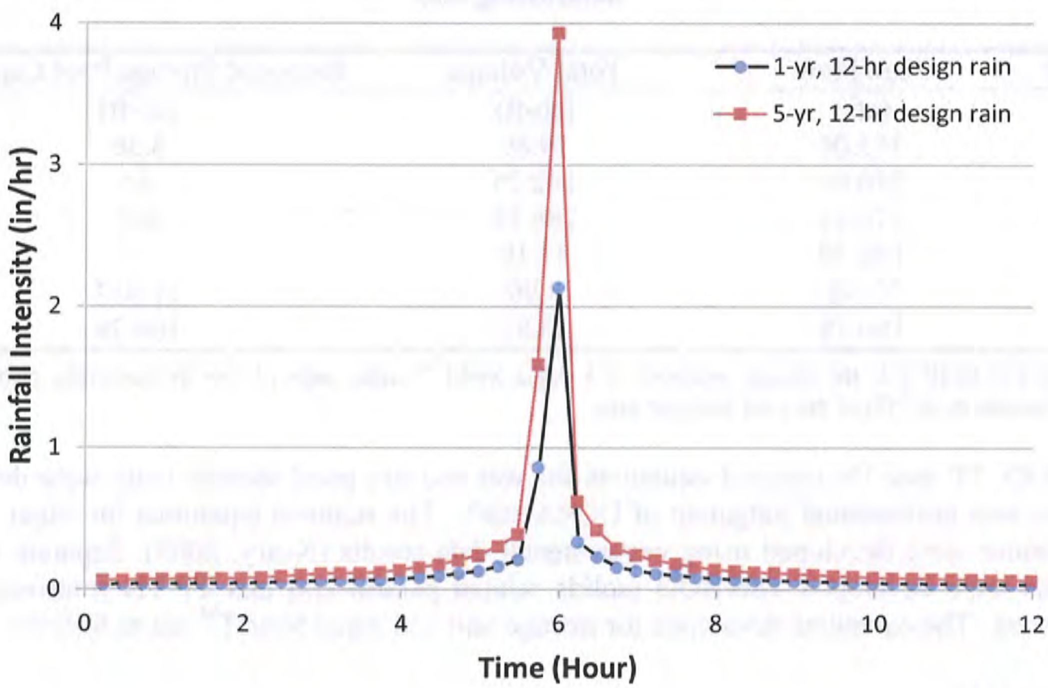


Figure A-14 12 Hour rainfall Event with 1 and 5 Year Recurrence Interval Design Storm

Seven BMPs are implemented at seven monitoring site. Some BMPs are located in the single sub-basin and other BMPs are connected to several upstream sub-basins. The detailed information is described in the Table A-13.

Table A-13 Information of BMPs and monitoring sites along with the connected upstream sub-basins and selected design storm

BMP	Near Monitoring Sites	Located on Sub-basin	Connected Upstream Sub-basins	Selected Design Storm
1	9	25	25	1 yr. 12 hr
2	8	30	30+32	5 yr. 12 hr
3	2	20	20+21+24+25+28+29+3031+32+33	1 yr. 12 hr
4[§]	3	13	4+5+7+9+10+13	-
5	5	15	15	1 yr. 12 hr
6[£]	10	12a	12a	1 yr. 12 hr
7[£]	1	12b	1+2+3+6+12a+12b	1 yr. 12 hr

[£] Sub-basin 12 is divided into sub-basin 12a and 12b.

[§] BMP4 is deleted due to excessive flows and existing topography by UCRA.

A-6.2 BMP Size Determination and Water Pollutant Removal Efficiency

Due to existing urban flooding problems, the BMP size is compared and determined to peak flow and total volume computed by using 1/5 year-12 hour storm. The detailed information for peak flow and total volume is shown in Table A-14.

Table A-14 Peak flow, total volume, and storage pool capacity for each BMP at each monitoring site

BMP	Peak Flow (cfs)	Total Volume (ac-ft)	Proposed Storage Pool Capacity (ac-ft)
1	315.06	79.89	8.36
2	550.09	142.25	43
3	476.65	286.18	290
5	156.79	34.19	—[§]
6	72.32	8.99	11.613
7	190.78	33.87	109.26

§ For BMP # 5, the design consisted of 8 Agua Swirl™ units, each 12 feet in diameters, providing for treatment of 25% of the total drainage area.

TSS, BOD, TP and TN removal equations for wet and dry pond storage units were developed based on best professional judgment of UCRA staff. The removal equations for Aqua Swirl™ Concentrator were developed using experimental data results (Neary, 2009). Separate removal equations were developed TSS/BOD (solids related parameters) and TP/TN (nutrient related parameters). The equations developed for storage unit and Aqua SwirlT[M] are as follows:

Storage Unit:

$R = 0.903+0.0049\times HRT$ (for TSS/BOD, for HRT > 1 hour)

$R = 0.511+0.00935\times HRT$ (for TP/TN, for HRT > 1 hour)

Aqua Swirl™:

$R=1-(1.199\times10^{-11}Q^4-2.385\times10^{-8}Q^3+1.389\times10^{-5}Q^2-8.3913\times10^{-4}Q+0.03316)$ (for TSS/BOD)

$R=1-(6.267\times10^{-12}Q^4-1.184\times10^{-8}Q^3+6.175\times10^{-6}Q^2-7.574\times10^{-5}Q+0.4676)$ (for TP/TN)

Where, R = fraction removal; HRT= hydrologic retention time (hour) and Q= flow (cfs). For the wet and dry ponds HRT was greater than 1 hour for the simulations, therefore the equations were focused on removal for HRT > 1 hour.

A-6.2BMP Efficiency Evaluation

Peak flow, total runoff, and water pollutants are considered and compared to provide an evaluation of the effectiveness of the BMPs (Table A-15). For BMPs 2 (dry pond) and 5 (Aqua Swirls™), the maximum inflow and water pollutants are reduced by BMP, while the total volume does not change. For BMPs 3, 6, and 7 that have a wet storage ponds, the maximum inflow, total volume, and water pollutants are reduced. Finally, for BMPs 3 and 7 a range of initial water volumes in the wet ponds were considered (i.e., 0, 25, 50, and 100% full) and this starting volume impacts the efficacy of the BMP..

Table A-15 SWMM Model SWSCN Predictions for the Selected Design Storm (Peak Flow in cfs, Total Volume in acre-feet, and Water Pollutants in lbs)

BMP	Condition Simulated	Storm Water Quantity		Storm Water Pollutant Loadings			
		Peak Flow	Total Volume	TSS	TP	TN	BOD
1	Without BMP	315	80	52,285	87	511	3,803
	With BMP	212	75	4,343	39	227	316
	Reduction (%)	33%	6%	92%	55%	56%	92%
2	Without BMP	558	142	144,564	224	1,020	5,195
	With BMP	432	142	12,876	106	483	463
	Reduction (%)	23%	0%	91%	53%	53%	91%
3	Without BMP	479	287	201,385	326	2,021	16,417
	With BMP (0%)	145	94	2884	39	240	235
	With BMP (25%)	232	141	4,709	61	375	384
	With BMP (50%)	248	189	6,513	83	511	531
	With BMP (Full)	384	283	10,369	107	660	845
	Each Condition Reduction (%)	70%	67%	99%	88%	88%	99%
		52%	51%	98%	81%	81%	98%
		48%	34%	97%	75%	75%	97%
		20%	1%	95%	67%	67%	95%
5	Without BMP	157	34	20,657	36	273	2147
	With BMP £	120	34	1,109	18	135	115
	Reduction (%)	24%	0%	95%	50%	51%	95%
6	Without BMP	81	9	6,100	11	72	560
	With BMP	0	0	0	0	0	0
	Reduction (%)	100%	100%	100%	100%	100%	100%
7	Without BMP	223	34	24,265	31	232	1188
	With BMP (0%)	0	0	0	0	0	0
	With BMP (25%)	0	0	0	0	0	0

BMP	Condition Simulated	Storm Water Quantity		Storm Water Pollutant Loadings			
		Peak Flow	Total Volume	TSS	TP	TN	BOD
	With BMP (50%)	8	3.5	63	1	9	6
	With BMP (Full)	149	34	1,301	9	61	116
		100%	100%	100%	100%	100%	100%
	Each Condition	100%	100%	100%	100%	100%	100%
	Reduction (%)	96%	90%	100%	97%	96%	99%
		33%	0%	95%	71%	74%	90%

£BMPs at this site are Aqua SwirlTM Concentrators which are set to treat 25% of the total storm volume. The information shown in Table A-15 is only for the portion of the storm water that is treated.

SECTION A-7
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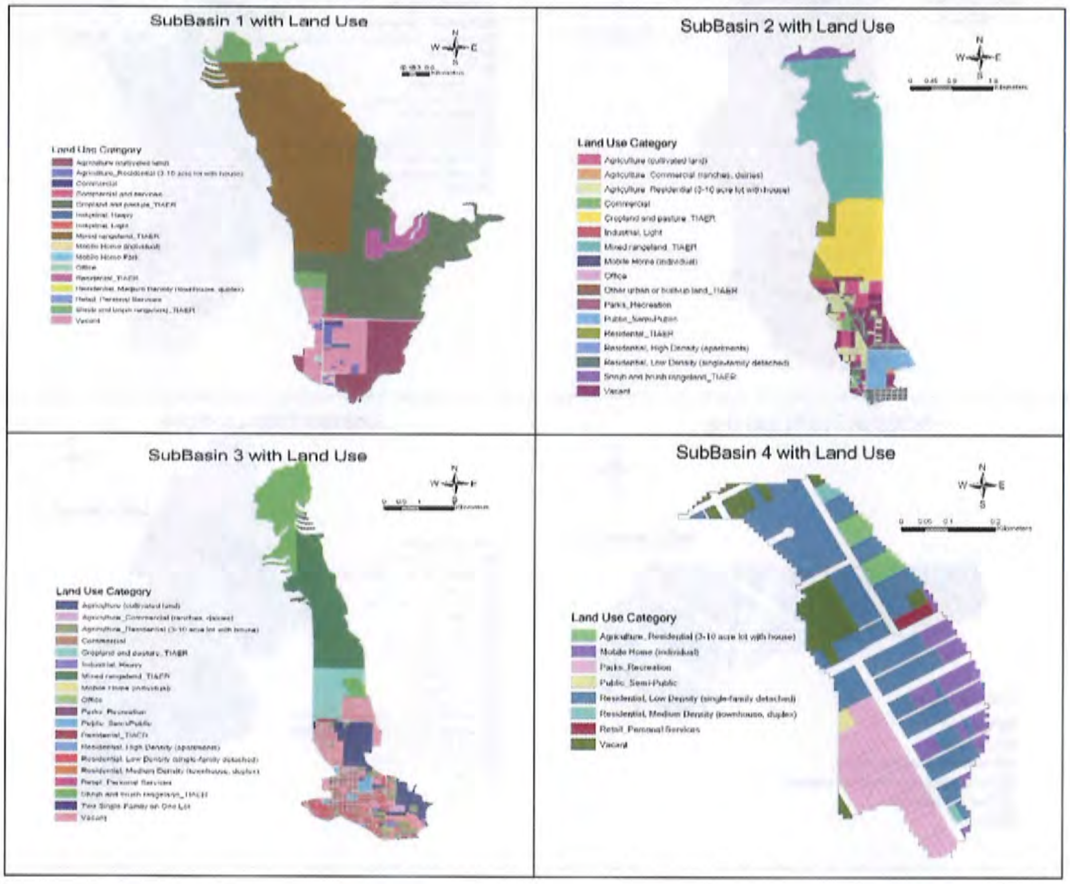
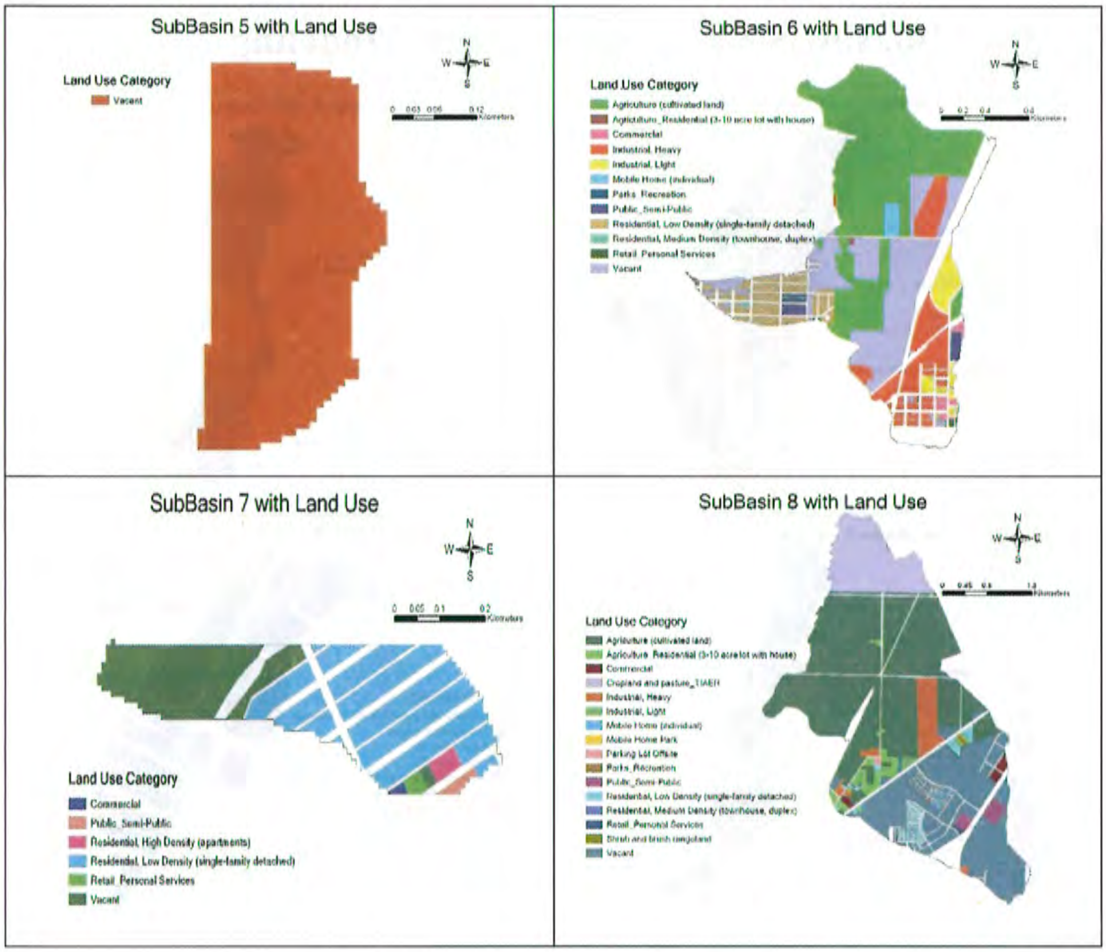
APPENDIX B

Summary of Land Use Categories of Subbasins Selected for SWMM Modeling

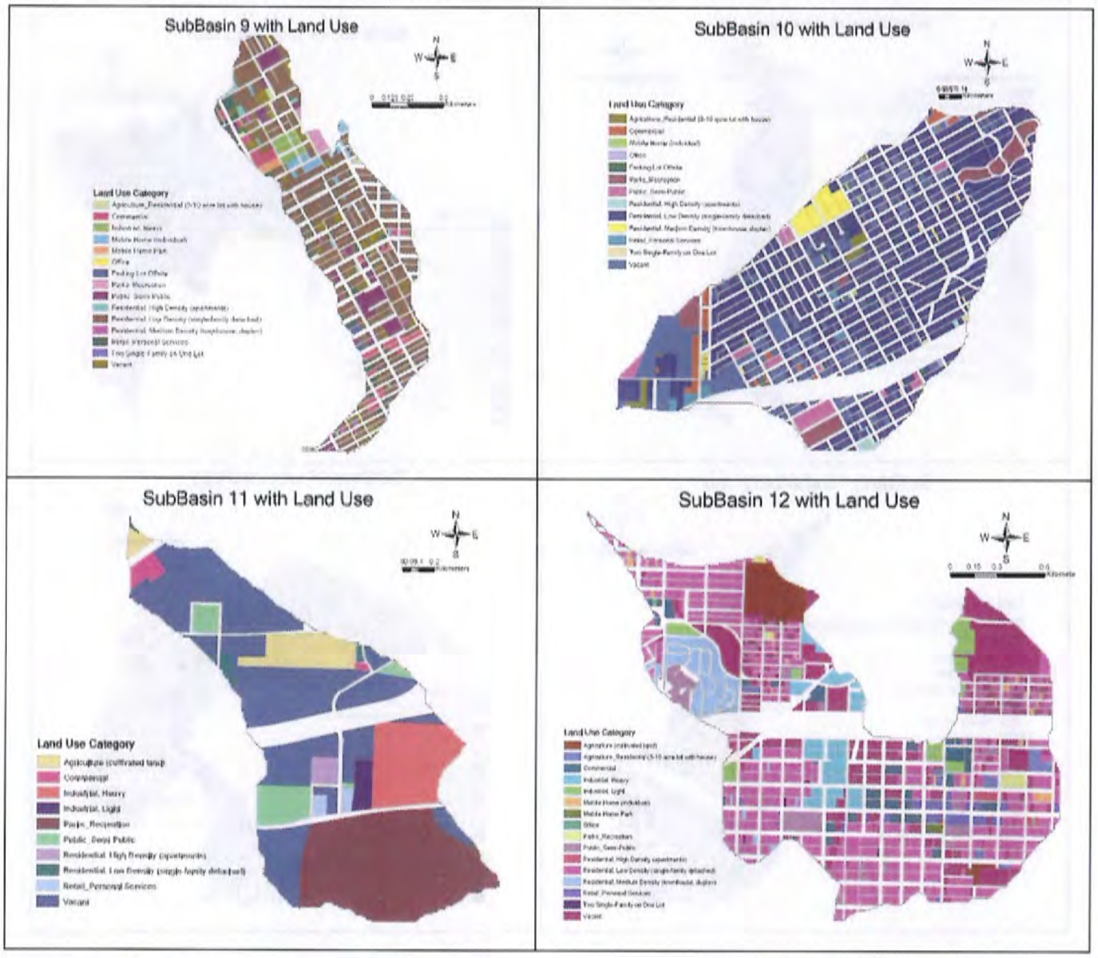
B-1. 35 Subbasins Selected for Detailed Modeling



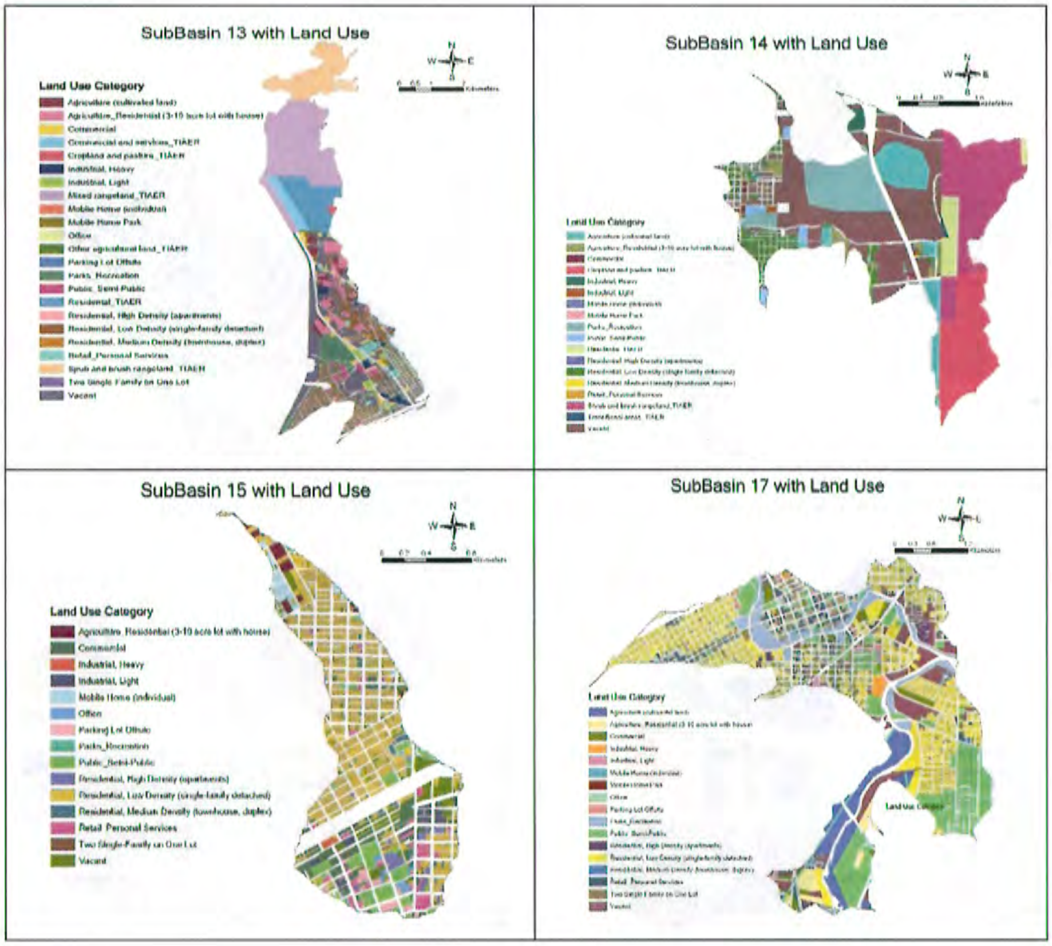
Land Use Categories	Area (acre) in each subbasin			
	1	2	3	4
Agriculture (cultivated land)	5,579.59	1,882.33	3,362.97	-
Agriculture_Commercial (ranches, dairies)	-	4.87	32.08	-
Agriculture_Residential (3-10 acre lot with house)	62.85	156.45	220.41	1.93
Commercial	10.26	27.99	12.47	-
Industrial, Heavy	12.31	-	27.12	-
Industrial, Light	3.30	23.50	-	-
Mobile Home (individual)	2.40	4.33	16.58	5.54
Mobile Home Park	0.30	-	-	-
Office	6.92	0.81	6.80	-
Parking Lot Offsite	-	-	-	-
Parks_Recreation	-	2.84	6.54	9.93
Public_Semi-Public	-	148.00	87.48	0.34
Residential, High Density (apartments)	-	0.37	1.52	-
Residential, Low Density (single-family detached)	-	204.13	375.98	22.22
Residential, Medium Density (townhouse, duplex)	211.86	-	4.01	0.53
Retail_Personal Services	6.62	-	4.72	0.60
Two Single-Family on One Lot	-	-	0.49	-
Vacant	507.51	232.84	754.98	5.58
Total	6,403.92	2,688.46	4,914.16	46.66



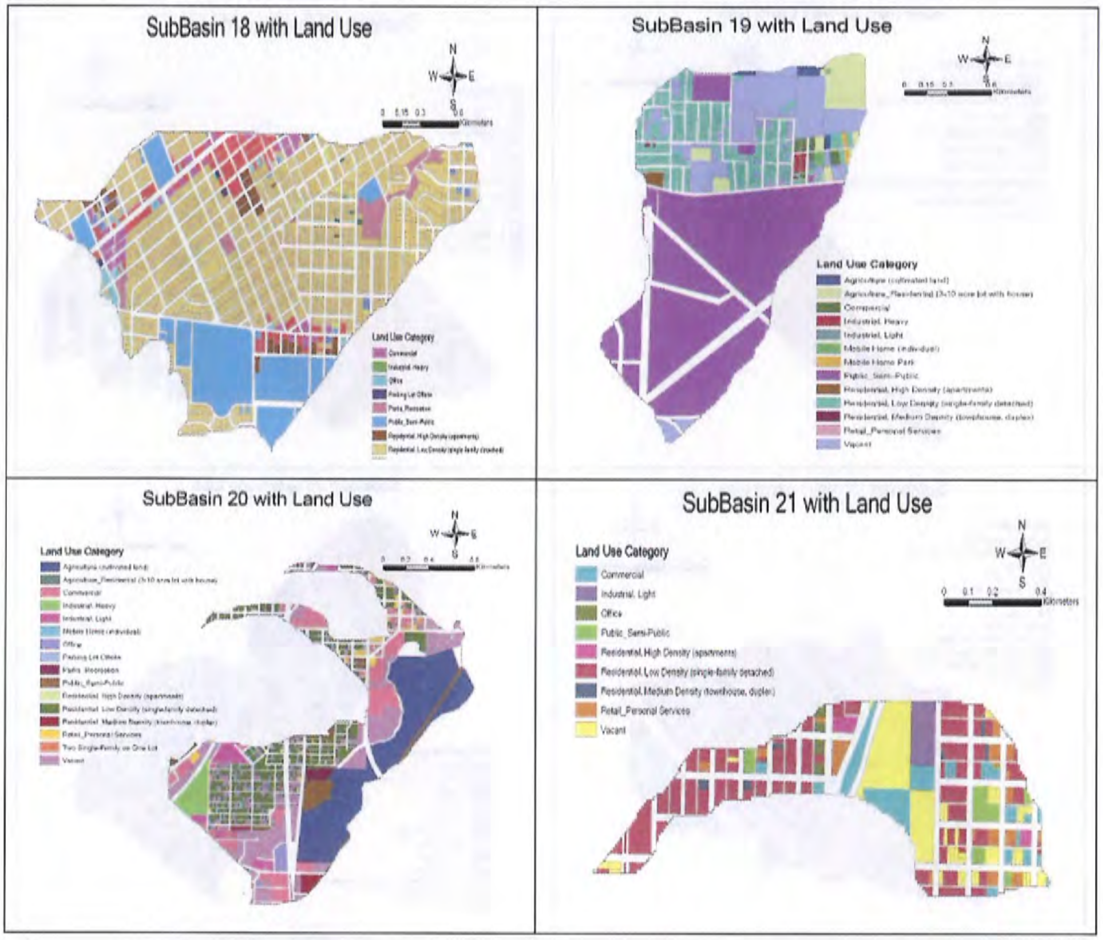
Land Use Categories	Area (acre) in each subbasin			
	5	6	7	8
Agriculture (cultivated land)	-	392.66	-	2,746.88
Agriculture_Commercial (ranches, dairies)	-	-	-	-
Agriculture_Residential (3-10 acre lot with house)	-	1.57	-	99.46
Commercial	-	7.46	0.14	33.57
Industrial, Heavy	-	112.33	-	184.36
Industrial, Light	-	31.93	-	30.81
Mobile Home (individual)	-	11.49	-	21.22
Mobile Home Park	-	-	-	0.60
Office	-	-	-	-
Parking Lot Offsite	-	-	-	5.05
Parks_Recreation	-	4.31	-	10.67
Public_Semi-Public	-	11.30	0.37	55.71
Residential, High Density (apartments)	-	-	0.60	-
Residential, Low Density (single-family detached)	-	55.23	15.82	89.78
Residential, Medium Density (townhouse, duplex)	-	0.61	-	2.13
Retail_Personal Services	-	1.29	0.36	5.87
Two Single-Family on One Lot	-	-	-	-
Vacant	27.53	215.37	10.33	1,189.88
Total	27.53	845.55	27.63	4,475.99



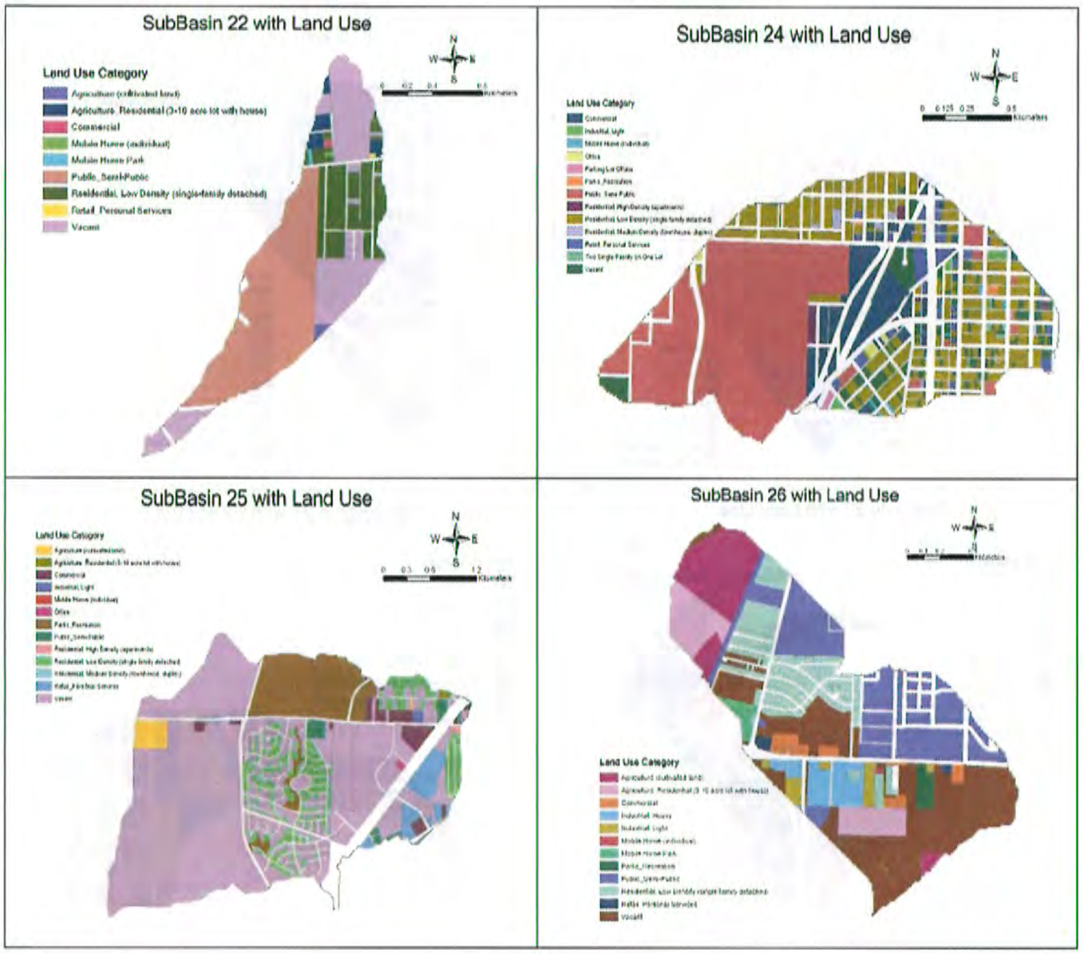
Land Use Categories	Area (acre) in each subbasin			
	9	10	11	12
Agriculture (cultivated land)	-	-	34.93	31.69
Agriculture_Commercial (ranches, dairies)	-	-	-	-
Agriculture_Residential (3-10 acre lot with house)	1.20	7.13	-	3.57
Commercial	13.93	10.89	7.84	11.42
Industrial, Heavy	5.95	-	60.74	12.40
Industrial, Light	-	-	8.98	8.04
Mobile Home (individual)	7.87	1.13	-	2.79
Mobile Home Park	2.25	-	-	0.62
Office	0.18	0.58	-	0.22
Parking Lot Offsite	1.55	1.15	-	-
Parks_Recreation	3.87	23.68	159.02	1.68
Public_Semi-Public	23.54	20.70	29.53	10.03
Residential, High Density (apartments)	2.22	2.34	7.07	1.22
Residential, Low Density (single-family detached)	163.13	297.08	4.78	96.96
Residential, Medium Density (townhouse, duplex)	1.52	17.35	-	12.61
Retail_Personal Services	11.94	5.45	5.50	5.51
Two Single-Family on One Lot	0.23	1.47	-	0.33
Vacant	26.75	101.63	244.04	59.88
Total	266.14	490.58	562.43	593.30



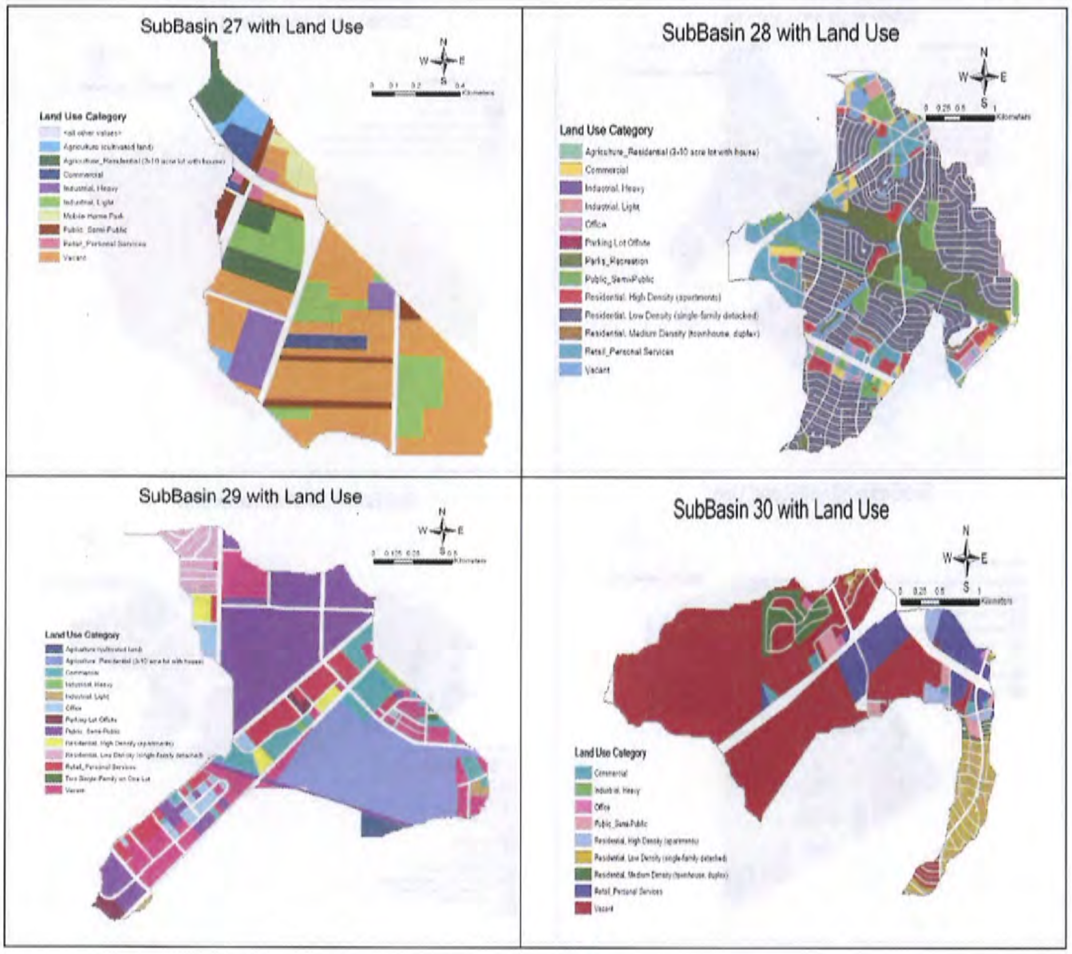
Land Use Categories	Area (acre) in each subbasin			
	13	14	15	17
Agriculture (cultivated land)	2,428.19	1,692.00	-	190.21
Agriculture_Commercial (ranches, dairies)	-	-	-	-
Agriculture_Residential (3-10 acre lot with house)	296.19	95.40	12.52	58.36
Commercial	337.99	15.29	42.26	116.81
Industrial, Heavy	110.40	34.84	2.27	19.37
Industrial, Light	71.26	10.97	13.59	19.86
Mobile Home (individual)	12.73	4.54	12.75	4.51
Mobile Home Park	19.94	3.62	-	0.74
Office	6.24	-	5.56	45.45
Parking Lot Offsite	4.27	-	9.79	39.80
Parks_Recreation	325.49	430.40	0.37	155.32
Public_Semi-Public	107.32	63.15	44.11	502.19
Residential, High Density (apartments)	29.84	3.80	12.26	35.95
Residential, Low Density (single-family detached)	1,442.76	371.72	216.86	746.94
Residential, Medium Density (townhouse, duplex)	12.52	0.38	5.81	26.28
Retail_Personal Services	125.18	3.52	24.03	85.80
Two Single-Family on One Lot	2.92	-	0.58	9.08
Vacant	1,028.51	1,319.19	48.99	284.96
Total	6,361.73	4,048.81	451.77	2,341.64



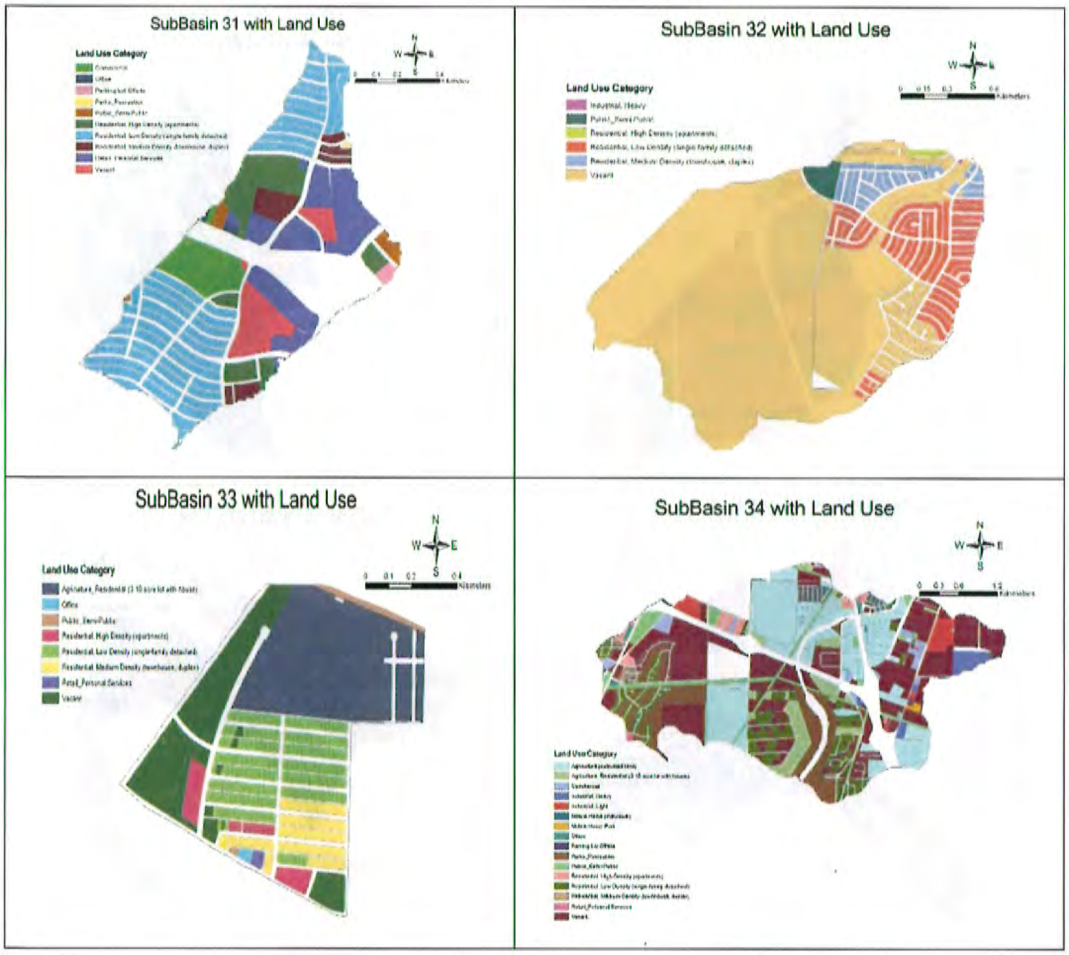
Land Use Categories	Area (acre) in each subbasin			
	18	19	20	21
Agriculture (cultivated land)	-	5.78	182.42	-
Agriculture_Commercial (ranches, dairies)	-	-	-	-
Agriculture_Residential (3-10 acre lot with house)	-	41.69	0.36	-
Commercial	19.86	6.09	72.80	12.83
Industrial, Heavy	0.19	3.26	20.57	-
Industrial, Light	-	0.75	19.24	5.07
Mobile Home (individual)	-	2.79	1.71	-
Mobile Home Park	-	1.94	-	-
Office	6.99	-	7.31	1.56
Parking Lot Offsite	1.20	-	0.78	-
Parks_Recreation	21.53	-	5.80	-
Public_Semi-Public	132.13	401.21	31.86	4.58
Residential, High Density (apartments)	16.91	3.48	0.58	1.80
Residential, Low Density (single-family detached)	396.94	99.54	107.42	37.49
Residential, Medium Density (townhouse, duplex)	2.61	0.50	8.43	1.29
Retail_Personal Services	37.40	0.26	11.24	7.02
Two Single-Family on One Lot	0.87	-	1.00	-
Vacant	4.40	131.26	141.25	23.51
Total	641.03	698.55	612.78	95.15



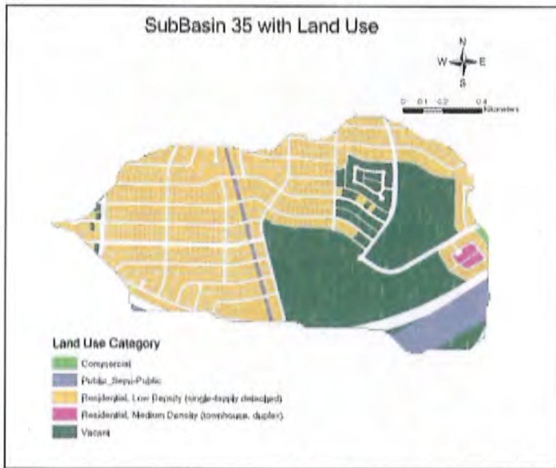
Land Use Categories	Area (acre) in each subbasin			
	22	24	25	26
Agriculture (cultivated land)	2.47	-	35.68	53.37
Agriculture_Commercial (ranches, dairies)	-	-	-	-
Agriculture_Residential (3-10 acre lot with house)	12.57	-	2.93	41.51
Commercial	1.01	43.84	58.89	13.86
Industrial, Heavy	-	-	-	23.74
Industrial, Light	-	2.24	4.62	10.49
Mobile Home (individual)	0.70	1.05	0.19	0.39
Mobile Home Park	0.98	-	-	6.23
Office	-	1.71	2.50	-
Parking Lot Offsite	-	0.98	-	-
Parks_Recreation	-	0.88	266.76	6.56
Public_Semi-Public	218.37	192.78	27.38	115.93
Residential, High Density (apartments)	-	3.55	2.55	-
Residential, Low Density (single-family detached)	83.35	97.31	187.34	66.47
Residential, Medium Density (townhouse, duplex)	-	2.25	1.55	-
Retail_Personal Services	0.48	14.39	70.38	2.67
Two Single-Family on One Lot	-	0.92	-	-
Vacant	137.78	29.40	1,506.13	157.77
Total	457.72	391.31	2,166.89	498.99

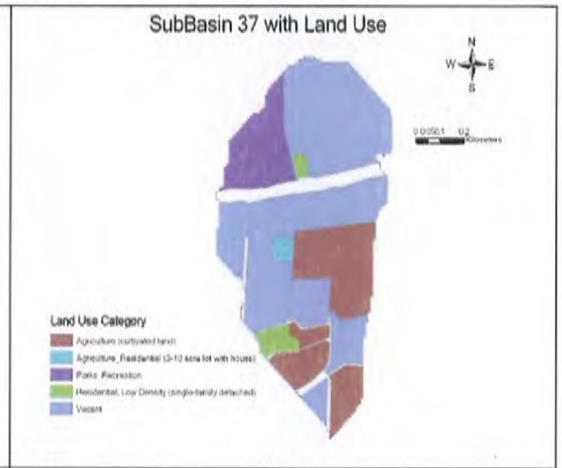


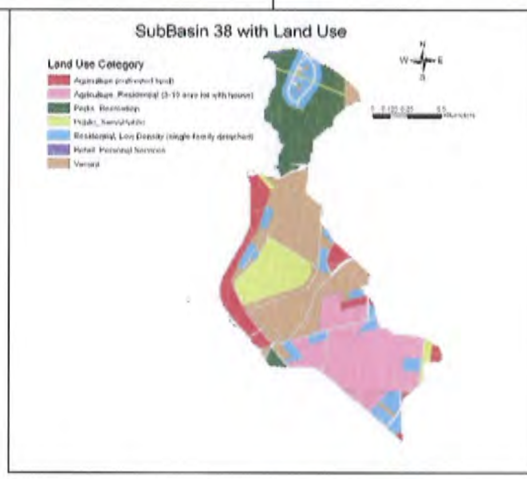
Land Use Categories	Area (acre) in each subbasin			
	27	28	29	30
Agriculture (cultivated land)	6.72	-	6.00	-
Agriculture_Commercial (ranches, dairies)	-	-	-	-
Agriculture_Residential (3-10 acre lot with house)	22.84	0.00	131.52	-
Commercial	11.47	60.91	45.25	12.65
Industrial, Heavy	17.33	0.65	3.65	0.11
Industrial, Light	40.63	9.92	3.79	-
Mobile Home (individual)	-	-	-	-
Mobile Home Park	5.91	-	-	-
Office	-	31.12	16.75	5.11
Parking Lot Offsite	-	0.36	6.29	-
Parks_Recreation	-	230.13	-	0.25
Public_Semi-Public	16.27	161.37	181.21	27.87
Residential, High Density (apartments)	-	99.27	10.86	24.26
Residential, Low Density (single-family detached)	-	821.92	20.38	75.61
Residential, Medium Density (townhouse, duplex)	-	21.41	-	59.33
Retail_Personal Services	2.52	230.38	38.15	143.04
Two Single-Family on One Lot	-	-	0.67	-
Vacant	143.47	104.58	80.25	866.45
Total	267.16	1,772.01	544.75	1,214.67



Land Use Categories	Area (acre) in each subbasin			
	31	32	33	34
Agriculture (cultivated land)	-	-	-	699.96
Agriculture_Commercial (ranches, dairies)	-	-	-	-
Agriculture_Residential (3-10 acre lot with house)	-	-	64.17	142.94
Commercial	18.26	-	-	55.90
Industrial, Heavy	-	0.14	-	52.82
Industrial, Light	-	-	-	76.79
Mobile Home (individual)	-	-	-	24.64
Mobile Home Park	-	-	-	5.99
Office	1.04	-	0.54	11.16
Parking Lot Offsite	1.47	-	-	1.47
Parks_Recreation	0.15	-	-	286.68
Public_Semi-Public	4.34	9.31	3.16	149.91
Residential, High Density (apartments)	28.18	2.69	7.41	39.36
Residential, Low Density (single-family detached)	81.42	76.56	32.80	240.42
Residential, Medium Density (townhouse, duplex)	12.84	26.18	13.71	14.40
Retail_Personal Services	45.14	-	0.71	7.62
Two Single-Family on One Lot	-	-	-	-
Vacant	19.28	602.53	38.71	955.11
Total	212.13	717.40	161.22	2,765.18







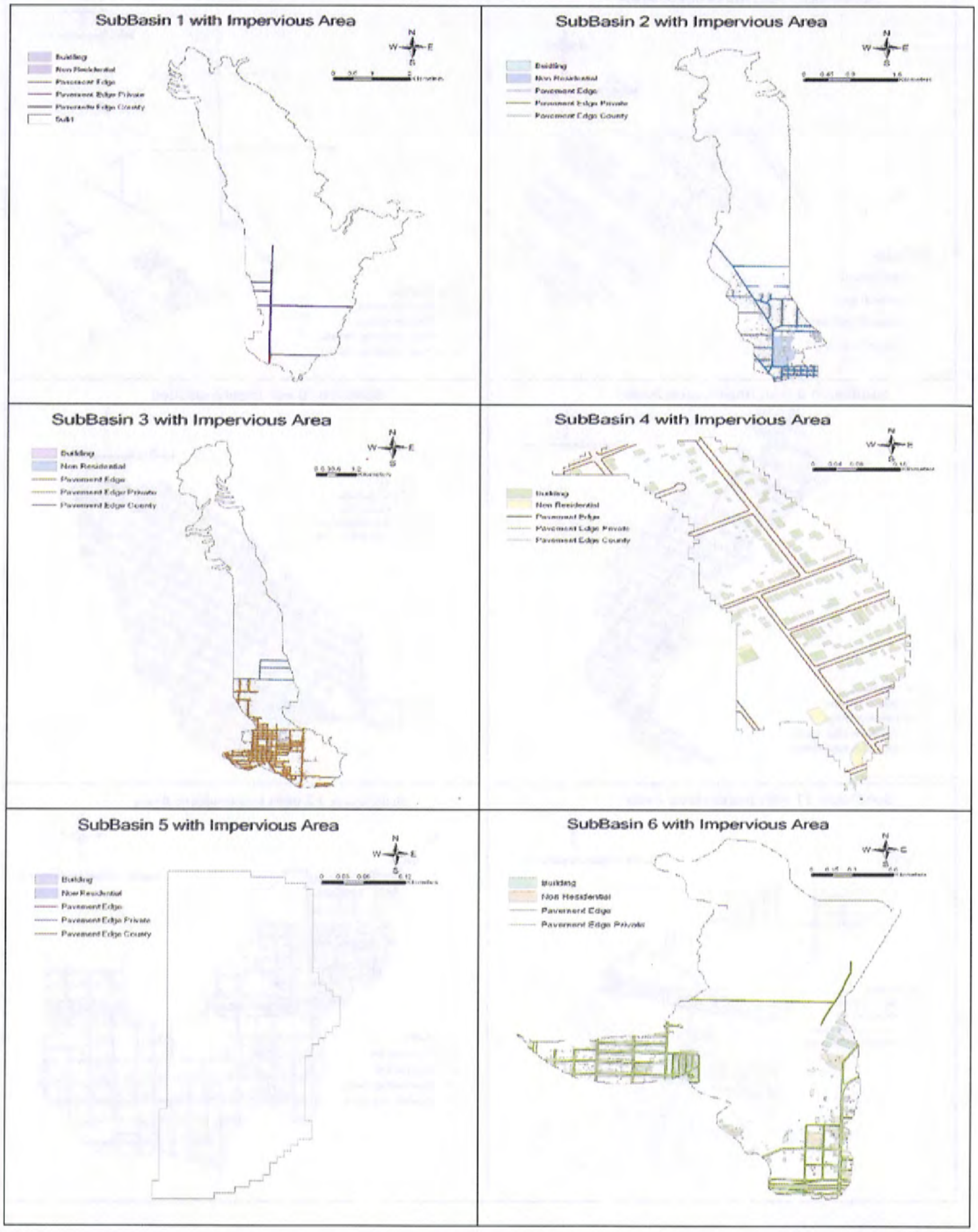
Land Use Categories	Area (acre) in each subbasin		
	35	37	38
Agriculture (cultivated land)	-	37.68	43.90
Agriculture_Commercial (ranches, dairies)	-	-	-
Agriculture_Residential (3-10 acre lot with house)	-	1.68	112.41
Commercial	0.64	-	-
Industrial, Heavy	-	-	-
Industrial, Light	-	-	-
Mobile Home (individual)	-	-	-
Mobile Home Park	-	-	-
Office	-	-	-
Parking Lot Offsite	-	-	-
Parks_Recreation	-	18.48	70.71
Public_Semi-Public	24.21	-	48.03
Residential, High Density (apartments)	-	-	-
Residential, Low Density (single-family detached)	181.28	4.75	49.81
Residential, Medium Density (townhouse, duplex)	2.55	-	-
Retail_Personal Services	-	-	0.55
Two Single-Family on One Lot	-	-	-
Vacant	140.14	96.39	131.42
Total	348.83	3,761.60	158.99

APPENDIX C

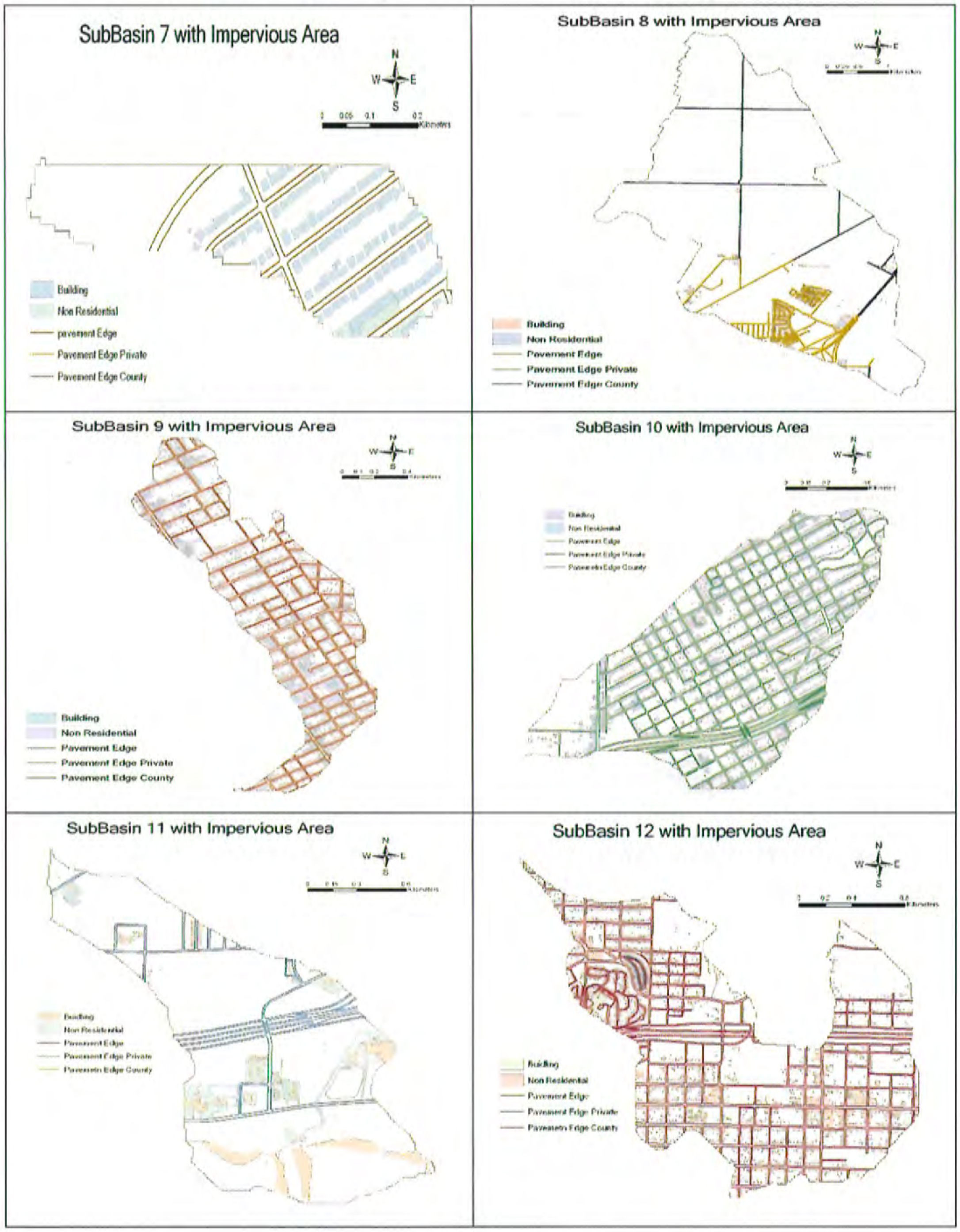
Summary of Impervious Area Categories of Subbasins

Selected for SWMM Modeling

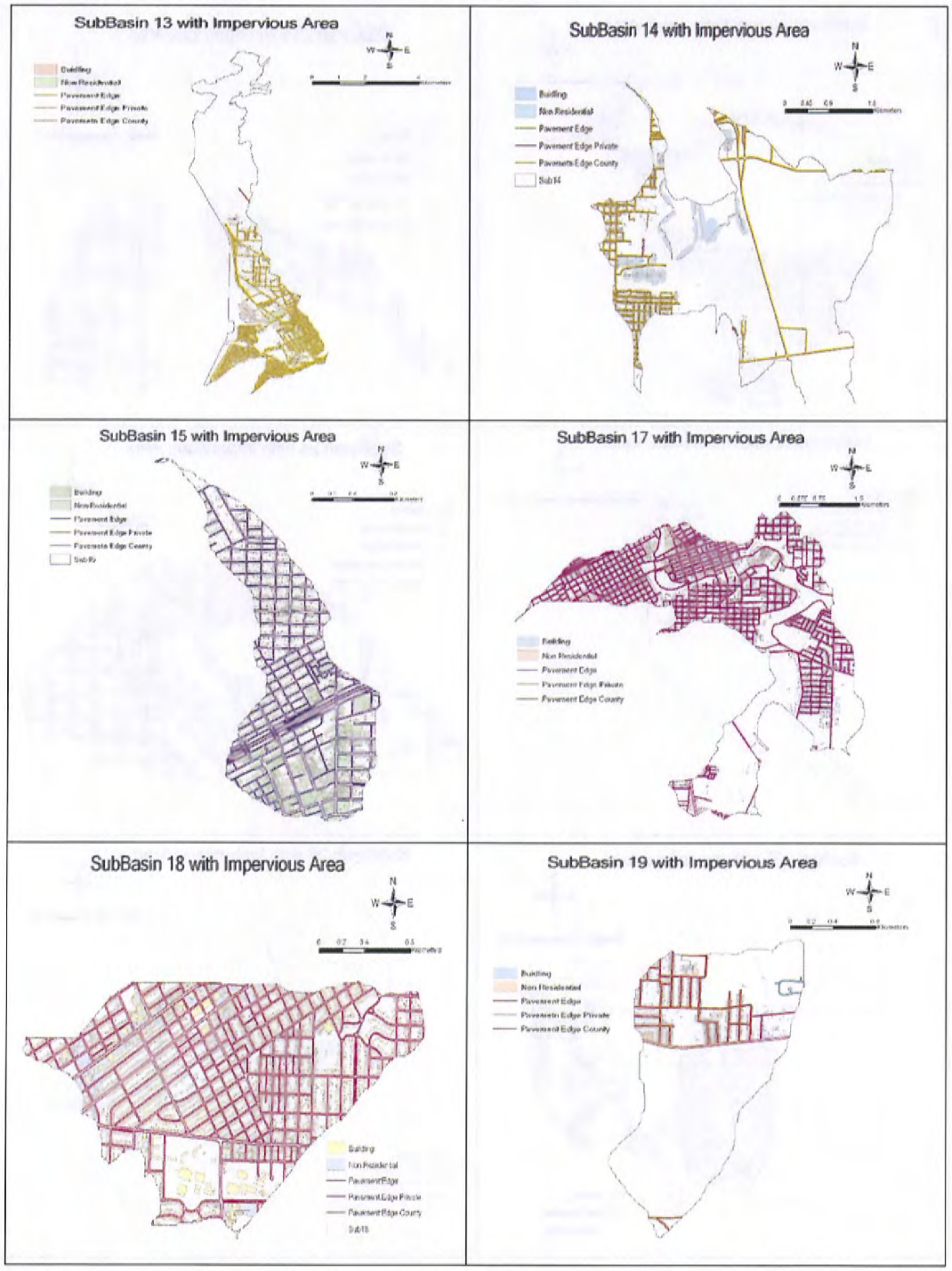
35 Subbasins Selected for Detailed Modeling



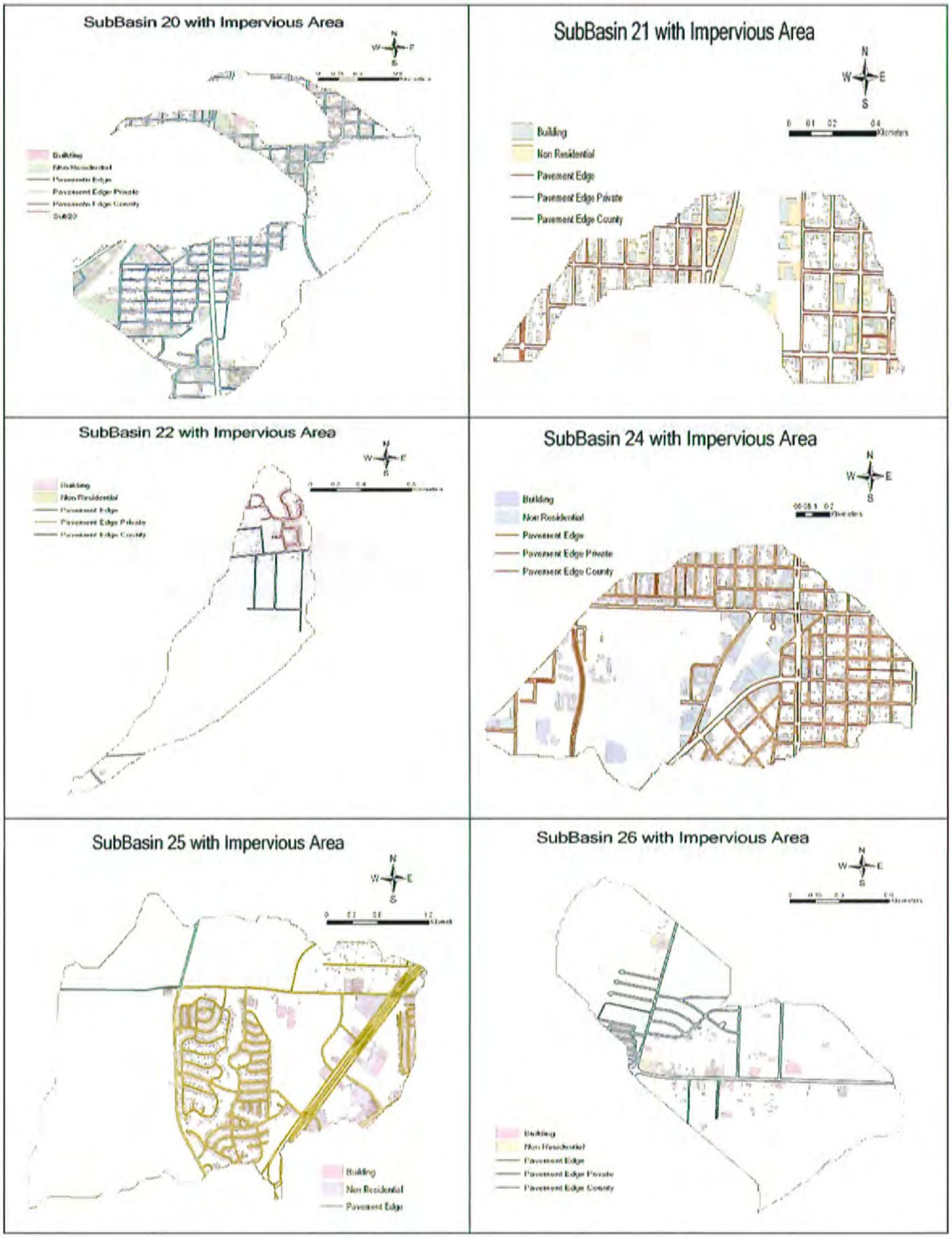
Impervious Area Categories	Area (acre) in each subbasin					
	1	2	3	4	5	6
Building Footprints	0.02	42.36	99.19	5.30	0.00	31.54
Non residential	0.10	82.53	40.52	0.95	0.00	32.55
Pavement	24.40	44.91	115.91	7.17	0.00	36.65
Total	24.52	169.80	255.62	13.41	0.00	100.75



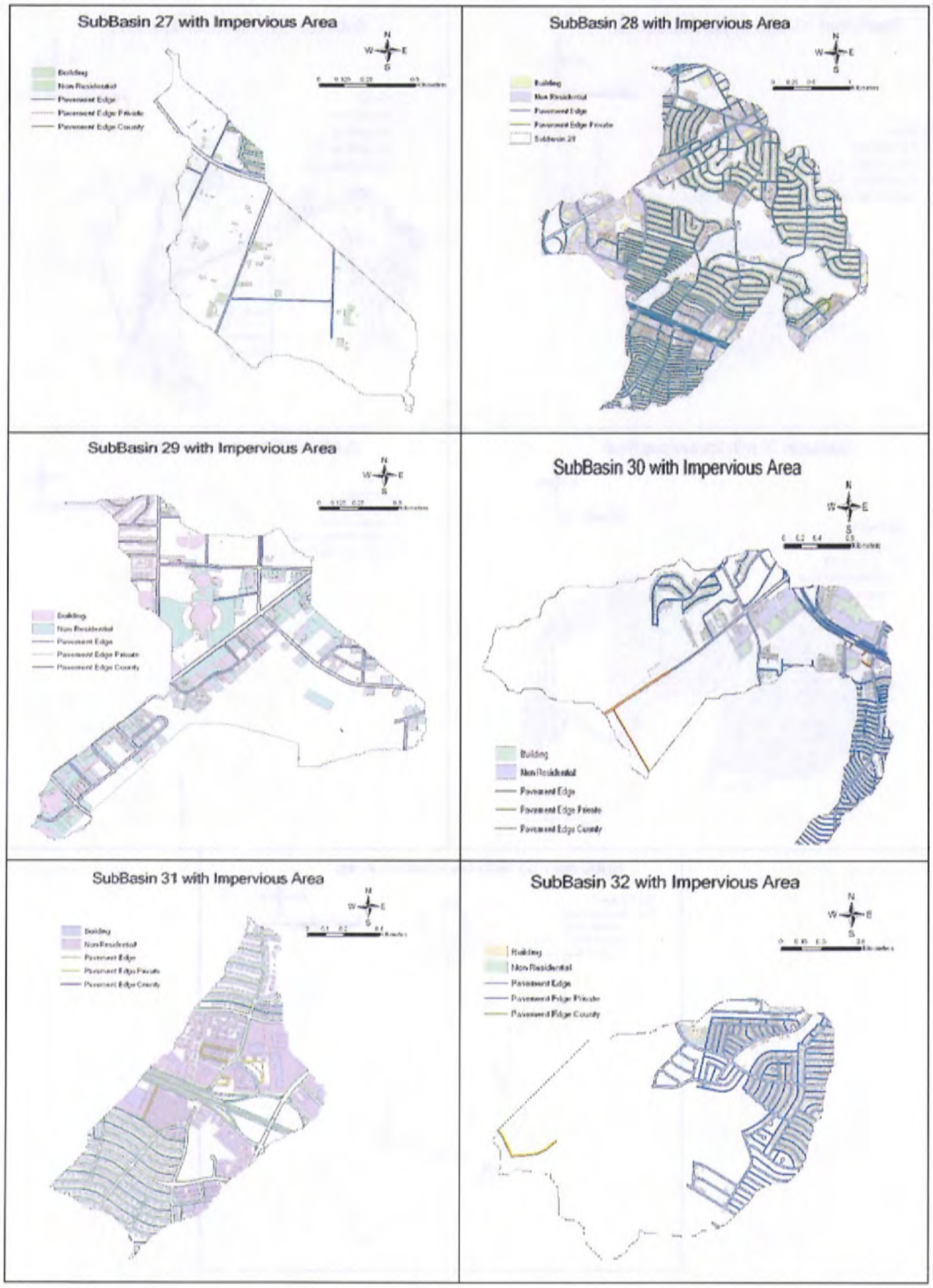
Impervious Area Categories	Area (acre) in each subbasin					
	7	8	9	10	11	12
Building Footprints	5.20	46.43	49.43	77.53	37.71	82.29
Non residential	1.45	55.50	35.41	22.68	50.31	67.14
Pavement	4.79	149.54	66.16	142.78	29.43	123.05
Total	11.45	251.46	151.00	242.99	117.45	272.49



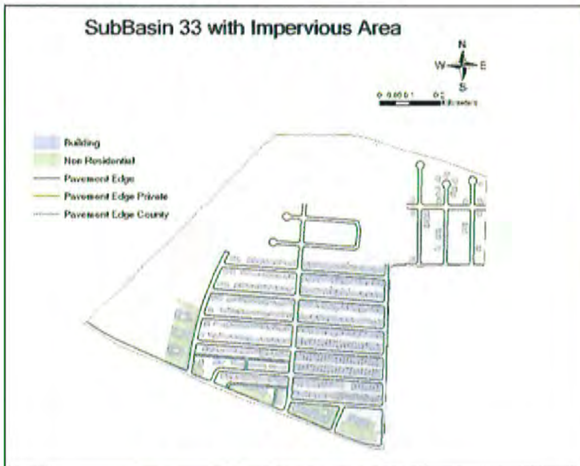
Impervious Area Categories	Area (acre) in each subbasin					
	13	14	15	17	18	19
Building Footprints	335.44	163.27	97.29	345.92	159.14	31.04
Non residential	261.80	51.12	126.32	361.74	83.54	6.94
Pavement	400.85	103.90	132.05	363.97	148.06	28.67
Total	998.09	318.29	355.66	1,071.62	390.74	66.65

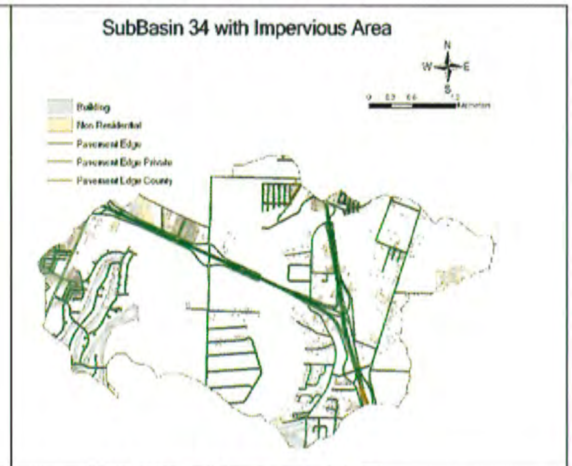


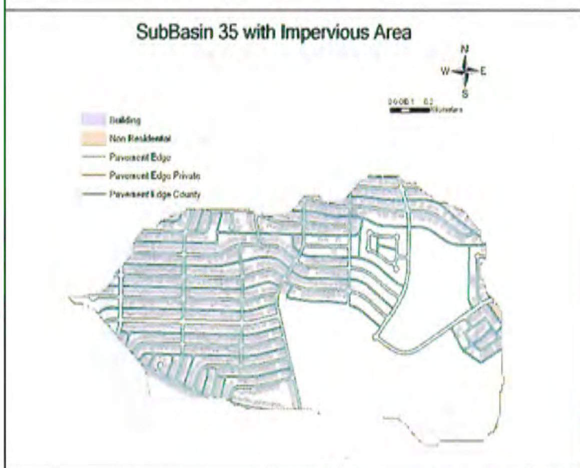
Impervious Area Categories	Area (acre) in each subbasin					
	20	21	22	24	25	26
Building Footprints	53.98	19.94	5.93	52.55	102.00	12.63
Non residential	91.61	21.75	0.36	53.61	94.04	18.23
Pavement	61.17	15.63	15.84	54.44	133.23	27.13
Total	206.76	57.32	22.13	160.59	329.27	57.98

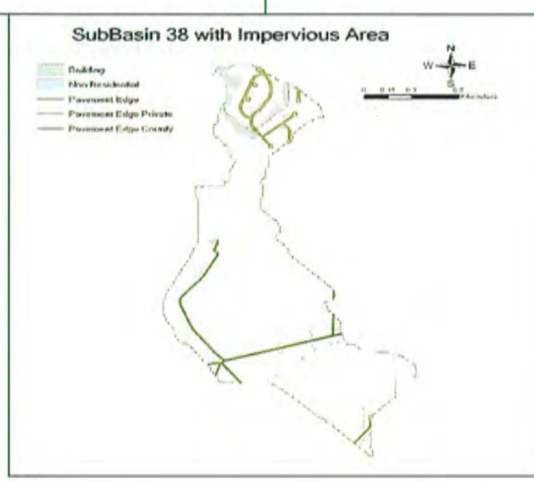


Impervious Area Categories	Area (acre) in each subbasin					
	27	28	29	30	31	32
Building Footprints	6.24	397.85	65.13	91.80	55.91	39.25
Non residential	9.06	404.25	169.18	154.25	84.08	5.44
Pavement	14.64	367.98	36.95	56.57	53.82	74.21
Total	29.94	1,170.08	271.26	302.62	193.82	118.91









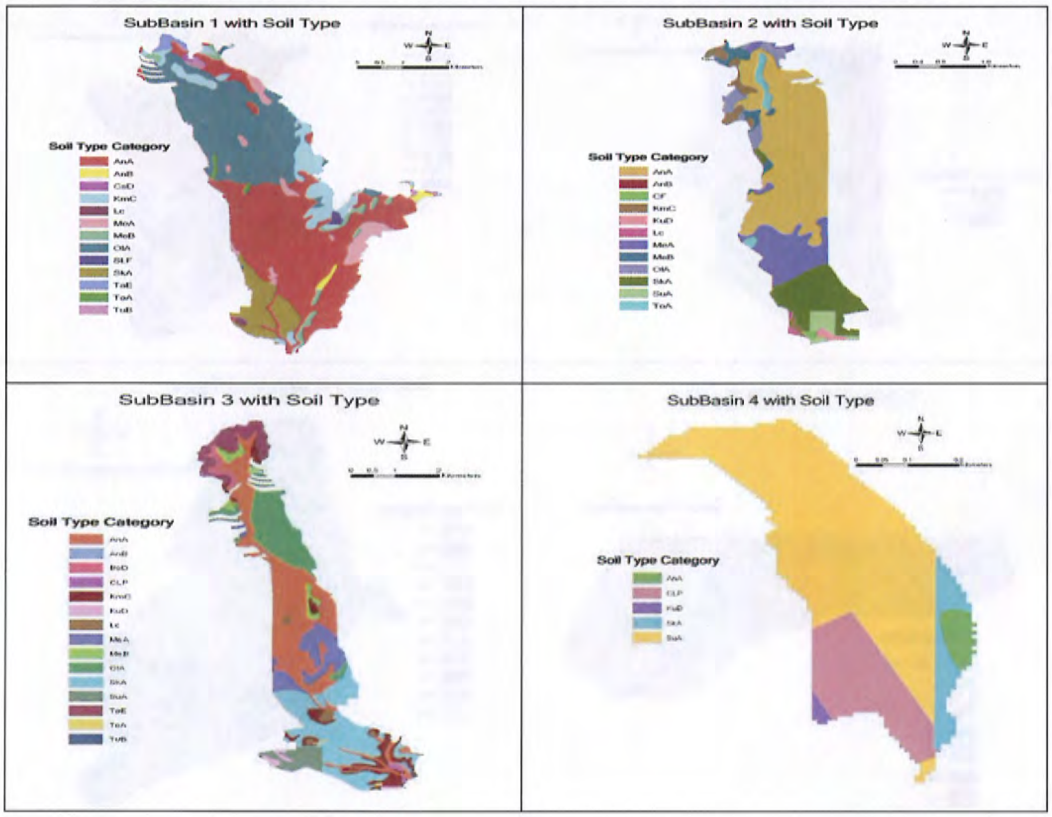
Impervious Area Categories	Area (acre) in each subbasin				
	33	34	35	37	38
Building Footprints	s	139.43	49.85	0.00	12.19
Non residential	8.45	144.43	0.39	0.00	0.97
Pavement	20.84	238.65	73.47	1.26	21.05
Total	52.31	522.51	123.70	1.26	34.21

APPENDIX D

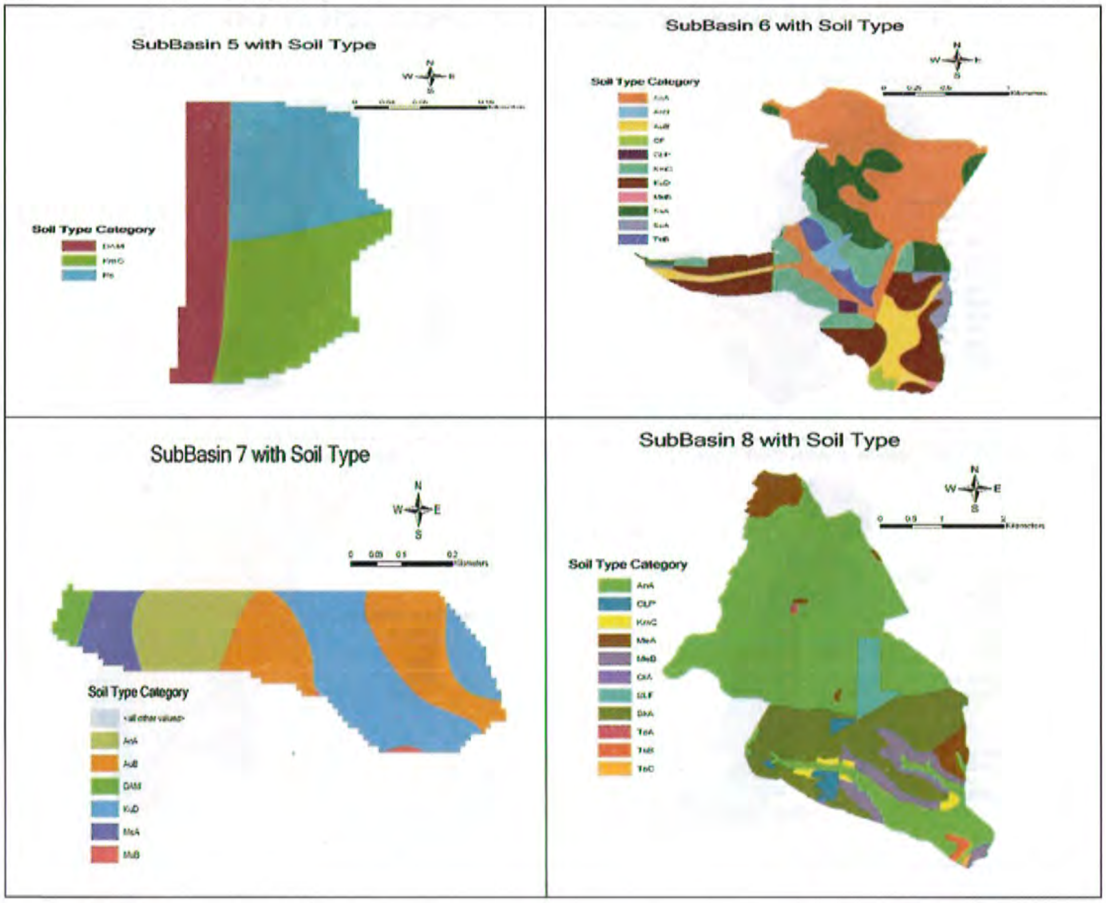
Summary of Soil Type Categories of Subbasins

Selected and Not Selected for SWMM Modeling

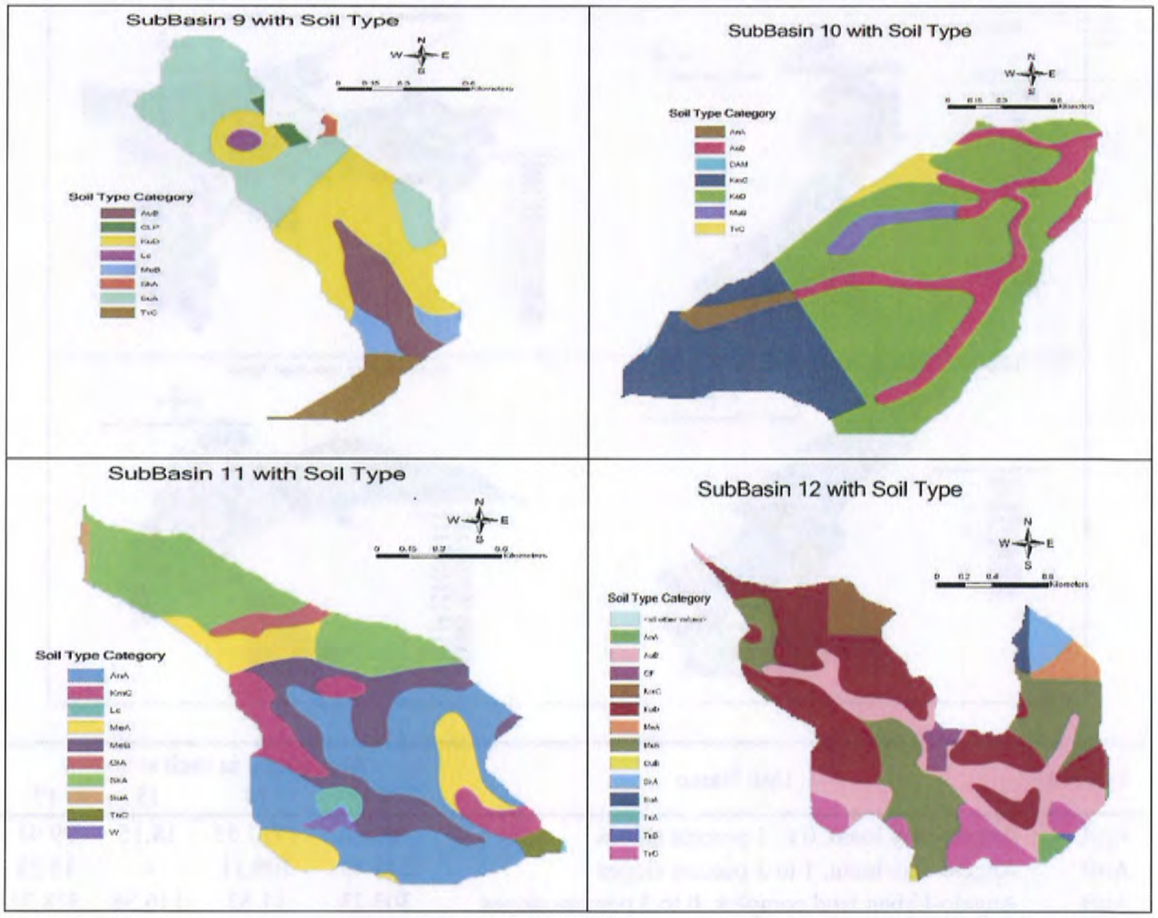
35 Subbasins Selected for Detailed Modeling



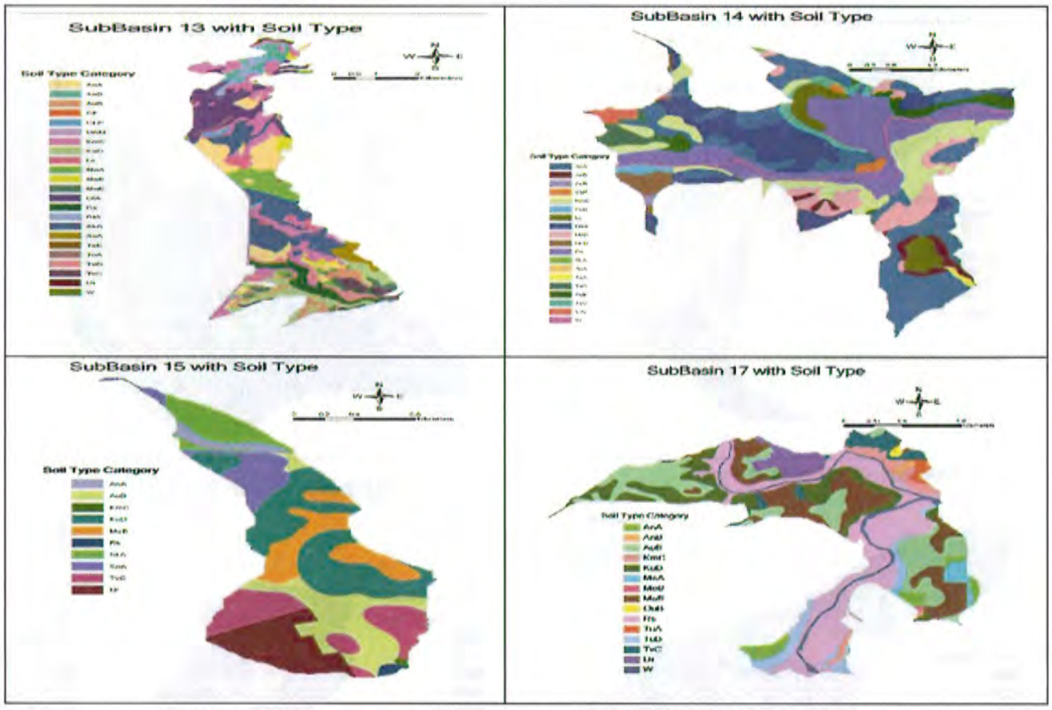
Symbol	Unit Name	Area (acre) in each subbasin 1	2	3	4
AnA	Angelo clay loam, 0 to 1 percent slopes	2835.0	1399.1	1660.6	1.9
AnB	Angelo clay loam, 1 to 3 percent slopes	51.0	0.6	13.7	-
BeD	Berda loam, 3 to 8 percent slopes	-	-	67.0	
CF	Cut and fill,		10.2	-	
CLP	Pits, caliche	-	-	25.4	11.2
CsD	Oben-Latom complex, 1 to 8 percent slopes	9.6		-	-
KmC	Cho association, undulating	561.5	110.0	386.4	-
KoD	Cho-Vernon complex, 1 to 8 percent slopes		21.0	46.3	-
KuD	Cho-Urban land complex, 1 to 8 percent slopes	-	-		0.4
Lc	Lipan clay	15.7	8.5	52.1	-
MeA	Mereta clay loam, 0 to 1 percent slopes	282.9	424.6	416.1	-
MeB	Mereta clay loam, 1 to 3 percent slopes	147.7	87.3	110.2	-
OlA	Sagerton clay loam, 0 to 1 percent slopes	1936.7	112.9	711.4	-
SkA	Slaughter-Cho complex, 0 to 1 percent slopes	466.5	433.6	1084.2	4.1
SLF	Sanitary landfill 267 *	26.3	-	-	-
SuA	Slaughter-Urban land complex, 0 to 1 percent slopes	-	81.1	202.7	-
TaC	Tarrant association, undulating	-	-	-	39.4
TaE	Tarrant association, hilly	51.7	-	335.6	-
ToA	Tobosa clay, 0 to 1 percent slopes	28.8	65.2	10.8	-
ToB	Tobosa clay, 1 to 3 percent slopes	49.6	-	-	-
TuB	Tulia loam, 1 to 3 percent slopes	-	-	2.5	-



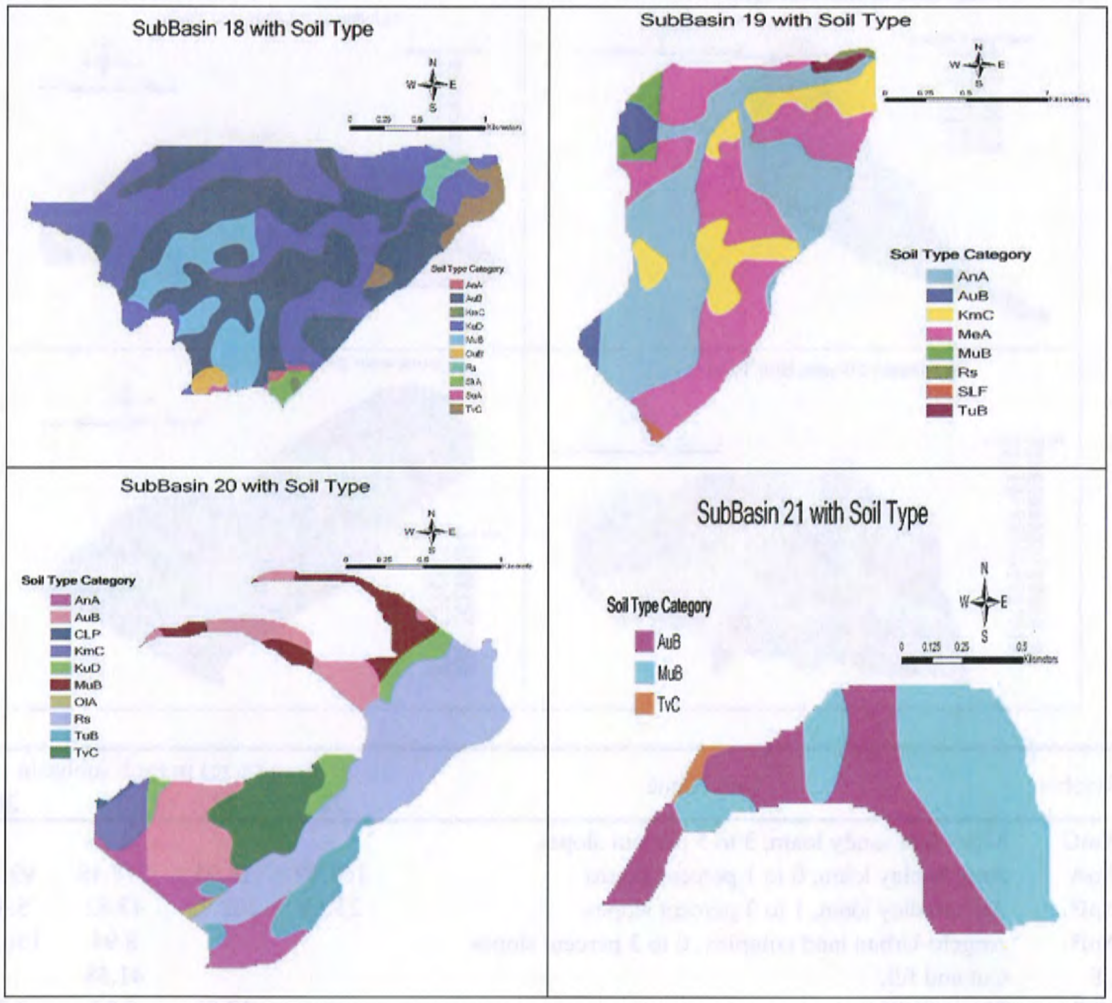
Symbol	Unit Name	Area (acre) in each subbasin			
		5	6	7	8
AnA	Angelo clay loam, 0 to 1 percent slopes	-	376.94	6.25	3026.20
AnB	Angelo clay loam, 1 to 3 percent slopes	-	15.70	11.60	-
AuB	Angelo-Urban land complex, 0 to 3 percent slopes	-	79.83	-	-
CF	Cut and fill,	-	8.58	-	-
CLP	Pits, caliche	-	6.00	-	73.18
DAM	Dams	7.15	-	1.18	-
KmC	Cho association, undulating	10.65	129.73	-	50.82
KuD	Cho-Urban land complex, 1 to 8 percent slopes	-	178.47	13.14	-
MeA	Mereta clay loam, 0 to 1 percent slopes	-	-	2.85	245.46
MeB	Mereta clay loam, 1 to 3 percent slopes	-	-	0.16	285.88
MuB	Mereta-Urban land complex, 0 to 3 percent slopes	-	2.21	-	-
OlA	Sagerton clay loam, 0 to 1 percent slopes	-	-	-	1.31
Rs	Rioconcho and Spur soils	9.73	-	-	-
SkA	Slaughter-Cho complex, 0 to 1 percent slopes	-	143.73	-	997.04
SLF	Sanitary landfill 267 *	-	-	-	148.19
SuA	Slaughter-Urban land complex, 0 to 1 percent slopes	-	20.79	-	-
ToA	Tobosa clay, 0 to 1 percent slopes	-	-	-	5.51
TuB	Tulia loam, 1 to 3 percent slopes	-	30.09	-	27.65
TuC	Tulia loam, 3 to 5 percent slopes	-	-	-	5.68



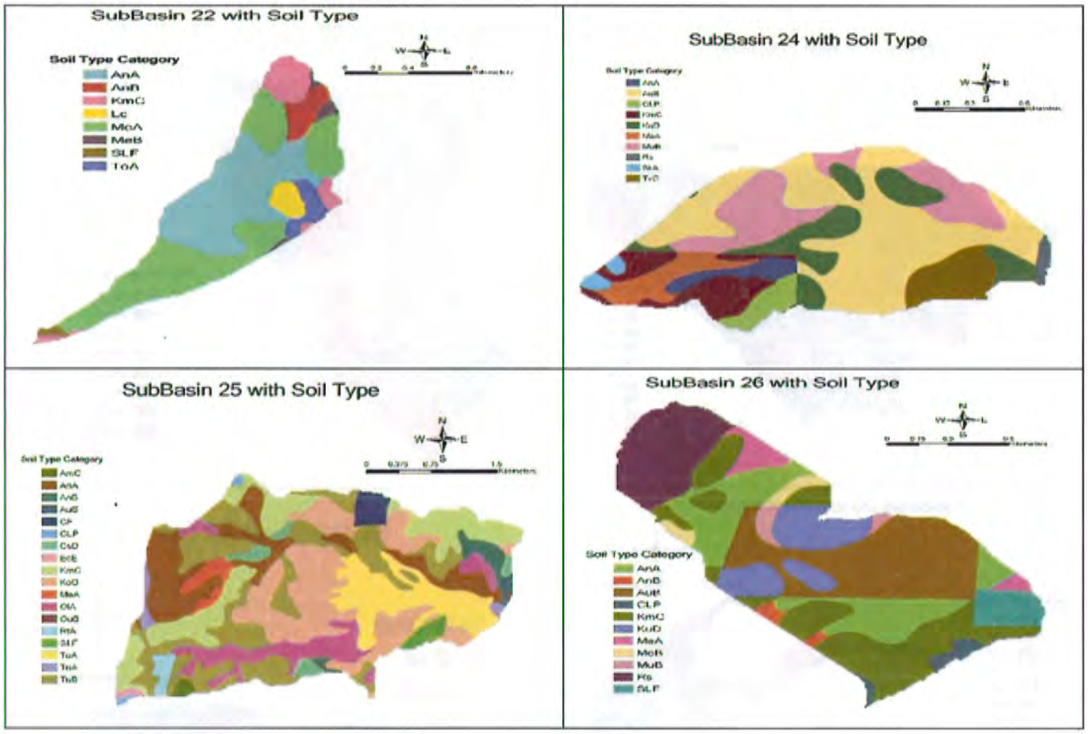
Symbol	Unit Name	Area (acre) in each subbasin 9	10	11	12
AnA	Angelo clay loam, 0 to 1 percent slopes	45.48	16.64	201.08	8.87
AuB	Angelo-Urban land complex, 0 to 3 percent slopes	-	106.85	-	174.60
CF	Cut and fill,		-	-	14.69
CLP	Pits, caliche	4.96	-	-	-
DAM	Dams	-	0.36	-	-
KmC	Cho association, undulating		165.84	54.33	35.66
KuD	Cho-Urban land complex, 1 to 8 percent slopes	132.02	400.06	-	311.52
Lc	Lipan clay	4.78	-	9.11	-
MeA	Mereta clay loam, 0 to 1 percent slopes	-	-	79.56	21.12
MeB	Mereta clay loam, 1 to 3 percent slopes	-	-	103.54	-
MuB	Mereta-Urban land complex, 0 to 3 percent slopes	19.95	19.66	-	204.41
OlA	Sagerton clay loam, 0 to 1 percent slopes	-	-	15.02	-
OuB	Sagerton-Urban land complex, 0 to 3 percent slopes	-	-	-	1.22
SkA	Slaughter-Cho complex, 0 to 1 percent slopes	2.25	-	150.05	21.55
SuA	Slaughter-Urban land complex, 0 to 1 percent slopes	138.05	-	2.81	9.86
TuA	Tulia loam, 0 to 1 percent slopes	-	-	-	0.05
TuB	Tulia loam, 1 to 3 percent slopes	-	-	-	1.22
TuC	Tulia loam, 3 to 5 percent slopes	32.25	-	7.06	-
TvC	Tulia-Urban land Complex, 0 to 5 percent slopes	-	13.72	-	73.18
W	Water	-	-	5.58	-



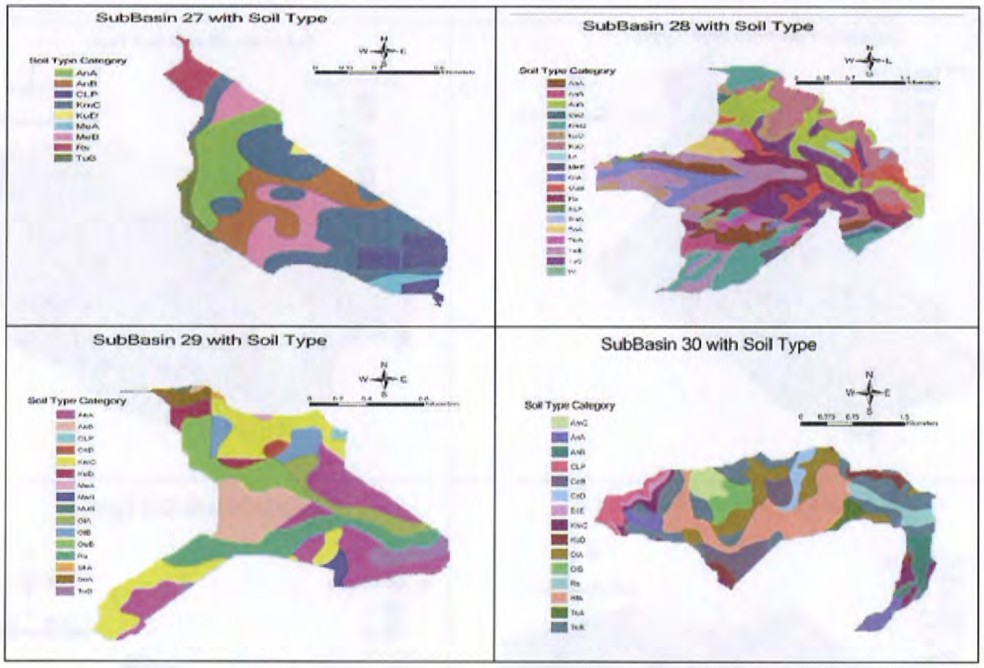
Symbol	Unit Name	Area (acre) in each subbasin			
		13	14	15	17
AnA	Angelo clay loam, 0 to 1 percent slopes	840.30	1117.55	18.15	99.91
AnB	Angelo clay loam, 1 to 3 percent slopes	244.45	109.11	-	13.29
AuB	Angelo-Urban land complex, 0 to 3 percent slopes	303.23	11.52	116.56	578.32
CF	Cut and fill,	0.05	-	-	-
CLP	Pits, caliche	42.51	35.41	-	-
DAM	Dams	77.07	-	-	-
KmC	Cho association, undulating	1,201.66	553.14	1.71	108.24
KuD	Cho-Urban land complex, 1 to 8 percent slopes	474.68	36.96	185.08	387.84
Lc	Lipan clay	124.62	186.24	-	-
MeA	Mereta clay loam, 0 to 1 percent slopes	461.94	656.43	-	57.28
MeB	Mereta clay loam, 1 to 3 percent slopes	145.75	323.18	-	2.55
MuB	Mereta-Urban land complex, 0 to 3 percent slopes	173.18	91.76	84.87	524.37
OlA	Sagerton clay loam, 0 to 1 percent slopes	803.78	-	-	-
OuB	Sagerton-Urban land complex, 0 to 3 percent slopes	-	-	-	8.94
Rs	Rioconcho and Spur soils	346.17	840.48	4.37	857.49
RtA	Rotan clay loam, 0 to 1 percent slopes	111.18	-	-	-
SkA	Slaughter-Cho complex, 0 to 1 percent slopes	1,142.34	4.72	56.31	-
SuA	Slaughter-Urban land complex, 0 to 1 percent slopes	154.77	0.03	54.15	-
TaE	Tarrant association, hilly	26.76	-	-	-
ToA	Tobosa clay, 0 to 1 percent slopes	43.02	15.35	-	-
TuA	Tulia loam, 0 to 1 percent slopes	-	89.79	-	27.30
TuB	Tulia loam, 1 to 3 percent slopes	212.56	150.17	-	159.88
TuC	Tulia loam, 3 to 5 percent slopes	-	95.73	-	-
TvC	Tulia-Urban land Complex, 0 to 5 percent slopes	167.26	44.60	101.82	121.16
Ur	Urban land	0.80	-	93.33	133.06
W	Water	23.20	75.49	-	127.74



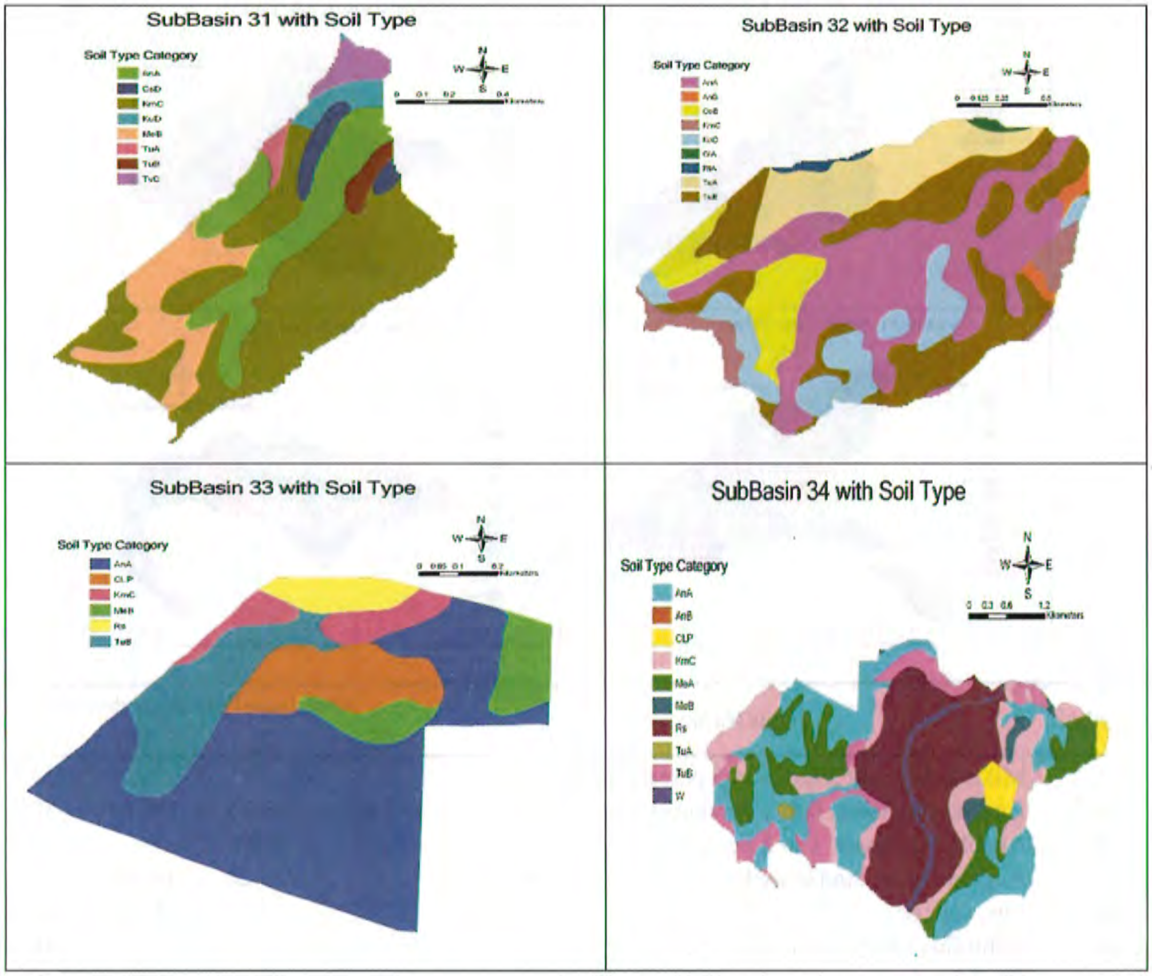
Symbol	Unit Name	Area (acre) in each subbasin			
		18	19	20	21
AnA	Angelo clay loam, 0 to 1 percent slopes	2.02	344.68	74.09	-
AuB	Angelo-Urban land complex, 0 to 3 percent slopes	376.05	26.32	139.31	59.01
CLP	Pits, caliche	-	-	2.44	-
KmC	Cho association, undulating	1.67	117.07	30.99	-
KuD	Cho-Urban land complex, 1 to 8 percent slopes	342.82	-	41.63	-
MeA	Mereta clay loam, 0 to 1 percent slopes	-	299.49	-	-
MuB	Mereta-Urban land complex, 0 to 3 percent slopes	102.58	18.26	54.56	75.96
OlA	Sagerton clay loam, 0 to 1 percent slopes	-	-	3.36	-
OuB	Sagerton-Urban land complex, 0 to 3 percent slopes	8.70	-	-	-
Rs	Rioconcho and Spur soils	13.25	2.88	281.67	-
SkA	Slaughter-Cho complex, 0 to 1 percent slopes	7.88	-	-	-
SLF	Sanitary landfill 267 *	-	2.86	-	-
SuA	Slaughter-Urban land complex, 0 to 1 percent slopes	3.04	-	-	-
TuB	Tulia loam, 1 to 3 percent slopes	-	7.88	54.43	-
TvC	Tulia-Urban land Complex, 0 to 5 percent slopes	29.91	-	86.12	1.86



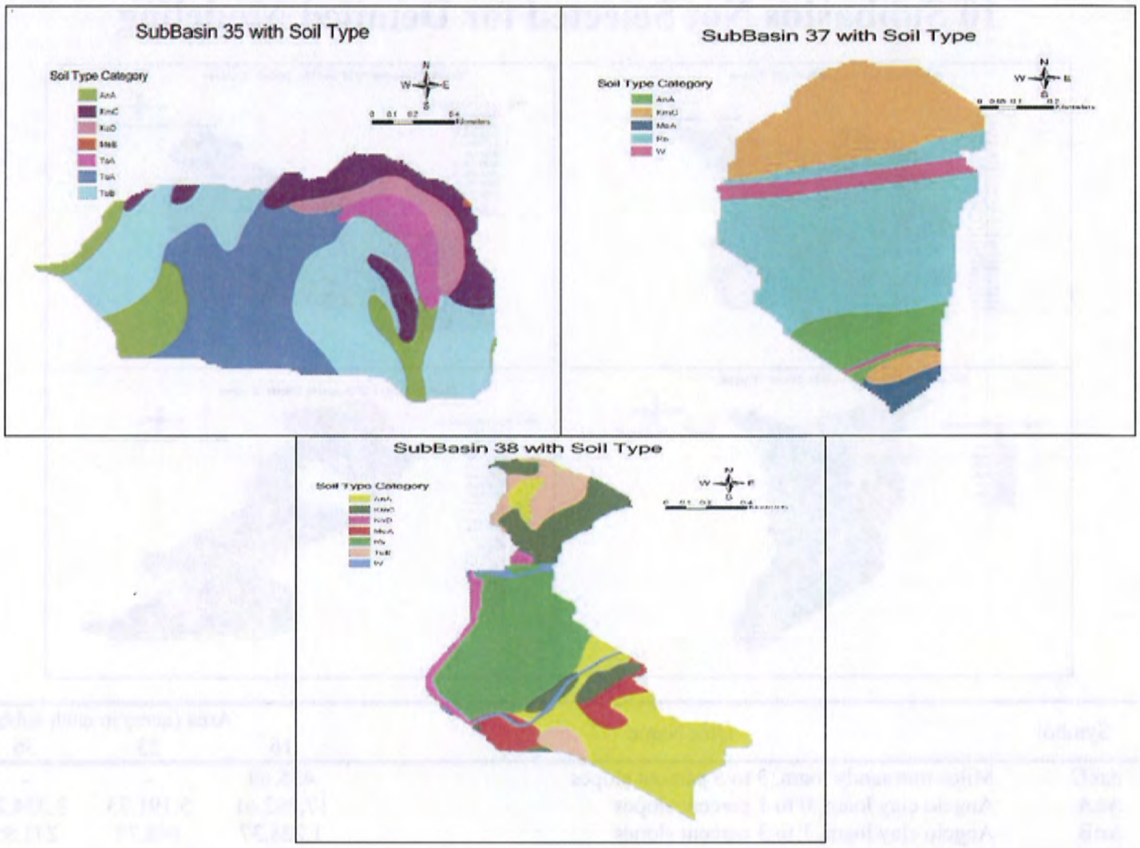
Symbol	Unit Name	Area (acre) in each subbasin			
		22	24	25	26
AmC	Miles fine sandy loam, 3 to 5 percent slopes	-	-	11.30	-
AnA	Angelo clay loam, 0 to 1 percent slopes	169.59	16.95	318.48	99.25
AnB	Angelo clay loam, 1 to 3 percent slopes	23.15	202.73	47.82	5.47
AuB	Angelo-Urban land complex, 0 to 3 percent slopes		-	8.94	130.61
CF	Cut and fill,		-	41.58	-
CLP	Pits, caliche	-	17.09	7.33	9.22
CsD	Oben-Latom complex, 1 to 8 percent slopes	-	-	46.32	-
EcE	Ector association, hilly	-	-	6.81	-
KmC	Cho association, undulating	43.37	45.81	340.37	123.41
KoD	Cho-Vernon complex, 1 to 8 percent slopes	-	-	490.34	-
KuD	Cho-Urban land complex, 1 to 8 percent slopes	-	75.64	-	57.47
Lc	Lipan clay	16.91	-	-	-
MeA	Mereta clay loam, 0 to 1 percent slopes	196.27	28.48	44.65	18.10
MeB	Mereta clay loam, 1 to 3 percent slopes	8.86	89.50	-	10.53
MuB	Mereta-Urban land complex, 0 to 3 percent slopes		-	-	8.72
OlA	Sagerton clay loam, 0 to 1 percent slopes		-	201.94	-
OuB	Sagerton-Urban land complex, 0 to 3 percent slopes	-	-	1.24	-
Rs	Rioconcho and Spur soils	-	4.98	-	75.03
RtA	Rotan clay loam, 0 to 1 percent slopes	-	-	26.01	-
SkA	Slaughter-Cho complex, 0 to 1 percent slopes	4.18	5.95	-	-
SLF	Sanitary landfill 267 *	-	-	27.37	22.57
ToA	Tobosa clay, 0 to 1 percent slopes	18.98	-	268.57	-
TuA	Tulia loam, 0 to 1 percent slopes		-	20.46	-
TuB	Tulia loam, 1 to 3 percent slopes	-	-	533.85	-
TvC	Tulia-Urban land Complex, 0 to 5 percent slopes		35.29	-	-



Symbol	Unit Name	Area (acre) in each subbasin			
		27	28	29	30
AmC	Miles fine sandy loam, 3 to 5 percent slopes	-	-	-	51.11
AnA	Angelo clay loam, 0 to 1 percent slopes	43.62	139.40	138.89	58.52
AnB	Angelo clay loam, 1 to 3 percent slopes	46.46	39.31	-	60.68
AuB	Angelo-Urban land complex, 0 to 3 percent slopes	-	269.26	67.40	-
CLP	Pits, caliche	27.97	-	2.64	52.81
CoB	Cobb fine sandy loam, 1 to 3 percent slopes	-	-	-	102.06
CsD	Oben-Latom complex, 1 to 8 percent slopes	-	20.60	5.53	36.57
EcE	Ector association, hilly	-	-	-	18.94
KmC	Cho association, undulating	103.84	266.39	120.78	65.90
KoD	Cho-Vernon complex, 1 to 8 percent slopes	-	95.88	-	50.02
KuD	Cho-Urban land complex, 1 to 8 percent slopes	1.04	274.98	17.95	-
Lc	Lipan clay	-	12.98	-	-
MeA	Mereta clay loam, 0 to 1 percent slopes	6.36	-	1.60	-
MeB	Mereta clay loam, 1 to 3 percent slopes	40.89	15.76	8.24	-
MuB	Mereta-Urban land complex, 0 to 3 percent slopes	-	-	1.13	-
OlA	Sagerton clay loam, 0 to 1 percent slopes	-	107.04	36.03	172.72
OlB	Sagerton clay loam, 1 to 3 percent slopes	-	-	26.64	57.08
OuB	Sagerton-Urban land complex, 0 to 3 percent slopes	-	134.38	55.71	-
Rs	Rioconcho and Spur soils	14.37	209.72	79.63	54.75
RtA	Rotan clay loam, 0 to 1 percent slopes	-	-	-	298.37
SkA	Slaughter-Cho complex, 0 to 1 percent slopes	-	-	1.35	-
SLF	Sanitary landfill 267 *	-	9.54		
SuA	Slaughter-Urban land complex, 0 to 1 percent slopes	-	5.39	12.40	-
ToA	Tobosa clay, 0 to 1 percent slopes	-	53.67		-
TuA	Tulia loam, 0 to 1 percent slopes	-	74.69	-	25.93
TuB	Tulia loam, 1 to 3 percent slopes	9.02	345.57	23.29	296.16
TvC	Tulia-Urban land Complex, 0 to 5 percent slopes	-	256.44	-	-
W	Water	-	6.86	-	-

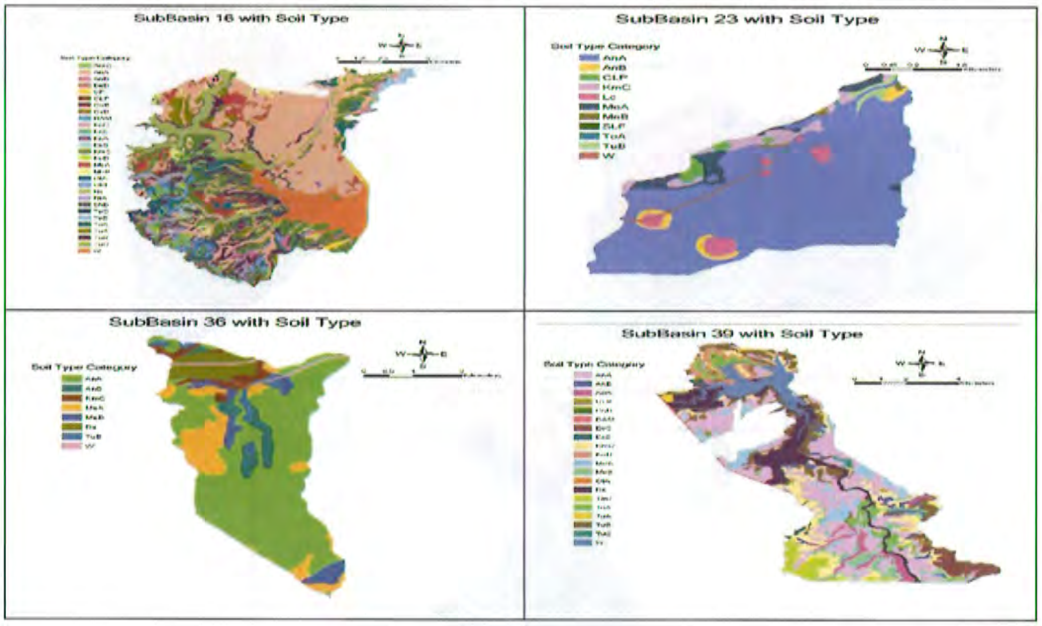


Symbol	Unit Name	Area (acre) in each subbasin			
		31	32	33	34
AnA	Angelo clay loam, 0 to 1 percent slopes	59.5	250.8	115.9	881.4
AnB	Angelo clay loam, 1 to 3 percent slopes	-	10.5	-	0.7
CLP	Pits, caliche	-	-	21.0	83.8
CoB	Cobb fine sandy loam, 1 to 3 percent slopes	-	68.7	-	-
CsD	Oben-Latom complex, 1 to 8 percent slopes	10.7	-	-	-
KmC	Cho association, undulating	154.4	34.5	11.1	521.4
KoD	Cho-Vernon complex, 1 to 8 percent slopes	-	94.6	-	-
KuD	Cho-Urban land complex, 1 to 8 percent slopes	9.2	-	-	-
MeA	Mereta clay loam, 0 to 1 percent slopes	-	-	-	446.9
MeB	Mereta clay loam, 1 to 3 percent slopes	41.6	-	16.1	52.6
OlA	Sagerton clay loam, 0 to 1 percent slopes	-	3.8	-	-
Rs	Rioconcho and Spur soils	-	-	8.0	993.4
RtA	Rotan clay loam, 0 to 1 percent slopes	-	5.4	-	-
TuA	Tulia loam, 0 to 1 percent slopes	3.7	105.2	-	11.1
TuB	Tulia loam, 1 to 3 percent slopes	6.6	210.0	26.7	284.8
TvC	Tulia-Urban land Complex, 0 to 5 percent slopes	9.8	-	-	-
W	Water	-	-	-	63.5

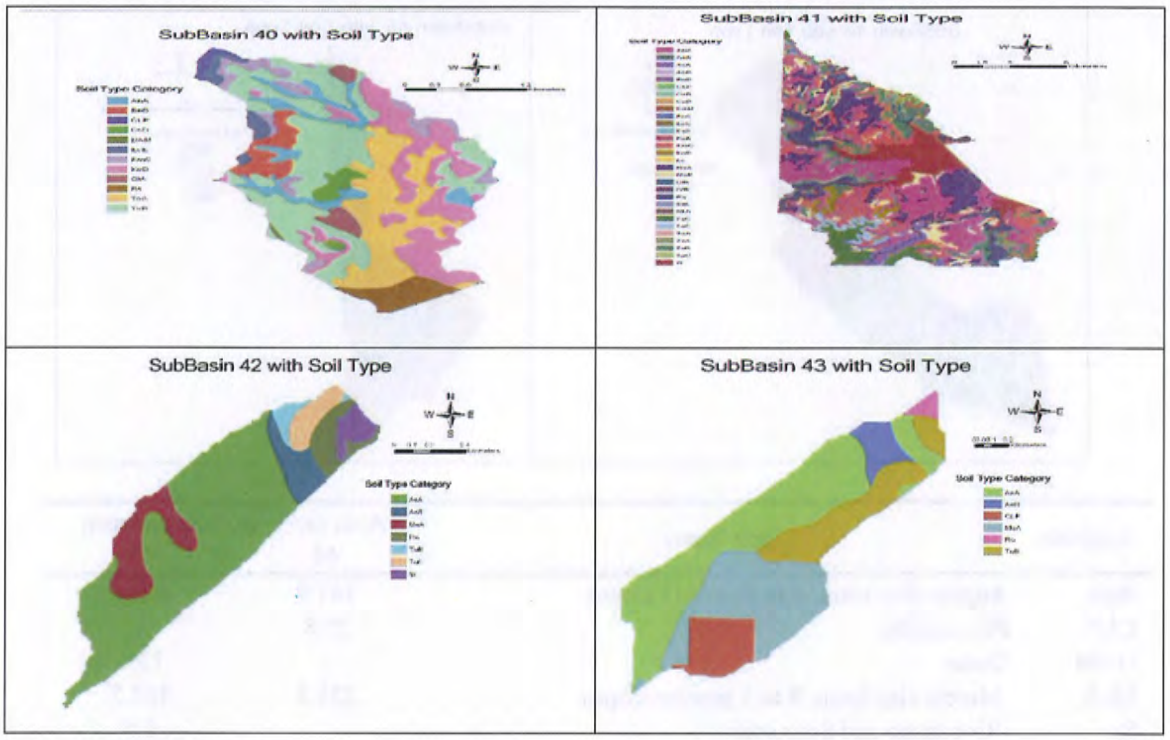


Symbol	Unit Name	Area (acre) in each subbasin		
		35	37	38
AnA	Angelo clay loam, 0 to 1 percent slopes	51.50	17.65	147.00
KmC	Cho association, undulating	54.61	52.10	71.00
KoD	Cho-Vernon complex, 1 to 8 percent slopes	26.18	-	16.00
MeA	Mereta clay loam, 0 to 1 percent slopes		4.00	36.00
MeB	Mereta clay loam, 1 to 3 percent slopes	0.29	-	-
Rs	Rioconcho and Spur soils		85.06	157.00
ToA	Tobosa clay, 0 to 1 percent slopes	25.28	-	-
TuA	Tulia loam, 0 to 1 percent slopes	114.51		
TuB	Tulia loam, 1 to 3 percent slopes	169.59	-	43.00
W	Water	-	12.06	12.00

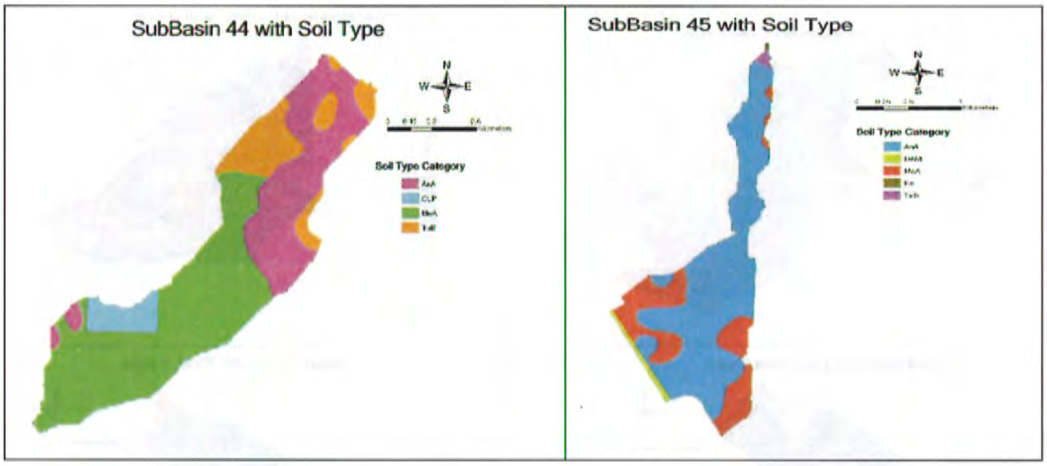
10 Subbasins Not Selected for Detailed Modeling



Symbol	Unit Name	Area (acre) in each subbasin			
		16	23	36	39
AmC	Miles fine sandy loam, 3 to 5 percent slopes	435.60	-	-	-
AnA	Angelo clay loam, 0 to 1 percent slopes	17,892.61	5,191.73	3,334.25	5,190.62
AnB	Angelo clay loam, 1 to 3 percent slopes	1,228.37	148.77	271.95	516.07
AoA	Angelo silty clay, 0 to 1 percent slopes	-	-	-	719.01
BeD	Berda loam, 3 to 8 percent slopes	35.82	-	-	-
CF	Cut and fill,	288.67	-	-	-
CLP	Pits, caliche	159.34	91.14	-	112.14
CoB	Cobb fine sandy loam, 1 to 3 percent slopes	108.49	-	-	
CsD	Oben-Latom complex, 1 to 8 percent slopes	29.86	-	-	31.27
DAM	Dams	102.74	-	-	109.48
Dr	Dev and Rioconcho soils	-	-	-	817.11
EcC	Ector association, undulating	26.30	-	-	-
EcE	Ector association, hilly	463.57	-	-	43.21
EsA	Estacado loam, 0 to 1 percent slopes	30.67	-	-	-
EsB	Estacado loam, 1 to 3 percent slopes	96.95	-	-	-
KmC	Cho association, undulating	8,542.94	251.99	220.72	2,756.41
KoD	Cho-Vernon complex, 1 to 8 percent slopes	271.28	-	-	643.37
Lc	Lipan clay	-	195.88	-	-
MeA	Mereta clay loam, 0 to 1 percent slopes	2,657.76	302.46	669.89	1,182.15
MeB	Mereta clay loam, 1 to 3 percent slopes	857.32	38.66	256.66	1,005.08
OlA	Sagerton clay loam, 0 to 1 percent slopes	2,045.32	-	-	14.94
OlB	Sagerton clay loam, 1 to 3 percent slopes	951.37	-	-	-
Rs	Rioconcho and Spur soils	3,859.70	-	339.17	2,548.41
RtA	Rotan clay loam, 0 to 1 percent slopes	1,047.75	-	-	-
ShB	Slaughter clay loam, 1 to 3 percent slopes	68.58	-	-	-
SLF	Sanitary landfill 267 *	-	0.01	-	-
TaC	Tarrant association, undulating	287.90	-	-	675.76
TaE	Tarrant association, hilly	474.26	-	-	-
ToA	Tobosa clay, 0 to 1 percent slopes	7.29	10.32	-	901.14
TuA	Tulia loam, 0 to 1 percent slopes	1,643.29	-	-	99.55
TuB	Tulia loam, 1 to 3 percent slopes	6,583.02	75.44	109.11	1,814.52
TuC	Tulia loam, 3 to 5 percent slopes	423.05	-	-	88.37
W	Water	5,104.27	49.52	78.72	1,350.19



Symbole	Unit Name	Area (acre) in each subbasin			
		40	41	42	43
AnA	Angelo clay loam, 0 to 1 percent slopes	153.3	13035.1	199.6	198.3
AnB	Angelo clay loam, 1 to 3 percent slopes	-	1450.8	19.6	22.6
AoA	Angelo silty clay, 0 to 1 percent slopes	-	1585.0	-	-
AoB	Angelo silty clay, 1 to 3 percent slopes	-	13.0	-	-
BeD	Berda loam, 3 to 8 percent slopes	89.7	57.1	-	-
CLP	Pits, caliche	22.3	86.7	-	44.1
CoB	Cobb fine sandy loam, 1 to 3 percent slopes	-	14.1	-	-
CsD	Oben-Latom complex, 1 to 8 percent slopes	46.4	35.9	-	-
DAM	Dams	3.9	174.2	-	-
EcC	Ector association, undulating	-	3.4	-	-
EcE	Ector association, hilly	44.7	393.0	-	-
EsB	Estacado loam, 1 to 3 percent slopes	-	116.7	-	-
KaB	Kavett clay, 1 to 3 percent slopes	-	50.0	-	-
KmC	Cho association, undulating	129.4	7630.4	-	-
KoD	Cho-Vernon complex, 1 to 8 percent slopes	399.9	975.6	-	-
Lc	Lipan clay	-	8.4	-	-
MeA	Mereta clay loam, 0 to 1 percent slopes	-	6542.6	37.7	120.7
MeB	Mereta clay loam, 1 to 3 percent slopes	-	3283.4	-	-
OlA	Sagerton clay loam, 0 to 1 percent slopes	48.4	106.4	-	-
OlB	Sagerton clay loam, 1 to 3 percent slopes	-	112.6	-	-
Rs	Rioconcho and Spur soils	92.2	4073.3	17.5	6.5
RtA	Rotan clay loam, 0 to 1 percent slopes	-	253.5	-	-
SkA	Slaughter-Cho complex, 0 to 1 percent slopes	-	58.4	-	-
TaC	Tarrant association, undulating	-	2492.5	-	-
TaE	Tarrant association, hilly	-	808.5	-	-
ToA	Tobosa clay, 0 to 1 percent slopes	392.8	52.1	-	-
TuA	Tulia loam, 0 to 1 percent slopes	-	635.6	-	-
TuB	Tulia loam, 1 to 3 percent slopes	611.0	3779.9	6.0	74.5
TuC	Tulia loam, 3 to 5 percent slopes	-	362.4	13.7	-
W	Water	-	5000.3	11.1	-



Symbole	Unit Name	Area (acre) in each subbasin 44	45
AnA	Angelo clay loam, 0 to 1 percent slopes	141.9	474.6
CLP	Pits, caliche	25.8	-
DAM	Dams	-	13.1
MeA	Mereta clay loam, 0 to 1 percent slopes	251.5	167.7
Rs	Rioconcho and Spur soils	-	0.5
TuB	Tulia loam, 1 to 3 percent slopes	67.5	5.0

APPENDIX E

Estimated Runoff at Monitoring Sites 1-10

Table E-1 Total Runoff Estimated by UCRA and TIAER at Monitoring Site 1

Events	Storm Event Periods From	To	Total Rainfall (in)	Mean Depth (ft)	Total Volume (ft3)	Mean Runoff (cfs)	Peak Runoff (cfs)
1	7/7/2010 1:28 PM	7/7/2010 6:03PM	0.00	0.031	4.41E+03	0.27	0.82
2	7/7/2010 8:27 PM	7/9/2010 8:00 AM	0.00	0.292	1.70E+06	13.27	117.10
3	7/9/2010 9:48 AM	7/9/2010 1:17 PM	0.00	0.036	4.09E+03	0.32	0.82
4	7/9/2010 2:53 PM	7/10/2010 10:03AM	0.00	0.346	1.57E+06	22.79	243.12
5	8/24/2010 19:15 AM	8/25/2010 11:09 AM	0.00	0.356	1.13E+06	19.65	111.30
6	9/3/2010 1:29 AM	9/3/2010 16:23 PM	0.00	0.102	1.23E+05	2.30	21.83
7	9/25/2010 13:31 PM	9/26/2010 7:27 AM	0.00	0.141	2.25E+05	3.47	21.83
8	10/23/2010 9:30 AM	10/24/2010 9:05 AM	0.00	0.234	9.64E+05	11.31	103.91
9	1/9/2011 4:15 AM	1/9/2011 7:50 AM	0.00	0.061	1.17E+04	0.88	3.71
10	1/31/2011 23:35 PM	2/2/2011 8:00 AM	0.00	0.129	3.14E+05	2.68	26.27
11	2/6/2011 8:10 AM	2/6/2011 8:30 PM	0.00	0.037	6.16E+04	1.38	3.20
12	5/2/2011 3:45AM	5/2/2011 12:10 PM	0.00	0.318	4.09E+05	13.35	27.25
13	5/20/2011 6:25AM	5/20/2011 10:55 AM	0.00	0.218	1.32E+05	8.00	42.16
14	6/21/2011 8:30 PM	6/22/2011 6:55 PM	0.00	0.204	7.54E+05	9.30	71.45
15	8/11/2011 10:00 PM	8/12/2011 5:00 AM	0.00	0.013	7.25E+03	0.28	5.69
16	8/13/2011 6:00AM	8/14/2011 8:40 AM	0.00	0.519	5.49E+06	57.00	815.38
17	10/8/2011 11:00AM	10/9/2011 11:00 PM	0.00	0.311	2.59E+06	19.94	170.14
18	12/3/2011 8:00 PM	1/0/1900 12:00 AM	0.00	0.117	8.95E+05	4.13	31.44
19	1/9/2012 3:00 AM	1/9/2012 11:20 AM	0.00	0.273	4.47E+05	14.76	40.20
20	1/24/2012 8:00 PM	1/26/2012 11:00 PM	0.00	0.192	1.66E+06	9.01	52.40
21	2/16/2012 11:00 PM	2/20/2012 2:00 AM	0.00	0.186	2.39E+06	8.85	92.61
22	3/8/2012 10:00 PM	3/10/2012 1:45 PM	0.00	0.150	2.13E+06	14.89	92.61
Min Event	7/7/2010 1:28PM	7/7/2010 6:03:00 PM	0.00	0.031	4.09E+03	-	-
Max Event	08/13/2011 6:00 AM	08/14/2011 8:40 AM	0.00	0.519	5.49E+06	-	-
Median Event	-	-	0.00	0.189	6.00E+05	-	-
Mean Event	-	-	0.00	0.194	1.05E+06	-	-

* No Rainfall Gage

Table E-2 Total Runoff Estimated by UCRA and TIAER at Monitoring Site 2

	Storm Event Periods		Total	Mean	Total	Mean	Peak
Events	From	To	Rainfall	Depth	Volume	Runoff	Runoff
			(in)	(ft)	(ft3)	(cfs)	(cfs)
1	6/27/2010 3:16 PM	6/28/2010 12:41 PM	0.79	0.551	2.01E+06	26.04	72.59
2	7/1/2010 5:55 PM	7/5/2010 4:56 AM	0.88	0.529	7.23E+06	24.18	91.11
3	7/7/2010 9:40 PM	7/9/2010 6:00 AM	0.48	0.739	4.93E+06	42.35	166.97
4	7/9/2010 8:52 AM	7/13/2010 12:00 AM	1.20	0.610	1.20E+07	38.31	250.38
5	8/24/2010 6:37 PM	8/26/2010 1:10 PM	1.46	0.878	9.05E+06	59.03	254.62
6	8/24/2010 6:38 PM	8/26/2010 1:11 PM	1.46	0.878	4.52E+07	59.03	254.62
7	9/7/2010 11:05:00 AM	9/8/2010 2:45 AM	0.19	0.001	4.80E+01	0.00	0.01
8	9/8/2010 4:55 AM	9/10/2010 3:45 AM	0.00	0.152	4.96E+05	2.94	11.51
9	9/25/2010 1:50 AM	9/28/2010 11:20 PM	1.51	0.128	2.29E+07	67.97	817.35
10	10/23/2010 9:05 AM	10/25/2010 1:50 PM	1.50	1.543	3.09E+07	162.59	939.65
11	1/9/2011 9:20 AM	1/12/2011 4:00 AM	0.01	0.177	7.93E+05	3.30	11.63
12	1/31/2011 8:30 PM	2/9/2011 9:45 AM	0.39	0.231	4.51E+06	6.10	54.48
13	5/4/2011 4:50 PM	5/4/2011 7:00 PM	0.00	0.113	1.18E+04	1.45	1.83
14	5/11/2011 9:35 AM	5/11/2011 1:40 PM	0.15	0.020	2.89E+03	0.19	1.30
15	5/20/2011 5:50 AM	5/22/2011 8:15 AM	0.35	0.283	1.34E+06	7.39	27.53
16	6/21/2011 7:45 PM	6/23/2011 5:50 PM	0.89	0.331	1.50E+06	9.04	27.19
17	8/13/2011 9 AM	8/17/2011 7:00 PM	3.73	1.254	4.92E+07	128.73	1,254.94
18	10/8/2011 8:00 AM	10/11/2011 5:00 PM	2.71	1.352	3.89E+07	133.37	834.07
19	11/8/2011 6 AM	11/9/2011 11:00 PM	0.00	0.132	4.19E+05	2.84	14.19
20	1/24/2012 2:25 PM	1/30/2012 2:00 AM	1.67	0.747	2.63E+07	55.54	411.18
21	2/13/2012 1:25 AM	2/23/2012 5:00 PM	2.05	0.462	3.19E+07	34.70	746.50
22	3/8/2012 10:00 PM	3/10/2012 9:25 AM	0.74	0.921	7.63E+06	59.68	257.10
Min Event	5/4/2011 4:50 PM	5/4/2011 7:00 PM	0.01	0.113	4.80E+01	-	-
Max Event	8/13/2011 9:00 AM	8/17/2011 7:00 PM	3.73	1.254	4.92E+07	-	-
Median Event	-	-	0.84	0.53	6.08E+06	-	-
Mean Event	-	-	1.01	0.58	1.35E+07	-	-

Table E-3 Total Runoff Estimated by UCRA and TIAER at Monitoring Site 3

Events	Storm Event Periods From	To	Total Rainfall	Mean Depth	Total Volume	Mean Runoff	Peak Runoff
			(in)	(ft)	(ft3)	(cfs)	(cfs)
1	6/27/2010 8:36PM	6/28/2010 5:11AM	0.35	0.093	7.68E+05	24.29	67.17
2	7/1/2010 3:44PM	7/3/2010 11:52AM	0.73	0.182	9.88E+06	62.18	171.52
3	7/9/2010 7:20AM	7/10/2010 12:23PM	0.90	0.181	6.84E+06	65.34	1,324.10
4	8/24/2010 11:20AM	8/25/2010 12:06PM	1.24	0.206	1.19E+07	133.32	573.10
5	9/7/2010 11:25 AM	9/9/2010 6:15AM	0.05	0.044	1.09E+06	7.07	19.21
6	9/24/2010 6:25 PM	9/25/2010 1:15AM	0.03	0.038	1.73E+05	6.95	22.88
7	9/25/2010 12:45PM	9/26/2010 6:15AM	0.84	0.187	4.94E+06	77.97	343.91
8	10/8/2010 4:10 PM	10/11/2010 5:30: PM	0.00	0.013	3.16E+05	1.19	3.03
9	10/23/2010 9:05AM	10/24/2010 3:25AM	0.67	0.286	9.94E+06	149.97	620.95
11	5/20/2011 5:55AM	5/20/2011 11:30AM	0.13	0.112	7.20E+05	35.28	91.54
12	6/21/2011 8:15PM	6/22/2011 2:15AM	0.40	0.100	6.06E+05	28.83	74.67
13	8/13/2011 9:05 AM	8/14/2011 1:00 PM	3.18	0.559	3.98E+07	395.18	2,369.39
14	10/8/2011 12:00 PM	10/9/2011 11:55 PM	1.71	0.260	1.55E+07	119.79	432.01
15	12/2/2011 10:00 PM	12/4/2011 7:55 PM	0.33	0.030	1.27E+06	7.69	57.11
16	12/4/2011 8:00 PM	12/5/2011 8:00 PM	0.12	0.102	2.92E+06	33.63	121.29
17	1/9/2012 5:00 AM	1/9/2012 3:35 PM	0.19	0.306	5.46E+06	142.14	295.97
18	1/24/2012 6:00 PM	1/26/2012 12:35 PM	1.28	0.491	4.23E+07	275.19	599.41
Min Event	10/8/2010 4:10:00 PM	10/11/2010 5:30:00 PM	0.03	0.013	1.73E+05	-	-
Max Event	8/13/2011 9:05 AM	8/14/2011 1:00 PM	3.18	0.559	4.23E+07	-	-
Median Event	-	-	0.40	0.18	4.94E+06	-	-
Mean Event	-	-	0.71	0.188	9.08E+06	-	-

Table E-4 Total Runoff Estimated by UCRA and TIAER at Monitoring Site 4

	Storm Event Periods		Total	Mean	Total	Mean	Peak
	From	To	Rainfall	Depth	Volume	Runoff	Runoff
			(in)	(ft)	(ft3)	(cfs)	(cfs)
1	6/27/2010 3:08PM	6/30/2010 3:01 PM	0.88	0.160	2.72E+06	10.50	146.52
2	7/1/2010 4:10 PM	7/3/2010 9:10 AM	0.81	0.269	2.33E+06	15.79	149.76
3	7/4/2010 2:52 PM	7/4/2010 8:45 PM	0.08	0.031	7.11E+03	0.33	0.98
4	7/7/2010 2:49 AM	7/7/2010 3:44 PM	0.19	0.084	1.09E+05	2.35	15.82
5	7/7/2010 7:58 PM	7/8/2010 4:06 PM	0.38	0.165	7.46E+05	10.28	104.74
6	7/9/2010 8:01 AM	7/12/2010 12:31 PM	0.58	0.123	2.04E+06	7.41	159.29
7	7/26/2010 6:19 PM	7/26/2010 7:26 PM	0.08	0.021	8.00E+02	0.20	0.52
8	8/24/2010 6:43 PM	8/25/2010 10:45 AM	1.65	0.493	2.72E+06	47.05	306.40
9	9/3/2010 1:19 AM	9/5/2010 3:30 AM	0.12	0.020	2.68E+04	0.15	0.37
10	9/7/2010 10:45 AM	9/8/2010 5:06 PM	0.25	0.103	2.95E+05	2.70	13.18
11	9/24/2010 6:35 PM	9/25/2010 12:18 PM	0.02	0.113	8.47E+01	0.02	0.04
12	9/25/2010 12:19 PM	9/25/2010 12:19 PM	1.08	0.317	2.35E+06	29.33	334.76
13	10/23/2010 8:50 AM	10/26/2010 12:00 AM	1.72	0.168	2.84E+06	12.48	393.41
14	1/9/2011 2:25 AM	1/9/2011 8:40 AM	0.20	0.205	2.02E+05	8.84	38.95
15	1/31/2011 10:35 PM	2/1/2011 7:55 PM	0.30	0.290	1.22E+06	15.81	126.34
16	3/15/2011 5:50 PM	3/16/2011 4:35 AM	0.00	0.013	2.97E+03	0.08	0.26
17	3/21/2011 11:15 PM	3/22/2011 11:10 AM	0.00	0.039	2.05E+04	0.48	1.21
18	5/4/2011 7:30 PM	5/4/2011 7:30 PM	0.00	0.079	6.66E+05	1.31	1.97
19	5/11/2011 9:30 AM	5/11/2011 2:20 PM	0.15	0.052	1.54E+04	0.87	2.80
20	5/20/2011 5:45 AM	5/20/2011 8:10 AM	0.44	0.830	7.13E+05	79.19	198.41
21	6/21/2011 8:10 PM	6/21/2011 10:45 PM	0.68	0.554	4.06E+05	42.29	117.08
22	6/21/2011 8:15 PM	6/21/2011 10:50 PM	0.66	0.554	4.06E+05	42.29	117.08
23	8/13/2011 9:05 AM	8/13/2011 10:45 PM	4.01	0.857	5.89E+06	119.00	1111.51
24	10/8/2011 12:00 AM	10/9/2011 11:55 PM	2.64	0.264	3.51E+06	20.34	168.01
25	11/8/2011 12:00 AM	11/11/2011 11:55 PM	0.31	0.043	6.26E+05	1.81	101.02
26	11/30/2011 9:00 AM	12/23/2011 9:20 AM	0.75	0.071	3.35E+06	1.69	52.90
27	1/24/2012 12:25 PM	1/26/2012 1:05 PM	2.56	0.259	2.91E+06	16.60	125.73
28	2/12/2012 12:00 PM	2/19/2012 12:00 PM	2.37	0.109	3.74E+06	6.18	146.52
29	3/8/2012 6:00 PM	3/10/2012 3:30 PM	0.95	0.211	1.78E+06	10.85	137.88
Min Event	3/15/2011 5:50:00 PM	3/16/2011 4:35 AM	0.08	0.013	8.47E+01	-	-
Max Event	8/13/2011 9:05 AM	10/26/2010 12:00 AM	4.01	0.857	5.89E+06	-	-
Median Event	-	-	0.44	0.160	7.13E+05	-	-
Mean Event	-	-	0.82	0.224	1.44E+06	-	-

Table E-5 Total Runoff Estimated by UCRA and TIAER at Monitoring Site 5

	Storm Event Periods From	To	Total Rainfall (in)	Mean Depth (ft)	Total Volume (ft3)	Mean Runoff (cfs)	Peak Runoff (cfs)
1	6/27/2010 3:22 PM	6/28/2010 10:30 PM	0.81	0.071	2.75E+05	2.46	19.11
2	7/1/2010 6:18 AM	7/3/2010 4:37 AM	1.18	0.197	1.87E+06	11.18	99.27
3	7/4/2010 2:54 PM	7/5/2010 4:57 AM	0.09	0.098	1.50E+05	2.97	12.17
4	7/7/2010 2:52 AM	7/7/2010 8:32 PM	0.17	0.099	1.98E+05	3.11	18.78
5	7/10/2010 2:25 AM	7/9/2010 11:59 PM	1.57	0.208	2.07E+06	16.76	383.24
6	10/23/2010 8:55 AM	10/23/2010 2:59 PM	1.53	0.293	6.94E+05	31.70	212.00
7	1/31/2011 10:40 PM	2/2/2011 2:10 AM	0.26	0.135	5.14E+05	5.51	19.84
8	5/2/2011 12:50 AM	5/2/2011 11:45 AM	0.70	0.177	2.24E+05	5.66	15.62
9	5/20/2011 5:50 AM	5/20/2011 10:25 AM	0.46	0.132	6.29E+04	3.74	22.29
10	6/21/2011 8:05 PM	6/22/2011 9:35 AM	0.74	0.062	8.80E+04	1.80	38.23
11	8/11/2011 11:25 PM	8/12/2011 4:00 PM	0.24	0.033	3.19E+04	0.53	3.04
12	8/13/2011 1:00 AM	8/15/2011 9:45 AM	5.01	0.206	2.81E+06	13.71	264.33
13	10/8/2011 12:00 AM	10/11/2011 6:00 AM	2.84	0.090	8.41E+05	2.99	110.90
14	11/8/2011 12:00 AM	11/8/2011 6:00 PM	0.22	0.021	2.22E+04	0.34	4.35
15	11/21/2011 12:00 PM	12/20/2011 4:45 AM	1.05	0.021	6.69E+05	0.27	10.06
16	1/24/2012 11:20 AM	1/26/2012 10:45 AM	1.97	0.098	4.44E+05	2.60	94.21
17	2/16/2012 12:00 PM	1/0/1900 12:00 AM	2.05	0.015	1.67E+05	0.10	0.88
18	3/8/2012 8:15 PM	3/10/2012 1:10 PM	0.78	0.081	2.33E+05	1.58	8.38
Min Event	7/4/2010 2:54:00 PM	7/5/2010 4:570 AM	0.09	0.098	2.22E+04	-	-
Max Event	8/13/2011 1:00 AM	8/15/2011 9:45 AM	5.01	0.208	2.81E+06	-	-
Median Event	-	-	0.80	0.132	2.54E+05	-	-
Mean Event	-	-	1.20	0.137	6.31E+05	-	-

Table E-6 Total Runoff Estimated by UCRA and TIAER at Monitoring Site 6

	Storm Event Periods		Total	Mean	Total	Mean	Peak
	From	To	Rainfall	Depth	Volume	Runoff	Runoff
			(in)	(ft)	(ft3)	(cfs)	(cfs)
1	7/8/2010 12:18:00 AM	7/8/2010 5:56:00 AM	0.28	0.651	4.94E+05	24.27	66.36
2	7/8/2010 9:07:00 PM	7/9/2010 1:58:00 AM	0.05	0.193	5.50E+04	3.14	8.66
3	7/9/2010 9:07:00 AM	7/10/2010 2:56:00 AM	0.67	0.566	1.31E+06	20.38	122.18
4	7/26/2010 6:16:00 PM	7/26/2010 10:23:00 PM	0.11	0.378	1.68E+05	11.27	42.43
5	7/27/2010 8:10:00 PM	7/28/2010 12:46:00 AM	0.09	0.262	1.00E+05	6.05	21.01
6	8/22/2010 5:57:00 AM	8/22/2010 1:47:00 PM	0.00	0.266	1.34E+05	4.73	7.79
7	8/24/2010 6:40:00 PM	8/25/2010 5:31:00 AM	1.49	0.754	1.53E+06	39.10	171.52
8	9/3/2010 1:20:00 AM	9/3/2010 7:57:00 AM	0.26	0.290	1.53E+05	6.40	18.82
9	9/7/2010 9:49:00 AM	9/8/2010 6:49:00 AM	0.21	0.300	5.55E+05	7.34	29.59
10	9/25/2010 12:28:00 PM	9/25/2010 10:23:00 PM	0.83	0.580	8.45E+05	23.62	108.17
11	10/23/2010 9:00:00 AM	10/23/2010 9:30:00 PM	1.68	0.574	1.28E+06	28.32	183.09
12	1/9/2011 2:30:00 AM	1/9/2011 7:25:00 AM	0.21	0.642	4.10E+05	22.78	45.17
13	1/31/2011 10:40:00 PM	2/2/2011 6:00:00 PM	0.14	0.466	2.45E+06	15.65	78.13
14	2/5/2011 11:00:00 AM	2/6/2011 2:45:00 AM	0.11	0.076	4.54E+04	0.80	2.50
15	5/2/2011 12:55:00 AM	5/2/2011 10:10:00 AM	0.48	0.200	1.27E+05	3.77	18.41
16	5/20/2011 6:00:00 AM	5/20/2011 9:15:00 AM	0.43	0.279	7.78E+04	6.49	24.03
17	6/21/2011 8:15:00 PM	6/22/2011 1:50:00 AM	0.76	0.431	2.99E+05	14.64	68.25
18	8/11/2011 11:20 PM	8/12/2011 5:35 AM	0.18	0.352	2.10E+05	9.23	26.75
19	8/13/2011 12:00 AM	8/14/2011 6:00 PM	3.51	0.466	6.09E+06	40.22	560.81
20	11/8/2011 12:00 AM	11/8/2011 12:00 PM	0.37	0.160	2.44E+05	5.61	66.51
21	12/3/2011 2:00 PM	12/5/2011 1:00 PM	0.45	0.096	3.80E+05	2.24	24.12
22	12/19/2011 5:00 AM	1/9/2012 2:10 PM	0.72	0.009	3.48E+05	0.19	40.92
23	1/24/2012 2:15 PM	1/26/2012 6:00 AM	1.58	0.118	3.73E+05	2.60	23.54
24	3/8/2012 6:00 PM	3/10/2012 12:00 AM	0.82	0.105	2.16E+05	1.99	25.05
Min Event	8/22/2010 5:57:00 AM	8/22/2010 1:47:00 PM	0.05	0.076	4.54E+04	-	-
Max Event	8/13/2011 12:00 AM	8/14/2011 6:00 PM	3.51	0.466	6.09E+06	-	-
Median Event	-	-	0.40	0.365	3.23E+05	-	-
Mean Event	-	-	0.64	0.403	7.46E+05	-	-

Table E-7 Total Runoff Estimated by UCRA and TIAER at Monitoring Site 7

	Storm Event Periods		Total	Mean	Total	Mean	Peak
	From	To	Rainfall	Depth	Volume	Runoff	Runoff
			(in)	(ft)	(ft3)	(cfs)	(cfs)
1	9/22/2010 3:25 PM	9/23/2010 2:30 AM	0.00	0.174	8.27E+04	10.29	91.79
2	9/24/2010 5:15 PM	9/28/2010 11:35 PM	0.00	1.121	1.03E+07	140.32	911.78
3	10/23/2010 9:10 AM	10/27/2010 4:40 PM	0.00	0.742	6.56E+06	15.09	864.60
4	1/9/2011 3:00 AM	1/12/2011 10:15 AM	0.00	0.578	1.27E+07	44.45	177.55
5	1/17/2011 5:00 AM	1/19/2011 12:50 AM	0.00	0.507	5.81E+06	36.73	113.07
6	1/31/2011 11:15 PM	2/1/2011 11:55 PM	0.00	1.607	1.59E+07	178.37	257.78
7	2/4/2011 12:55 PM	2/7/2011 10:35 PM	0.00	0.489	8.06E+06	27.38	55.20
8	5/2/2011 3:10 AM	5/2/2011 1:45 PM	0.00	1.479	6.28E+06	163.50	273.14
9	5/20/2011 6:00 AM	5/22/2011 10:05 AM	0.00	0.600	1.01E+07	53.68	305.33
10	6/21/2011 8:35 PM	6/22/2011 5:20 PM	0.00	0.688	4.05E+06	54.17	312.60
11	8/11/2011 8:00 PM	8/16/2011 5:00 AM	0.00	1.038	5.33E+07	140.81	1,277.35
12	10/8/2011 10:00 AM	10/10/2011 10:00 AM	0.00	1.129	2.24E+07	129.68	371.89
13	11/8/2011 1:00 AM	11/9/2011 4:00 AM	0.00	0.399	3.06E+06	31.35	146.67
14	12/3/2011 6:00 PM	12/6/2011 5:00 PM	0.00	0.439	8.34E+06	32.59	177.21
15	1/9/2012 2:00 AM	1/9/2012 2:40 PM	0.00	1.197	6.65E+06	144.83	322.78
16	1/24/2012 12:05 PM	1/29/2012 12:00 AM	0.00	0.811	3.52E+07	90.60	445.18
17	2/12/2012 9:00 PM	2/15/2012 11:00 AM	0.00	0.307	4.40E+06	19.71	104.76
18	2/16/2012 9:00 PM	2/20/2012 1:25 PM	0.00	1.224	4.31E+07	135.28	492.24
19	3/8/2012 10:00 PM	3/10/2012 10:30 AM	0.00	1.208	1.71E+07	129.48	362.61
Min Event	9/22/2010 3:25 PM	9/23/2010 2:30 AM	0.00	0.174	8.27E+04	-	-
Max Event	8/11/2011 8:00 PM	8/16/2011 5:00 AM	0.00	1.038	5.33E+07	-	-
Median Event	-	-	0.00	0.742	8.34E+06	-	-
Mean Event	-	-	0.00	0.828	1.44E+07	-	-

* No Rainfall Gage

Table E-8 Total Runoff Estimated by UCRA and TIAER at Monitoring Site 8

	Storm Event Periods From	To	Total Rainfall	Mean Depth	Total Volume	Mean Runoff	Peak Runoff
			(in)	(ft)	(ft3)	(cfs)	(cfs)
1	6/25/2010 4:36 PM	6/25/2010 9:12 PM	0.12	0.065	2.18E+04	1.31	10.19
2	6/27/2010 3:36 PM	6/28/2010 10:13 AM	0.80	0.256	7.10E+05	9.72	39.31
3	6/29/2010 6:47 PM	6/30/2010 12:00 PM	0.09	0.087	9.49E+04	1.53	11.23
4	6/30/2010 7:26 PM	7/1/2010 5:47 AM	0.11	0.113	8.75E+04	2.35	14.92
5	7/1/2010 7:29 PM	7/3/2010 11:59 PM	0.61	0.167	1.03E+06	5.43	46.04
6	7/4/2010 4:09 PM	7/5/2010 10:11 PM	0.08	0.081	1.67E+05	1.55	6.81
7	7/7/2010 4:32 AM	7/7/2010 5:00 PM	0.04	0.025	8.15E+03	0.18	0.69
8	8/6/2010 11:39 PM	8/7/2010 2:45 AM	0.08	0.053	1.09E+04	0.97	5.20
9	8/24/2010 5:49 PM	8/25/2010 4:07 PM	1.14	0.238	1.10E+06	13.70	106.06
10	9/3/2010 1:54 AM	9/3/2010 4:52 AM	0.05	0.034	3.96E+03	0.37	0.99
11	9/7/2010 9:57 AM	9/8/2010 8:37 PM	0.44	0.086	2.22E+05	1.78	10.70
12	9/24/2010 5:51 PM	9/25/2010 8:01 AM	0.28	0.065	9.14E+04	1.79	33.53
13	9/25/2010 12:47 PM	9/26/2010 8:16 AM	1.43	0.375	2.07E+06	29.51	324.27
14	10/23/2010 8:50 AM	10/24/2010 6:35 AM	1.69	0.348	2.24E+06	28.55	278.76
15	1/9/2011 2:35 AM	1/9/2011 7:15 AM	0.21	0.051	1.13E+04	0.66	1.93
16	1/31/2011 10:35 PM	2/1/2011 9:15 AM	0.26	0.138	1.41E+05	3.65	9.13
17	2/17/2011 4:30 PM	2/17/2011 10:20 PM	0.00	0.010	8.40E+02	0.04	0.09
18	5/2/2011 2:05 AM	5/2/2011 1:00 PM	0.73	0.426	8.56E+05	21.63	50.40
19	5/11/2011 9:45 AM	5/20/2011 11:50 AM	0.38	0.011	3.88E+05	0.51	50.18
20	6/21/2011 8:25 PM	6/22/2011 4:50 PM	0.35	0.130	3.06E+05	4.15	46.34
21	7/17/2011 6:45 PM	7/18/2011 1:50 AM	0.00	0.050	2.23E+04	0.86	5.47
22	8/13/2011 9:10 AM	8/15/2011 11:55 AM	4.19	0.335	6.12E+06	33.43	1,189.45
23	10/8/2011 12:15 PM	10/12/2011 7:15 PM	2.37	0.153	3.29E+06	8.86	137.43
24	11/8/2011 4:20 AM	11/16/2011 12:50 AM	0.34	0.031	4.83E+05	0.71	63.88
25	12/3/2011 6:00 PM	1/8/2012 10:55 PM	0.76	0.060	2.61E+06	0.83	22.07
26	1/8/2012 11:00 PM	1/9/2012 12:35 PM	0.60	0.280	6.48E+05	13.18	64.58
27	1/24/2012 9:15 PM	2/10/2012 11:55 PM	1.60	0.057	3.30E+06	2.23	106.89
28	2/11/2012 2:25 AM	2/17/2012 3:45 PM	0.69	0.093	8.72E+05	2.02	31.04
29	3/9/2012 12:00 AM	3/10/2012 10:45 AM	0.00	0.171	8.46E+05	6.74	76.93
Min Event	2/17/2011 4:30:00 PM	2/17/2011 10:20:00 PM	0.04	0.010	8.40E+02	-	-
Max Event	8/13/2011 9:10 AM	8/15/2011 11:55 AM	4.19	0.335	6.12E+06	-	-
Median Event	-	-	0.35	0.086	3.88E+05	-	-
Mean Event	-	-	0.67	0.14	9.57E+05	-	-

Table E-9 Total Runoff Estimated by UCRA and TIAER at Monitoring Site 9

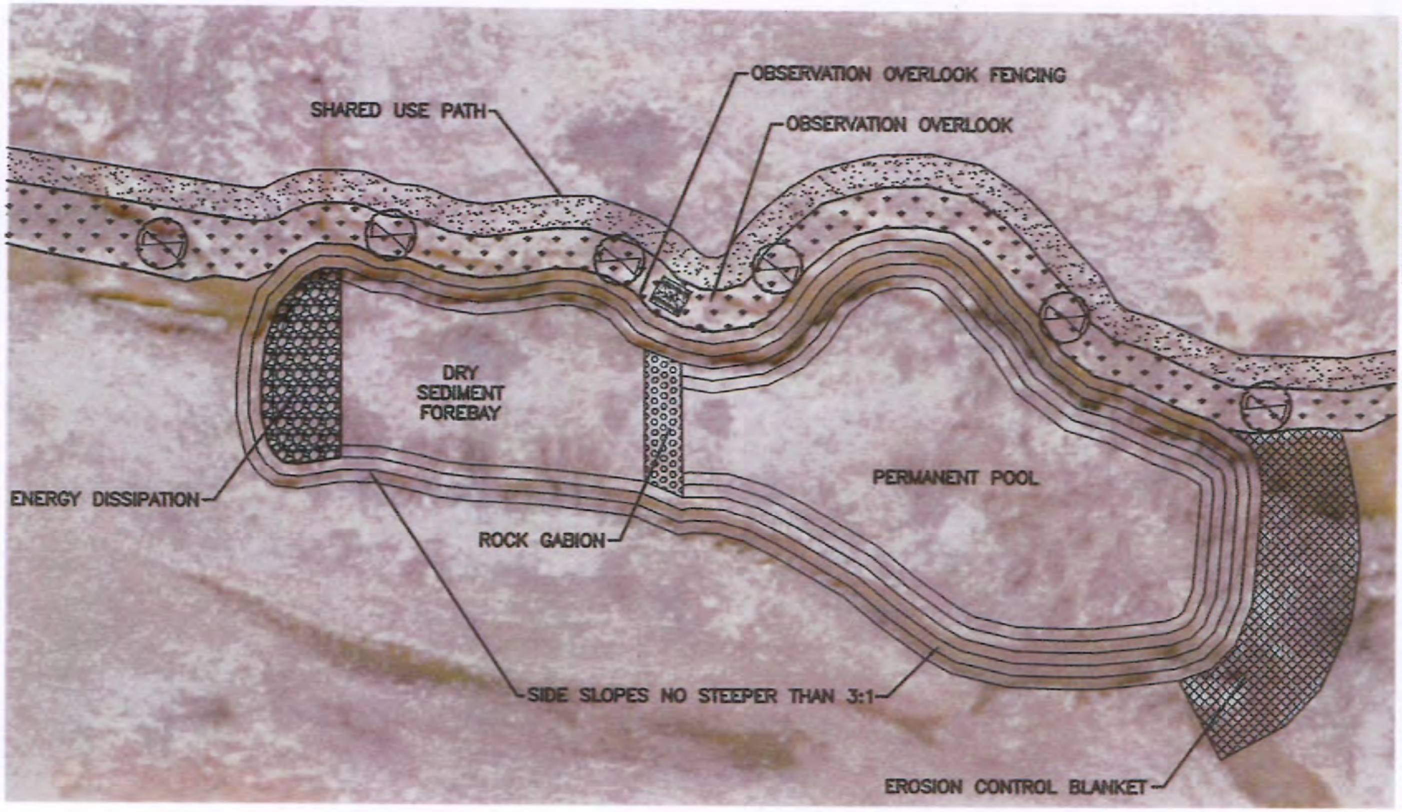
	Storm Event Periods		Total	Mean	Total	Mean	Peak
	From	To	Rainfall	Depth	Volume	Runoff	Runoff
			(in)	(ft)	(ft3)	(cfs)	(cfs)
1	12/28/2010 1:05 PM	2/23/2011 1:25 PM	0.40	0.113	4.27E+07	8.67	8.67
2	5/2/2011 1:50 AM	5/2/2011 12:20 PM	0.00	0.469	5.05E+06	132.46	479.11
3	5/20/2011 5:50 AM	5/20/2011 4:00 PM	0.49	0.351	3.83E+06	103.80	555.43
4	6/21/2011 8:05 PM	6/22/2011 1:15 AM	0.47	0.554	3.37E+06	178.34	543.27
5	8/13/2011 9:10 AM	8/15/2011 10:05 AM	3.87	0.642	5.07E+07	287.17	3,276.40
6	10/8/2011 8:00 AM	10/10/2011 10:00 AM	2.71	0.619	4.14E+07	229.61	1,463.09
7	11/8/2011 1:00 AM	11/8/2011 4:00 PM	0.20	0.113	1.06E+06	19.52	334.32
8	12/3/2011 6:00 PM	12/5/2011 5:00 PM	0.56	0.083	1.74E+06	10.29	87.05
9	12/10/2011 7:50 PM	12/11/2011 6:00 AM	0.07	0.020	5.37E+04	1.46	13.06
10	12/19/2011 7:00 AM	12/19/2011 7:00 PM	0.05	0.048	1.55E+05	3.57	17.25
11	12/24/2011 11:00 AM	12/24/2011 7:00 PM	0.05	0.015	2.96E+04	1.02	9.70
12	1/8/2012 11:00 PM	1/9/2012 3:10 PM	0.57	0.133	8.44E+05	14.43	71.66
13	1/24/2012 8:00 PM	1/26/2012 4:00 PM	1.82	0.250	7.08E+06	44.61	229.00
14	2/12/2012 10:00 PM	2/19/2012 10:00 PM	2.20	0.070	5.75E+06	9.50	396.50
15	3/8/2012 7:00 PM	3/11/2012 11:00 AM	1.00	0.172	7.84E+06	33.99	454.65
Min Event	5/2/2011 1:50 AM	5/2/2011 12:20 PM	0.05	0.469	2.96E+04	-	-
Max Event	8/13/2011 9:10 AM	8/15/2011 10:05 AM	3.87	0.642	5.07E+07	-	-
Median Event	-	-	0.53	0.153	3.83E+06	-	-
Mean Event	-	-	1.00	0.253	1.14E+07	-	-

Table E-10 Total Runoff Estimated by UCRA and TIAER at Monitoring Site 10

	Storm Event Periods From	To	Total Rainfall	Mean Depth	Total Volume	Mean Runoff	Peak Runoff
			(in)	(ft)	(ft3)	(cfs)	(cfs)
1	8/24/2010 6:37 PM	8/25/2010 5:44 AM	1.85	0.189	1.23E+06	30.73	169.70
2	10/23/2010 8:58 AM	10/25/2010 7:04 AM	1.43	0.152	3.05E+06	18.38	239.80
3	5/2/2011 12:55 AM	5/2/2011 8:55 AM	0.68	0.015	1.64E+04	2.82	18.85
4	5/20/2011 5:550 AM	5/20/2011 11:10 AM	0.43	0.061	7.81E+04	20.33	67.09
5	6/21/2011 8:05 PM	6/22/2011 2:30 AM	0.78	0.127	3.44E+05	73.45	357.45
6	8/13/2011 8:45 AM	8/14/2011 1:00 AM	4.27	0.279	3.60E+06	306.44	3,034.24
7	10/8/2011 10:00 AM	10/9/2011 2:00 PM	3.13	0.131	1.82E+06	90.03	808.07
8	12/3/2011 5:05 AM	12/5/2011 11:00 AM	0.66	0.009	7.18E+04	2.67	46.27
9	1/24/2012 8:25 PM	1/26/2012 9:00 AM	1.95	0.105	1.38E+06	52.42	343.08
10	2/12/2012 11:00 PM	2/19/2012 7:00 AM	2.25	0.040	2.38E+06	21.71	513.70
11	3/8/2012 10:00 PM	3/11/2012 7:00 AM	0.83	0.054	8.20E+05	19.97	212.64
Min Event	5/20/2011 5:55 AM	5/20/2011 11:10 AM	0.43	0.061	1.64E+04	-	-
Max Event	8/13/2011 8:45 AM	8/14/2011 1:00 AM	4.27	0.279	3.60E+06	-	-
Median Event	-	-	1.43	0.105	1.23E+06	-	-
Mean Event	-	-	1.66	0.106	1.35E+06	-	-

APPENDIX F

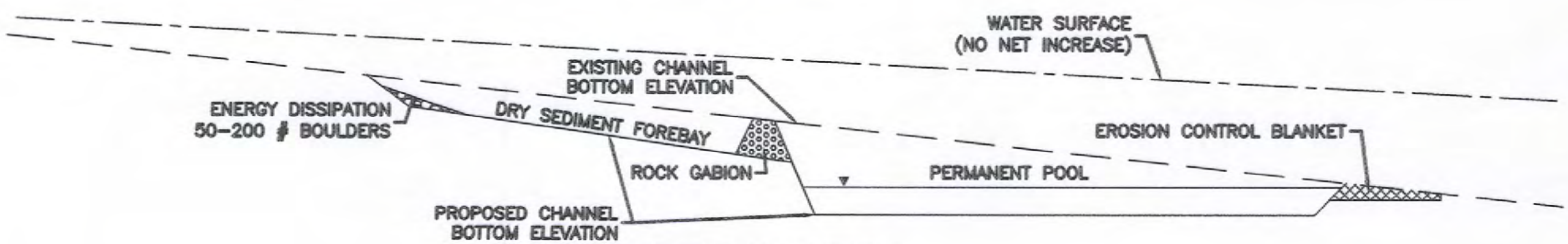
Project Design Development for Selected Sites



PLAN VIEW

VICINITY MAP

N.T.S.



PROFILE VIEW

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1122 SOUTH BRYANT BLVD. SAN ANGELO, TEXAS 76903
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FIRM REGISTRATION NUMBER F-7600
www.skge.com

LOW IMPACT BMP
RED ARROYO
SAN ANGELO, TEXAS

CONCEPTUAL PLAN

UCRA
FRED TEAGARDEN

REVISIONS	
DWG BY: EBC	DWG. DATE: 3/1/2011
JOB NO. 11-E-0036	SHEET NO. I-1
SCALE: 1"=30'	

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UCRA BMP CONCEPTUAL PLANS - ITEM 1

SAN ANGELO, TEXAS

ENGINEER'S PRELIMINARY OPINION OF PROBABLE COST

ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	AMOUNT
BASE BID					
1	Mobilization	1	LS	$2,491.00	$2,491.00
Temporary Erosion Control					
2	Silt Fence	105	LF	5.94	$624.00
Rock Gabion					
4	Stone+components	12	CY	269.87	$3,238.44
Permenant Erosion Control					
5	Reno Mattress (9")	220	SY	71.92	$15,823.00
6	Energy Dissipation (Rip Rap)	60	CY	103.32	$6,199.20
Excavation					
7	Pond Excavation	2130	CY	11.23	$23,919.90

* Prices are based on quotes from Reece Albert.
** This cost analysis is based on a conceptual plan and could change when actual design is completed.

TOTAL CONSTRUCTION OPC	$52,295.54
CONSTRUCTION CONTENGENCIES (15%)	$7,845.00
TOTAL PROJECT OPC	$60,140.54

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FIRM REGISTRATION NUMBER F-7809
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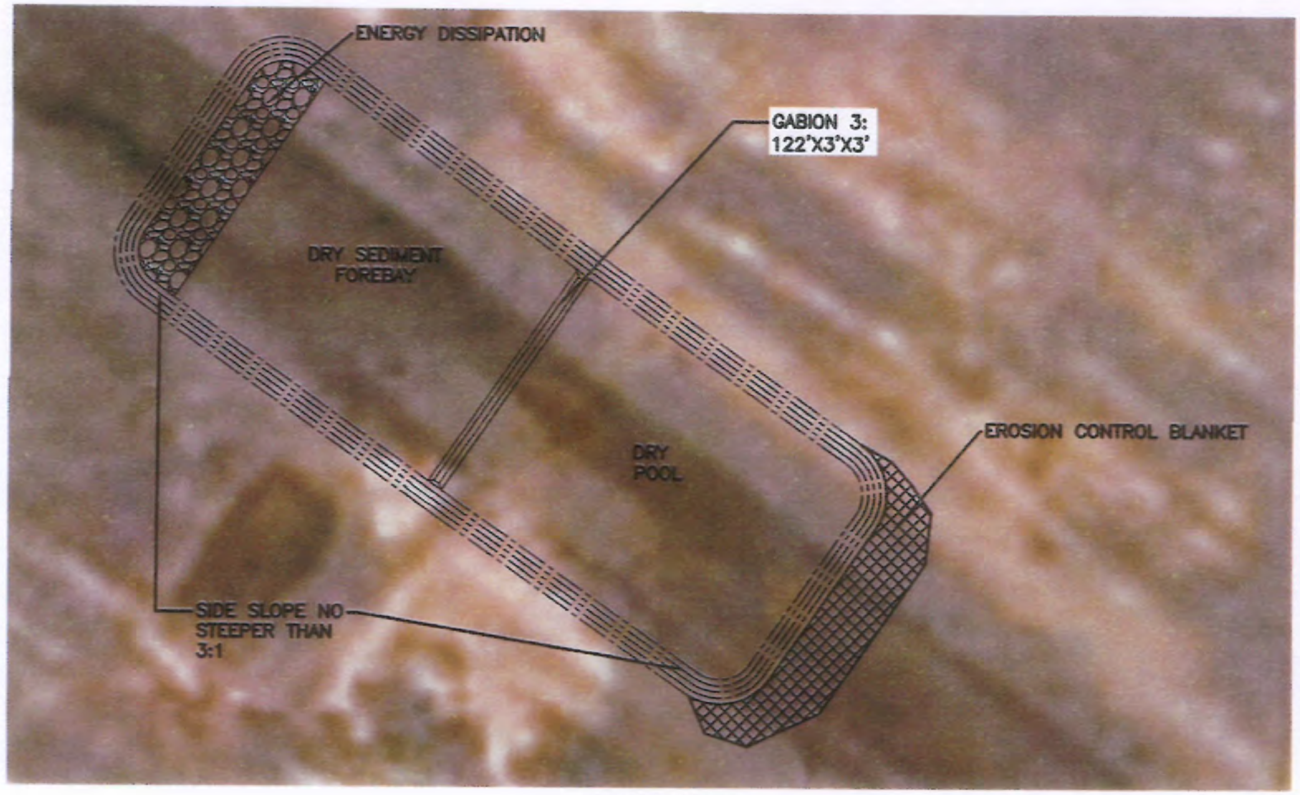
LOW IMPACT BMP
SOUTH WEST DRAW
RED ARROYO
SAN ANGELO, TEXAS

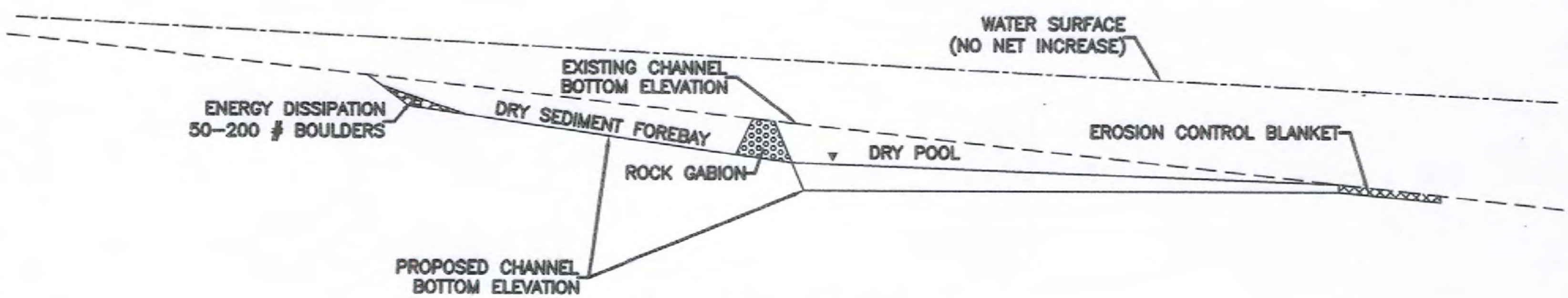
CONCEPTUAL PLAN

UCRA
FRED TEAGARDEN

REVISIONS	
DWG BY: EBC	DWG. DATE: 3/1/2011
JOB NO. 11-E-0036	SHEET NO. I-2a
SCALE: NONE	



PLAN VIEW



TYPICAL PROFILE

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LOW IMPACT BMP
SOUTH WEST DRAW
RED ARROYO
SAN ANGELO, TEXAS

CONCEPTUAL PLAN

UCRA
FRED TEAGARDEN

REVISIONS	
DWG BY: EBC	DWG. DATE: 3/1/2011
JOB NO. 11-E-0036	SHEET NO. I-2b
SCALE: NONE	

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SAN ANGELO, TEXAS 76903
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UCRA BMP CONCEPTUAL PLANS - ITEM 2, GABION 3

SAN ANGELO, TEXAS

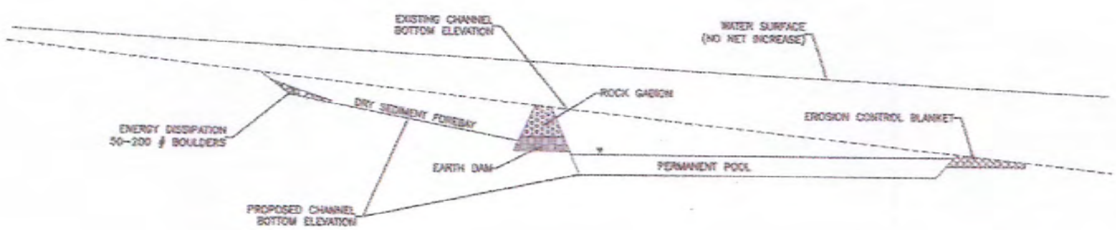
ENGINEER'S PRELIMINARY OPINION OF PROBABLE COST

ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	AMOUNT
BASE BID					
1	Mobilization	1	LS	$5,640.00	$5,640.00
Temporary Erosion Control					
2	Silt Fence	140	LF	5.94	$832.00
Rock Gabion					
4	Stone+components	44	CY	181.61	$7,990.84
Permenant Erosion Control					
5	Reno Mattress (9")	170	SY	70.68	$12,016.00
6	Energy Dissipation (Rip Rap)	140	CY	98.7	$13,818.00
Excavation					
7	Pond Excavation	7528	CY	10.38	$78,140.64

* Prices are based on quote from Reece Albert
** This cost analysis is based on a conceptual plan and could change when actual design is completed.

TOTAL CONSTRUCTION OPC	$118,437.48
CONSTRUCTION CONTENGENCIES (15%)	$17,766.00
TOTAL PROJECT OPC	$136,203.48

VICINITY MAP
N.T.S.



SKG ENGINEERING, LLC

LOW IMPACT BMP
CHADBOURNE AND
RED ARROYO
SAN ANGELO, TEXAS

CONCEPTUAL PLAN

NONE

13

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UCRA BMP CONCEPTUAL PLANS - ITEM 3

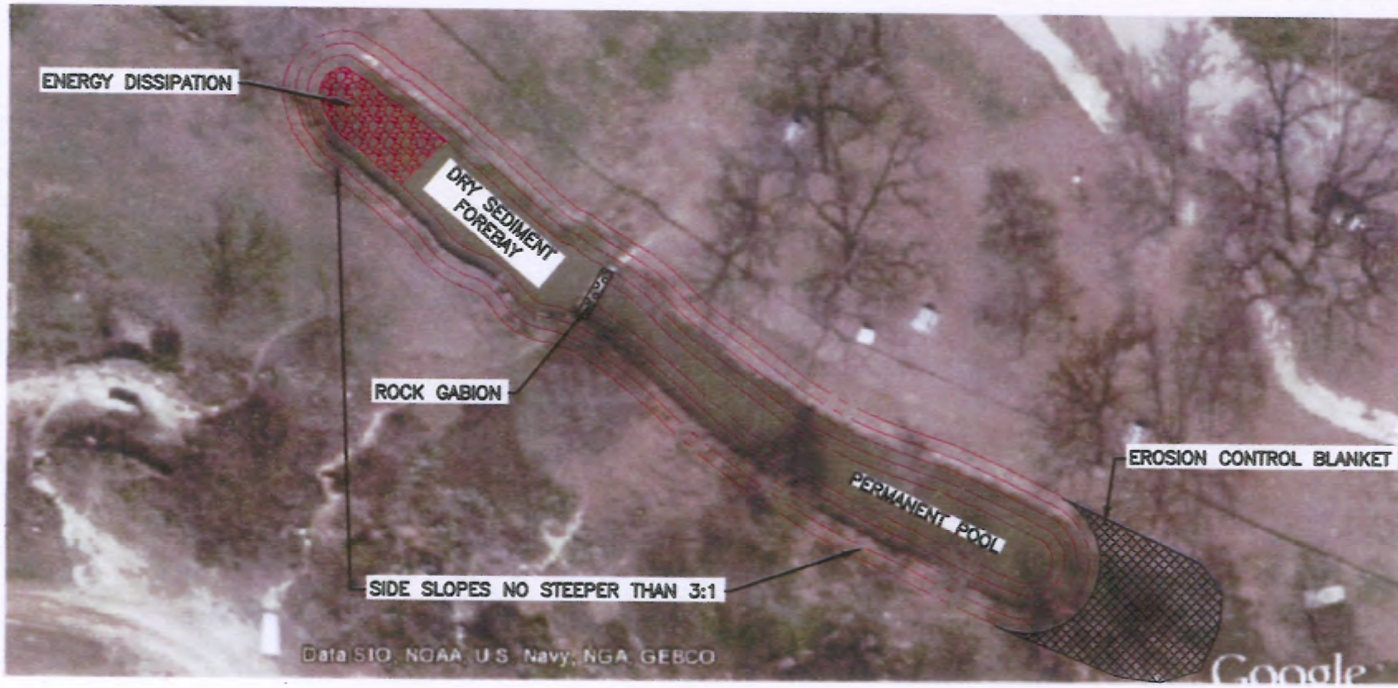
SAN ANGELO, TEXAS

ENGINEER'S PRELIMINARY OPINION OF PROBABLE COST

ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	AMOUNT
BASE BID					
1	Mobilization	1	LS	$101,848.00	$101,848.00
Temporary Erosion Control					
2	Silt Fence	310	LF	5.93	$1,839.00
Rock Gabion					
4	Stone+components	388	CY	159.77	$61,990.76
Permenant Erosion Control					
5	Reno Mattress (9")	1964	SY	52.86	$103,818.00
6	Energy Dissipation (Rip Rap)	1240	CY	86.49	$107,247.60
Excavation					
7	Pond Excavation	235055	CY	7.39	$1,737,056.45
Allowances					
8	Gated Weir Allowance	1	UNIT	25000	$25,000.00

* Prices are based on quotes from Reece Albert.
** This cost analysis is based on a conceptual plan and could change when actual design is completed.

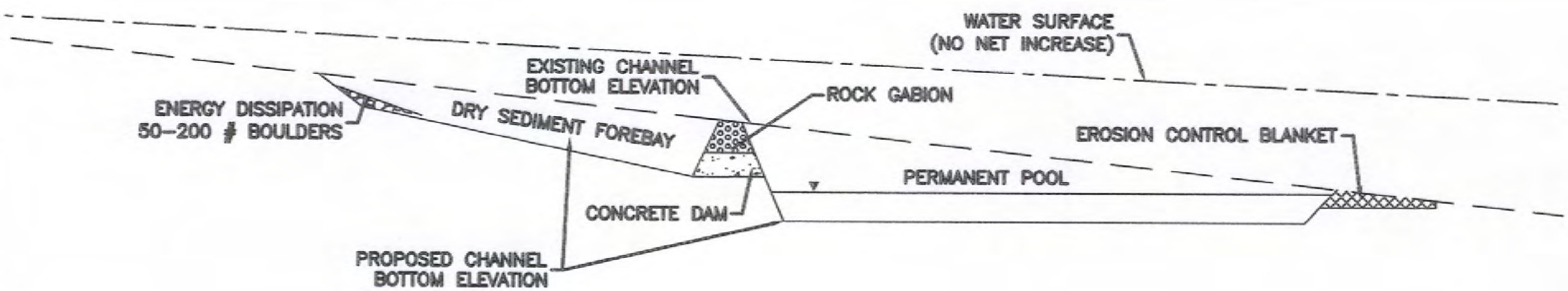
TOTAL CONSTRUCTION OPC	$2,138,799.81
CONSTRUCTION CONTENGENCIES (15%)	$320,820.00
TOTAL PROJECT OPC	$2,459,619.81



PLAN VIEW

VICINITY MAP

N.T.S.



PROFILE VIEW

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LOW IMPACT BMP
NORTH CONCHO RIVER
@ 14TH STREET
SAN ANGELO, TEXAS

CONCEPTUAL PLAN

UCRA
FRED TEAGARDEN

REVISIONS	
DWG BY: EBC	DWG. DATE: 3/1/2011
JOB NO. 11-E-0036	SHEET NO. I-4
SCALE: 1"=30'	

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UCRA BMP CONCEPTUAL PLANS - ITEM 4

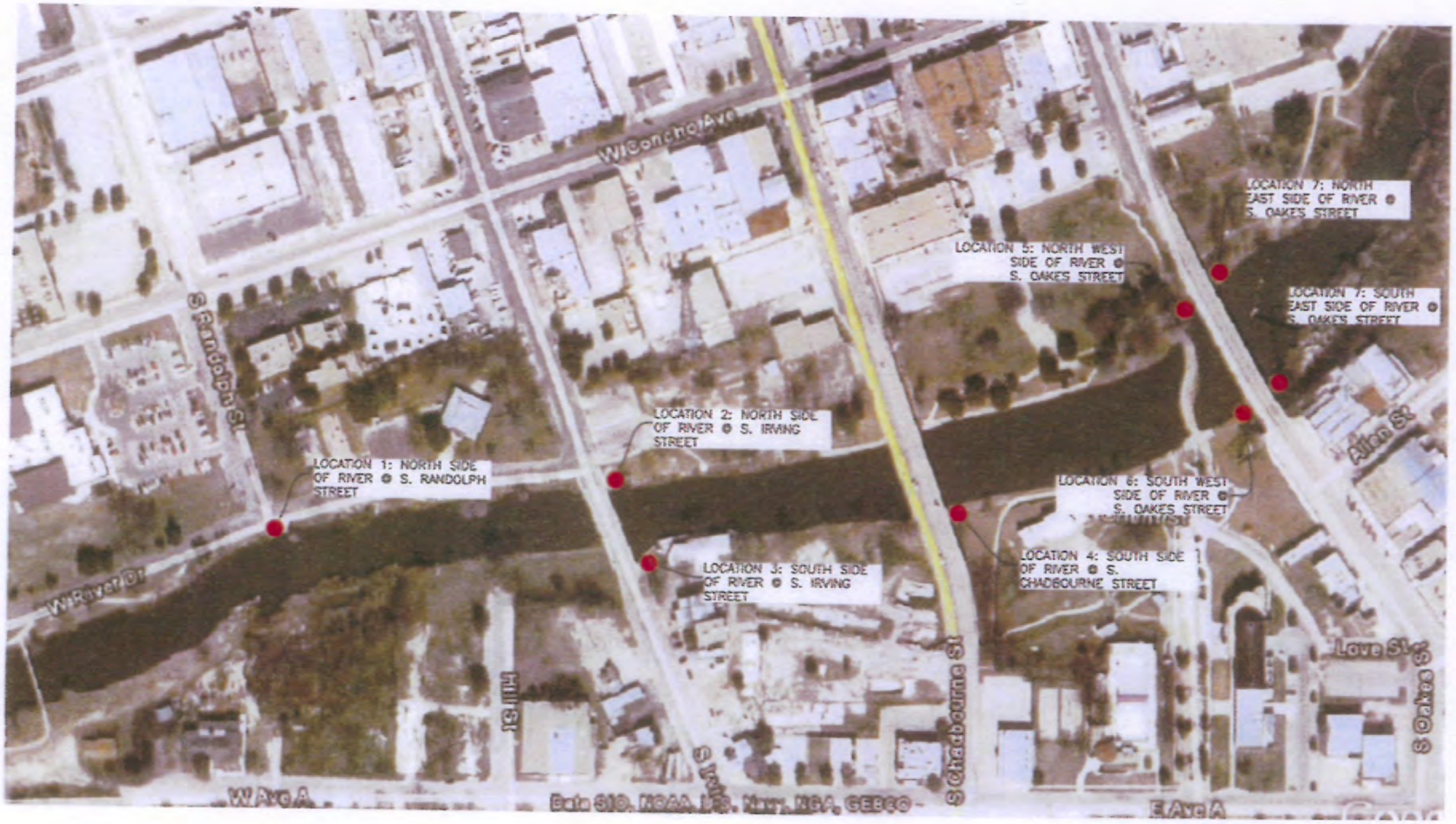
SAN ANGELO, TEXAS

ENGINEER'S PRELIMINARY OPINION OF PROBABLE COST

ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	AMOUNT
BASE BID					
1	Mobilization	1	LS	$1,720.00	$1,720.00
Temporary Erosion Control					
2	Silt Fence	55	LF	5.93	$327.00
Rock Gabion					
4	Stone+components	8	CY	269.93	$2,159.44
Permenant Erosion Control					
5	Reno Mattress (9")	124	SY	68.4	$8,482.00
6	Energy Dissipation (Rip Rap)	100	CY	100.08	$10,008.00
Excavation					
7	Pond Excavation	650	CY	18.78	$12,207.00
Dam					
8	Concrete	3	CY	400	$1,200.00

* Prices are based on quotes from Reece Albert.
** This cost analysis is based on a conceptual plan and could change when actual design is completed.

TOTAL CONSTRUCTION OPC	$36,103.44
CONSTRUCTION CONTENGENCIES (15%)	$5,416.00
TOTAL PROJECT OPC	$41,519.44



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LOW IMPACT BMP
DOWNTOWN
SAN ANGELO, TEXAS

POTENTIAL LOCATION MAP

1"=100'

I5-1

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STORMWATER TREATMENT PACKAGES

* Capacities were calculated with a Time of Concentration of 20 mins and a Runcoefficient of 0.5.

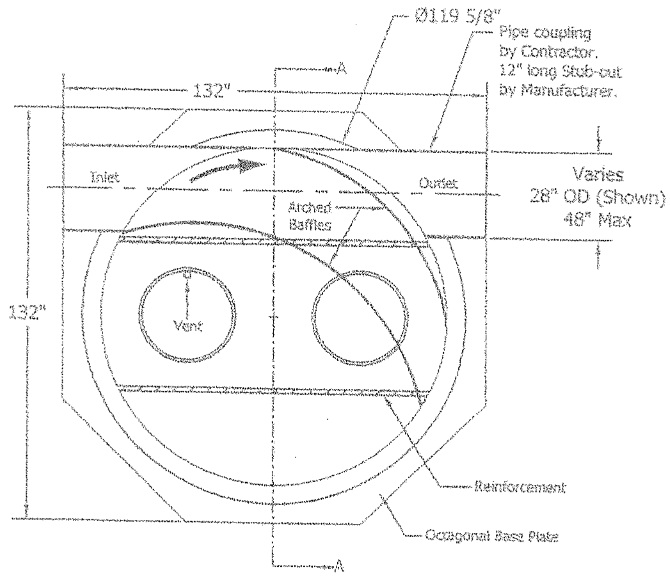
LOCATION NUMBER	Estimated 2-YR Rainfall Amount (CFS)	STORM TROOPER MODEL #	CAPACITY OF TREAMENT PACKAGE (CFS)	NUMBER OF PACKAGES NEEDED TO TREAT ALL OF DRAINAGE BASIN
1	25	AS-9	14.2	2
		AS-10	17.5	1
		AS-12	25.2	1
2	10	AS-9	14.2	1
		AS-10	17.5	1
		AS-12	25.2	0
3	15	AS-9	14.2	1
		AS-10	17.5	1
		AS-12	25.2	1
4	10	AS-9	14.2	1
		AS-10	17.5	1
		AS-12	25.2	0
5	15	AS-9	14.2	1
		AS-10	17.5	1
		AS-12	25.2	1
6	15	AS-9	14.2	1
		AS-10	17.5	1
		AS-12	25.2	1
7	15	AS-9	14.2	1
		AS-10	17.5	1
		AS-12	25.2	1
8	15	AS-9	14.2	1
		AS-10	17.5	1
		AS-12	25.2	1

STANDARD NOTE:

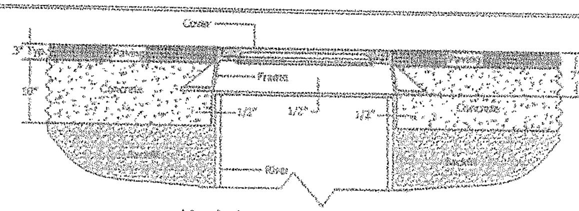
1. System shall be designed for the following capacities:
   Peak Treatment Flow: 14.0 cfs
   Sediment Storage: 145 ft³
   Oil/Debris Storage: 910 gal.

* Please see accompanied Aqua-Swirl specification notes.

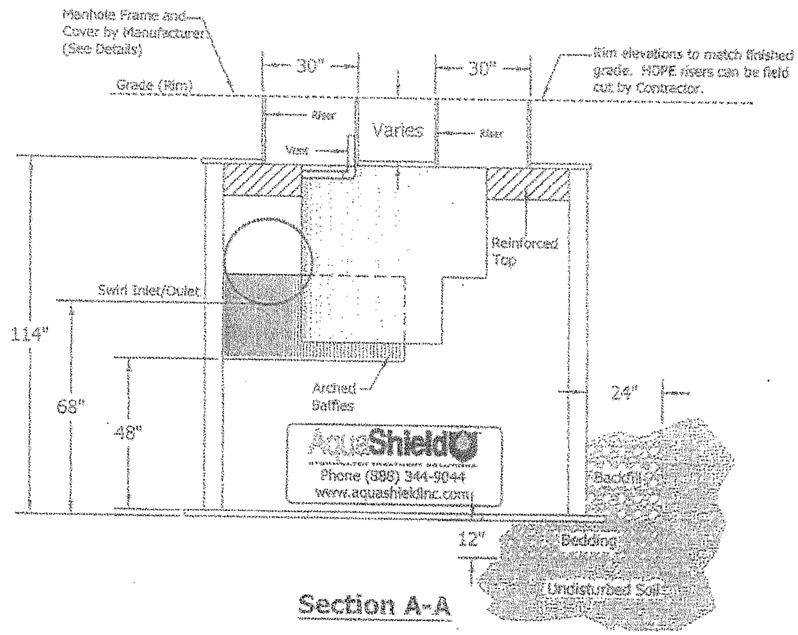
* See Site Plan for actual system orientation.



Plan View



Manhole Frame & Cover Detail
For H-20 Traffic Loading Areas
NTS



Section A-A

AquaShield

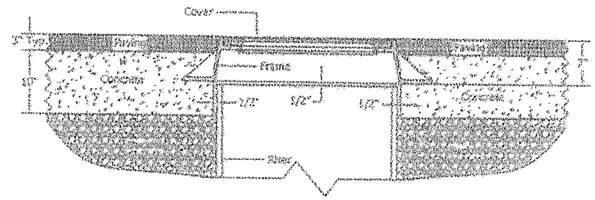
Document:	AS-9 STD
Drawn By:	LZJ
Scale:	1:30
Date:	03/03/04

Aqua-Swirl Concentrator Model AS-9 Standard Detail

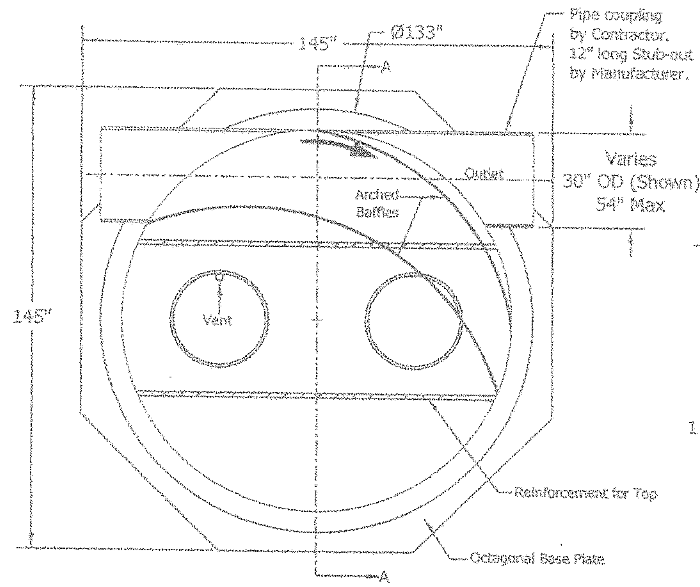
STANDARD NOTE:

1. System shall be designed for the following capacities:
   Peak Treatment Flow: 17.5 cfs
   Sediment Storage: 180 ft³
   Oil/Debris Storage: 1130 gal.

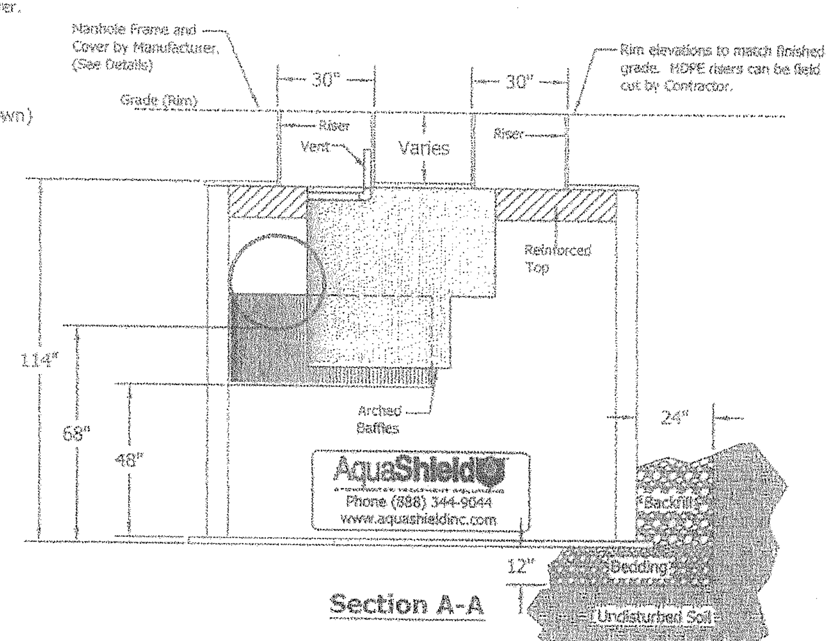
* Please see accompanied Aqua-Swirl specification notes.
* See Site Plan for actual system orientation.



Manhole Frame & Cover Detail For H-20 Traffic Loading Areas
NTS



Plan View



Section A-A

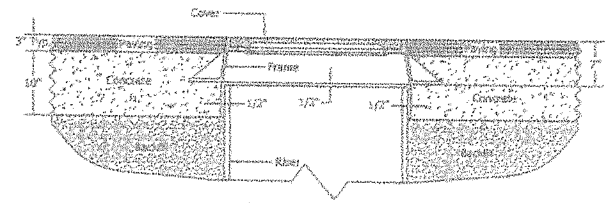
AquaShield	Document:	AS-10 STD
2733 Kanasita Drive, Suite A, Chattanooga, TN 37343	Drawn By:	LZJ
Phone (888) 344-9044 Fax (423) 870-1005	Scale:	1:30
	Date:	03/04/04
	U.S. Patent No. 6524473 and other Patents Pending	

Aqua-Swirl Concentrator Model AS-10 Standard Detail

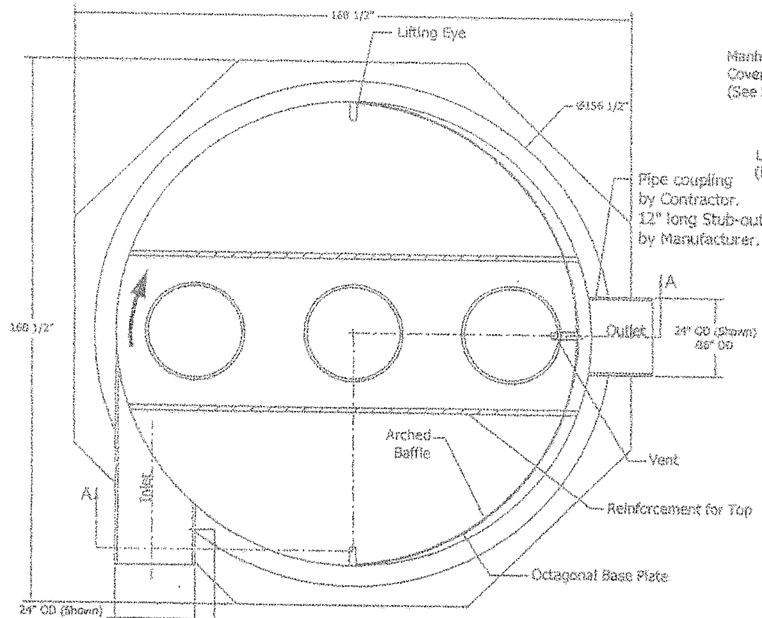
STANDARD NOTE:

1. System shall be designed for the following capacities:
   Peak Treatment Flow: 25 cfs
   Sediment Storage: 270 ft³
   Oil/Debris Storage: 1690 gal.

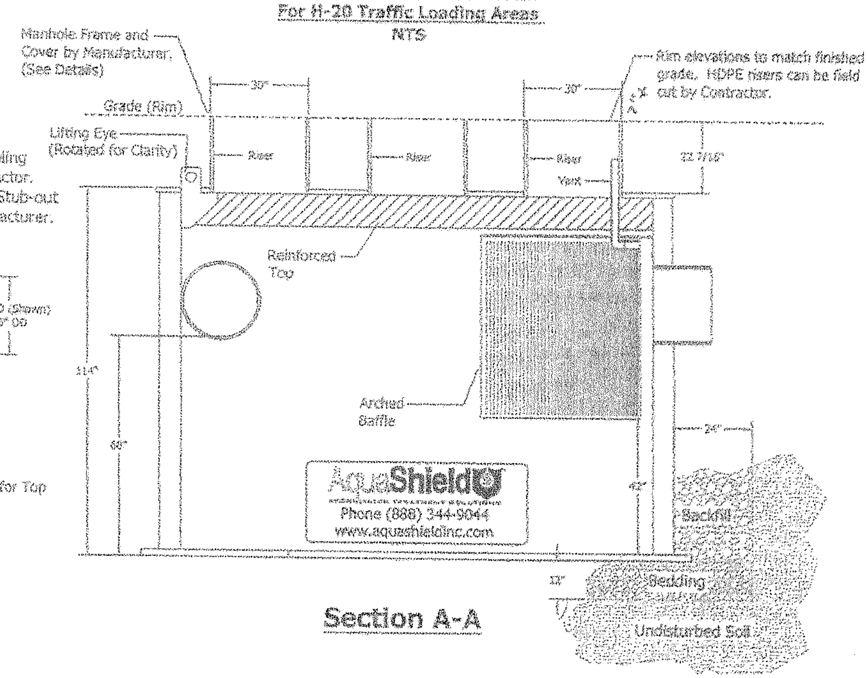
* Please see accompanied Aqua-Swirl specification notes.
* See Site Plan for actual system orientation.



Manhole Frame & Cover Detail
For H-20 Traffic Loading Areas
NTS



Plan View



Section A-A

AquaShield
2733 Kanasita Drive, Suite A, Chattanooga, TN 37343
Phone (888) 344-9044 Fax (423) 870-1005
www.aquashieldinc.com

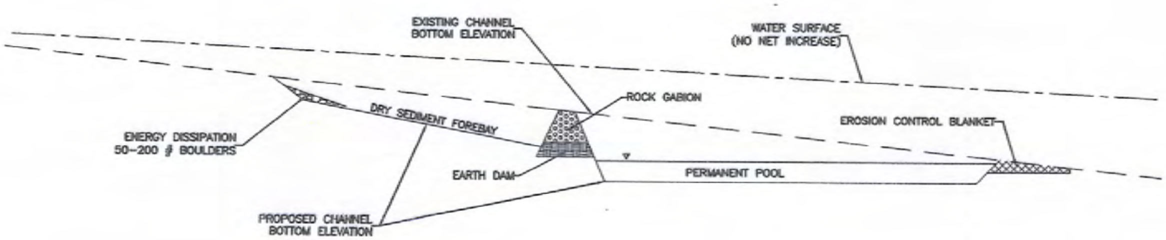
Document:	AS-12 STD
Drawn By:	LZJ
Scale:	1:30
Date:	12/01/05

U.S. Patent No. 6524473 and other Patent Pending

Aqua-Swirl Concentrator Model AS-12 Off-Line Standard Detail

VICINITY MAP

N.T.S.



SKG
ENGINEERING, LLC
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1122 SOUTH BRYANT BLVD., SAN ANGELO, TEXAS 76903
PHONE 325.655.1288 FAX 325.657.3189
FIRM REGISTRATION NUMBER F-7008

UCRA
FRED TEAGARDEN
512 ORIENT
SAN ANGELO, TEXAS 76903

LOW IMPACT BMP BAPTIST MEMORIAL SAN ANGELO, TEXAS

CONCEPTUAL PLAN

SCALE: NONE

SHEET NO. 16

SKG
ENGINEERING, LLC
SURVEYING • ENVIRONMENTAL • LAB/CMT
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SAN ANGELO, TEXAS 76903
PHONE: 325.655.1288
FAX: 325.657.8189

UCRA BMP CONCEPTUAL PLANS - ITEM 6

SAN ANGELO, TEXAS

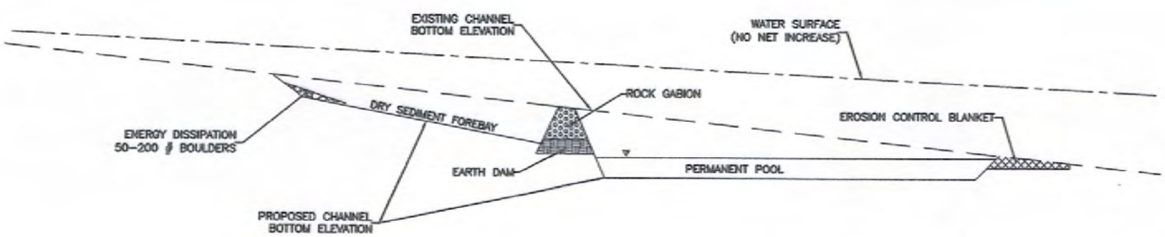
ENGINEER'S PRELIMINARY OPINION OF PROBABLE COST

ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	AMOUNT
BASE BID					
1	Mobilization	1	LS	$16,163.00	$16,163.00
Temporary Erosion Control					
2	Silt Fence	184	LF	5.94	$1,093.00
Rock Gabion					
4	Stone+components	48	CY	181.62	$8,717.76
Permenant Erosion Control					
5	Reno Mattress (9")	730	SY	58.69	$42,844.00
6	Energy Dissipation (Rip Rap)	464	CY	98.7	$45,796.80
Excavation					
7	Pond Excavation	23687	CY	9.49	$224,789.63

* Prices are based on quotes from Reece Albert.
** This cost analysis is based on a conceptual plan and could change when actual design is completed.

TOTAL CONSTRUCTION OPC	$339,404.19
CONSTRUCTION CONTENGENCIES (15%)	$50,911.00
TOTAL PROJECT OPC	$390,315.19

VICINITY MAP
N.T.S.



SKG ENGINEERING, LLC
SURVEYING • ENVIRONMENTAL • LAB/CMT

UCRA
FRED TEAGARDEN
912 ORIENT
SAN ANGELO, TEXAS 76903

LOW IMPACT BMP
PULLIAM DRAW NEAR
CONCHO RIVER
SAN ANGELO, TEXAS

CONCEPTUAL PLAN

11-E-0036
SCALE: NONE
17

SKG ENGINEERING, LLC

SURVEYING • ENVIRONMENTAL • LAB/CMT

1122 SOUTH BRYANT BLVD.
SAN ANGELO, TEXAS 76903

PHONE: 325.655.1288
FAX: 325.657.8189

UCRA BMP CONCEPTUAL PLANS - ITEM 7

SAN ANGELO, TEXAS

ENGINEER'S PRELIMINARY OPINION OF PROBABLE COST

ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	AMOUNT
BASE BID					
1	Mobilization	1	LS	$130,959.00	$130,959.00
Temporary Erosion Control					
2	Silt Fence	753	LF	5.93	$4,466.00
Rock Gabion					
4	Stone+components	440	CY	159.77	$70,298.80
Permenant Erosion Control					
5	Reno Mattress (9")	3408	SY	52.86	$180,147.00
6	Energy Dissipation (Rip Rap)	1589	CY	86.49	$137,432.61
Excavation					
7	Pond Excavation	223183	CY	9.87	$2,202,816.21
Weir					
8	Weir Allowance	1	UNIT	24,000	$24,000.00

* Prices are based on quotes from Reece Albert.
** This cost analysis is based on a conceptual plan and could change when actual design is completed.

TOTAL CONSTRUCTION OPC	$2,750,119.62
CONSTRUCTION CONTENGENCIES (15%)	$412,518.00
TOTAL PROJECT OPC	$3,162,637.62

APPENDIX G

Stormwater Monitoring Data and Loading Calculations

DATE	SITE	Total P mg/L	NO3-NO2 mg/L	TKN mg/L	TOC mg/L	TSS mg/L	BOD	VOLUME(AC-FT)	P load(lbs)	N load(lbs)	TSS (lbs)	BOD (lbs)	TOC (lbs)	
6.28.10	2	0.17	0.3	1.45		57.4	9.6	17.9	8.2	70.6	2794	467.0	0.0	
6.28.10	3	0.07	0.55	1.51		30.7	11.2	9.8	1.9	40.2	818	298.0	0.0	
6.28.10	4	0.12	0.21	2.37		20	12.8	10.2	3.3	65.7	555	355.0	0.0	
6.28.10	5 first flush	1.36	<0.02	11.4	147	1060	73.9	0.02475	0.1	0.8	71	5.0	9.9	
6.28.10	5	0.185	<0.02	1.98		41.2	19.7	0.836	0.4	4.5	94	44.8	0.0	
6.28.10	8	0.194	0.134	2.11		42.4	14.2	116.65	61.5	669.3	13450	4504.4	0.0	
									0.0	0.0	0	0.0	0.0	
8.24.10	2	1.29	0.545	2.95		412	10.2	93.547	328.2	750.4	104807	2594.7	0.0	
8.24.10	3	0.32	0.343	3.64		62	12.6	23.482	20.4	232.4	3959	804.6	0.0	
8.24.10	4FF	1.21	0.072	5.67	41.4	403	29.2	0.25	0.8	3.9	274	19.9	28.1	(first 15 min of storm)
8.24.10	4	0.347	0.394	2.64		148	8.9	16.084	15.2	115.5	6473	389.3	0.0	
8.24.10	6	0.637	0.656	3.04	0.162	354	13.4	15.818	27.4	130.8	15227	576.4	7.0	
8.24.10	8	0.523	0.305	2.96		636	12	44.371	63.1	357.2	76739	1447.9	0.0	
8.24.10	10	0.379	0.525	1.86		31	21.3	6.363	6.6	32.2	536	368.6	0.0	
9.25.10	1	0.301	0.265	2.17		138	11.4	8.952	7.3	52.8	3359	277.5	0.0	
9.25.10	4	0.176	0.209	1.86		60.8	6.6	16.642	8.0	84.2	2752	298.7	0.0	
9.25.10	6	0.352	0.122	1.99		207	11.3	15.818	15.1	85.6	8904	486.1	0.0	
9.25.10	7FF	0.428	0.048	3.5		163	14.7	0.586	0.7	5.6	260	23.4	0.0	
9.25.10	7	0.306	0.147	1.97	13	167	10	200	166.4	1071.4	90826	5438.7	7070.3	
9.25.10	8	0.524	0.141	2.74		322	7.3	28.77	41.0	214.4	25192	571.1	0.0	
									0.0	0.0	0	0.0	0.0	
10.25.10	1	0.575	0.726	3.16		368	5.4	7.66	12.0	65.8	7665	112.5	0.0	
10.25.10	2	0.452	0.336	1.98		212	5.1	319.782	393.1	1721.8	184354	4434.9	0.0	
10.25.10	3	0.276	0.321	3.33		53.2	8.7	38.509	28.9	348.7	5571	911.1	0.0	
10.25.10	6	0.691	0.308	3.47		403	9.3	13.265	24.9	125.2	14537	335.5	0.0	
10.25.10	7	0.363	0.26	1.87		214	6.1	199.29	196.7	1013.4	115974	3305.8	0.0	
10.25.10	8	0.378	0.271	1.87		284	5	91.25	93.8	464.0	70472	1240.7	0.0	
10.25.10	10	0.393	0.772	1.95		50	7.8	15.766	16.8	83.6	2144	334.4	0.0	

5.1.11	1FF	0.728	0.765	4.15	35.3	418	37.5	1.261	2.5	14.2	1433	128.6	121.0
5.1.11	1	0.603	1.41	3.59	32	171	25.5	8.118	13.3	79.3	3775	562.9	706.4
5.1.11	4FF	1.31	0.559	7.02	59.1	500	66	0.66	2.4	12.6	897	118.5	106.1
5.1.11	4	0.545	0.473	3.23	27.6	139	28.6	41.83	62.0	367.4	15811	3253.2	3139.5
5.1.11	5FF	1.36	2.8	11.4	144	490	69.6	0.123	0.5	3.8	164	23.3	48.2
5.1.11	6FF	2.16	1.48	9.33	101	3380	69.1	0.244	1.4	6.2	2243	45.8	67.0
5.1.11	6	0.934	0.591	5.32		552	30.8	1.28	3.3	18.5	1921	107.2	0.0
5.1.11	7FF	1.03	1.49	6.31	69.4	515	59.8	1.114	3.1	19.1	1560	181.2	210.2
5.1.11	7	0.538	0.762	3.83	32.2	79	26.6	141.6	207.2	1474.8	30420	10242.5	12398.9
5.1.11	8	0.469	0.586	3.26	30.5	165	24.9	92.26	117.7	817.9	41396	6247.1	7652.0
5.1.11	9FF	0.731	0.653	4.51	27.6	966	21.7	4.05	8.1	49.7	10639	239.0	304.0
5.1.11	9	0.491	0.889	2.37	23.3	342	16.2	56.75	75.8	365.7	52778	2500.0	3595.7
5.20.11	1	0.545	0.875	3.69		253	16.5	3.029	4.5	30.4	2084	135.9	0.0
5.20.11	2	0.259	0.561	1.88		35	9	51.4	36.2	262.8	4892	1258.0	0.0
5.20.11	3	0.408	0.697	3.67		139	17.1	6.484	7.2	64.7	2451	301.5	0.0
5.20.11	4	0.621	<0.02	4.4		365	15.5	16.405	27.7	196.3	16283	691.5	0.0
5.20.11	5	0.814	0.694	4.68		550	20.5	1.462	3.2	18.6	2187	81.5	0.0
5.20.11	6	0.637	<0.02	4.47		500	15.3	0.805	1.4	9.8	1095	33.5	0.0
5.20.11	7	0.357	0.114	3.21		111	18	140	135.9	1222.1	42258	6852.7	0.0
5.20.11	8FF	0.432	0.257	4.14		272	20.8	5.755	6.8	64.8	4257	325.5	0.0
5.20.11	8	0.428	0.617	3.41		118	19	37.2	43.3	345.0	11937	1922.0	0.0
5.20.11	9	0.487	0.025	2.86		394	11	88.037	116.6	684.7	94324	2633.4	0.0
5.20.11	10	0.379	1.53	3.34		92	38.3	2.017	2.1	18.3	505	210.1	0.0
DATE	SITE	Total P mg/L	NO3-NO2 mg/L	TKN mg/L	TOC mg/L	TSS mg/L	BOD	VOLUME(AC-FT)	P load(lt	N load(lbs)	TSS (lbs)	BOD (lbs)	TOC (lbs)
6.22.11	2	0.453	0.252	2.24		91	14	38.17	47.0	232.5	9446	1453.2	0.0
6.22.11	4	0.822	<0.02	5.41		326	37.6	9.38	21.0	138.0	8315	959.1	0.0
6.22.11	5	0.757	0.033	4.38		293	22.9	2.05	4.2	24.4	1633	127.7	0.0
6.22.11	6	0.475	0.026	2.91		240	18.9	3.09	4.0	24.5	2017	158.8	0.0
6.22.11	7	0.482	0.08	3.6		162	25.9	93.08	122.0	911.2	41005	6555.7	0.0
6.22.11	8	0.566	0.026	3.3		119	23.7	33.9	52.2	304.2	10970	2184.8	0.0
6.22.11	9	0.534	0.092	2.75		219	14.6	77.39	112.4	578.7	46088	3072.6	0.0
6.22.11	10	0.729	0.36	3.89		137	27.1	8.88	17.6	93.9	3308	654.4	0.0
6.22.11	Sunset Lake	0.183	<0.02	1.82		25	15.5	1	0.5	4.9	68	42.1	0.0

8.13.11	1	0.981	0.603	3.72		369	8.3	125.97	336.0	1274.3	126403	2843.2	0.0	#### Volumes in this dataset
8.13.11	2	0.75	0.3	2.28		782	5.3	1851.7	3776.5	11480.7	3937676	26687.6	0.0	reflect total volume of water past each
8.13.11	3	0.372	0.435	2.39		232	5.6	473.5	479.0	3077.4	298724	7210.6	0.0	station
8.13.11	5	0.501	0.096	2.13		368	4.5	66.9	91.1	387.5	66948	818.7	0.0	
8.13.11	7	0.429	0.178	2.12		388	6.2	1214.98	1417.4	7004.3	1281927	20484.4	0.0	
8.13.11	8	0.578	0.112	2.14		672	7.3	687.44	1080.5	4000.5	1256223	13646.5	0.0	
8.13.11	9	0.618	0.045	1.99		296	7.9	1130.9	1900.5	6119.8	910287	24294.8	0.0	
8.13.11	10	0.73	1.08	3		163	9.5	93.07	184.8	759.3	41253	2404.3	0.0	
10.10.11	1	0.637	0.269	3.27		392	8.3	59.47	103.0	528.8	63394	1342.3	0.0	
10.10.11	2	0.455	0.147	2.19		360	11.5	1466	1813.9	8730.5	1435156	45845.3	0.0	
10.10.11	3	0.259	0.36	2.2		125	10.9	152	107.1	909.3	51667	4505.4	0.0	
10.10.11	4	0.417	0.549	2.75		208	93.7	70	79.4	523.5	39594	17836.1	0.0	
10.10.11	5	0.486	0.15	2.9		298	11.7	13	17.2	102.5	10535	413.6	0.0	
10.10.11	7	0.43	0.166	2.34		305	10.2	270	315.7	1718.1	223937	7489.0	0.0	**** Volume only through sampling period
10.10.11	8	0.511	0.174	2.61		412	9.4	204	283.5	1447.9	228555	5214.6	0.0	**** Volume only through sampling period
10.10.11	9	0.509	0.673	2.27		372	13.4	441	610.4	2722.2	446112	16069.6	0.0	**** Volume only through sampling period
10.10.11	10	0.361	0.325	1.9		105	9.8	44.3	43.5	228.9	12649	1180.6	0.0	
10.8.11	PV Bkgd	0.292	<0.02	3.58		98	10.1	1	0.8	9.7	266	27.5	0.0	
10.10.11	PV In	0.391	0.813	3.13		284	37.3	1	1.1	8.5	772	101.4	0.0	
10.10.11	PV Out	0.162	0.11	1.93		33	7.1	1	0.4	5.2	90	19.3	0.0	
DATE	SITE	Total P mg/L	NO3-NO2 mg/L	TKN mg/L	TOC mg/L	TSS mg/L	BOD	VOLUME(AC-FT)	P load(lt	N load(lbs)	TSS (lbs)	BOD (lbs)	TOC (lbs)	
11.9.11	2	0.222	0.128	2.06		77	26.2	15.886	9.6	89.0	3326	1131.8	0.0	
11.9.11	4	0.49	0.051	4.12		169	231	13.411	17.9	150.3	6163	8424.3	0.0	
11.9.11	5	0.449	<0.02	2.66		565	208	0.92	1.1	6.7	1414	520.4	0.0	
11.9.11	6	0.582	<0.02	3.98		272	104	2.522	4.0	27.3	1865	713.2	0.0	
11.9.11	7	0.266	<0.02	2.04		134	24.5	70.18	50.8	389.3	25573	4675.7	0.0	
11.9.11	8	0.452	0.13	2.99		182	17.3	40.4	49.7	328.5	19995	1900.6	0.0	
11.9.11	9	55.1	0.442	2.67		133	55.1	24.355	3649.2	176.8	8809	3649.2	0.0	
12.5.11	1	0.241	0.738	1.84		73	11	20.54	13.5	102.8	4077	614.4	0.0	
12.5.11	2	0.247	0.91	1.21		48	13.2	75	50.4	246.8	9790	2692.1	0.0	
12.5.11	3	0.166	0.395	1.2		28	8.6	26.7	12.1	87.1	2033	624.4	0.0	
12.5.11	4	0.286	0.476	2.9		181	22.5	14	10.9	110.4	6891	856.6	0.0	**** Volume only through sampling period
12.5.11	5	0.236	0.69	1.81		109	16.6	6.2	4.0	30.5	1838	279.9	0.0	
12.5.11	6	0.222	0.544	1.43		100	13.5	3.9	2.4	15.2	1061	143.2	0.0	
12.5.11	7	0.18	0.496	1.63		63	12.7	50.5	24.7	223.8	8652	1744.0	0.0	**** Volume only through sampling period
12.5.11	8	0.277	0.329	2		146	10.4	57.6	43.4	313.3	22869	1629.0	0.0	
12.5.11	9	0.343	0.905	2.06		78	14.7	17.5	16.3	98.0	3712	699.5	0.0	

1.9.12	3	0.209	0.921	2.19		90	10.2	55.5	31.5	330.5	13583	1539.4	0.0	
1.9.12	6	0.316	0.58	1.62		132	16.3	3.3	2.8	14.5	1185	146.3	0.0	
1.9.12	7	0.308	0.451	1.97		210	17.9	152.6	127.8	817.5	87144	7428.0	0.0	
1.9.12	8	0.379	0.589	1.62		212	16.4	72.1	74.3	317.6	41566	3215.4	0.0	
1.9.12	9	0.324	0.946	1.71		190	16.8	15.5	13.7	72.1	8008	708.1	0.0	
1.9.12	10	1.14	0.984	4.98		134	28.8	5.2	16.1	70.4	1895	407.2	0.0	
1.26.12	1	0.271	0.476	1.14		177	10.1	37.9	27.9	117.5	18242	1040.9	0.0	
1.26.12	2	0.348	0.377	1.5		338	60.8	650	615.1	2651.4	597438	107468.1	0.0	**** Volume only through sampling period
1.26.12	3	0.175	0.432	1.68		105	25.2	456.2	217.1	2084.1	130259	31262.1	0.0	
1.26.12	4	0.138	0.388	1.37		93	36.2	33.7	12.6	125.5	8523	3317.4	0.0	**** Volume only through sampling period
1.26.12	5	0.444	0.309	2.4		315	31.7	10	12.1	65.3	8566	862.0	0.0	
1.26.12	6	0.249	0.256	1.31		174	26.4	3.5	2.4	12.5	1656	251.3	0.0	
1.26.12	7	0.304	0.308	1.93		294	33.7	266	219.9	1396.1	212663	24376.7	0.0	**** Volume only through sampling period
1.26.12	8	0.238	0.301	1.31		254	57.9	170.5	110.3	607.4	117766	26845.1	0.0	**** Volume only through sampling period
1.26.12	9	0.351	0.475	1.43		190	30.6	52.3	49.9	203.4	27022	4352.0	0.0	**** Volume only through sampling period
1.26.12	10	0.249	0.753	1.34		125	18.7	26.7	18.1	97.3	9076	1357.7	0.0	**** Volume only through sampling period
2.19.12	1	0.192	0.957	1.03		128	4.7	15.27	8.0	42.8	5315	195.2	0.0	**** Volume only through sampling period
2.19.12	2	0.126	0.165	0.777		84	4.6	262.8	90.0	555.3	60030	3287.3	0.0	**** Volume only through sampling period
2.19.12	4	0.099	0.789	1.32		32	7.1	16.1	4.3	57.8	1401	310.8	0.0	**** Volume only through sampling period
2.19.12	7	0.084	0.069	1.27		70	7	124.5	28.4	430.0	23699	2369.9	0.0	**** Volume only through sampling period
2.19.12	8	0.121	0.294	0.995		94	9.3	50.7	16.7	137.2	12960	1282.2	0.0	
2.19.12	10	0.138	1.74	1.2		69	7.5	15.7	5.9	51.2	2946	320.2	0.0	**** Volume only through sampling period
					Ammonia - N									
3.10.12	1	0.308	1.3		0.291	198	10	14.05	11.8	0.0	7565	382.1	11.1	**** Volume only through sampling period
3.10.12	2	0.297	0.453		0.113	106	13.1	291.8	235.7	0.0	84111	10394.9	89.7	
3.10.12	4	0.298	1.01		0.255	115	34.3	28.7	23.3	0.0	8975	2676.9	19.9	**** Volume only through sampling period
3.10.12	6	0.286	0.473		0.231	178	17.7	2.3	1.8	0.0	1113	110.7	1.4	
3.10.12	8	0.284	0.482		0.129	184	13.1	92.1	71.1	0.0	46083	3280.9	32.3	
3.10.12	9	0.321	0.794		0.223	120	67.6	141	123.1	0.0	46011	25919.6	85.5	**** Volume only through sampling period
3.10.12	10	0.23	1.45		0.23	87	13	19.9	12.4	0.0	4708	703.5	12.4	

DATE	SITE	Total P mg/L	NO3-NO2 mg/L	TKN mg/L	TOC mg/L	TSS mg/L	BOD	VOLUME(AC-FT)	P load(lb:	N load(lbs)	TSS (lbs)	BOD (lbs)	TOC (lbs)	
4.10.12	5	0.257	0.49	1.44		66	8.1	4.9	3.4	19.2	879	107.9	0.0	
4.10.12	4	0.284	0.324	2.37		34	12.2	28.3	21.9	182.4	2617	938.9	0.0	
4.10.12	7	0.301	0.136	2.78		82	14.7	59	48.3	446.0	13156	2358.5	0.0	
4.10.12	8	0.415	0.194	3.58		129	19.7	47.5	53.6	462.4	16663	2544.6	0.0	
4.10.12	9	0.352	0.419	2.61		84	9.1	42.4	40.6	300.9	9685	1049.2	0.0	
4.10.12	6	0.308	0.216	1.85		94	12.1	2.1	1.8	10.6	537	69.1	0.0	
									0.0	0.0	0	0.0	0.0	
5.9.12	1	0.585	0.793	3.27		232	11.7	35.1	55.8	312.1	22144	1116.7	0.0	
5.9.12	2	0.369	0.32	1.94		321	8.9	750.7	753.3	3960.3	655291	18168.5	0.0	
5.9.12	3	0.224	0.449	4.11		91	7.6		0.0	0.0	0	0.0	0.0	
5.9.12	4	0.315	0.44	2.35		182	10.3	40.4	34.6	258.2	19995	1131.6	0.0	
5.9.12	6	0.384	0.62	2.5		270	22.1	7.6	7.9	51.7	5580	456.7	0.0	
5.9.12	7	0.446	0.787	3.19		361	13.8	458	555.5	3973.0	449609	17187.3	0.0	
5.9.12	8	0.319	0.275	1.81		187	10.3	137.2	119.0	675.3	69768	3842.9	0.0	
5.9.12	9	0.383	0.49	1.94		263	9.1	309	321.8	1630.1	220992	7646.5	0.0	
5.9.12	10	0.374	0.722	2.23		76	22.3		0.0	0.0	0	0.0	0.0	
									0.0	0.0	0	0.0	0.0	
8.13.12	4	0.434	0.042	4.36		146	37.3	14.5	17.1	171.9	5757	1470.8	0.0	
8.13.12	5	0.539	0.548	3.93		318	26.5	0.9	1.3	9.6	778	64.9	0.0	
8.13.12	6	0.429	0.297	2.73		311	21.4	1.1	1.3	8.2	930	64.0	0.0	
8.13.12	7	0.292	0.08	2.9		143	16.4	35.8	28.4	282.3	13921	1596.6	0.0	
8.13.12	8	0.66	0.133	6.1		690	16.7	10.5	18.8	174.2	19702	476.8	0.0	
8.13.12	9	0.372	0.868	3.62		360	19	13.4	13.6	131.9	13118	692.3	0.0	
									0.0	0.0	0	0.0	0.0	
9.14.12	1	0.347	0.436	1.63		72	6.6	16.2	15.3	71.8	3172	290.8	0.0	
9.14.12	2	0.391	0.38	1.92		95	4.9	175.3	186.4	915.3	45286	2335.8	0.0	
9.14.12	4	0.264	0.098	2.22		94	23.9	72.6	52.1	438.3	18558	4718.4	0.0	
9.14.12	5	0.376	0.205	2.6		120	19.7	4.4	4.5	31.1	1436	235.7	0.0	
9.14.12	6	0.303	0.345	2.05		88	10.1	2.9	2.4	16.2	694	79.6	0.0	
9.14.12	7	0.382	0.395	2.48		198	7.6	315.3	327.5	2126.4	169766	6516.3	0.0	
9.14.12	9	0.447	0.319	1.76		256	5.5	370.6	450.5	1773.7	257993	5542.8	0.0	
									0.0	0.0	0	0.0	0.0	
10.02.12	2	0.306	0.063	1.76		118	41.1	0	0.0	0.0	0	0.0	0.0	**** Volume only through sampling period
10.02.12	4	0.317	<0.02	2.94		145	112		0.0	0.0	0	0.0	0.0	**** Volume only through sampling period
10.02.12	5	0.215	0.093	1.12		172	37.6		0.0	0.0	0	0.0	0.0	**** Volume only through sampling period
10.02.12	6	0.359	0.12	2.26		258	44.1		0.0	0.0	0	0.0	0.0	**** Volume only through sampling period
10.02.12	7	0.232	0.142	1.99		98	38.1		0.0	0.0	0	0.0	0.0	**** Volume only through sampling period
10.02.12	8	0.274	0.139	1.83		196	38.5		0.0	0.0	0	0.0	0.0	**** Volume only through sampling period
10.02.12	9	0.308	0.25	2.91		300	38.4		0.0	0.0	0	0.0	0.0	**** Volume only through sampling period

APPENDIX H

Red Arroyo Potential Public Water Supply Summary

Red Arroyo Potential Public Water Supply Summary

As mentioned in Section 3.66 and elsewhere herein, UCRA personnel identified Red Arroyo near South Chadbourne Street as a potential public water source for the City of San Angelo. A brief, factual summary of pertinent observations, the site's characteristics, development potential and possible ways to move forward follows.

The UCRA, through an agreement with the City of San Angelo, has conducted an extensive storm water data gathering program to provide the necessary inputs for the development of comprehensive storm water model for the city. As a part of that effort, flows and water quality has been measured at 10 permanent monitoring sites located throughout the city. Large volumes of storm water flows have been regularly measured during storm events at Monitoring Site 2, located on Red Arroyo immediately upstream of its confluence with the South Concho River. During the time period from August 2010 to July 2012, UCRA personnel measured over 9,700 acre feet of storm water that flowed through this site and into the South Concho River just below San Angelo's water intake at the water treatment plant. These flows were generated during a period of record drought with cumulative precipitation of less than 19 inches over the entire 22 month period. By extrapolation it is estimated that under normal conditions with average precipitation, the amount of storm water that would annually flow down Red Arroyo would exceed 10,000 acre feet. This represents in excess of 60% of San Angelo's typical annual usage. Moreover, chemical analyses conducted on samples collected during storm events exhibited good quality water.

These observations provided the impetus that led to the development of a potential project to capture storm water and reuse it as a public water supply source. The project, as envisioned, would not only provide a significant water supply from the standpoint of volume, but would also have ancillary benefits as well, not the least of which would be storm water reuse, which is one of EPAs preferred methods of storm water treatment.

A block of privately owned acreage exists that is sufficient in size for the project and which is also optimally located.

The project would consist of a small lake, constructed in such a way as to not adversely impact the flood zone. It would not be a dammed structure, but essentially be an excavated area. It would be located within a few hundred yards of San Angelo's water treatment plant and be constructed in such a manner as to allow for the settling of suspended solids and other pollutants and provide good quality water to the plant. It would be managed in such a way as to maintain a certain amount of free board to capture small events for the city's use, and in the case of large storm events, the design would spill excess storm water back into the Red Arroyo channel and on to the South Concho River.

The project proximity to the water treatment plant would significantly contribute to low capital expense and low operations and maintenance costs. Moreover, the fact that the water is storm water generated from impermeable surfaces of the various developments situated on Red Arroyo's drainage acreage, the reliability of the supply would be exceptional and guaranteed.

Permitting is an issue that needs to be researched and vetted, however preliminary opinions from two law firms indicate that it is a workable project for which permits would likely be approved. The first step to fruition, is the need for a facility planning study to be undertaken by a qualified engineering firm.