Ashley Valley

Storm Water Master Plan

June 2008

Final Issued December 2008

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Uintah county

People Serving People
City of Naples

VERNAL City

Storm Water System
Master Plan

June 2008

Final Issued December 2008

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This report is intended to provide the necessary guidance to the local governing bodies within the Ashley Valley to ensure that the Valley will be protected from future large flooding events. The project was commissioned in 2006 by the governmental entities within the Ashley Valley: Vernal City, Naples City, and Uintah County. The region is currently experiencing rapid growth. This growth is continually encroaching upon natural stream channels and other previously undeveloped portions of the Valley. This study is intended to provide guidelines to ensure that development is regulated in a manner that will provide adequate protection from large storm events.

The purpose of the study is to:

1) Evaluate the major components of the existing storm water network based on existing conditions as well as determine how the existing network will behave with future planned development;

2) Determine deficiencies within the system and portions of the Valley that are at risk of flooding currently as well as areas that may be at risk in the future;

3) Provide a comprehensive plan to control storm water now and in the future.

EVALUATIONS

The first step in the evaluation process is to determine the major components that comprise the storm water management system and determine the adequacy of the existing system. Through meeting with the local staff, field investigations and research of previous studies, the major components of the existing storm water conveyance system were determined to consist of natural drainage channels throughout the basin, a series of irrigation canals, roadside swales, culverts, and a few storm drain pipes throughout the highly developed regions of the basin.

Using advanced modeling techniques, the existing system was modeled under the 10-, 25-, 50-, 100-, and 500-year storm events. The evaluation of the existing system indicated:

1) Natural flood channels have been modified and/or filled throughout the basin;

2) The irrigation canals could not safely convey storm water during large storm events;

3) Portions of the Valley are at risk of flooding during a 25-year or larger storm event;

4) The capacity of Upper Ashley Creek and the major bridges were inadequate above the 50-year event;

5) Existing regulations were not sufficient to provide adequate flooding and water quality protection with the growing population;

6) Peak velocities in many of the stream channels are likely to cause erosion, degraded water quality, and potential migration of the stream channels.

Once the existing system evaluation was complete and deficiencies noted, the modeling process was repeated assuming the Valley continues to grow in accordance with the current zoning and building standards. Results of the future conditions evaluation indicated that the existing problems would be exacerbated by additional development and some portions of the new anticipated growth would also be at risk of flooding.

RECOMMENDED IMPROVEMENTS

After evaluating the existing system and determining a number of deficiencies, improvement methodologies were evaluated and compared to the existing standards throughout the Ashley Valley. Three possible methodologies were identified: 1) do nothing, 2) preserve the drainages, and 3) divert and protect. Through numerous discussions with the elected officials and staff, a hybrid improvement methodology was identified. The hybrid methodology focused on preserving the natural drainages wherever possible, and diverting water around existing highly developed regions only when natural drainages could not be restored.

Using the selected improvement methodology, a series of potential improvements were input into the model and evaluated for potential benefit, cost, and risk. Through an iterative trial and error process a total of 100 recommendations were developed. The recommendations consist of preserving natural drainages, which are identified in this report, converting existing irrigation canals into storm water channels, building new storm water channels, upgrading stream crossings, as well as constructing a series of detention and debris basins.

OPINION OF PROBABLE COSTS

Each recommendation provided in this report includes an estimated cost to design and construct the improvement. The total improvement costs to correct the deficiencies along Ashley Creek are estimated to be $189,658,000 which includes the construction of two dams to regulate the flow. The proposed improvements to Ashley Creek will not only provide flood protection but will also provide many acres of wetlands, as well as valuable open space for the community to enjoy. An additional $15,366,813 will be required to construct the debris / detention basins as well as new channels to divert storm water. Finally, this report recommends that over 60 crossings be upgraded to ensure that critical transportation corridors remain passable during large storm events. Crossing upgrades are estimated to cost $4,418,063 for an average protection to the 25-year storm event. These costs are based on 2008 construction cost estimates at an Engineering News Record construction cost index of 8,184.94.

Chapter 1 INTRODUCTION

This study provides a comprehensive evaluation of current and future storm water conditions of the Ashley Valley (Valley), including a short history of the area, potential areas of development, and historical, current and projected storm water flows. This study includes a review of the current storm water management practices as well as recommendations for future storm water management strategies. The report also identifies the major capital improvements within the Valley that will be required to manage future storm water runoff effectively.

Each of the recommended capital improvement projects has been identified to provide flood protection for certain hydrologic conditions that are anticipated to only occur once every 10, 25, 50, 100, or 500 years depending on the structure. The recommended improvements will not protect the Valley from all flood damage during all flood events. Rather, the recommendations are intended to greatly minimize flooding during typical large precipitation events and lessen the damage that will occur during the most extreme precipitation events. Additionally, this report focuses on the large-scale flooding concerns throughout the Valley. This study does not examine, evaluate, or provide recommendations to prevent or minimize localized flooding. In summary, the recommendations in this report are intended to manage the risks associated with large precipitation events and reduce flooding damage, but will not protect the entire Valley from all precipitation events.

1.1 HISTORY

Valley is located in north-central Uintah County in eastern Utah, approximately 175 miles east of Salt Lake City and in close proximity to the Colorado state line. It is bordered on the north by the Uintah Mountains, one of the few mountain ranges in the world which lies in an east-west, rather than the more common north-south, direction. The Book Cliff Mountains lie to the south and Blue Mountain to the east. The Valley, and Ashley Creek, a major water course in the Valley, are named after William H. Ashley, an early fur trader who entered the area in 1825 via the Green River. In 1861, President Abraham Lincoln set the area aside as the Uintah Indian Reservation, and appointed Captain Dodds as Indian agent for this reservation.

When Dodds retired, he moved to Valley to raise livestock, along with other agency workers. They arrived on February 14, 1873 and settled on the banks of Ashley Creek. Dodds built the first cabin in the Valley, located about four miles northwest of present day Vernal. Many trappers, prospectors, and home seekers moved in and out of the Valley until 1878. Alva Hatch came to the Valley looking for a place to homestead in May 1978. He returned later with his family and his father, Jeremiah Hatch. The fall of 1879 brought many settlers to the Valley.

As the Valley was settled, large portions of the basin developed into crop lands. The arid climate severely limited the type and quantity of crops that could be grown. To increase the agricultural productivity of the area, a series of irrigation canals were constructed to provide water to the crops. Today, modern irrigation channels traverse the entire basin providing water to the large majority of crops. Most of these canals capture large volumes of storm water during rain and snow events. The current irrigation system within the Valley has a dual purpose: to convey essential water to the crops and to safely route storm water through the basin.

The first town in the basin, Vernal, was incorporated in 1897. In 1948, Vernal had its first oil boom, and from that time on it has been a boom and bust town. Naples was the second incorporated area in the Valley, named after the prominent city in Italy. A thriving tourist business located near the popular Dinosaur National Monument, combined with livestock and agriculture production, have helped to diversify the local economy and in turn keep Vernal, Naples and the surrounding area prosperous.

Maeser is an unincorporated community of the Valley, located approximately three miles northwest of Vernal. The community was named after an educator by the name of Karl G. Maeser. The community of Maeser has a total area of approximately 6.5 miles and is located north of State Route 121 on the west side of the Valley.

1.2 THE NEED FOR STORM DRAIN MASTER PLAN

Presently, the majority of land within the Valley is open space or has been developed for agricultural purposes. However, as the local economy continues to diversify, the Valley is becoming increasingly urbanized as agricultural fields and open space are transformed into incorporated towns and cities. This increased development will affect the storm water runoff patterns within the region. Without a master plan, individual developments will be solely responsible for storm water run-on and run-off management strategies. This microscopic approach to storm water management often leads to costly and ineffective management styles. In some cases, different storm water mitigation approaches within the same basin can conflict with one another, creating potentially hazardous results.

1.3 PURPOSE

Currently, the Valley does not have a comprehensive basin-wide master plan. The existing storm water facilities are currently owned by numerous entities, including: Vernal City, Naples, various irrigation companies, and Uintah County. As the region continues to grow, the affects of development will intensify and the need for these networks to work together will increase dramatically. This master plan is intended to identify the existing backbone for the storm water conveyance and detention network throughout the basin and provide a list of the capital facilities that will be required to ensure the networks work together and effectively manage future storm water flows.

1.4 METHODOLOGY

This master plan begins by identifying the study area and defining the drainage boundaries of the Valley. Critical hydrologic parameters such as inflow, rainfall intensity, duration, and frequency ("design storm"), land use, soil type, and contour elevation data were collected as a basis for the analysis. This data was then compiled into a geospatial database, or Geographic Information System (GIS), to perform advanced computations and spatial analysis, described in more detail later in this report.

The design storms used in this study are established based upon the intensity/duration/frequency (IDF) curves that are generated by the National Oceanic and Atmospheric Administration (NOAA) for the Vernal Airport weather station. Land use, soil types, and contour elevation data are gathered from county, state, and federal agencies, as appropriate.

Drainage basins within the study area are identified intelligently to provide sufficient detail, while not over-complicating the modeling process. A hydrologic model, utilizing the defined parameters, is then used to determine the runoff potential from the individual basins by routing the flows through a series of irrigation canals, natural ditches and creeks, pipes and detention facilities.

Areas and types of future development are identified and the modeling process repeated to observe the affects of the anticipated development. Where the model indicates future flooding will occur, flows are re-routed or conveyance capacities increased to alleviate the problems. From the model, a list of the required capital facilities necessary to prevent future flooding is provided as well as the estimated cost of each improvement.

1.5 OBJECTIVES OF THE STUDY

The objectives of this study include the evaluation of the existing storm water facilities and the recommendation of improvements to be made in the existing storm water conveyance network to correct existing deficiencies as well as to convey future flows. These objectives will be accomplished by evaluating the effectiveness of the current faculties through advanced modeling.

1.6 LIMITATIONS OF THE STUDY

This study provides an extensive storm water evaluation of the entire Valley, and is designed to provide details inherent to the storm water system as a whole. As such, this model should be used in conjunction with site-specific hydrology studies; it is not designed to replace such studies.

The Valley encompasses an area of approximately 55 square miles; many of the storm events only affect a portion of the area or affect different regions of the basin uniquely. This study assumes a uniform rainfall distribution over the entire Valley. It is assumed that this form of modeling will provide accurate or slightly conservative estimates of storm water runoff for the large design storms.

The best calibration was achieved with a zero flow from the Steinaker Dam. This study does not attempt to delineate flooding that would result from a breach of the dam and assumes that flows that may result from controlled discharges are properly regulated and controlled. This study does, however, assume that the Steinaker Feeder Canal to the reservoir does not divert any water away from the flood during the storm events which produce flows in Ashley Creek in excess of what gauging stations have recorded to date.

Due to the size of the study area, the majority of the drainage basins were delineated using a two-meter digital elevation model (DEM), or aerial topology, that was provided by Uintah County, instead of traditional ground surveying methodology. Information regarding the location, capacity, and discharge points for major canals within the Valley is based on information obtained from operational personnel. Knowledge from City and County staff was used to determine existing known problem areas and other pertinent information in order to calibrate the model effectively.

Chapter 2 STUDY AREA CHARACTERISTICS

2.1 INTRODUCTION

The purpose of this chapter is to describe the pertinent physical, environmental, hydrologic, and land use characteristics of the study area to provide a basis for storm water flows outlined in this report. This chapter identifies the study area and drainage basin boundaries for the hydrologic analysis. It also describes the land use and soil data used to calculate runoff coefficients, and it outlines the hydrologic patterns that form the basis for the selection of IDF curves.

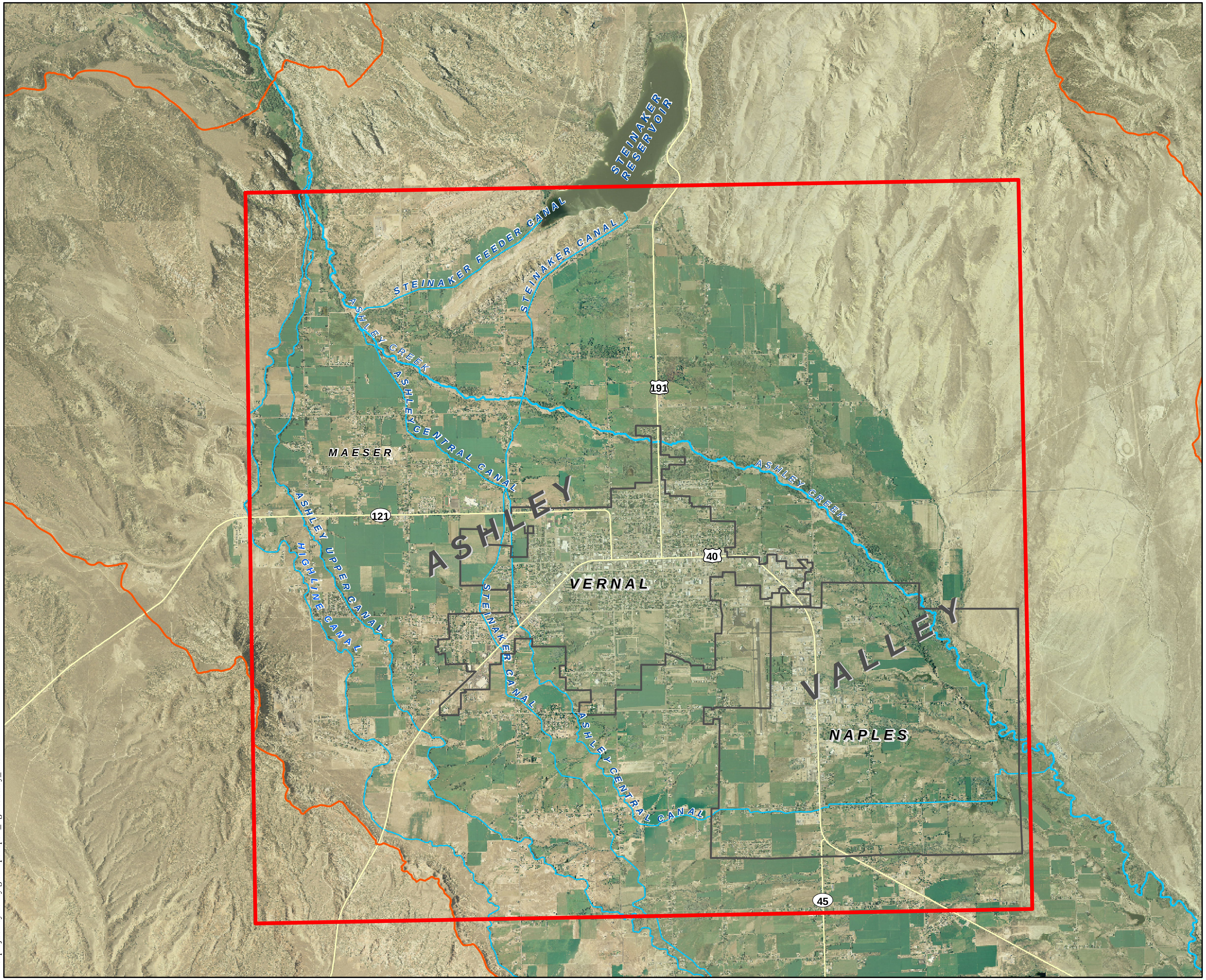
2.2 STUDY AREA BOUNDARIES AND COMPOSITION

The study area encompasses the city limits of Naples to the east, extends past Vernal to the bench on the west, and includes the Valley area between 3500 South to the south and Steinaker Reservoir to the north, for a total area of approximately 55 square miles. To ensure complete and accurate results, the drainage basins were extended to the ridgelines surrounding the Valley as shown in Figure 2-1. The full drainage area of Ashley Creek was not modeled due to the large contributing areas and numerous control structures along the stream course. Instead, stream gauge data located in the northwest corner of the Valley was utilized to provide accurate inflow data, as described in more detail later in this report.

The majority of the Valley consists of rural undeveloped lands or developed lands used for agricultural purposes. Portions of the central Valley have developed into cities that include commercial and industrial land uses. It is anticipated that the majority of future growth will result from the cities expanding from the center of the Valley into the outlying farmlands.

FIGURE 2-1
STUDY AREA
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008



Legend

Major Road

Major River or Canal

Ridgeline/Watershed

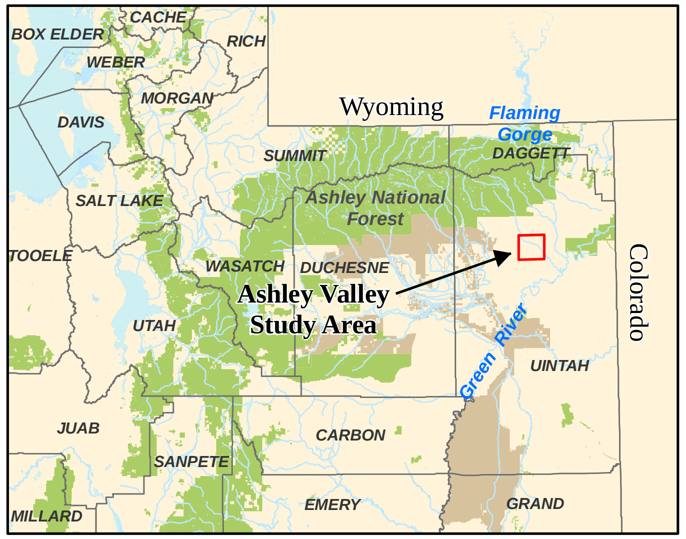
Study Area Boundary

Municipal Boundary

N
W E
S

0 5,000 10,000 Feet

1 INCH = 5,000 FEET



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Source: AGRC NAIP 2006 and Uintah County GIS.

2.3 GEOGRAPHICAL SETTING

The Valley is located in Uintah County in northeastern Utah near the Colorado border, north of the Green River and south of Flaming Gorge Reservoir. The region is a high-elevation (+5,000 feet) arid basin surrounded by mountains that are part of the larger Uinta Mountain Range to the north and extend over 1,500 feet above the Valley floor.

2.3.1 TOPOGRAPHY AND DRAINAGE

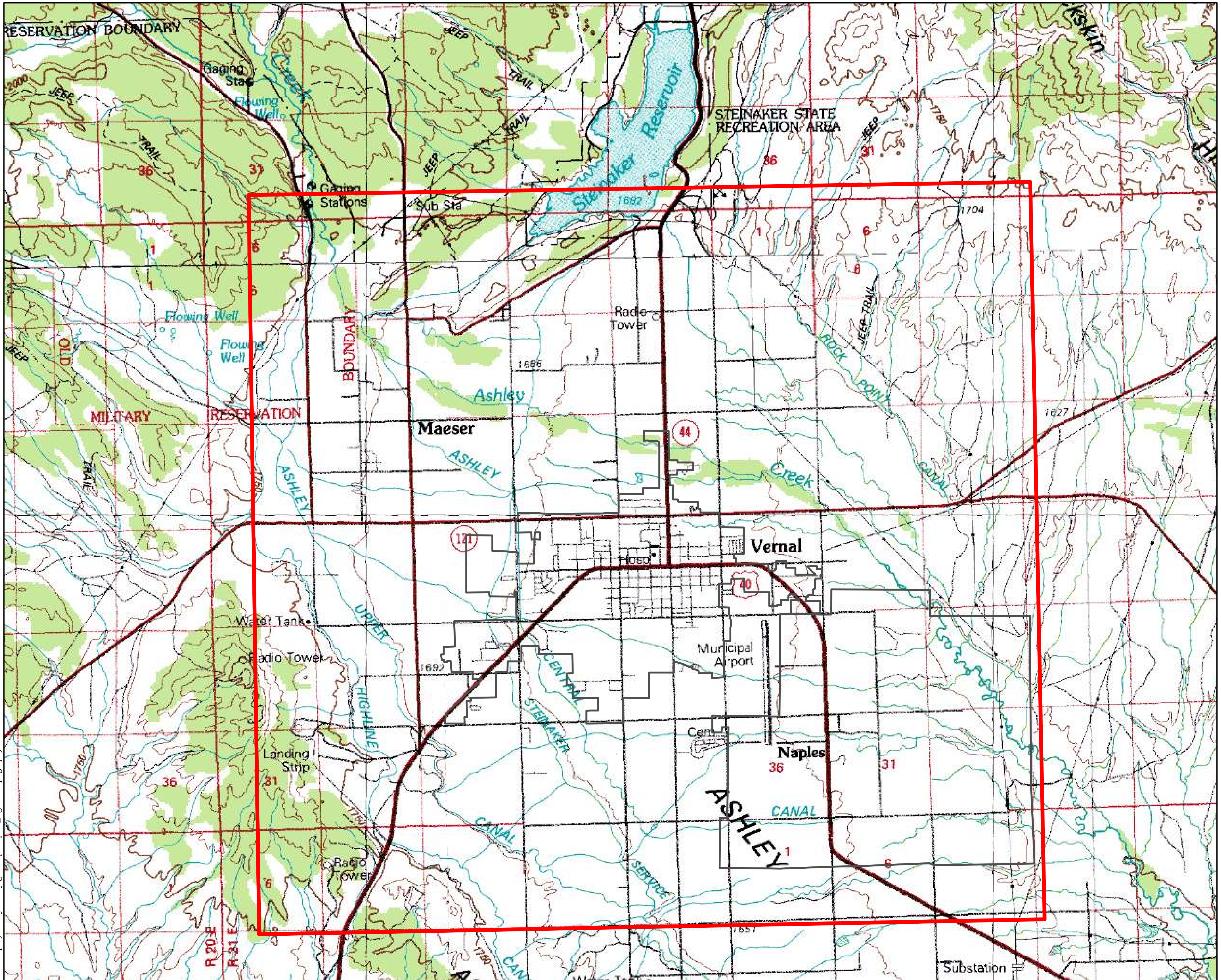
Ashley Creek provides the major drainage through the Valley, which is located within the greater Lower Ashley Creek watershed in the Ashley Creek/ Steinaker Reservoir/ Coal Mine Basin-Ashley Creek sub-basins. Ashley Creek generally flows in a southeasterly direction from the Ashley National Forest to the northwest, meanders through the Valley and exits at the southeast corner of the study area, eventually reaching the Green River.

Flows from Ashley Creek are diverted at numerous locations along the river for irrigation needs and other purposes. To provide for adequate water supply year-round, the Steinaker Dam and Reservoir were constructed in 1968 to store and distribute the excess spring flows of Ashley Creek. Water from Ashley Creek is diverted by Fort Thornburgh Diversion Dam, located approximately four miles northwest of Vernal and stored by the Steinaker Dam and Reservoir, located off-stream in Steinaker Draw about 3.5 miles north of Vernal. From the diversion dam, the water is conveyed eastward to the reservoir through the 2.8 mile-long Steinaker Feeder Canal. Reservoir water is released to Steinaker Service Canal and conveyed south 11.6 miles to other canals and ditches. Steinaker Reservoir has a total capacity of 38,173 acre-feet, and a surface area of 820 acres.

The Valley floor ranges in elevation from 5,000 feet to 5,600 feet. The basin is surrounded by mountains as high as 7,000 feet. The Valley topography and major drainage features are shown in Figure 2-2.

FIGURE 2-2
VALLEY TOPOGRAPHY
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008



Legend

Study Area Boundary

Municipal Boundary

N
W E
S

0 5,000 10,000 Feet

1 INCH = 5,000 FEET

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Source: AGRC NAIP 2006 and Uintah County GIS.

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2.3.2 SOILS

The type of soil can have a great affect on the quantity of storm water runoff in an area. Tightly bound clay soils generally have very high runoff potential while loose, well-graded sands generally have very low runoff potential. Based on the USDA Natural Resources Conservation Service (NRCS) soil maps, the Valley contains approximately 80 different soil types. For the purposes of quantifying storm water runoff it is not necessary to treat each soil type individually. Instead, the soils can be grouped with other soils that share similar hydrologic properties. The NRCS, formerly the Soils Conservation Service (SCS), classifies soils into four hydrologic soil groups. This classification system will be used for the purposes of this study, and is based on the soil's runoff potential as defined below:

Group A is sand, loamy sand or sandy loam types of soils. These soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist primarily of deep, well to excessively drained sands or gravels and have a high rate of water transmission.

Group B soils are silt loam or loam. These soils have a moderate infiltration rate when thoroughly wetted and primarily consist of moderately drained soils with moderately fine to moderately coarse textures.

Group C soils are sandy clay loam. These soils have low infiltration rates when thoroughly wetted and primarily consist of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure.

Group D soils are clay loam, silty clay loam, sandy clay, silty clay or clay. These soils have the highest runoff potential and very low infiltration rates when thoroughly wetted. They primarily consist of clay soils with a high swelling potential and/or soils with a permanent high water table.

Figure 2-3 shows the soil classification groups throughout the Valley. The majority of soils in the Valley are classified as types C and D with moderate to high runoff potential.

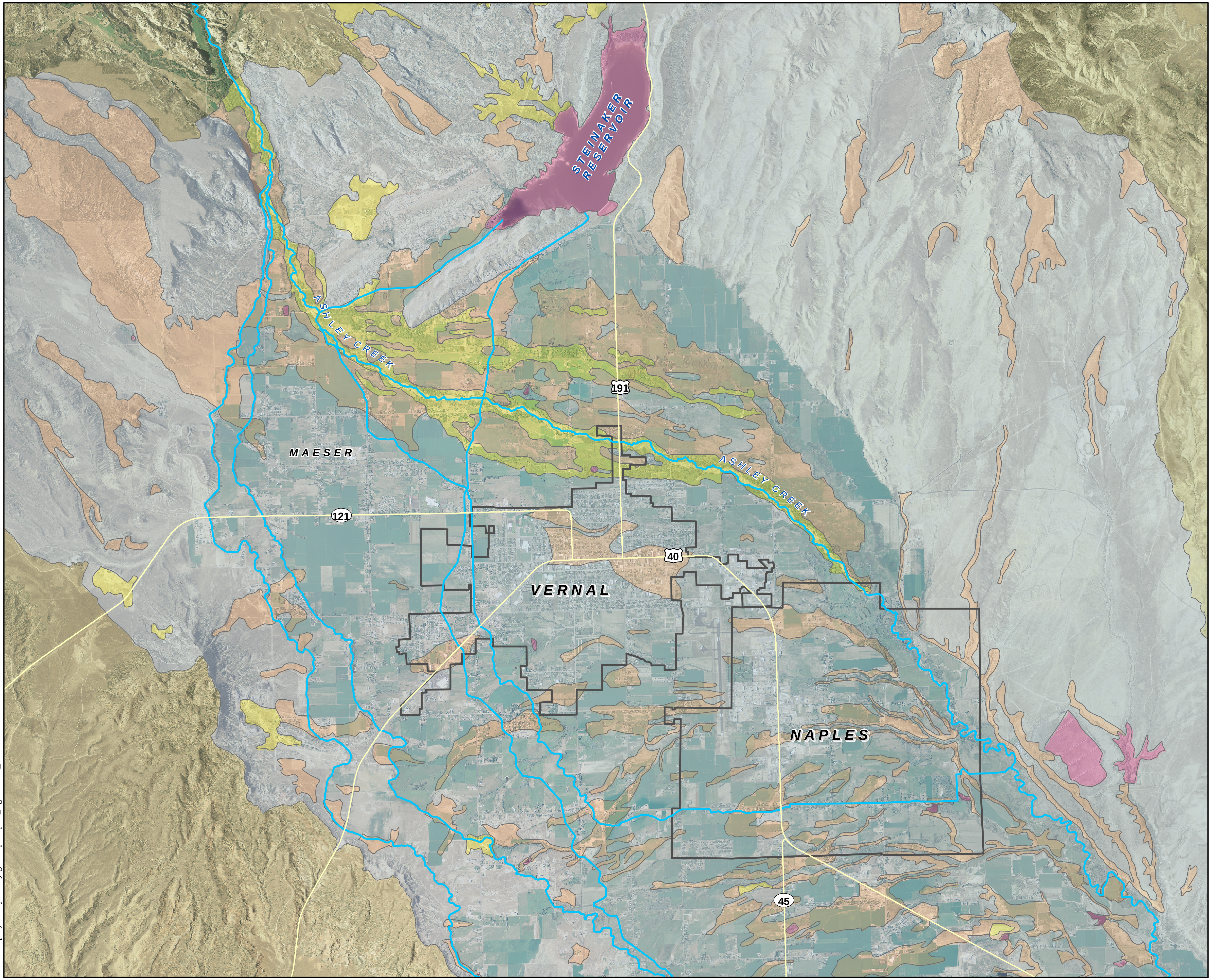

FIGURE 2-3
SOIL CLASSIFICATIONS
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008

Legend

- Major Road
- Major River or Canal
- Municipal Boundary

Hydrologic Soil Group

- A - Low runoff potential
- B - Moderate runoff potential
- C - Moderate to High runoff potential
- D - High runoff potential

N
W E
S

0 5,000 10,000 Feet

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Source: AGRC NAIP 2006 and Uintah County GIS.

2.3.3 VEGETATION

In addition to soils, the type of vegetation throughout an area can have a large affect on how rainfall is captured and the resulting runoff rates. Dense vegetation will generally trap a portion of rainfall as well as slow the rate at which the water can run off the basin and into channels. Conversely, bare soils or soils with little vegetation will generally hold less water and runoff velocities will be higher.

Vegetation in the Valley is widely varied. Being an arid desert, the region consisted primarily of prairie grasses and brush prior to development, except near the natural water courses where the vegetation is generally dense compared to the rest of the area. As the Valley was settled, however, large sections of the region were developed into irrigated crop lands. Mature crop lands generally provide dense vegetation while new crops or tilled fields between seasons will provide very little, if any, vegetation. The perimeter of the Valley is bounded by mountains with steep slopes. The mountainsides are largely un-vegetated hillsides, and as a result, have a high runoff potential.

2.4 CLIMATE

The Valley is a high desert with an arid climate. On average, the Valley receives less than 9 inches of rainfall annually. The climate is characterized by hot, dry summers, moderate autumns, cold winters with intermittent snow storms, and relatively wet springs during which the majority of rainfall occurs. Table 2-1 shows the average monthly temperature range and average precipitation for the area.

Table 2-1 Climate Data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	30	37	51	62	73	82	90	87	78	64	46	33	61.2
Average Min. Temperature (F)	4.9	11	22	30	39	45	52	50	41	31	20	9.3	29.5
Average Total Precipitation (in.)	0.5	0.5	0.7	0.8	0.8	0.7	0.5	0.7	0.9	1.1	0.6	0.6	8.31
Average Total Snowfall (in.)	4.7	2.9	1.6	0.2	0	0	0	0	0	0.3	0.9	4.6	15.3
Average Snow Depth (in.)	1	1	0	0	0	0	0	0	0	0	0	0	0

2.5 HYDROLOGY

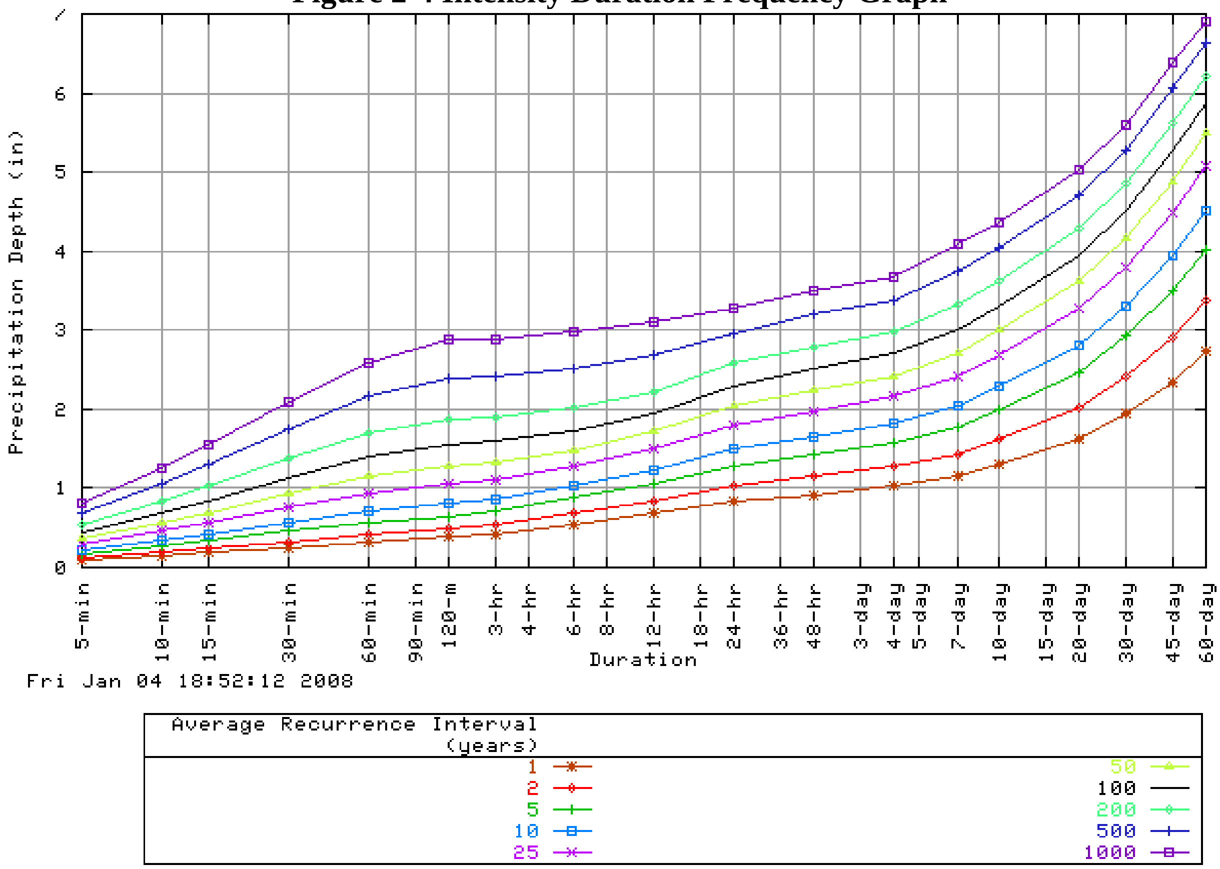
Storm water master planning and the design of drainage facilities are highly dependent upon the selection of the “design storm”. This storm, typically expressed in terms of its expected *recurrence interval* (e.g., 10 years), is used to determine rainfall intensity. The recurrence interval, also called a *return period* or *event frequency*, is the length of time expected to elapse between rainfall events of equal or greater magnitude. For example, a 10-year recurrence interval represents a storm event that is expected to occur once every 10 years, on average. This does not imply that two storm events of that same size will not occur in the same year, nor does it mean that the next storm event of that size will not occur for another 10 years. Rather, there is a 10-percent chance of occurrence in any given year. The length of the design storm also affects storm flows and runoff. For the purposes of this study, the 24-hour duration storm has been selected from the intensity/duration/frequency (IDF) data.

The IDF curves are created from precipitation records collected by the National Oceanic and Atmospheric Administration (NOAA). The precipitation station with the longest history, and the greatest amount of data, within the Valley is the Vernal Airport Station (Station 42-9111). The resulting rainfall depths and intensities for a range of durations for each return period are shown in Figure 2-4 and Table 2-2.

Table 2-2 Intensity Duration Frequency Data, Vernal Airport

Precipitation Frequency Estimates (inches)																			
		Storm Duration																	
		5 min	***10 min***	***15 min***	***30 min***	***60 min***	***120 min***	***3 hr***	***6 Hr***	***12 hr***	***24 hr***	***48 hr***	***4 day***	***7 day***	***10 day***	***20 day***	***30 day***	***45 day***	***60 day***
Return Period (years)	***1***	0.1	0.15	0.19	0.26	0.32	0.38	0.43	0.55	0.68	0.83	0.92	1.03	1.16	1.31	1.63	1.96	2.35	2.74
	2	0.13	0.2	0.24	0.33	0.41	0.48	0.54	0.69	0.85	1.03	1.15	1.28	1.44	1.63	2.02	2.42	2.91	3.38
	5	0.18	0.27	0.34	0.46	0.56	0.65	0.71	0.88	1.06	1.28	1.43	1.58	1.77	2.0	2.47	2.93	3.5	4.03
	10	0.23	0.34	0.43	0.58	0.71	0.8	0.87	1.04	1.24	1.5	1.66	1.82	2.04	2.3	2.82	3.31	3.94	4.5
	25	0.3	0.46	0.57	0.77	0.95	1.05	1.11	1.29	1.5	1.8	1.98	2.16	2.41	2.69	3.27	3.8	4.49	5.08
	50	0.37	0.56	0.7	0.94	1.16	1.28	1.33	1.49	1.72	2.04	2.24	2.43	2.71	3.0	3.61	4.16	4.89	5.49
	100	0.45	0.69	0.85	1.14	1.42	1.55	1.59	1.73	1.95	2.3	2.51	2.71	3.01	3.31	3.95	4.51	5.27	5.87
	200	0.54	0.83	1.02	1.38	1.71	1.88	1.9	2.01	2.21	2.58	2.79	2.99	3.33	3.63	4.28	4.85	5.63	6.22
	500	0.69	1.05	1.3	1.76	2.17	2.4	2.42	2.52	2.67	2.96	3.19	3.37	3.75	4.04	4.72	5.28	6.07	6.62
	1000	0.82	1.25	1.55	2.09	2.59	2.88	2.89	2.99	3.12	3.28	3.51	3.68	4.08	4.37	5.04	5.59	6.38	6.9

Figure 2-4 Intensity Duration Frequency Graph



2.6 MAJOR DRAINAGE BASINS

In order to model storm water flows in the Valley, a series of drainage basins are required that accurately reflect the true drainage boundaries of the area. The Valley was delineated intelligently into 200 basins using a high-resolution digital elevation model. Each of the basins contains an outlet which routes the flows from each basin into existing channels, pipes, natural streams or other drainages.

2.7 EXISTING LAND USE

The majority of the Valley is rural and currently used for grazing or agricultural purposes. Approximately 21% of the Valley has been developed into cities including commercial, industrial and other land intensive uses. Figure 2-5 shows the current land uses in the Valley, divided into the following five categories: irrigated/cultivated, residential, riparian, urban, and water. The open land currently used for agricultural purposes currently allows much of the storm water to infiltrate into the soil.

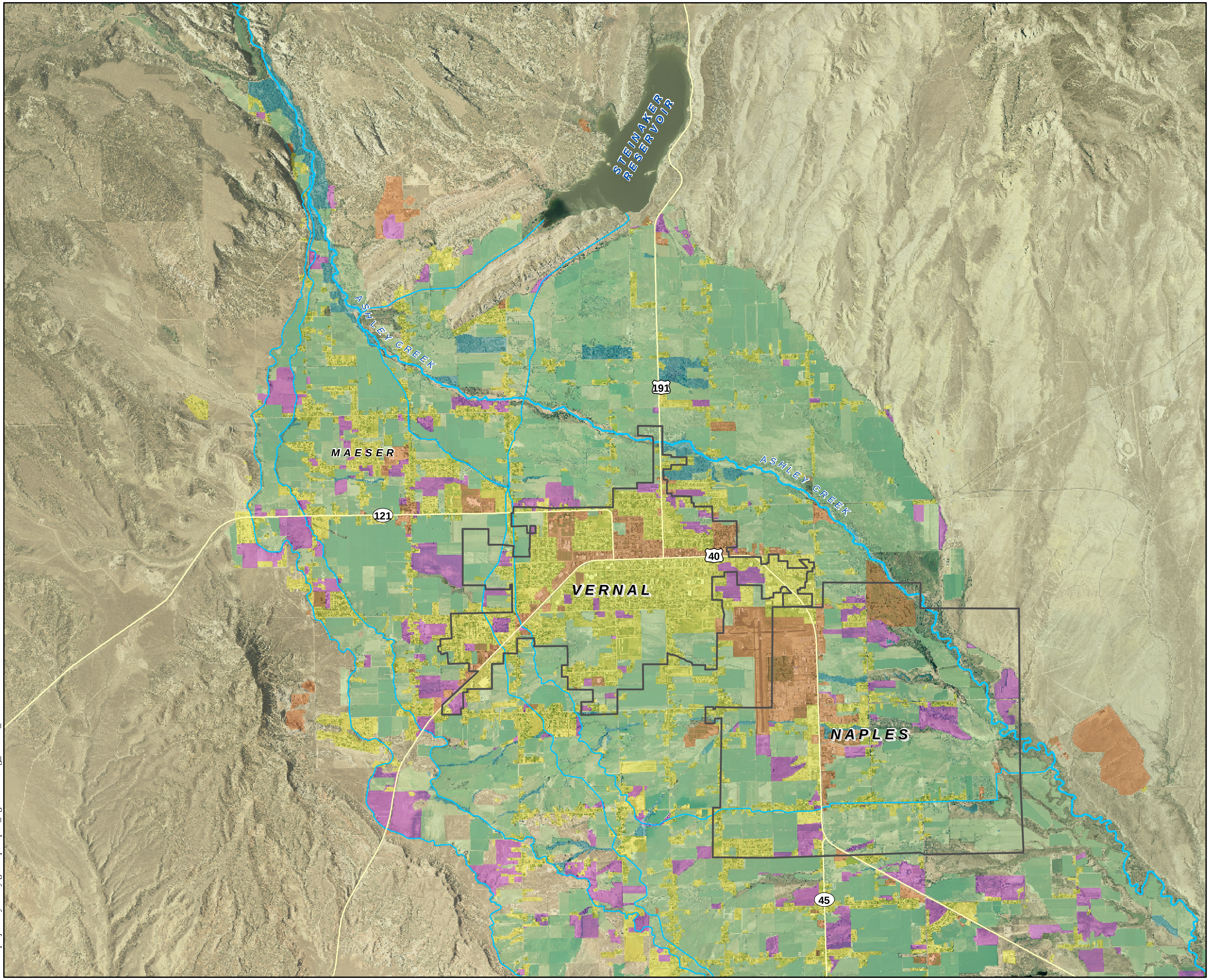


FIGURE 2-5
EXISTING LAND USE
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008

Legend

- Major Road
- Major River or Canal
- Municipal Boundary

Land Use

- Irrigated
- Not in Use
- Residential
- Riparian
- Urban

N
W E
S

0 5,000 10,000 Feet

1 INCH = 5,000 FEET

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Source: AGRC NAIP 2006 and Uintah County GIS.

2.8 *EXISTING SYSTEMS*

As development occurred in the Valley, numerous structures were built which altered the historic storm water flow patterns. Irrigation canals have been constructed throughout the Valley which capture and convey storm water runoff and divert them to agricultural fields.

The central portion of the Valley has been developed into the cities of Vernal and Naples. These and other developed regions (i.e. Maeser) have increased the amount of impervious surface and, consequently, the amount of storm water runoff from these areas. To convey and control the increased storm water runoff, Vernal has installed a number of pipes that are networked throughout the city. In the unincorporated areas, development under Uintah County code required the construction of retention basins to retain storm water runoff in most of the large-scale developments within the Valley.

2.8.1 STORM DRAIN PIPE NETWORK

The majority of the drainages in the Valley are natural channels and irrigation canals. Small portions of the Valley have closed-conduit, piped, storm water conveyance to move storm water from the heart of the developed areas to the perimeter. The existing pipe networks generally convey water within the defined basins; the pipe networks do not currently move significant volumes of storm water between defined basins.

2.8.2 STORM DRAIN DETENTION FACILITIES

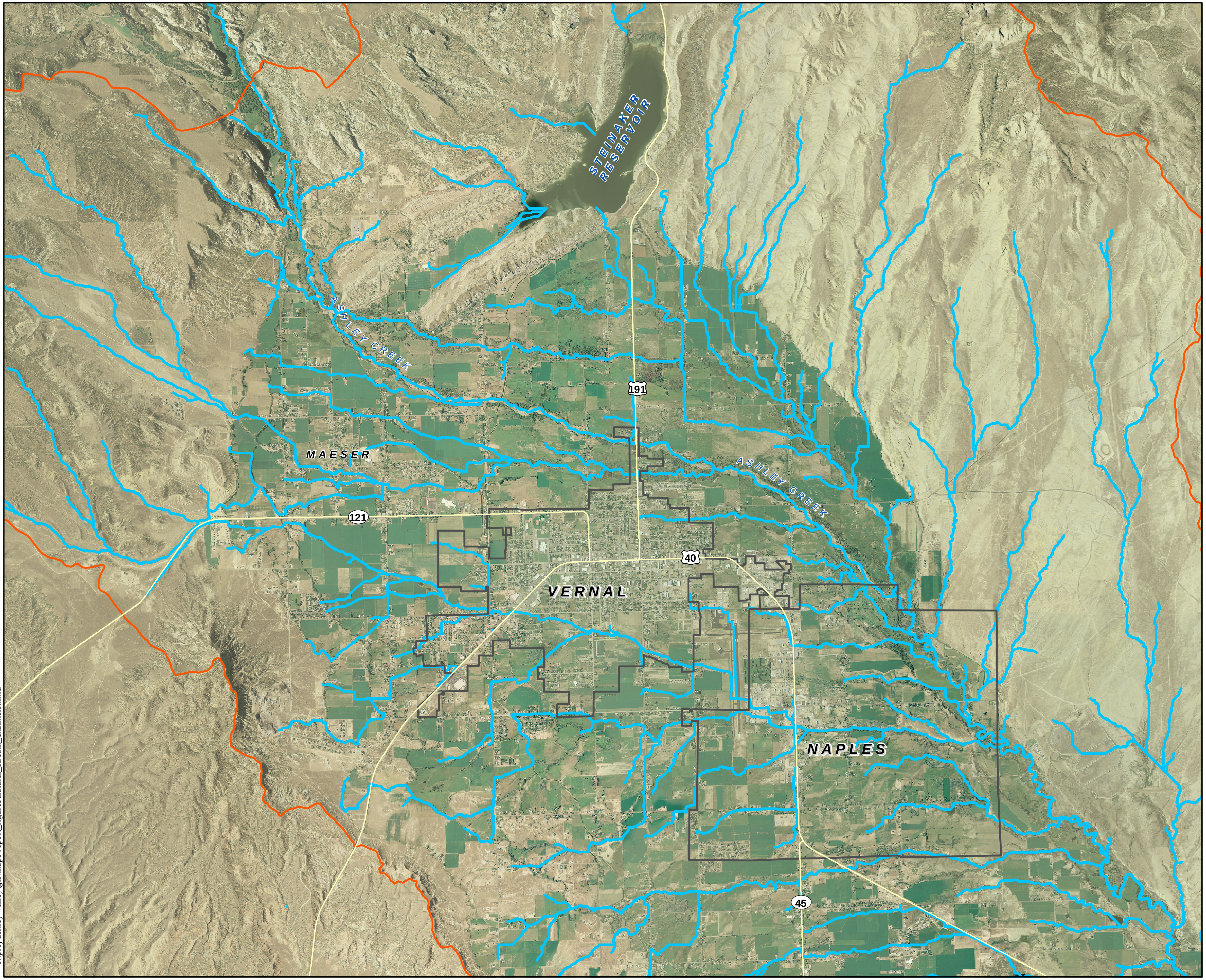
Uintah County requires complete retention of all storm water up to the 100-year event for all large developments located outside of the incorporated areas (i.e. Vernal or Naples City). This has resulted in a large number of local retention basins that minimize the volume of storm water that exits the site so long as the basins are properly maintained. The existing system also has a number of “natural detention basins” in the form of wetlands along natural channels within the Valley.

2.8.3 IRRIGATION CANALS

Meetings were held with the major irrigation companies to identify canals that affect the storm water runoff. Canal capacity and emergency turnout points were identified to improve the accuracy of the runoff flow rates. For the purposes of determining the worst case flooding potential, the analyses contained in this report assume the irrigation canals are full at the beginning of the storm event. The worst case flooding is then defined as the storm event plus the maximum turn out capacity within each basin.

2.8.4 NATURAL STREAMS

The natural stream channels throughout the basin provide the primary drainage mechanism to move water through the basin toward Ashley Creek. The natural channels vary from small depressions in the upper reaches of the basin to year round streams in the lower portions of the basin. Portions of the streams have been channelized as the basin developed. In places, the streams are routed through culverts or other structures. The minor culverts and ditch constructions were not accounted for in this macro-scale model. The larger structures such as major culverts, raised roadbeds or long sections of channelized stream were incorporated into the model. Figure 2-6 highlights the major natural stream channels throughout the basin.



Source: AGRC NAIP 2006 and Uintah County GIS.

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FIGURE 2-6
NATURAL STREAM CHANNELS
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008

Legend

- Natural Stream Channel
- Major Road
- Ridgeline/Watershed
- Municipal Boundary

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0 5,000 10,000 Feet

1 INCH = 5,000 FEET

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2.8.4.1 Ashley Creek Inflow

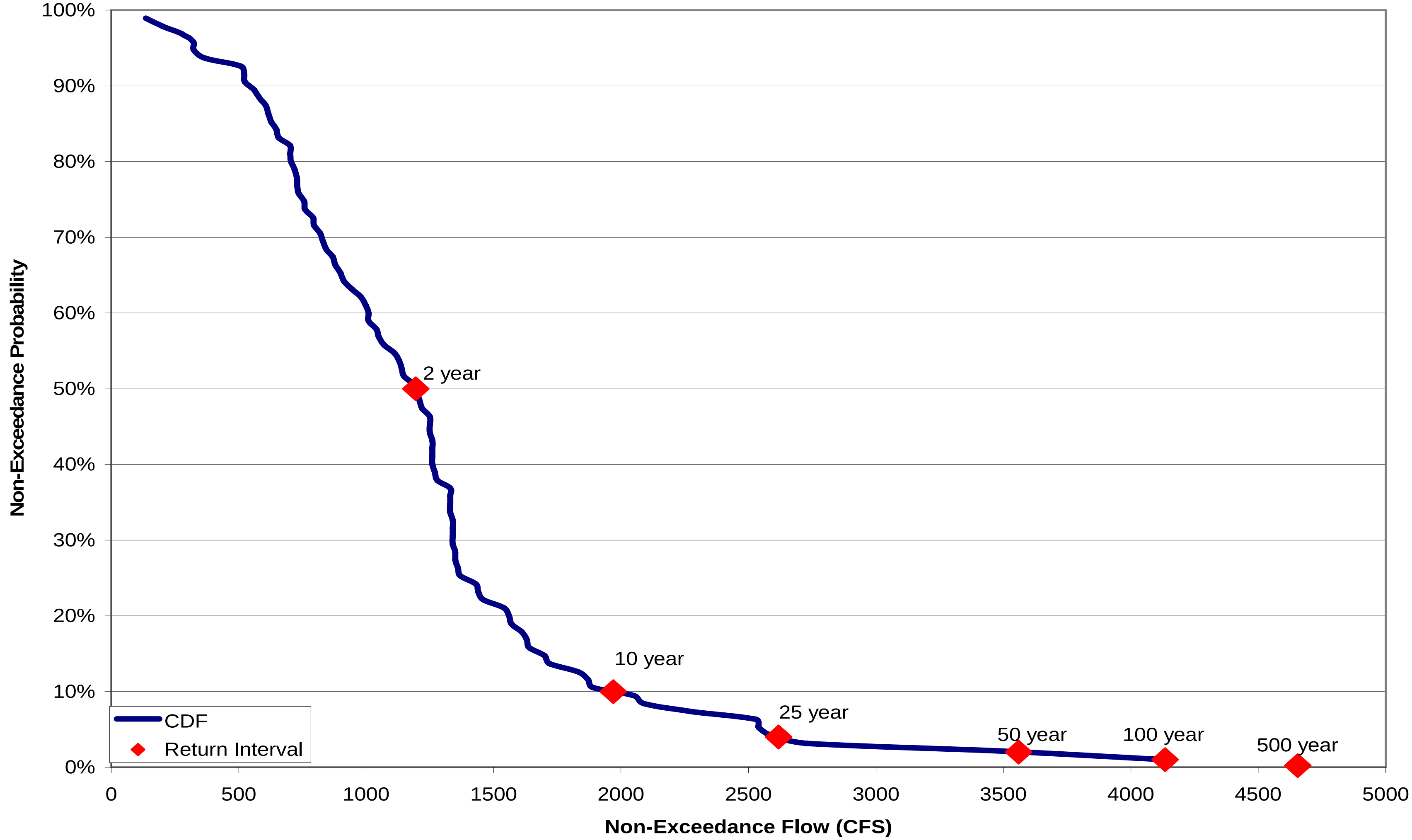
Similar to the irrigation turnouts, the inflow from Ashley Creek into the Valley is modeled as a steady state point flow. The inflow rate was established through statistical analysis of the recorded peak flows at the USGS gauging station (09266500) “sign of the main”. The record contains the annual peak flows for approximately 96 years which were used to produce a cumulative distribution curve (CDF) of the flow exceedance probability. Linear interpolation and extrapolation algorithms were then used to determine the peak inflow at the upper reaches of the Valley. The CDF curve is shown in Figure 2-7 and the inflow results for each storm intensity are shown in Table 2-3.

Table 2-3 Ashley Creek Inflow Rate Summary

Probability	Return Interval	CFS	Calculation
0.2%	500	4,655	Extrapolation
1.0%	100	4,134	Extrapolation
2.0%	50	3,560	Interpolation
4.0%	25	2,618	Interpolation
10.0%	10	1,970	Interpolation
50.0%	2	1,195	Interpolation

* Flows were extrapolated when insufficient data was available for interpolation

Figure 2-7 Upper Ashley Creek Non-Exceedance Probability Distribution Function



Chapter 3 STUDY AREA GROWTH

3.1 OVERVIEW

The Valley has been experiencing recent population growth. This growth is expected to continue through the next 50 years as the local economy continues to diversify and local oil production increases. Many portions of the Valley are developing to house and serve this increasing population. This section presents the historic population trends as well as the population projections based on the Utah Governors Office of Planning and Budgets 2005.

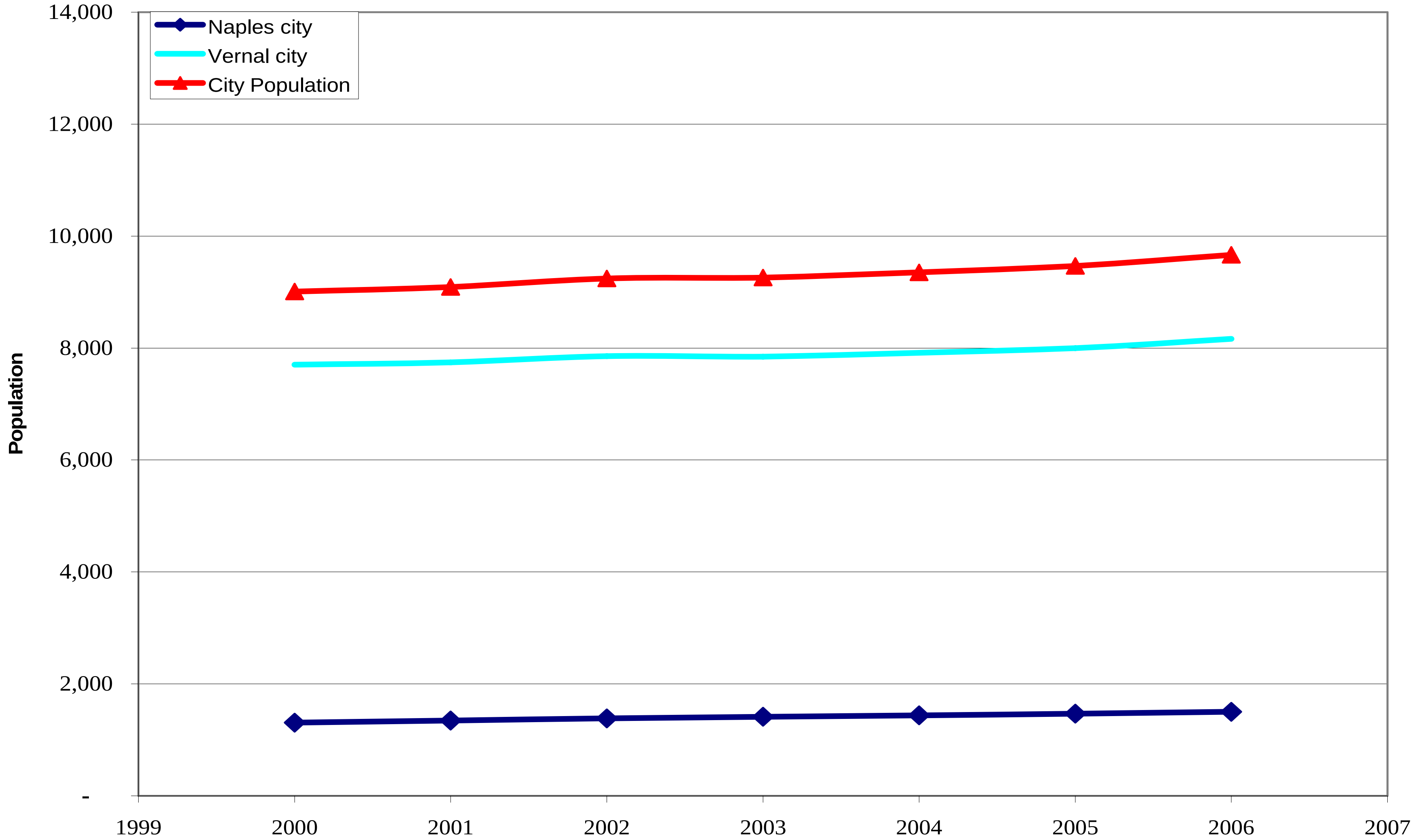
3.2 HISTORIC POPULATION TRENDS

The majority of the Valley's population resides within the cities of Vernal and Naples. Furthermore, the growth projections of the cities are likely indicative of the growth throughout the adjoining unincorporated areas of the Ashley Valley. The population within Vernal and Naples has grown by more then 500 people from 2000 to 2006 according to the State Governors office. Local officials indicate the growth rate has been much higher. Below, Table 3-2 presents the Governors population estimates for the cities of Vernal and Naples.

Table 3-1 Historic Population Growth

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Naples City	1300	1343	1384	1413	1439	1466	1502
Vernal City	7714	7746	7856	7845	7912	7999	8163
City Population	9014	9089	9240	9258	9351	9465	9665
Growth Rate %		0.9%	1.66%	0.19%	1.0%	1.22%	2.11%

Figure 3-1 Historic Population Trend



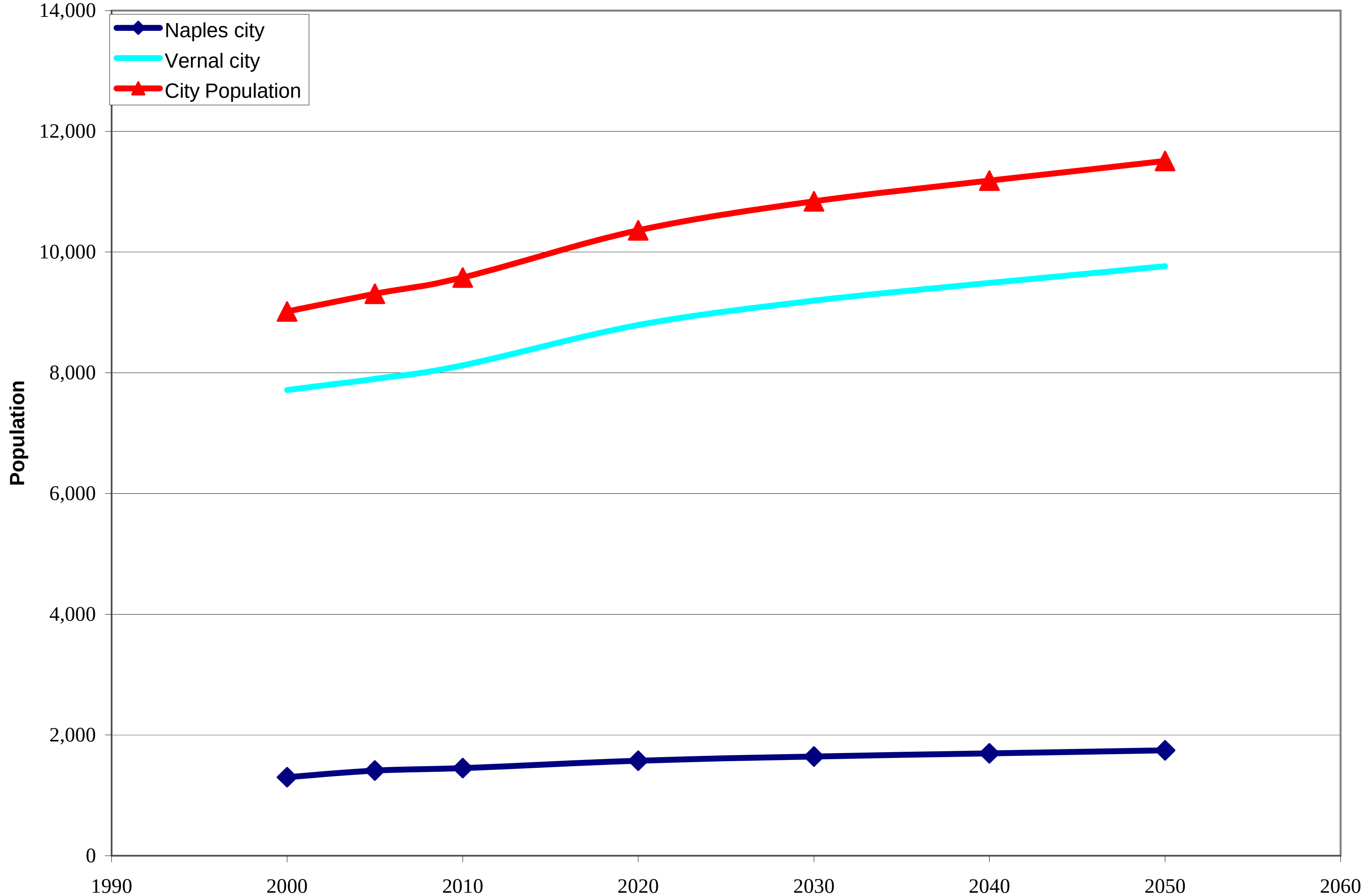
3.3 POPULATION GROWTH PROJECTIONS

Table 3-2 and Figure 3-2 below represent the population growth projections through the year 2050.

Table 3-2 Population Projections

	2010	2020	2030	2040	2050
Naples City	1,453	1,572	1,644	1,696	1,746
Vernal City	8,125	8,790	9,196	9,488	9,765
City Population	9,577	10,362	10,840	11,184	11,511
Growth Rate %	0.57%	0.79%	0.45%	0.31%	0.29%

Figure 3-2 Population Projections



3.4 AREAS OF FUTURE GROWTH

In order to provide for future population growth it is anticipated that the developed areas of the Valley will continue to expand into areas currently used for agricultural and other undeveloped purposes. As this development continues, the area available for storm water to infiltrate naturally will decrease, artificially increasing the magnitude of runoff during future events.
In order to model the future runoff potential throughout the basin, this report assumes that the current zoning map, shown in Figure 3-3, represents how the Valley will eventually be developed at build-out.

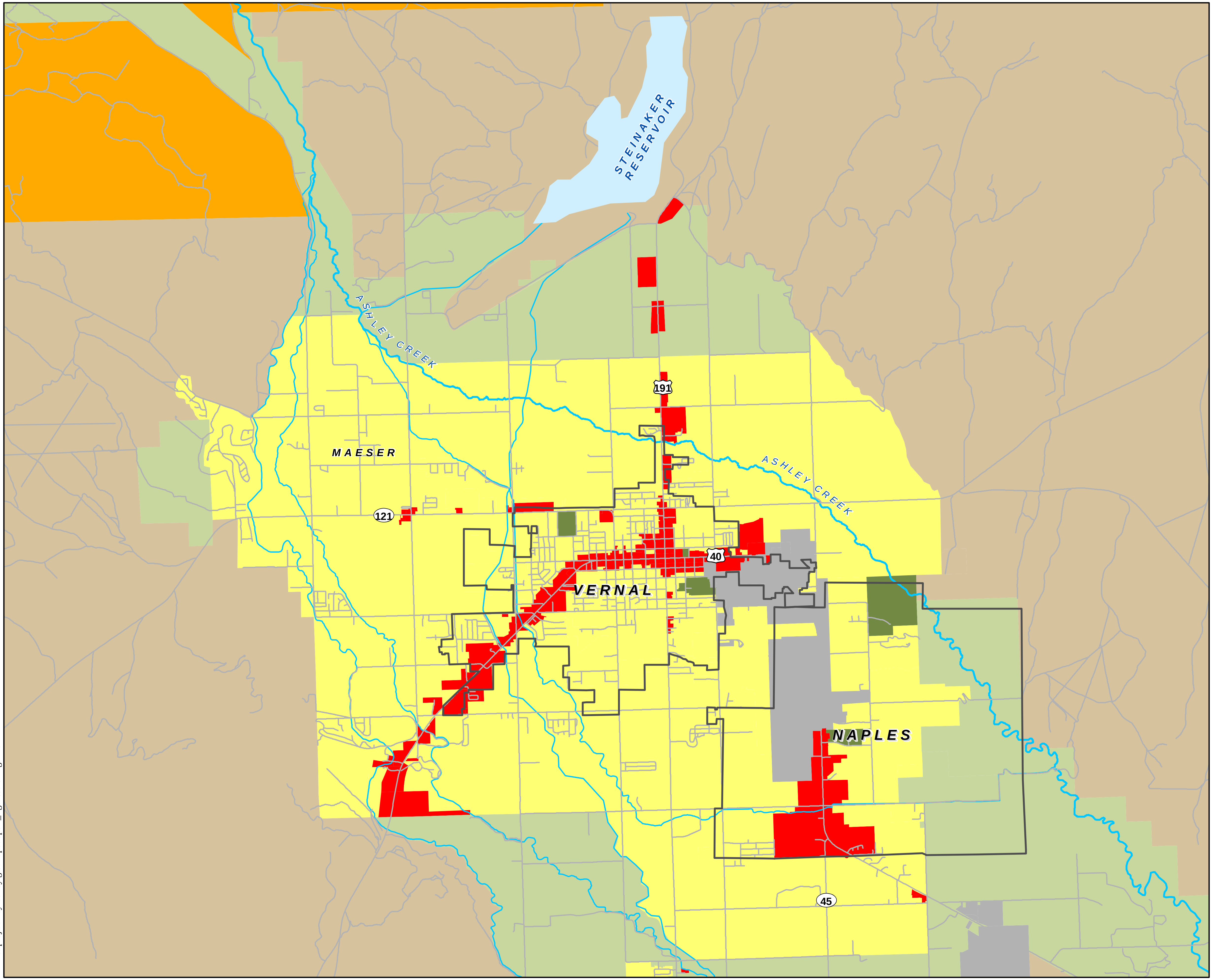


FIGURE 3-3
FUTURE LAND USE
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008

Legend

- Road
- Major River or Canal
- Municipal Boundary

Zoning

- Agricultural
- Commercial
- Industrial
- Mining & Grazing
- Park
- Recreation, Forestry & Mining
- Residential

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1 INCH = 5,000 FEET

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Source: AGRC NAIP 2006 and Uintah County GIS.

Chapter 4 STORM DRAINAGE MODELING METHODOLOGY

4.1 INTRODUCTION

The primary purpose of the storm water modeling is to develop criteria applicable to the design of the drainage facilities. This chapter discusses the modeling methods used and design criteria established to govern the modeling and establish the Level of Service (LOS) requirements for the existing and future build-out storm drain networks.

4.2 DESIGN CRITERIA

The following design criteria are used to complete the storm drain modeling:

1) The Level of Service for storm drain piping is to convey 110% of the 10-year storm event flows contributing to the pipe;

2) The Level of Service for irrigation ditches and artificial channels is to convey 100% of the 100-year event;

3) The Level of Service for natural channels is to convey 100% of the 100-year storm event;

4) The Level of Service for detention basins is to provide sufficient detention volume to contain the 100-year storm event with a peak outflow of less then pre-development levels;

5) The slope of the pipes is generally assumed to not be steeper than the slope of the ground surface above the pipe;

6) All closed conduit pipes are assumed to have a friction coefficient of 0.013;

7) Natural channels are initially assumed to have a friction coefficient of 0.035. During the calibration process, open channel friction coefficients may be adjusted to match field data;

8) Artificial channels are initially assumed to have a friction coefficient of 0.03.

4.3 HYDROLOGY MODEL

Given a number of parameters, the hydrology model predicts the volume of flow generated at any point in the watershed from the defined rainfall event. For this study, the soil conservation service (SCS) methods were selected to estimate the potential runoff. The SCS method is a series of empirical equations that were originally designed to compute the potential runoff from agricultural fields and other rural environments with similar characteristics to the Valley. This method has since been modified for use in both urban and rural settings and is the most effective method to estimate runoff from the drainage basins within the Valley.

The precipitation events of concern in this study are the extreme runoff events usually caused by cloudburst type storms that are characterized by short periods of high intensity rainfall. The SCS type II 24-hour storm distribution most closely reflects this type of event and is used to simulate the rainfall distribution within the model. Runoff from the drainage basins is computed using the SCS equation shown below and the runoff hydrograph. Peak discharge is estimated using simulated curvilinear hydrographs defined by the SCS TR-55 method. These methods account for the soil type, ground cover, ground slope, time of travel, and other parameters to accurately estimate the discharge hydrograph from each of the basins within the model.

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

Where:
Q = Runoff depth (inches)
P = Precipitation (inches)
Ia = Initial abstraction
S = Storage or maximum retention

The discharge hydrographs from each of the basins are routed in the model to the lowest point in the basin, or the outlet node. The outlet nodes are then connected via hydraulic links which route the flow through the system to the bottom of the Valley drainage area.

4.4 HYDRAULIC MODELS

Each of the watershed discharge nodes are connected via hydraulic links. These links are pipes, ditches or natural channels. The depth of flow in each of the hydraulic links is calculated using Manning's equations for open channel flow shown below.

$$Q = \frac{1.49}{N} * A * \left(\frac{A}{P}\right)^{2/3} * S^{1/2}$$

Where:
Q = Flow in cubic feet per second
N = Friction coefficient
A = Area of flow
P = Wetted perimeter
S = Slope

The wetted perimeter and area of the natural channels are based on irregular channel shapes and cross-sections that are typical of those at the hydraulic link, or outlet node, location. The channel cross-sections are assumed to be uniform throughout the length of each hydraulic segment, and are typically modeled as trapezoidal channel sections.

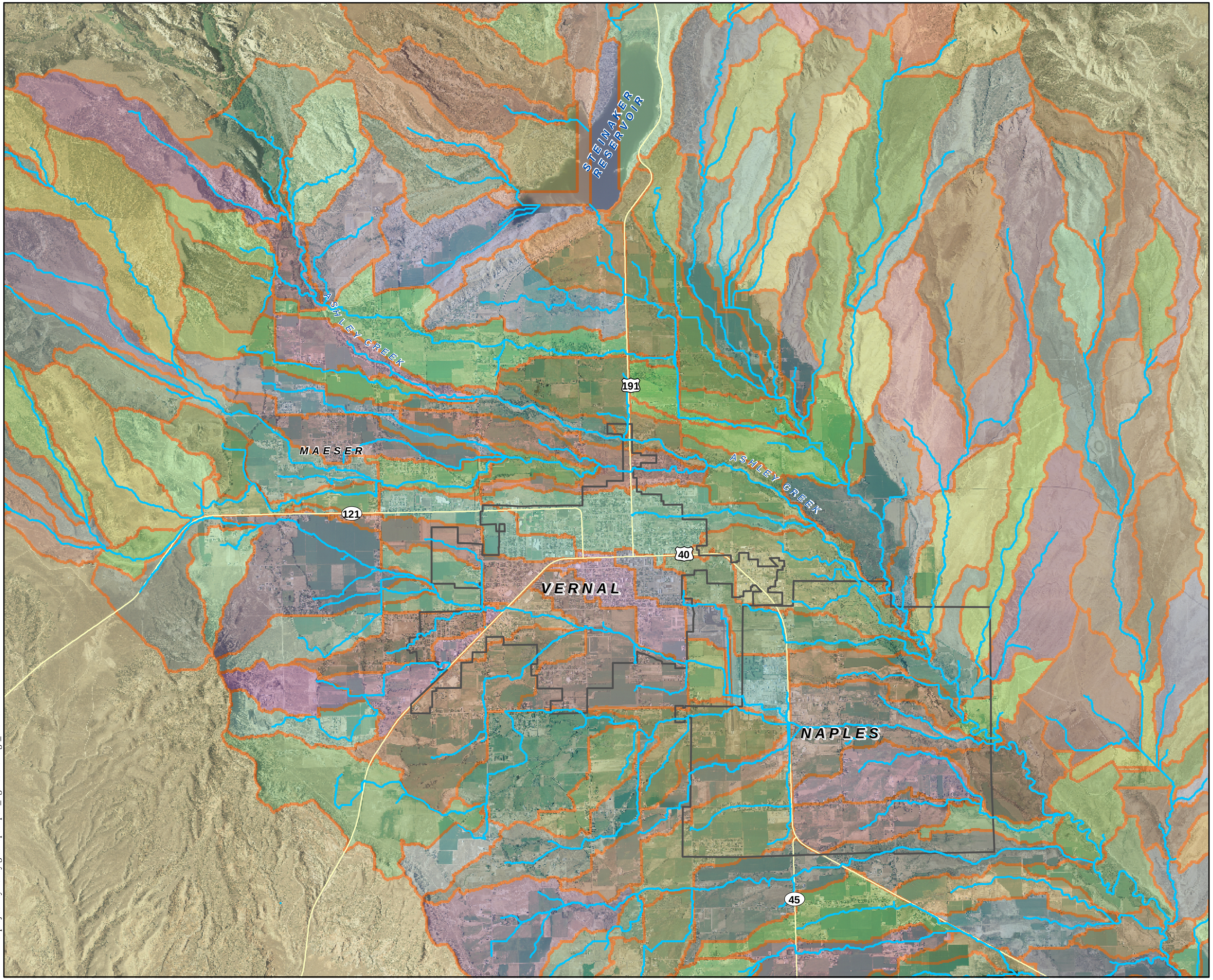
Detention basins are also incorporated into the model to simulate the effect of the basins on the hydraulic routing. Inflow to the ponds is based on the routed basin discharge hydrographs. The outflow is based on the outlet structure type and depth in the pond. A series of time steps are used to calculate the flow differential through the pond to estimate the storage during the rainfall event.

4.5 MODEL IMPLEMENTATION

To reasonable model an area the size of the Valley while requires a large number of individual drainage basins to be identified. For the purpose of this study 200 drainages were defined throughout the Valley. The defined basins are shown in Figure 4-1. The basins vary in size from 100 acres to 1,470 acres with an average size of 490 acres. The flow path lengths of the basins vary from 1.3 to 32 miles in length with an average flow path of 5.9 miles. Modeling storm water runoff from 200 basins through a complex system of pipes, canals, streams, and ponds would be extremely difficult without the use of computer-based modeling software. The first step in creating a model is to calculate all of the input parameters that will be used to determine end results and evaluate various scenarios. A Geographic Information System (GIS) is best suited to accurately calculate all of the necessary input parameters for a model as large as the Valley. ESRI's ArcView^{tm} 9.2 software program was utilized to delineate the drainage basins from a highly accurate digital elevation model, and process the numerous variables discussed above.

FIGURE 4-1
DRAINAGE BASINS
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008



Source: AGRC NAIP 2006 and Uintah County GIS.

Legend

Major Road

Stream Channel

Municipal Boundary

Drainage Basin

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1 INCH = 5,000 FEET

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Once these parameters were calculated, a storm and sanitary sewer modeling program called SewerGEMS^{tm} Version 8 was utilized to model the storm water runoff and routing throughout the Valley. SewerGEMS^{tm} was selected for several reasons, including its ability to (1) fully integrate with the GIS model, and (2) to provide calculation engines for runoff, open channel flow, pipe flow, and detention basin routing. Combining ArcView GIS software with the SewerGEMS modeling package results in an integrated, accurate, numerically robust model that can be efficiently updated to reflect future changing conditions as needed.

The first step in developing the model is to assemble a GIS database containing the relevant data, including: topography, soil type, land use, vegetation, hydrographic and other base map features. From the detailed topography, a series of drainage basins were developed. These basins were then verified through field observations and finalized through manual data entry. Next the soil type, land use, and vegetation layers were queried to determine a runoff coefficient for each of the defined basins, along with the average slope, flow path length and other critical information necessary for the hydrology model.

The information from the GIS is then compiled into the SewerGEMS model and the storm water runoff hydrograph for each basin is computed. Within the model, each basin was linked via stream channels or pipe segments to route the hydrographs through the system. To accurately model the natural stream channels “irregular cross sections” were selected as the channel type. Typical cross sections for the natural channels were entered manually from the detailed GIS data at key points in the system. The irrigation canals and other major ditches were modeled as “trapezoidal channels.” Detention facilities were inserted and modeled as part of the system where detention basins were known to exist and along wide portions of the natural streams to simulate the natural stream attenuation processes.

Once the model for the existing system was completed and calibrated, the results were queried to determine the maximum depth and peak flow in each channel segment. Segments that appear as over capacity are flagged as potential problems. Various alternatives are then modeled to find potential solutions to any existing problems identified by the initial model.

Once the existing system is considered satisfactory, the GIS data is reprocessed to calculate new runoff coefficients (CN values) based on the future land use types. These future values are used to produce future basin hydrographs which are then routed through the system. Problem areas and high water lines are recorded. Necessary improvements are made within the model until the system components are operating at their respective LOS discussed in the previous chapter.

Chapter 5 EXISTING STORM DRAINAGE SYSTEM ANALYSIS

5.1 STORM WATER MODEL

The majority of the storm drain network for the existing model consisted of 155 natural stream channels, 200 drainage basins and 4 point inflows to represent irrigation and basin inflows. The storm water model is considered a "trunkline model" whereby the major storm water conveyance channels are modeled on a macro scale that does not require precise input of every minor collector, roadway and catch basin. This type of model is able to accurately determine major drainage issues and aid in planning purposes without incurring the cost associated with an overly detailed analysis. Major drainages that are flagged as potential problems can then be analyzed individually on a more detailed level. Irrigation canals were assumed to be full at the beginning of the rainfall event and therefore unable to convey storm water. Based on discussions with the major irrigation canal companies, a series of turnout gates are typically opened when heavy rains occur in an effort to minimize canal over topping. The locations of the major turnouts have been included in the model to simulate the full effects of the storm plus the flow from the irrigation canal diversions. The typical inflow from Ashley Creek during large storm events was also simulated to ensure the worst case flooding was evaluated.

5.1.1 SIMULATED CONDITIONS

This section describes the conditions which were simulated to approximate a 10-, 25-, 50-, 100- and 500-year flood event throughout the entire Valley using assumptions that are both realistic and conservative.

5.1.1.1 Drainage Basins

As noted in previous sections, the Valley has been divided into 200 individual drainage areas. In order to accurately estimate the timing and magnitude of storm water runoff, knowledge of the longest length of flow, slope, soil group, land use, and vegetation parameters for each basin are required. These parameters were determined through a series of advanced queries within the GIS database.

These data were then used to calculate the time to concentration (Tc) and curve number (CN) values. Tc is a measure of the length of time that is required for a rain drop that lands on the highest point within a drainage basin to reach the outlet. CN values effectively determine what percentage of the total rainfall will contribute to runoff, and what component will infiltrate into the soil. Higher values of CN indicate basins with higher runoff potential. The methods used to calculate these parameters are described below.

Time to Concentration Calculations

The time to concentration Tc is a measure of the time required for a water droplet that is released at the upper most point of a basin to travel to the outlet of the basin. The Tc for each basin determines the magnitude and outflow hydrograph for each basin. For this report, Tc is calculated as the sum of the following three components: overland flow, channel flow, and stream flow. The overland flow component of Tc (Tc1) is used for the first portion of the drainage where the water is flowing across open fields. Tc1 is calculated using the USBR modified Kirpich equation shown below.

$$Tc1 = 11.8 * L^2 / S^{0.385}$$

Where: L is the length of the longest flow path or the maximum allowed overland flow length
S is the average slope of the flow path
Tc1 is the time of flow in hours

The channel and stream flow components Tc2 and Tc3, respectively, are calculated using the Chezy channel flow equation.

$$Tc2 = L/15 * S^{0.5}$$

$$Tc3 = L/25 * S^{0.5}$$

Where: L is the length of the stream or channel flow component
Tc2 and Tc3 are time of flow in seconds

After modifying the units, the sum of the Tcs were calculated to determine the basin’s Tc value. The maximum length of the overland flow and channel flow were determined as part of the calibration process. A maximum overland flow length of 1,500 ft and a maximum channel length of 74,000 feet were selected as parameters that resulted in the best calibrated model.

Curve Number Calculations

Curve numbers (CN) are empirically determined values that represent the fraction of rainfall that contributes to runoff. Higher CN values indicate greater runoff potential. The Soil Conservation Service has determined CN values for a wide variety of soil conditions. The CN values used in this report are shown in Table 5-1. Well vegetated areas were assumed over most of the Valley floor and poorly vegetated values were assumed on the slopes surrounding the Valley. Curve numbers were also increased where large portions of the basins were already developed.

Table 5-1 Existing Curve Numbers

Soil Type	Well vegetated	Poorly vegetated
A	68	39
B	61	79
C	74	86
D	80	89

The time to concentration calculations and the curve number ranges are presented in Table 5-2 below. Complete lists of the parameters for each basin are included in the appendix.

Table 5-2 Summary of Drainage Basin Input Parameters

	Area (acres)	Tc (hours)	CN
Min	102	2.8	65
Average	491	11.7	84
Max	1473	51.7	89
SD	264	12.7	5

5.1.1.2 Stream Channels

The stream channels in the model connect the basin outlet points to simulate storm water moving through the Valley. To accurately represent the flow width, depth, and velocity, an irregular cross-section for each segment was input. The model then used Manning's equation along with stream routing algorithms to calculate the flow rate at each segment over time. The model also determines the flow depth, width and other critical parameters used in determining stability and flooding concerns.

5.1.2 CALIBRATION

A key part of any complex storm water model is to verify that the simulated results match actual historic flows in the major stream channels. After the initial model simulations, the input parameters of time to concentration and Manning's n values are adjusted such that the simulated results better reflect the field data.

The basin contains a series of stream gauges on Ashley Creek and many of the tributary drainages. All of the stream gauge data were used in the calibration process, however, the irrigation channels often divert all or a large portion of the storm flows away from key drainages, thereby artificially decreasing the flow. In the model it is assumed that the irrigation channels are full prior to the rainfall event and therefore do not have capacity to carry storm water. The discrepancy between what has historically occurred throughout the basin and the model assumptions complicated the calibration process on the tributary stream level. The simulated flows generally exceed the recorded flows on the tributary streams; these results are expected given the conservative modeling assumptions. Table 5-3 indicates the USGS stations within the Valley along with peak flow and type of information available. The locations of the Stream Gauges are shown in Figure 5-1.

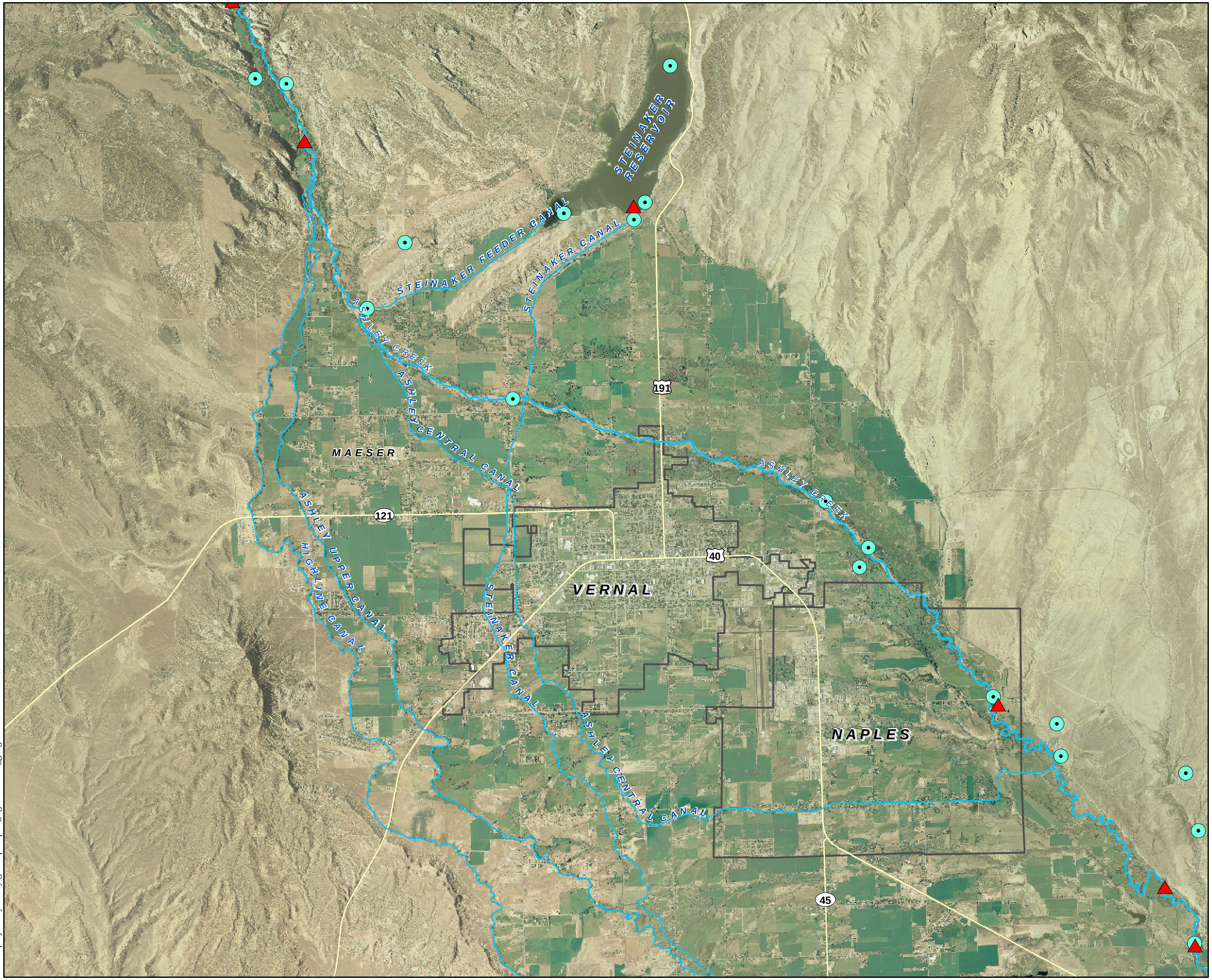

FIGURE 5-1
STREAM GAUGING STATION LOCATIONS
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008

Legend

- USGS Stream Gauges
- DWQ Stream Gauges
- Major Road
- Major River or Canal
- Municipal Boundary

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0 5,000 10,000 Feet

1 INCH = 5,000 FEET

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Source: AGRC NAIP 2006 and Uintah County GIS.

Table 5-3 Ashley Valley Stream Gauges

Location				Peak Flow		Record Length		
Site Number	Site Name	Lat	Long	Date	CFS	To	From	Years
9235600	POT CREEK ABOVE DIVERSIONS, NEAR VERNAL, UTAH	40°46'05"	109°19'06	May 10, 1973	286	1958	1993	35
9261500	BIG BRUSH CREEK (AB CAVE) NR VERNAL, UTAH	40°42'15	109°35'45"			1947	1955	8
9261700	BIG BRUSH CRK ABV RED FLEET RES, NR VERNAL, UT	40°35'20"	109°27'53"	May 22, 2005	423	1980	2006	26
9262000	BIG BRUSH CREEK NEAR VERNAL,UTAH	40°34'54"	109°26'03"	July 12, 1962	543	1940	1979	39
9262500	LT BRUSH CR BL E PK RES NR VERNAL UT	40°45'30"	109°32'00"			1950	1955	5
9263000	LITTLE BRUSH CREEK NR VERNAL, UT	40°42'58"	109°30'18"	May 30, 1950	608	1946	1952	6
9264000	ASHLEY C BELOW TROUT C NR VERNAL, UTAH	40°44'00"	109°40'40"	May 19, 1948	630	1944	1954	10
9264500	SOUTH FORK ASHLEY C NR VERNAL, UTAH	40°44'00"	109°42'10"	June 18, 1949	460	1944	1955	11
9265000	OAKS PARK CANAL NEAR VERNAL, UTAH	40°44'36"	109°37'18"			1946	1959	13
9265300	ASHLEY CREEK ABOVE RED PINE CREEK NR VERNAL, UT	40°40'47"	109°39'37"	June 10, 1965	7,400	1965	1975	10
9265500	ASHLEY CR ABV SP NR VERNAL UT	40°35'20"	109°37'20"			1941	1945	4
9266000	ASHLEY CR SPRING NR VERNAL UT	40°35'10"	109°37'20"			1943	1955	12
9266500	ASHLEY CREEK NEAR VERNAL, UT	40°34'39"	109°37'17"	June 15, 1995	4,100	1914	2006	92
9267100	ASHLEY CREEK ABOVE DRY FORK, NR VERNAL, UTAH	40°32'16"	109°36'33"	May 20, 1970	920	1969	1972	3
9271000	ASHLEY C, SIGN OF THE MAINE, NR VERNAL, UTAH	40°31'02"	109°35'45"	June 11, 1965	4,110	1939	1965	26
9271400	ASHLEY CREEK NEAR NAPLES, UT	40°26'01"	109°27'56"			2000	2003	3
9271450	ASHLEY CREEK BL SADLIER DRAW, NEAR NAPLES, UT	40°23'53"	109°25'44"			1999	2003	4

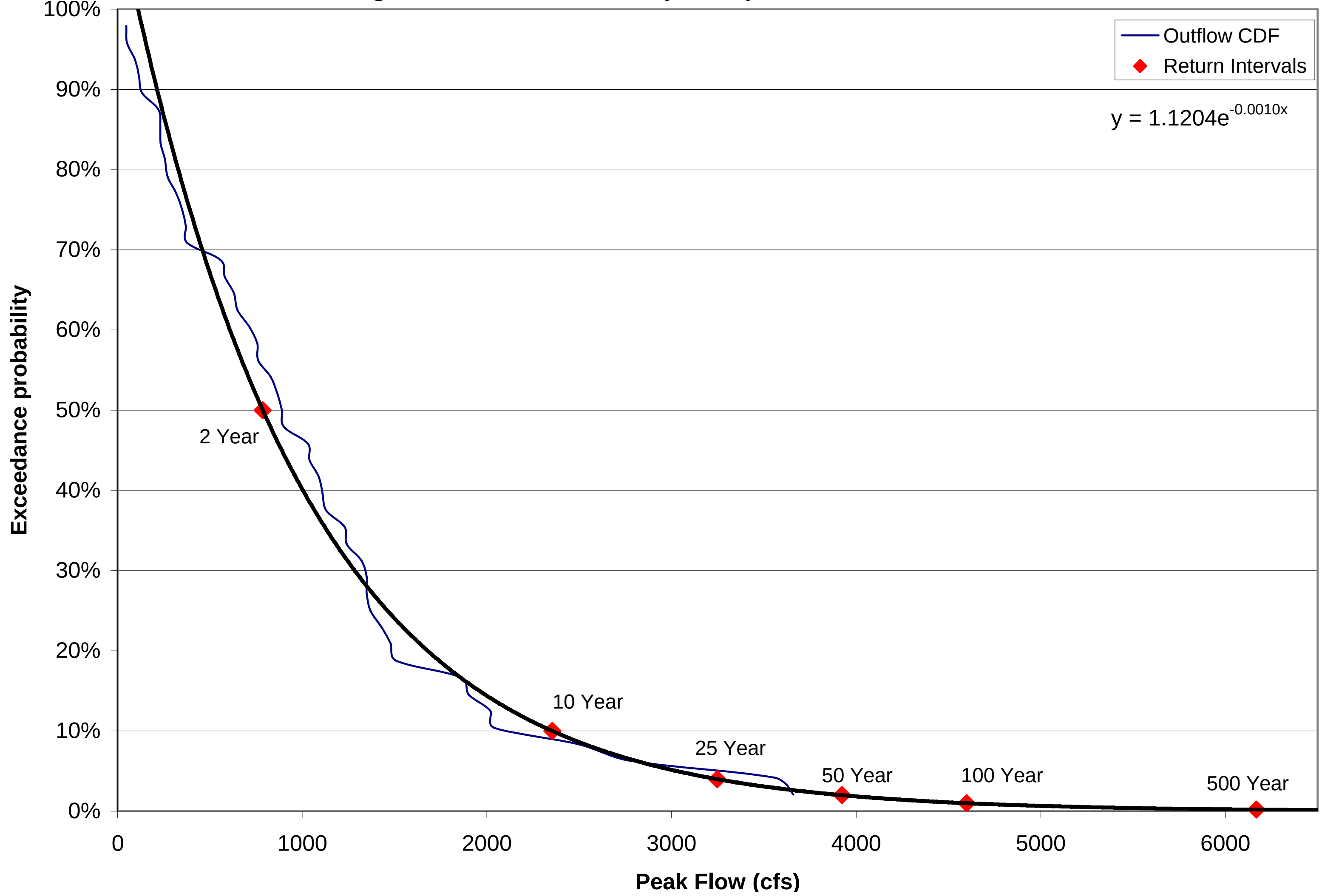
While the tributary stream gauging stations were able to provide only a qualitative calibration, a series of stream gauges along Ashley Creek were also analyzed to determine the total outflow from the basin. Evaluating the entire basin outflow provides a macro scale calibration of the model. The peak flow statistics from USGS stream gauge 9271500 (Ashley Creek near Jensen, Utah) is located below the study area and has recorded peak flows from approximately 1946 to 1983. This data was used to produce the cumulative distribution curve presented in Figure 5-2. The cumulative distribution curve is then used to statistically determine the 10-, 25-, 50-, 100- and 500-year historic flows. These flood flows are then compared to the simulated peak outflows and the model parameters adjusted through the calibration process. Statistically determined outflows as well as the calibrated model outflows are presented in Table 5-4.

Table 5-4 Outflow Calibration

		Stream Gauge Data	Valley Generated Flow (canals full)	Difference	% diff
Probability	Return Interval	CFS	CFS	CFS	
0.2%	500	6167	11,824	5,657	48%
1.0%	100	4599	7,697	3,098	40%
2.0%	50	3923	6,314	2,391	38%
4.0%	25	3248	4,924	1,676	34%
10.0%	10	2355	3,414	1,059	31%

The results of the peak flow analysis indicate that the model produces similar, but slightly elevated flows during the 10- and 25-year events. The elevated simulated peak flows are expected for two reasons. First, the model assumptions do not allow storm water to be routed through the irrigation canals. The irrigation canals increase the time to concentration and thereby artificially reduce the peak flows. Second, the tributary stream gauging data indicate that most storms affect only a portion of the Valley. The model simulates a basin-wide storm event. The basin-wide storm should produce elevated levels in Ashley Creek as all of the tributaries are contributing flow at the same time. Basin-wide storm events will result in less conformity to the statistical flows during large events, which is consistent with the calibration results presented in Table 5-4. By adjusting the Time to Concentration and Manning's n values, the model is adequately calibrated and appears to be producing conservatively realistic flows under the simulated conditions.

Figure 5-2 Estimated Ashley Valley Outflow Peak Values



5.2 EXISTING MODEL FINDINGS

The following section presents the results of the modeling analysis described above. The peak flow rates from the 10-, 25-, 50-, 100- and 500-year flows are presented. Based on these calculated flows, the following parameters were identified: the capacity of the major culverts in the area, channel stability under flood conditions, and developed areas that may become inundated. The predicted flood flows throughout the Valley are shown in Figure 5-3, Figure 5-4, Figure 5-5, Figure 5-6, and Figure 5-7 for the 10-, 25-, 50-, 100- and 500-year storm events, respectively. In general, the modeling indicates that the majority of the Valley will be able to transport storm water flows that are likely to result from storms up to the 100-year event. The 500-year storm is modeled for comparison considerations. However, it is generally not economically viable to construct storm water protection above the 100-year event except for the most critical structures. The modeling also indicated a number of potential concerns where flooding is likely to occur. These potential concerns are discussed in detail in the following sections.

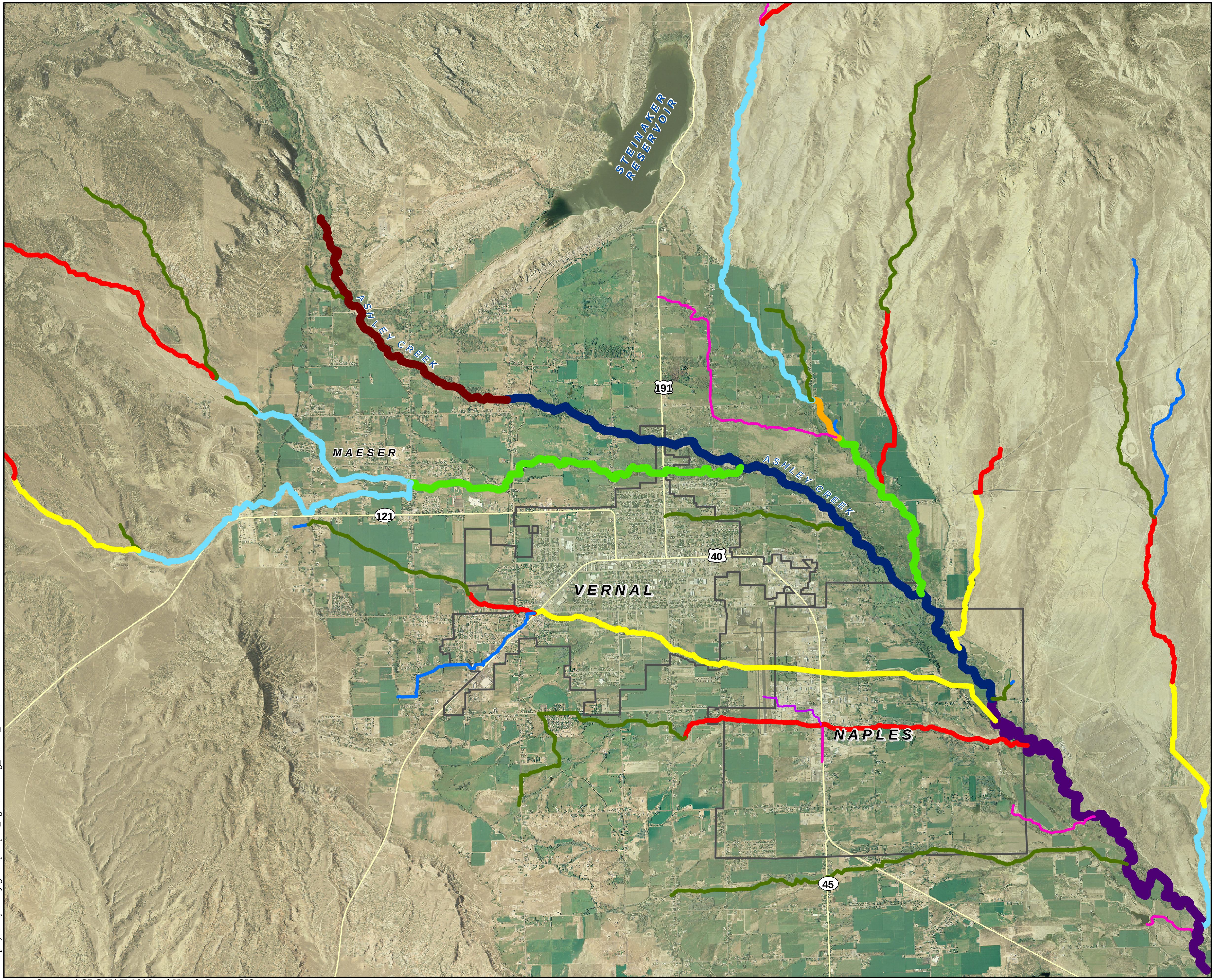


FIGURE 5-3
ESTIMATED EXISTING 10-YEAR CHANNEL FLOWS ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008

Legend

Major Road

Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

N W E S

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1 INCH = 5,000 FEET

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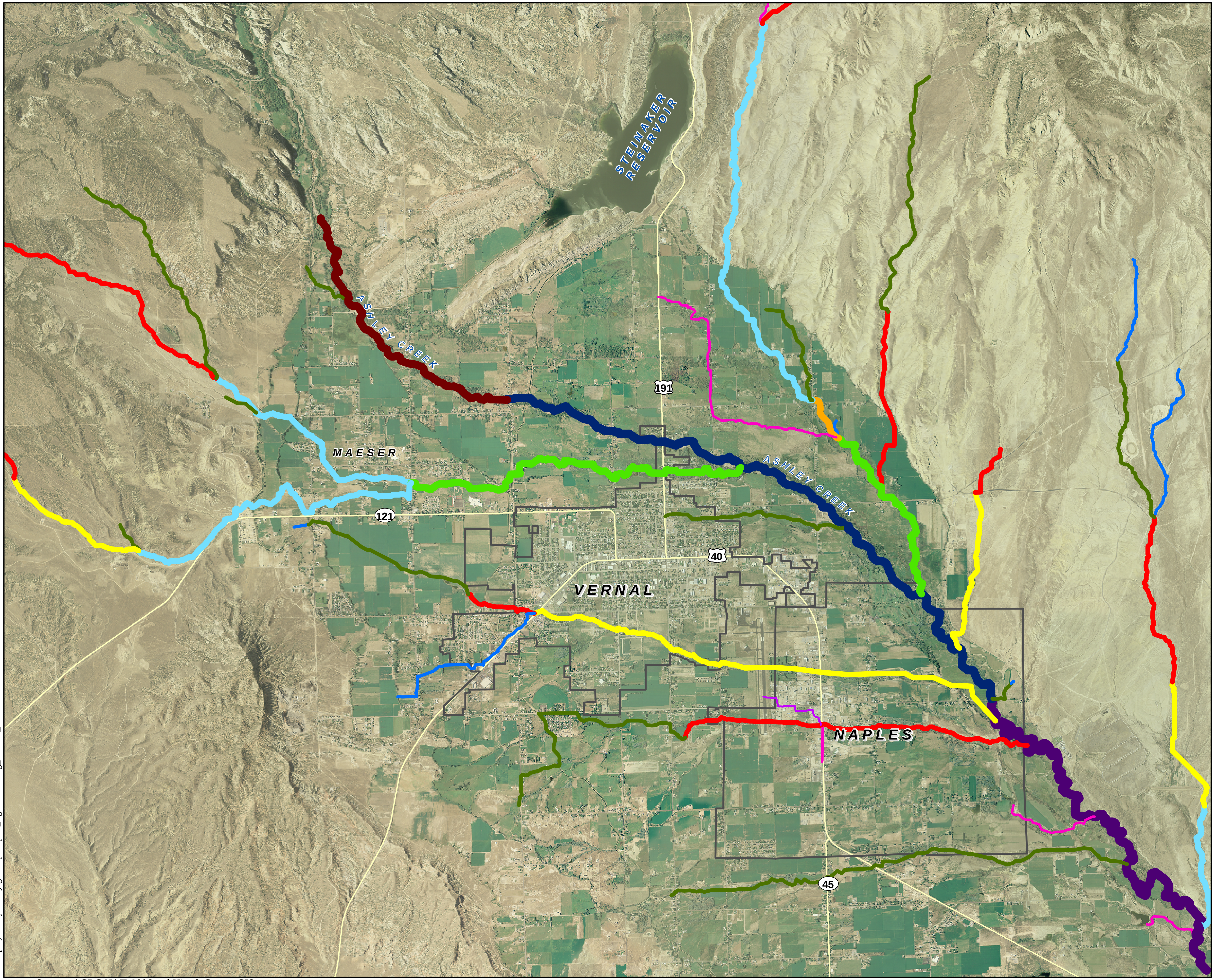
(435) 654-6600

s:\proj\ashley-valley\gis\maps\report_figures\existing_channel_flows.mxd

Source: AGRC NAIP 2006 and Uintah County GIS.



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Source: AGRC NAIP 2006 and Uintah County GIS.

FIGURE 5-4
ESTIMATED EXISTING 25-YEAR CHANNEL FLOWS ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008

Legend

Major Road

Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

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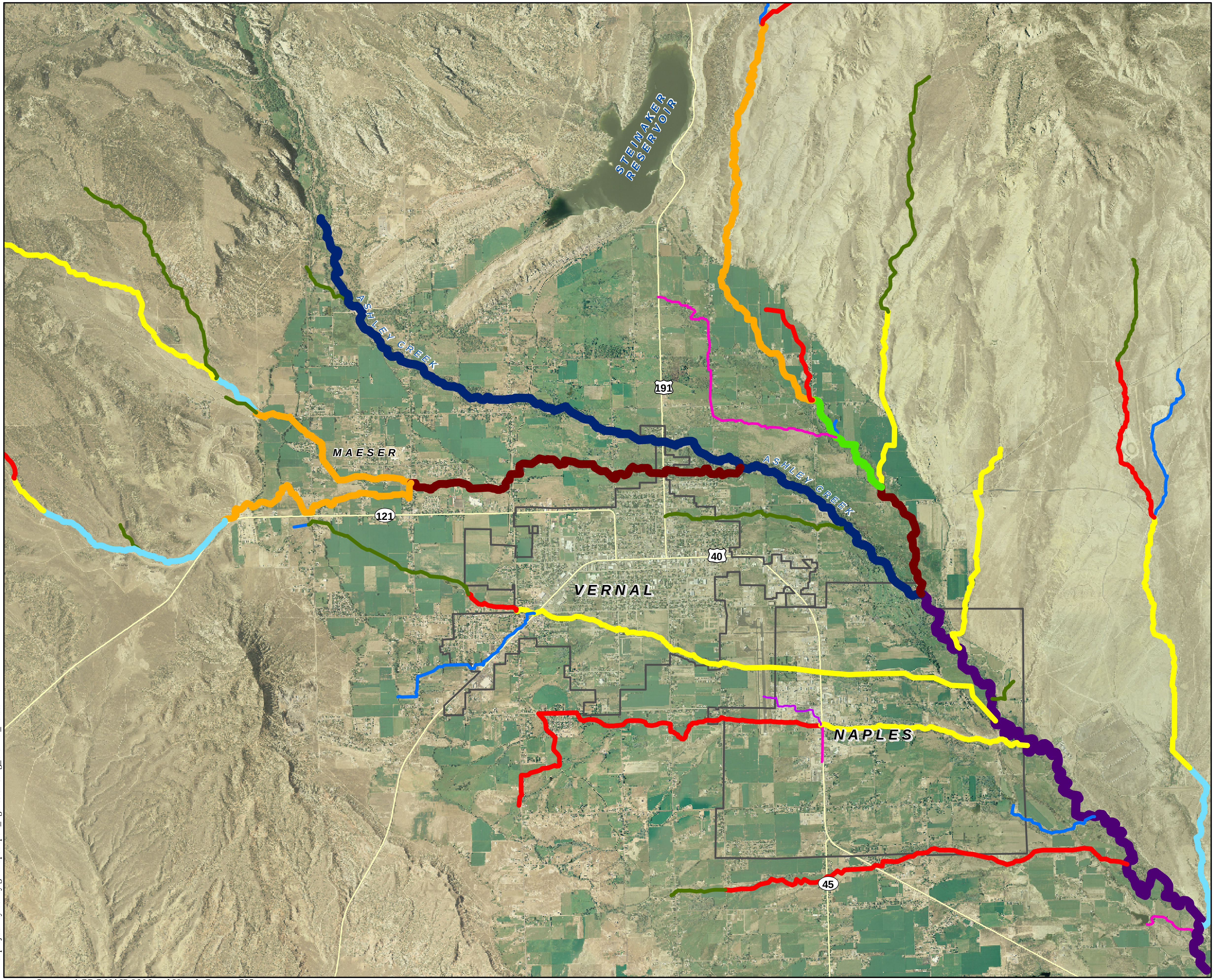
FIGURE 5-5
ESTIMATED EXISTING 50-YEAR CHANNEL FLOWS
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008



Legend

- Major Road
- Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

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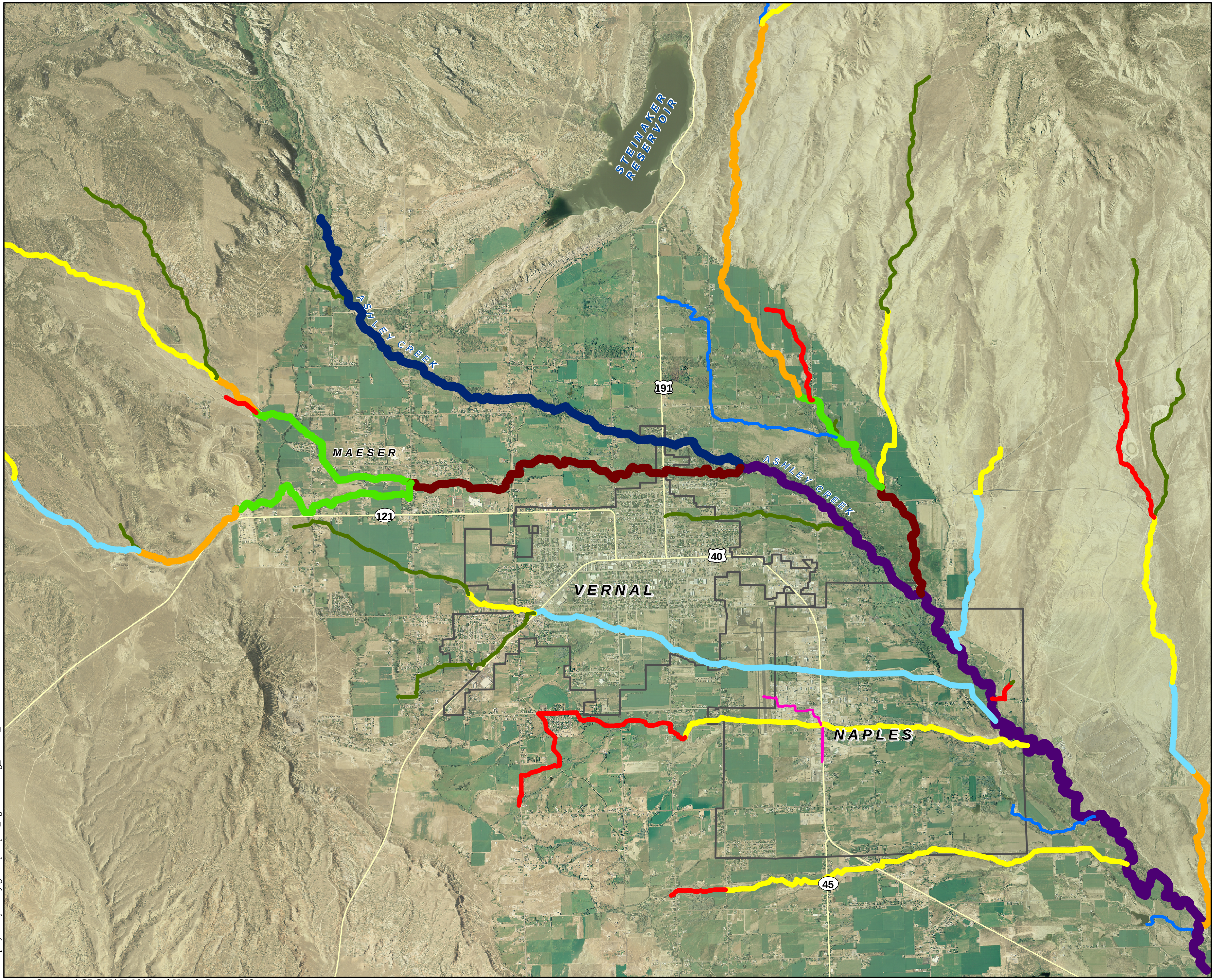
Source: AGRC NAIP 2006 and Uintah County GIS.

s:\proj\ashley-valley\gis\maps\report_figures\existing_channel_flows.mxd

FIGURE 5-6
ESTIMATED EXISTING 100-YEAR CHANNEL FLOWS ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008



Legend

Major Road

Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

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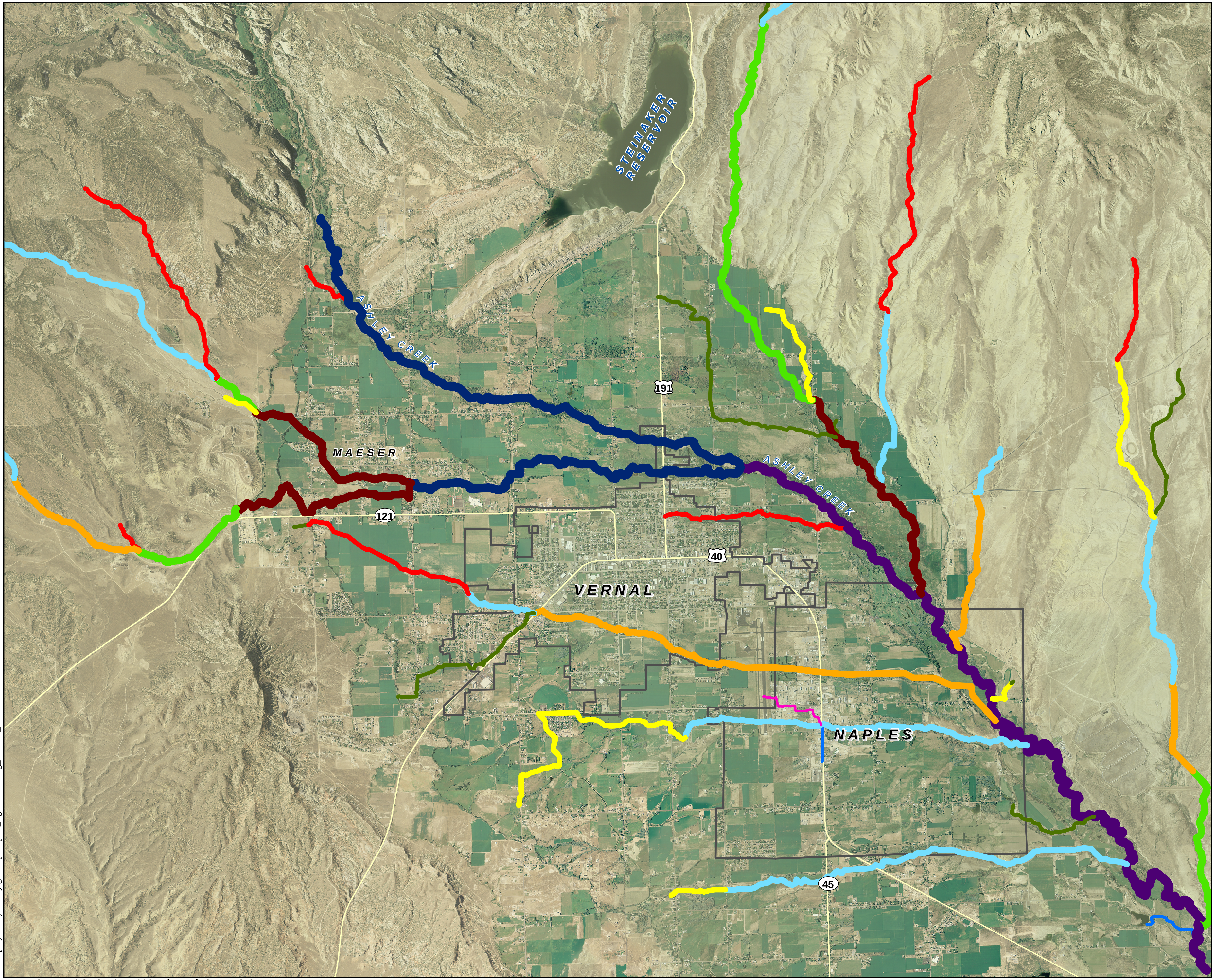
Source: AGRC NAIP 2006 and Uintah County GIS.

FIGURE 5-7
ESTIMATED EXISTING 500-YEAR CHANNEL FLOWS ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008



Legend

- Major Road
- Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

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Source: AGRC NAIP 2006 and Uintah County GIS.

5.2.1 Major Culvert Analysis

In an effort evaluate the general condition of the culvert crossings throughout the Valley, seventeen (17) culverts were selected for analysis in areas where the modeling predicted relatively high flows and the culverts appeared to be relatively small. Of the 17 culverts that were analyzed, 14 culverts were determined to have insufficient capacity to convey the 10-year event, 15 culverts will become overwhelmed in a 25-year event, and a total of 16 culverts are insufficient to prevent flooding during a 50-year event. Based on discussions with Naples, Vernal City and Uintah County personnel, ***it is recommended that all culverts be designed to capacitate the 25-year event at a minimum and that culverts under critical roadways be designed for a minimum of the 50-year event.*** The results of the culvert analyses are presented in Table 5-5. Flows and approximate recommended sizing for the major culverts throughout the Valley are identified later in this report.

Table 5-5 Culvert Capacities

		Simulated Flows (cfs)		
Culvert	Current Capacity	10 year	25 year	50 year
A	584	500	704	893
B	549	14	22	29
C	16	67	100	128
D	41	67	100	128
E	27	162	248	326
F	45	162	248	326
G	133	162	248	326
H	31	167	256	335
I	26	31	49	66
J	38	80	120	157
K	26	80	120	157
L	30	89	138	185
M	540	341	503	658
N	160	341	503	658
O	44	68	80	92
P	38	68	80	92
Q	27	68	80	92

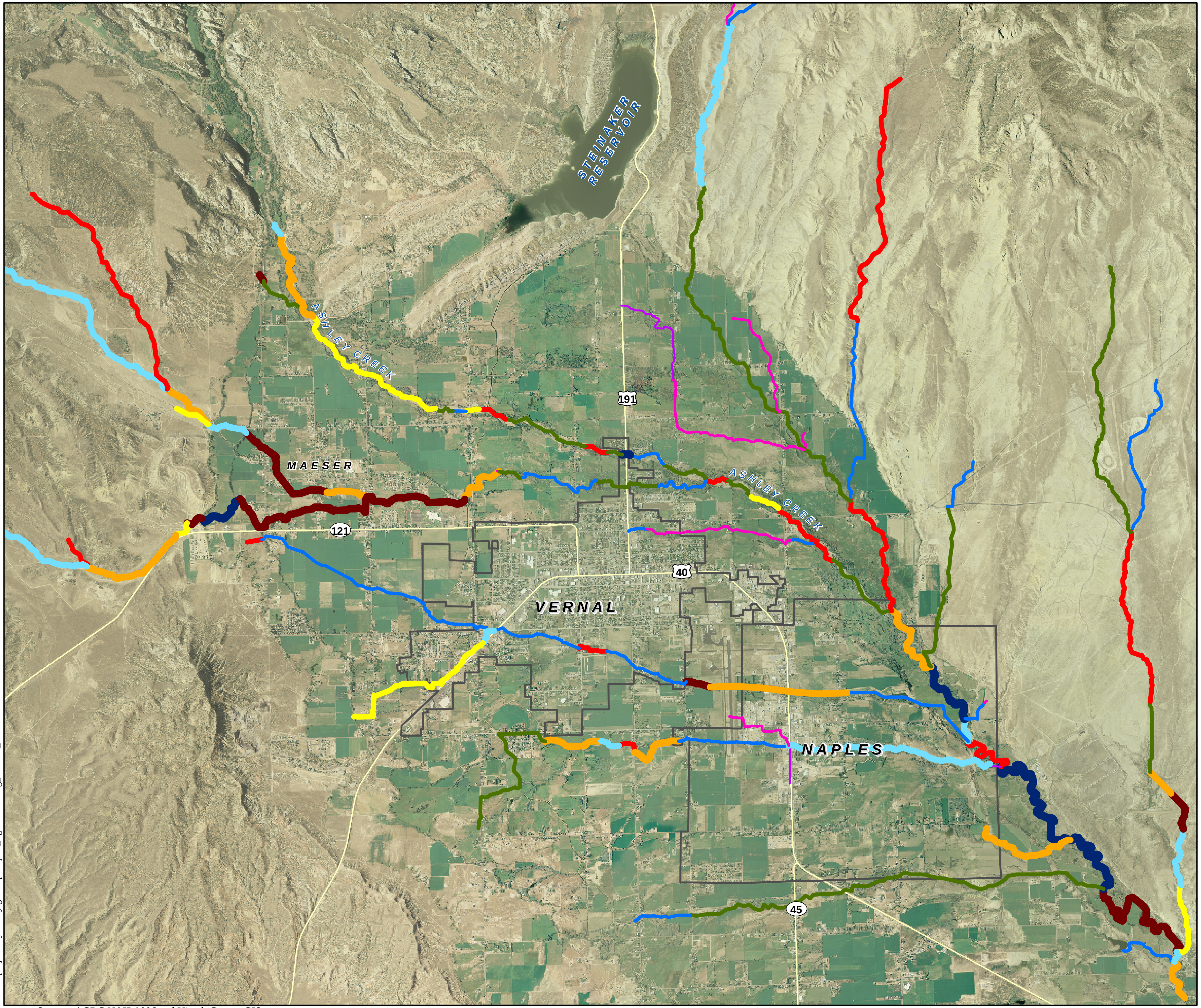
*Yellow cells denote simulated flows in excess of the culvert capacity
*Orange cells denote simulated flows in excess of 2x the culvert capacity

5.2.2 Channel Stability

As part of the modeling effort, the maximum stream velocity in each channel reach was determined for each storm event. Channels can become unstable when the water velocity reaches sufficient speed to cause large-scale bank erosion and destabilization of the channels. For the purposes of this report, peak flood velocities below 7 feet per second (fps) are not considered to be at risk of destabilization. Channels where the peak velocity is calculated to be in excess of 7 fps are more likely to become destabilized. Maximum stream velocities for the 10-, 25-, 50-, 100- and 500-year storm events are highlighted in Figure 5-8, Figure 5-9, Figure 5-10, Figure 5-11, and Figure 5-12, respectively.

FIGURE 5-8
ESTIMATED EXISTING 10-YEAR CHANNEL VELOCITIES ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008



Legend

- Major Road
- Municipal Boundary

Storm Event Maximum Velocity (ft/s)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 12.0
- 12.1 - 20.0
- > 20

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Source: AGRC NAIP 2006 and Uintah County GIS.

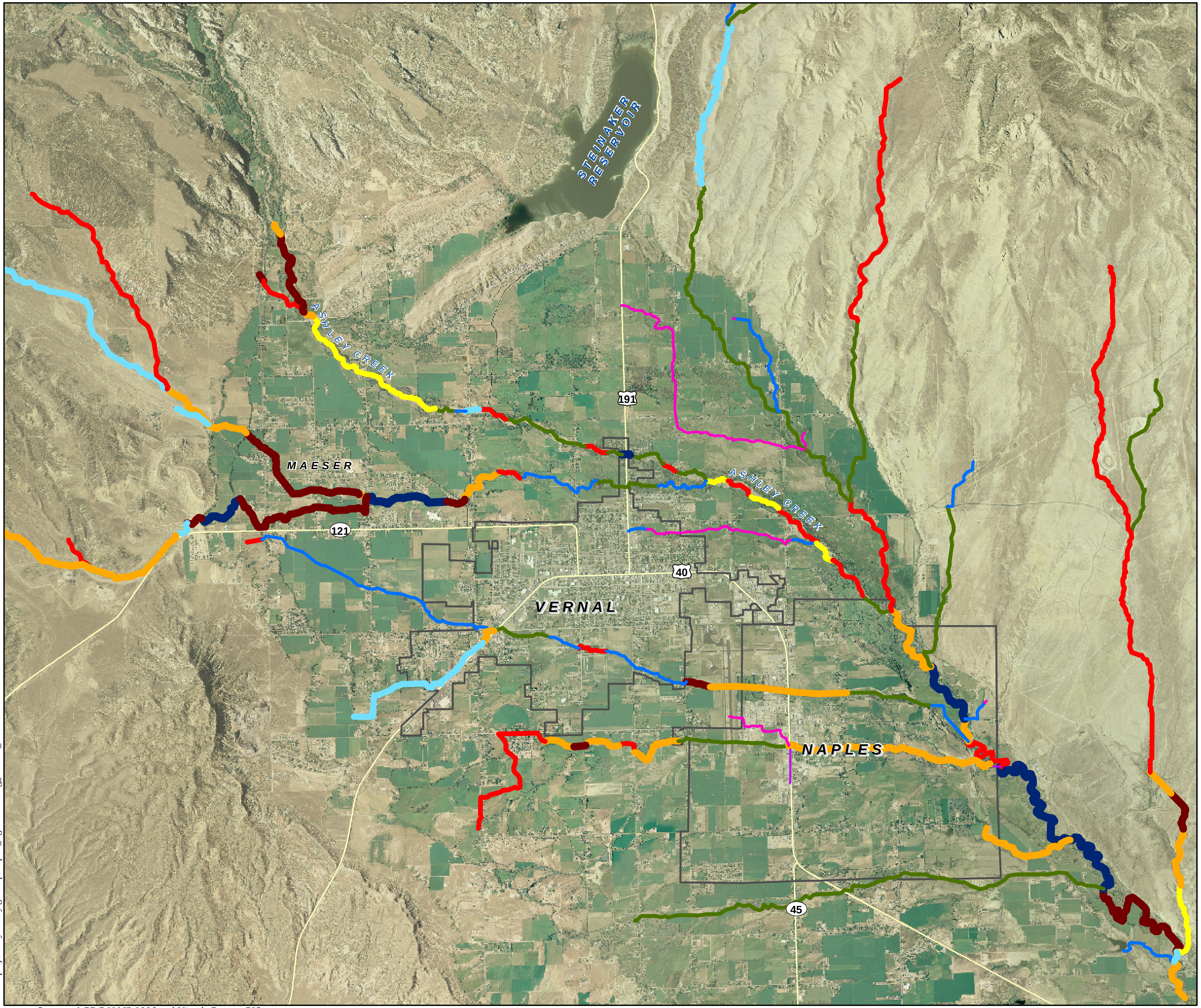

FIGURE 5-9
ESTIMATED EXISTING 25-YEAR CHANNEL VELOCITIES
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008

Legend

Major Road

Municipal Boundary

Storm Event Maximum Velocity (ft/s)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 12.0
- 12.1 - 20.0
- > 20

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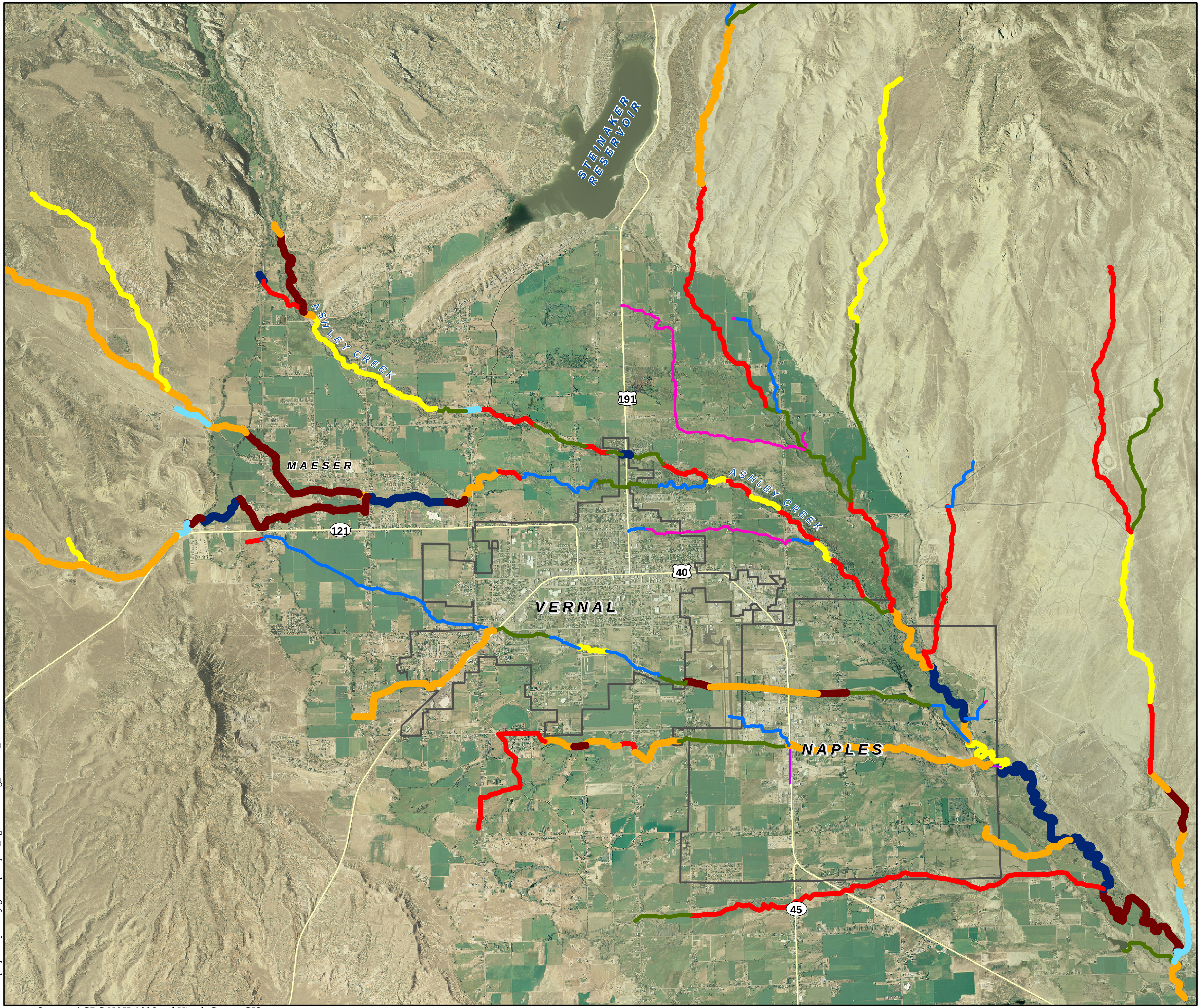
Source: AGRC NAIP 2006 and Uintah County GIS.



Source: AGRC NAIP 2006 and Uintah County GIS.

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FIGURE 5-10
ESTIMATED EXISTING 50-YEAR CHANNEL VELOCITIES ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008

Legend

Major Road

Municipal Boundary

Storm Event Maximum Velocity (ft/s)

< 1.0

1.1 - 2.0

2.1 - 3.0

3.1 - 4.0

4.1 - 5.0

5.1 - 6.0

6.1 - 7.0

7.1 - 12.0

12.1 - 20.0

> 20

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1 INCH = 5,000 FEET

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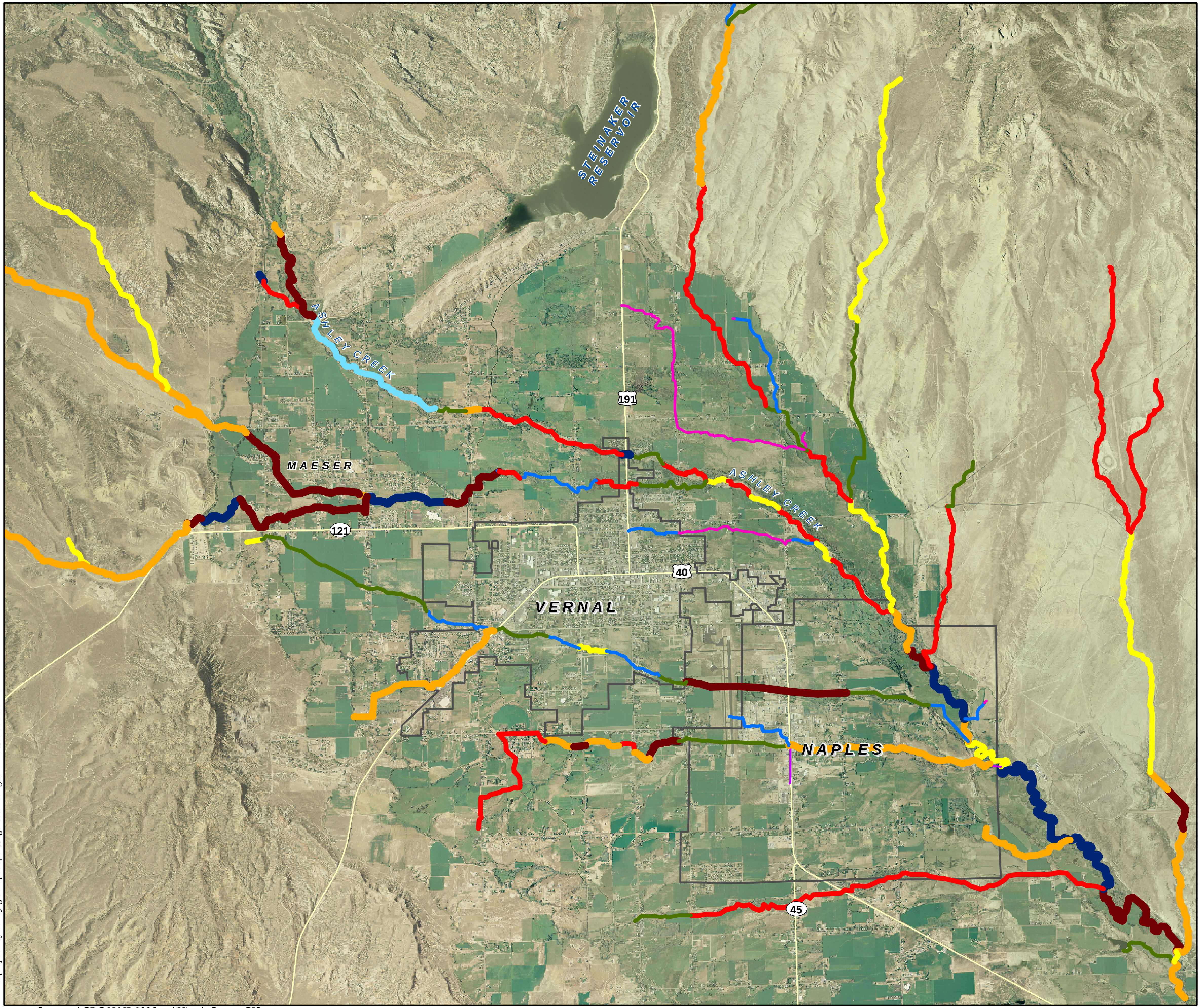

Source: AGRC NAIP 2006 and Uintah County GIS.

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FIGURE 5-11
ESTIMATED EXISTING 100-YEAR CHANNEL VELOCITIES
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008

Legend

Major Road

Municipal Boundary

Storm Event Maximum Velocity (ft/s)

< 1.0

1.1 - 2.0

2.1 - 3.0

3.1 - 4.0

4.1 - 5.0

5.1 - 6.0

6.1 - 7.0

7.1 - 12.0

12.1 - 20.0

> 20

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1 INCH = 5,000 FEET

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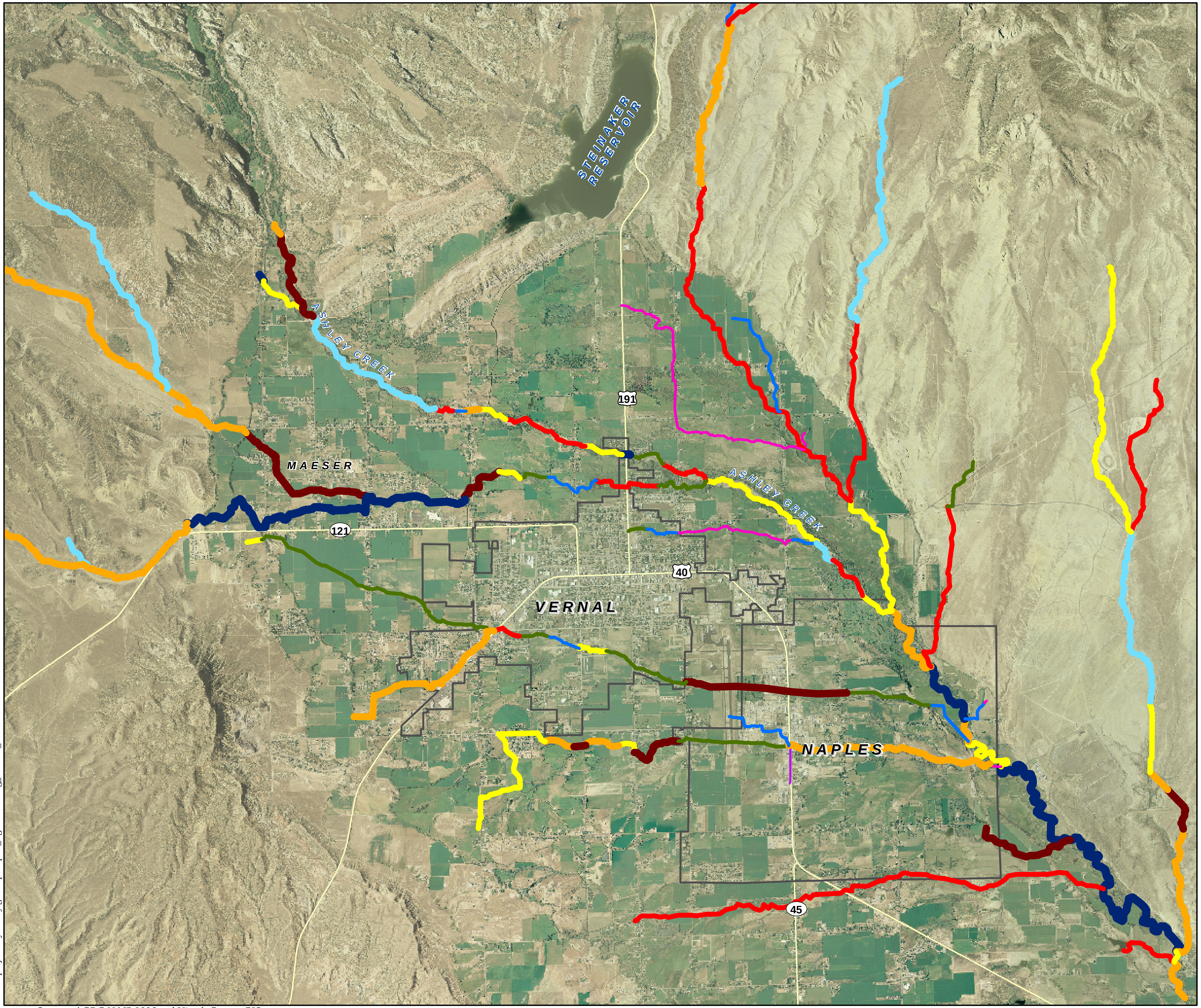
FIGURE 5-12
ESTIMATED EXISTING 500-YEAR CHANNEL VELOCITIES
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008



Legend

Major Road

Municipal Boundary

Storm Event Maximum Velocity (ft/s)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 12.0
- 12.1 - 20.0
- > 20

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1 INCH = 5,000 FEET

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Source: AGRC NAIP 2006 and Uintah County GIS.

5.2.3 INUNDATED ZONES

The Federal Emergency Management Administration (FEMA) generally requires that all major structures be constructed above the 100-year flood elevation. The majority of structures throughout the basin are above this minimum flood elevation and should not be inundated by flood waters under normal circumstances. Figure 5-13 highlights the zones throughout the basin that will likely become inundated during the 100-year event, based on the modeling results presented in this report. Existing structures within these zones should be closely evaluated and the construction of future structures limited or disallowed. Some of the areas of highest concern include the areas immediately north and south of Vernal City and through Naples. These areas are of high concern at this time because growth from the cities is rapidly encroaching upon these flood plains. At the time of this report FEMA is in the process up updating the current flood plain maps for Uintah County. ***When the final revisions are complete it is recommended that Figure 5-13 in this report be replaced with the basin wide FEMA map and the flooding recommendations updated accordingly.***

FIGURE 5-13
POTENTIAL 100-YEAR FLOOD ZONES
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008

Source: AGRC NAIP 2006 and Uintah County GIS.

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Legend

- Major Road
- Municipal Boundary
- 100-Year Floodplain

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1 INCH = 5,000 FEET

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Chapter 6 FUTURE STORM DRAIN CAPACITY ANALYSIS

6.1 FUTURE STORM WATER MODEL

As the Valley continues to develop, the network of systems used to control and direct storm water runoff safely through the Valley will become increasingly important. The developed lands will have a higher runoff potential. New development may also encroach on the historic flood plains reducing the Valleys capacity to efficiently transmit storm water through the Valley. The combination of higher runoff and smaller channels to carry the flow has the potential to create numerous and expensive flooding problems throughout the Valley. The purpose of this chapter is to identify the potential problem areas that will most likely result from additional development before they occur. Through proactive thinking and proper planning, the majority of future potential flooding can be prevented.

6.1.1 FUTURE DRAINAGE BASIN CONFIGURATION

The existing basin configuration is utilized for the future modeling. Using the same basin configuration requires that the future development will not affect the macro scale drainage basins throughout the Valley. Given the size of the delineated basins and minimal influence the existing basins have had on the natural flow, this is a reasonable assumption to make at this time.

While the basin configuration remains the same between the existing and future models, the CN values for each basin were recalculated to reflect the anticipated developed land use shown in Figure 3-3. The curve number assigned to each basin was calculated as an area weighted average of the soil types and zoning within each basin. The curve numbers assigned to each soil type and land use pair are shown in Table 6-1. For basins where development is not anticipated (i.e. the hill sides surrounding the Valley), the historic CN values were retained in the future analysis.

Table 6-1 Future CN values

	Soil Group			
Land Use	A	B	C	D
Commercial /industrial/ governmental	89	92	94	95
Developed Open Spaces / parks	49	69	79	84
Residential <1/8 acre lots	77	85	90	92
Residential 1/3 acre lots	57	72	81	86
Residential 1/2 acre lots	54	70	80	85
Residential >1 acre lots	51	68	79	84

The time to concentration calculations for the future modeling were also re-evaluated. Time to concentration values are typically much shorter in developed areas than in undeveloped areas. However, the Valley currently requires storm water mitigation through retention or detention basins. This future simulation assumes that the existing basins combined with similar requirements for all future development will generally prevent the macro scale Tc values from decreasing. When detention basins are sized and constructed properly, they function to keep the future peak flow at or below the historical flows. Retention basins capture a large portion of the storm event and then overflow beyond their capacity. To account for these basins throughout the future developed areas the Tc values were adjusted (increased) such that the peak storm event for the 100-year storm were not increased by more then 20%. This assumption provides conservative, yet realistic, flow predictions for the larger events where some basins may fail, others will prematurely overtop and others will function correctly. The Tc values that were used to model future conditions are included in the appendix.

6.2 Analysis of the Existing System Under Future Conditions

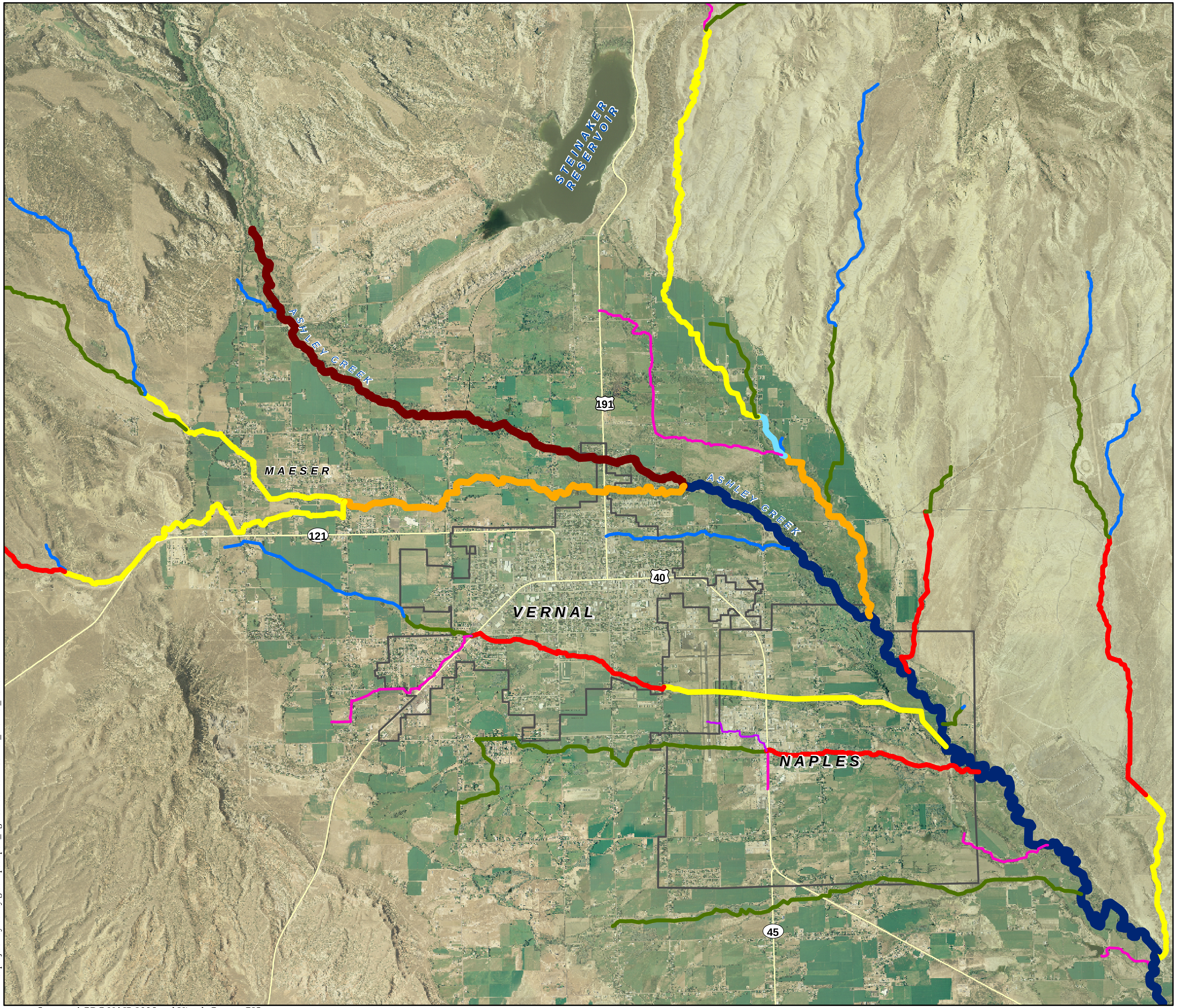
The following sections present the results of the future modeling effort, as well as highlight the areas of future concern as the Valley develops. The following chapter presents recommended modifications to zoning, ordinances, and resolutions, as well as capital improvement projects that will protect the Valley from flooding as development continues.

6.2.1 Future Predicted Flows

This section presents the anticipated future flows for the 10-, 25-, 50-, 100-, and 500-year storm events. The predicted future flows throughout the Valley are presented in Figure 6-1, Figure 6-2, Figure 6-3, Figure 6-4, and Figure 6-5 and discussed below.

FIGURE 6-1
ESTIMATED FUTURE UNMODIFIED 10-YEAR CHANNEL FLOWS ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008



Legend

- Major Road
- Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

N W E S

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1 INCH = 5,000 FEET

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Source: AGRC NAIP 2006 and Uintah County GIS.

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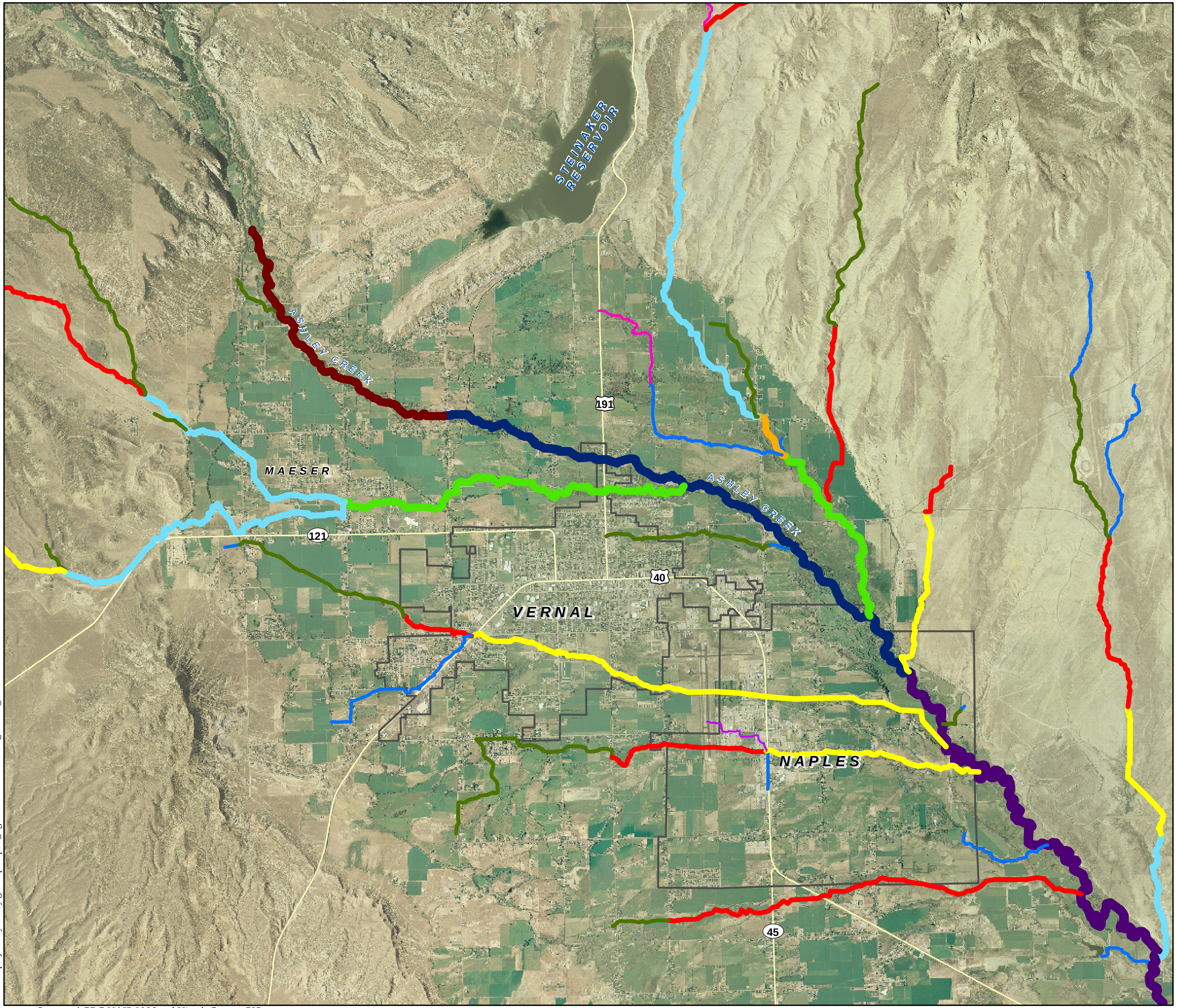

Source: AGRC NAIP 2006 and Uintah County GIS.

FIGURE 6-2
ESTIMATED FUTURE UNMODIFIED 25-YEAR CHANNEL FLOWS ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008

Legend

- Major Road
- Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

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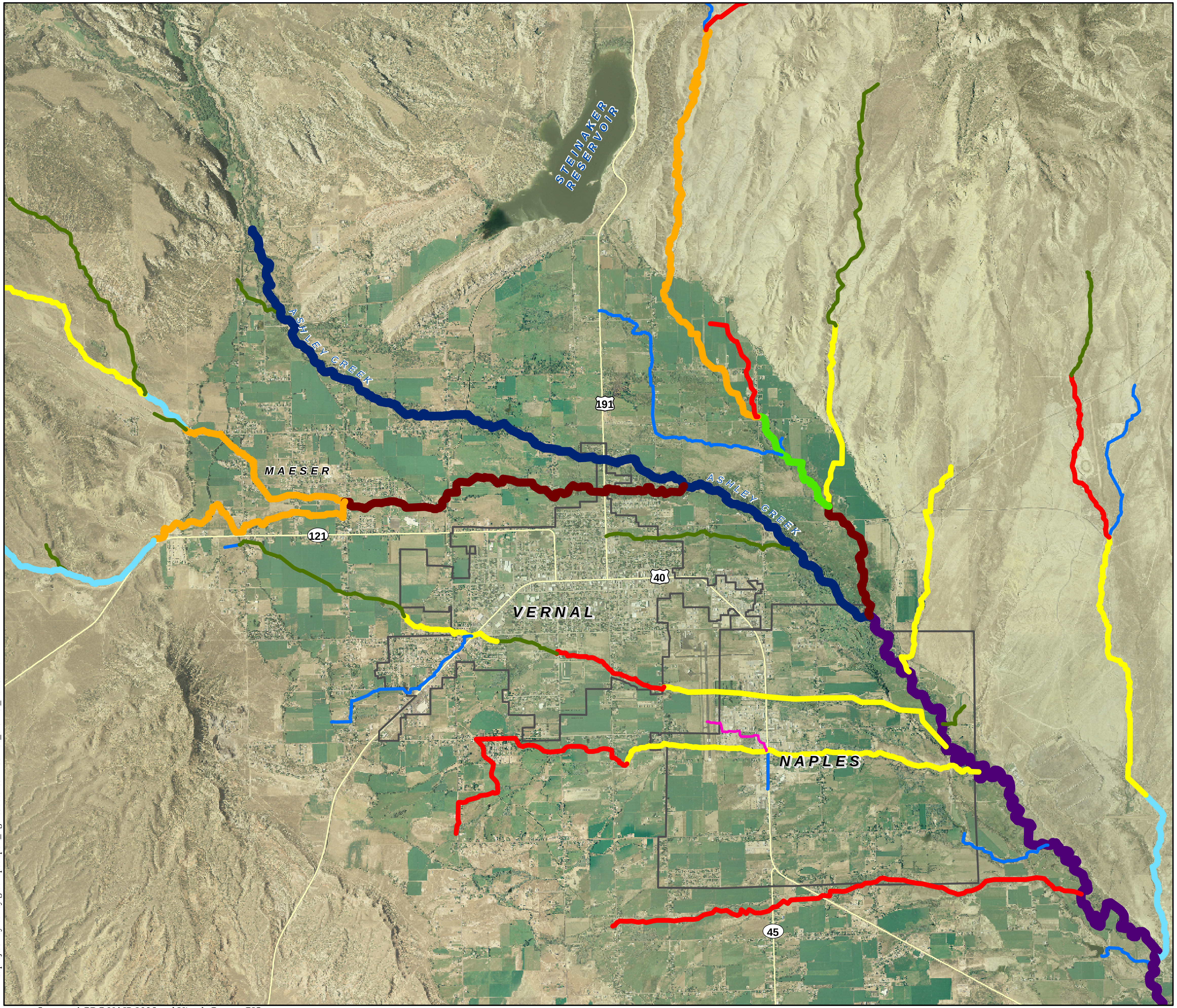

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Source: AGRC NAIP 2006 and Uintah County GIS.

FIGURE 6-3
ESTIMATED FUTURE UNMODIFIED 50-YEAR CHANNEL FLOWS ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008

Legend

- Major Road
- Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

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1 INCH = 5,000 FEET

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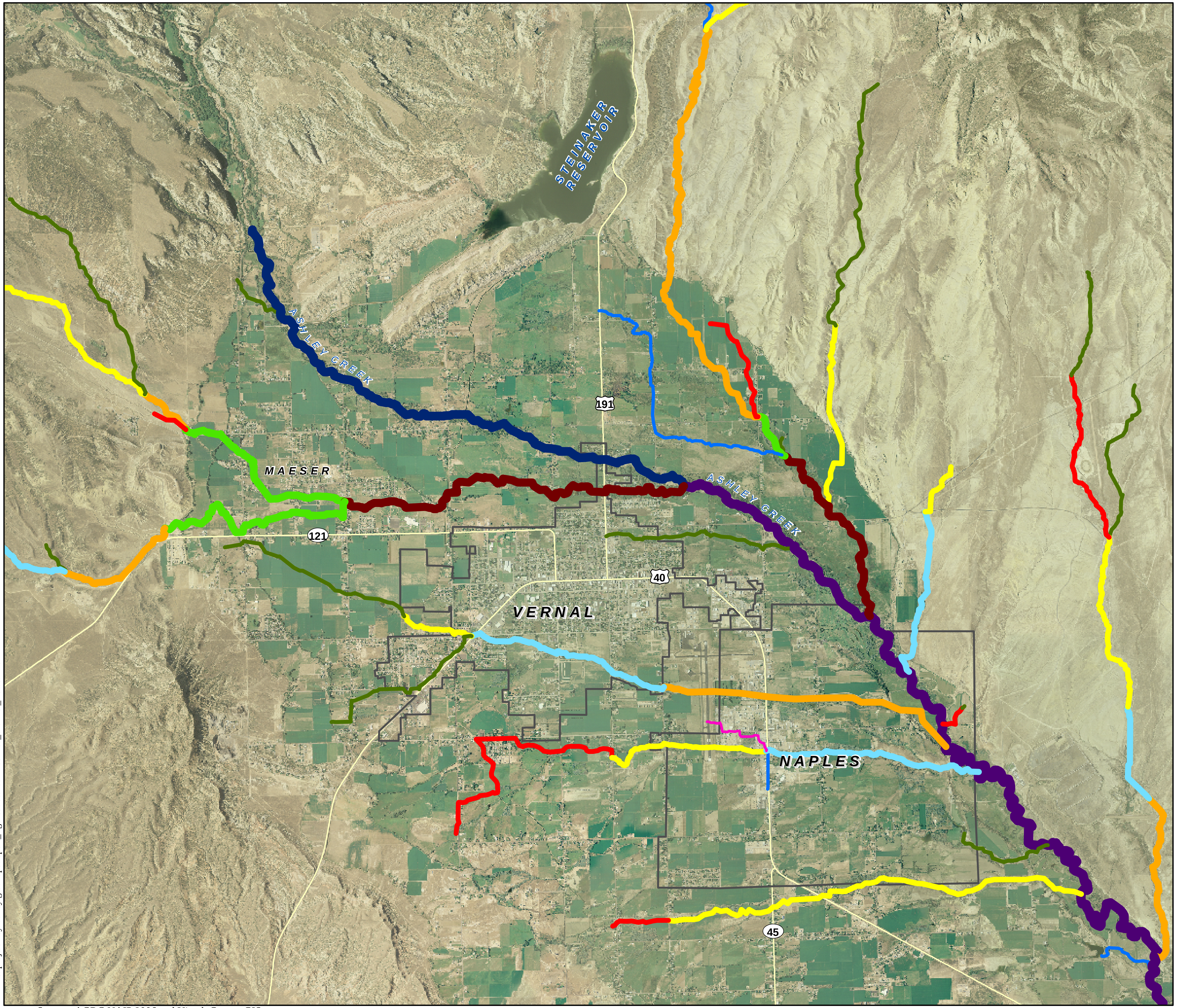
FIGURE 6-4
ESTIMATED FUTURE UNMODIFIED 100-YEAR CHANNEL FLOWS ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008



Legend

Major Road

Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

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1 INCH = 5,000 FEET

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50 EAST 100 SOUTH
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Source: AGRC NAIP 2006 and Uintah County GIS.

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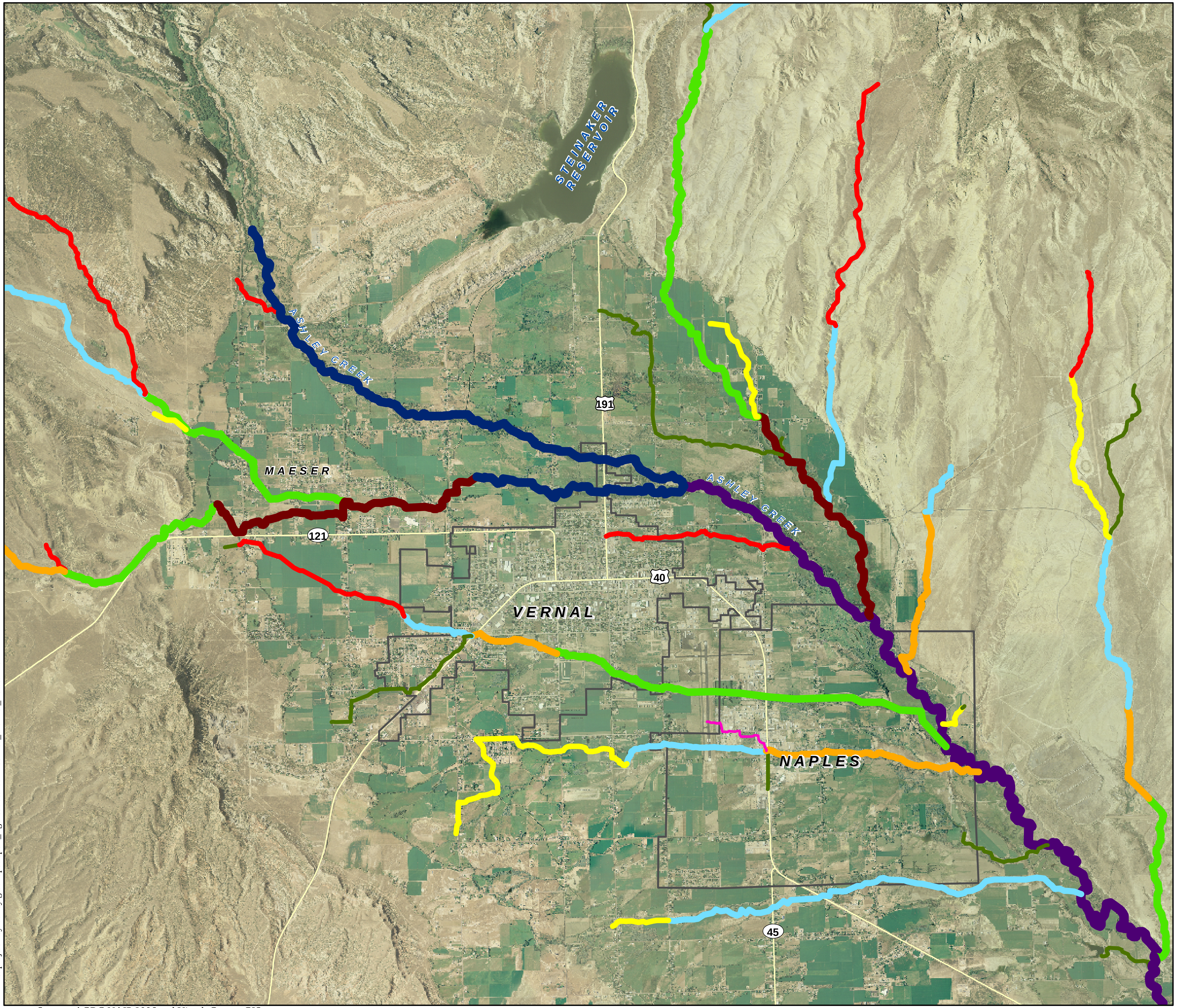
FIGURE 6-5
ESTIMATED FUTURE UNMODIFIED 500-YEAR CHANNEL FLOWS ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008



Legend

- Major Road
- Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

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0 5,000 10,000 Feet

1 INCH = 5,000 FEET

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WEST VALLEY CITY, UTAH 84120
(801) 955-5605

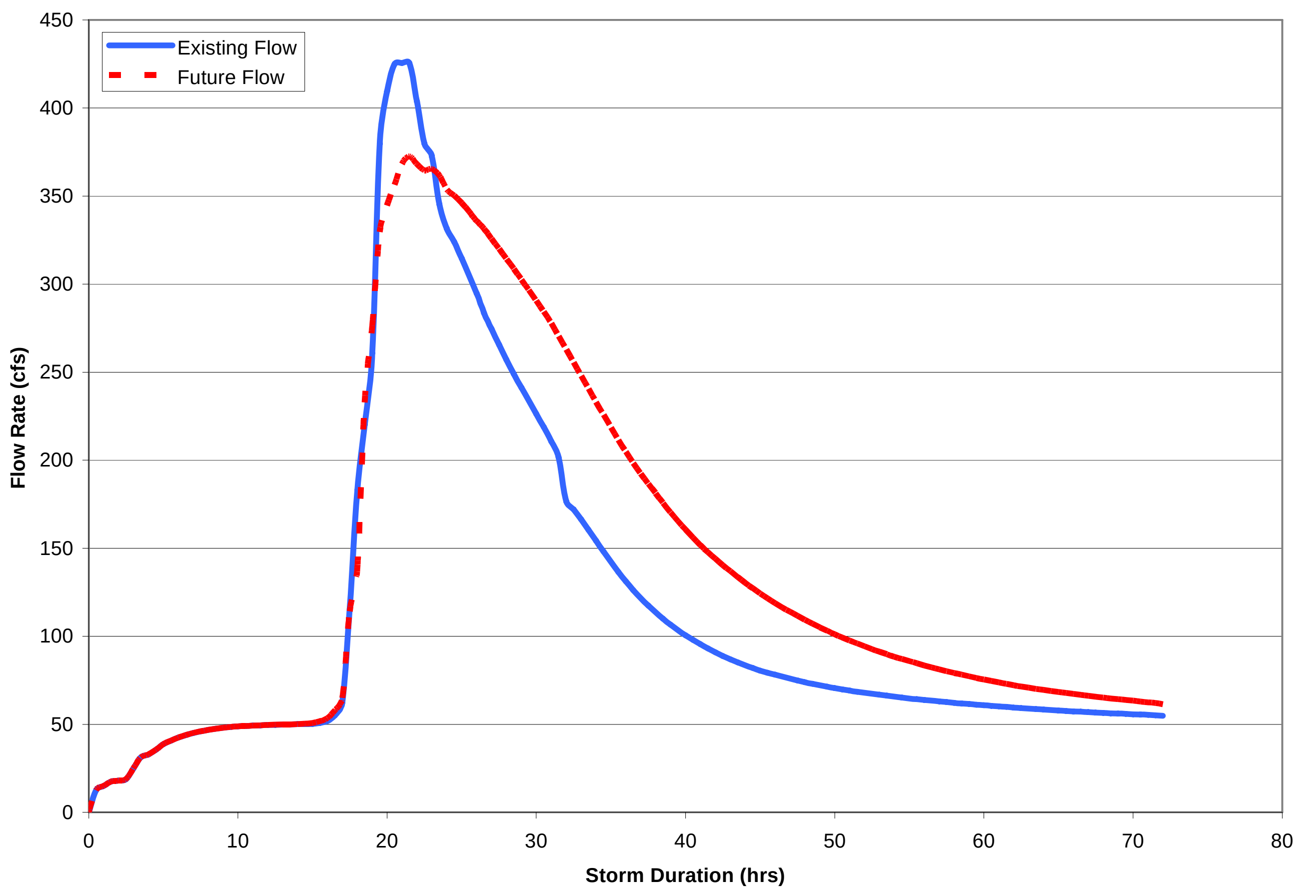
50 EAST 100 SOUTH
HEBER CITY, UTAH 84032
(435) 654-6600

Source: AGRC NAIP 2006 and Uintah County GIS.

s:\proj\ashley-valley\gis\maps\report_figures\futureunmodified_channel_flows.mxd

Generally, the peak flows entering the Valley from the mountains are equal in magnitude and duration, as expected with limited to no development in those areas. Similarly, flows immediately downstream from existing developments are comparable as the conditions are not greatly altered. The major changes between the simulations occur immediately downstream of areas that are anticipated to develop. Future peak flows may be slightly higher (see Tc assumptions above). More importantly, the storm hydrographs from the future developed areas are longer and the total volume of water to be conveyed is greater. The increased volume of water, even with a lower peak flow, may result in additional flooding, and potentially more stream channel erosion. The modified hydrographs must also be carefully considered when designing regional detention areas as a larger volume will be required to achieve the same reduction in flow. Figure 6-6 demonstrates the existing and predicted flows at a location East of Naples. In the figure the peak flow is actually decreased slightly as a result of local detention retention basins, however, the duration of the flow is increased by 20% to 30%.

Figure 6-6 Example Hydrograph

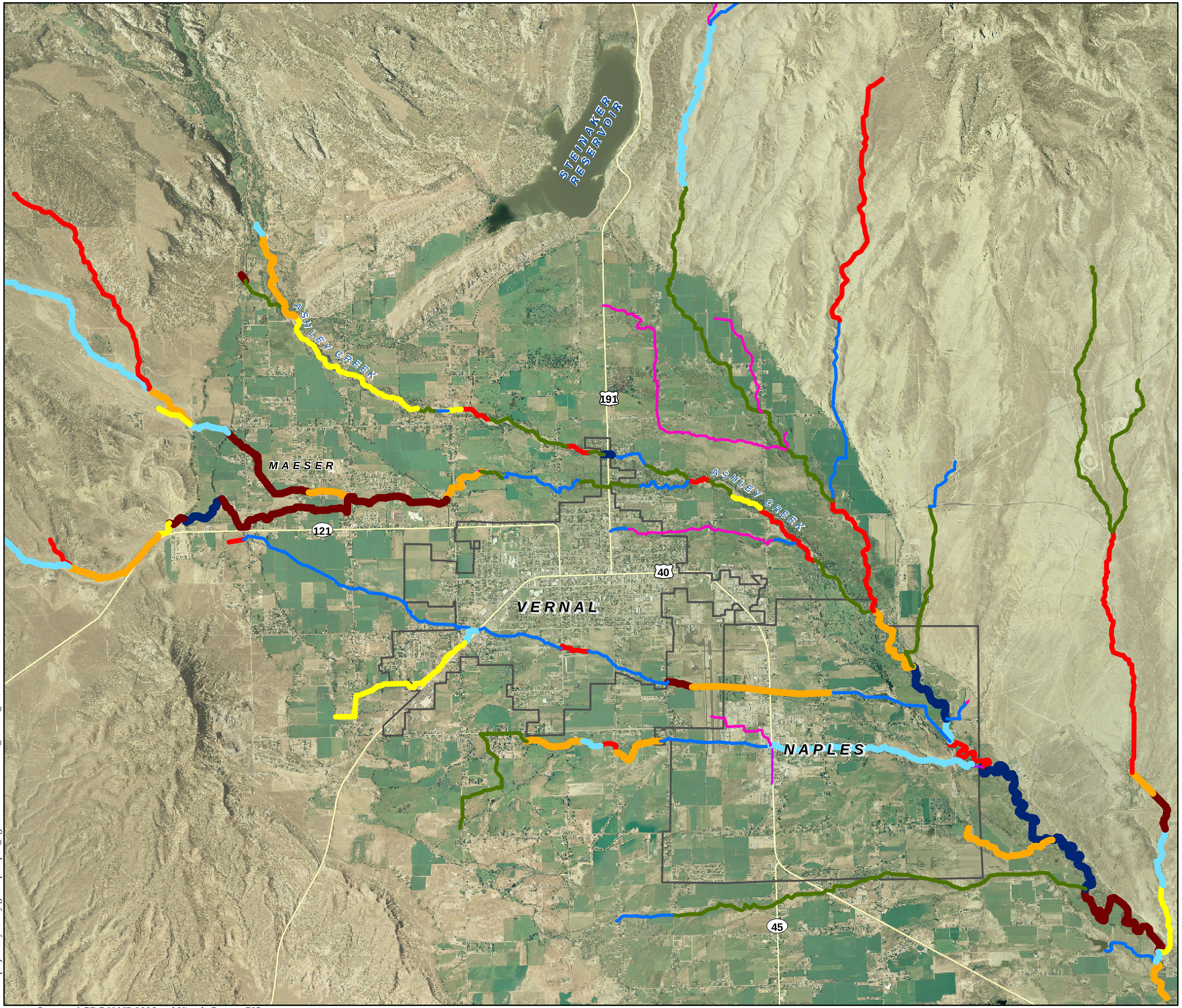


6.2.2 FUTURE PREDICTED VELOCITIES

The maximum stream velocity in each channel reach was determined for each storm event under the future conditions using a similar process described in Chapter 5. Channels can become unstable when the water velocity reaches sufficient speed to cause large-scale bank erosion and destabilization of the channels. For the purposes of this report, peak flood velocities below 7 feet per second (fps) are not considered to be at risk of destabilization. Channels where the peak velocity is calculated to be in excess of 7 fps are more likely to become destabilized. Maximum stream velocities for the 10-, 25-, 50-, 100- and 500-year storm events under the future conditions are highlighted in Figure 6-7, Figure 6-8, Figure 6-9, Figure 6-10, and Figure 6-11, respectively.

FIGURE 6-7
ESTIMATED FUTURE UNMODIFIED 10-YEAR CHANNEL VELOCITIES ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008



Source: AGRC NAIP 2006 and Uintah County GIS.

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Legend

- Major Road
- Municipal Boundary

Storm Event Maximum Velocity (ft/s)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 12.0
- 12.1 - 20.0
- > 20

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1 INCH = 5,000 FEET

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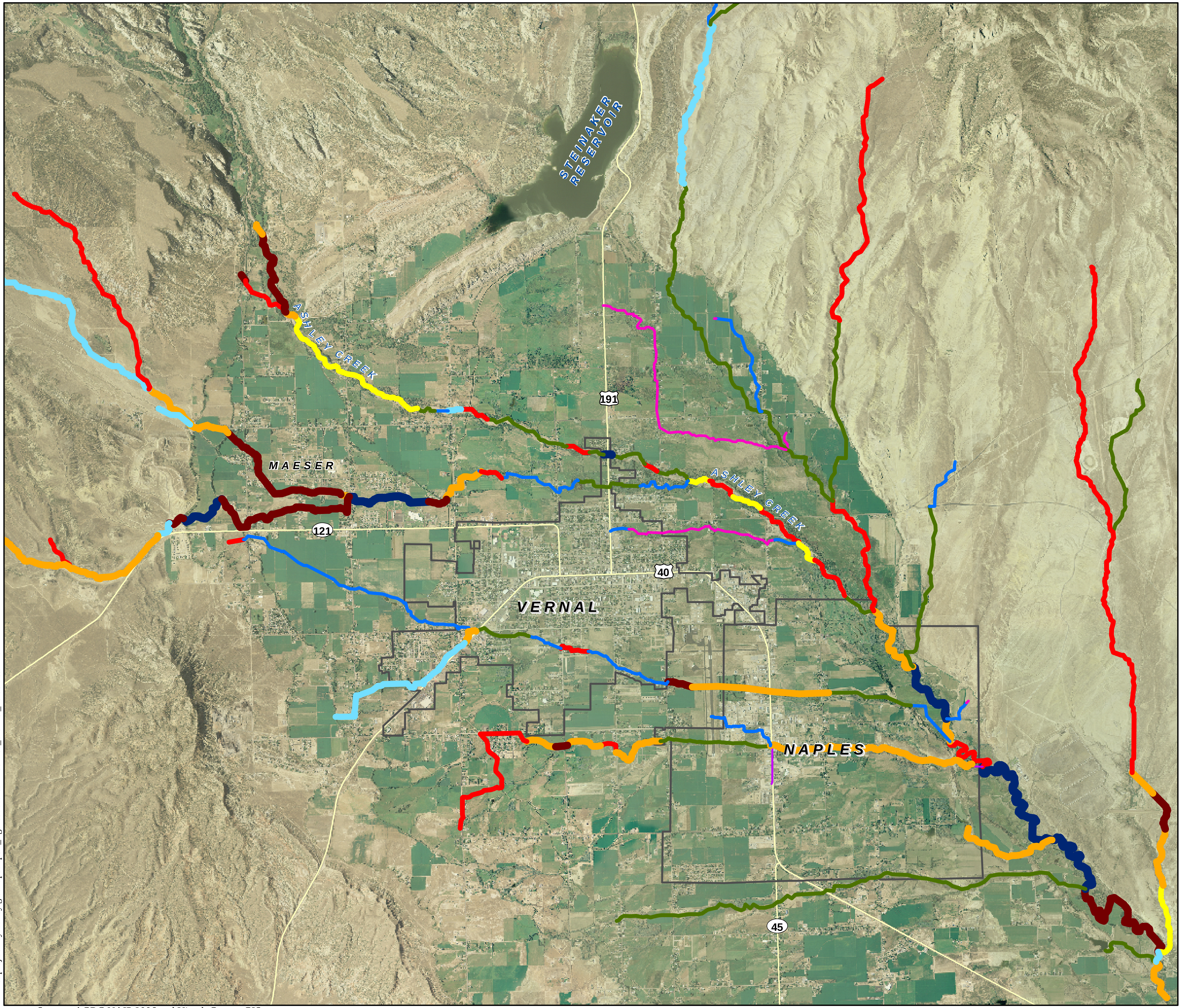

FIGURE 6-8
ESTIMATED FUTURE UNMODIFIED 25-YEAR CHANNEL VELOCITIES ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008

Legend

Major Road

Municipal Boundary

Storm Event Maximum Velocity (ft/s)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 12.0
- 12.1 - 20.0
- > 20

N W E S

0 5,000 10,000 Feet

1 INCH = 5,000 FEET

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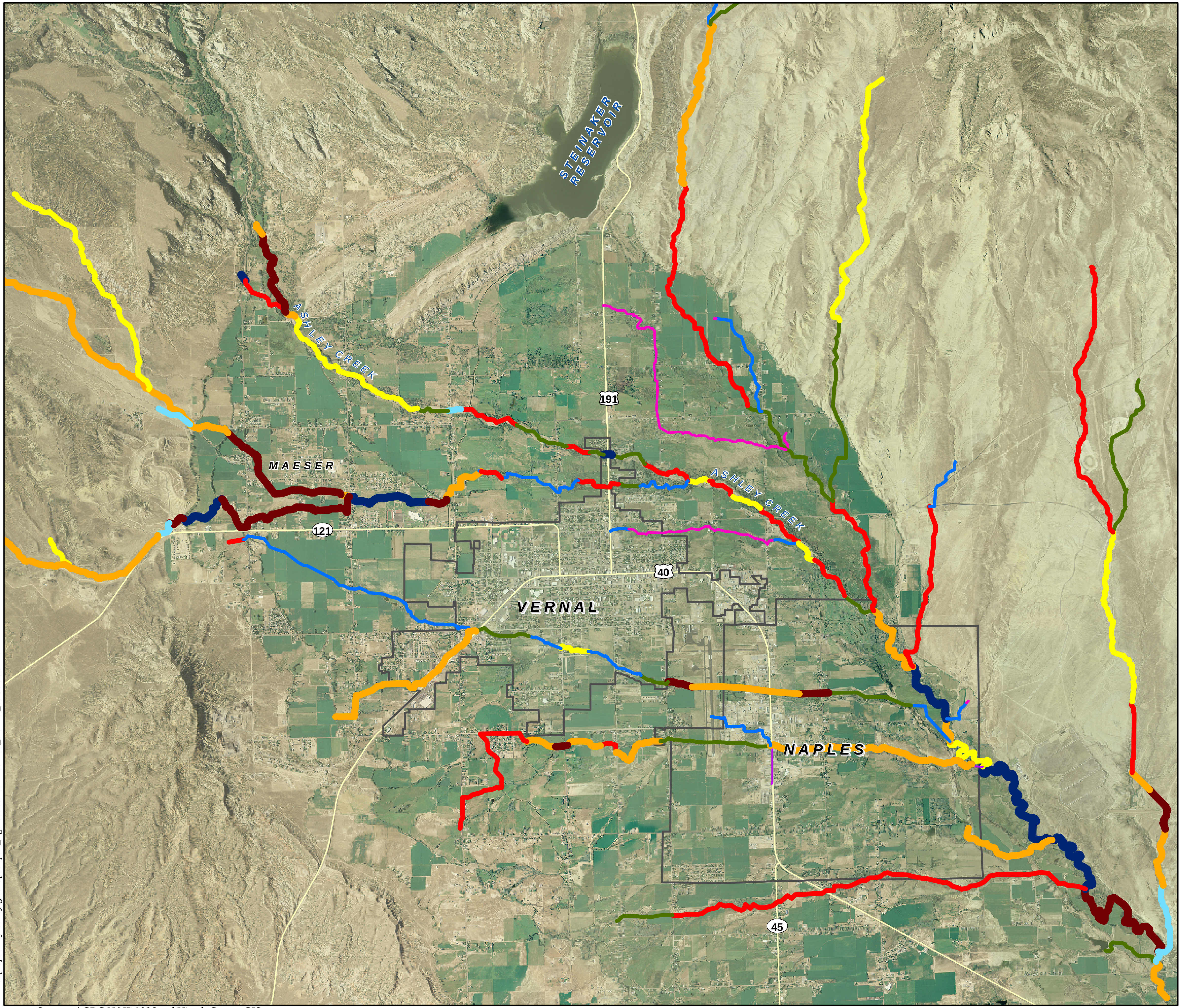
Source: AGRC NAIP 2006 and Uintah County GIS.

FIGURE 6-9
ESTIMATED FUTURE UNMODIFIED 50-YEAR CHANNEL VELOCITIES ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008



Source: AGRC NAIP 2006 and Uintah County GIS.

s:\proj\ashley-valley\gis\maps\report_figures\futureunmodified_channel_velocities.mxd

Legend

- Major Road
- Municipal Boundary

Storm Event Maximum Velocity (ft/s)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 12.0
- 12.1 - 20.0
- > 20

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1 INCH = 5,000 FEET

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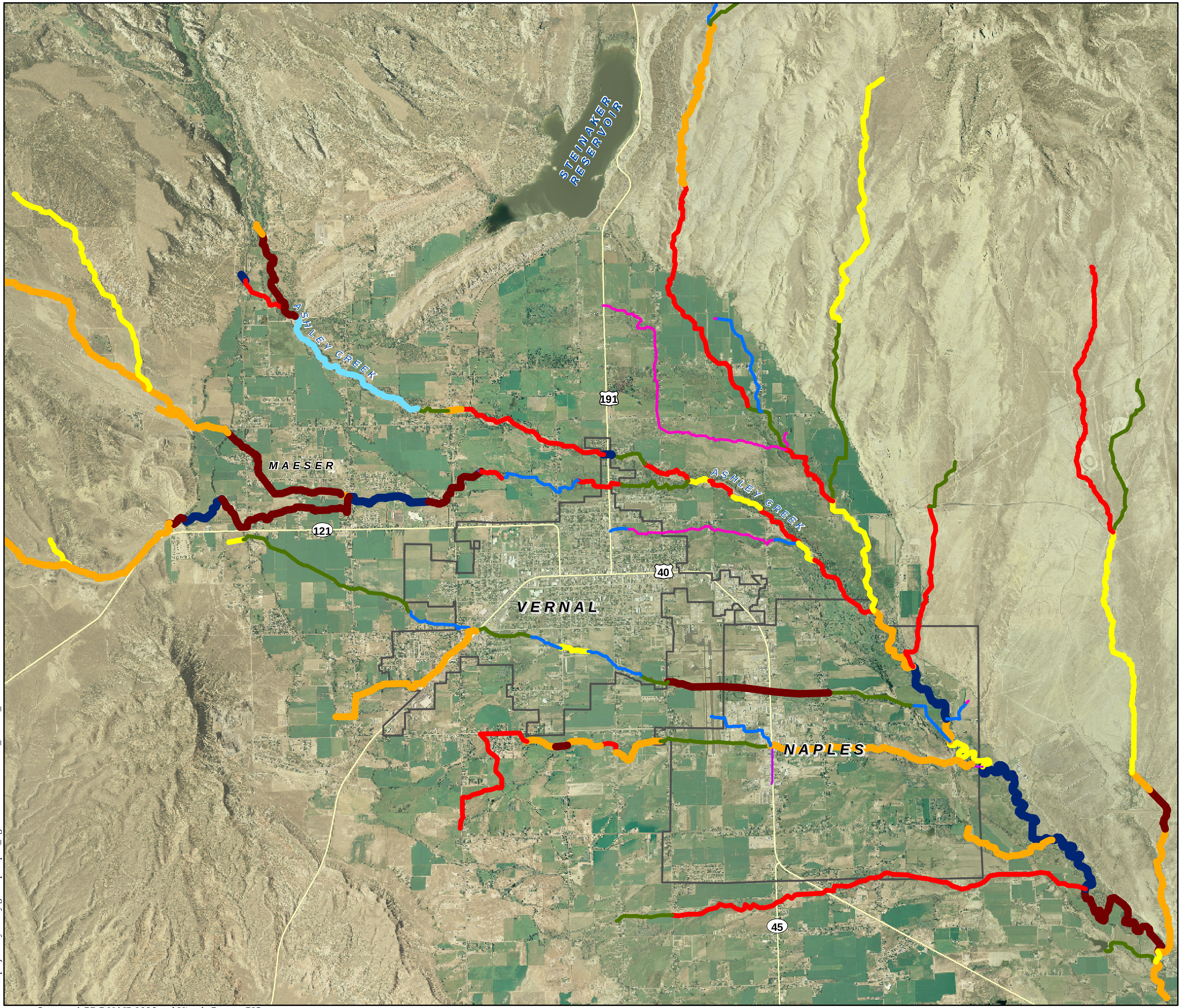
FIGURE 6-10
ESTIMATED FUTURE UNMODIFIED 100-YEAR CHANNEL VELOCITIES ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008



Source: AGRC NAIP 2006 and Uintah County GIS.

Legend

- Major Road
- Municipal Boundary

Storm Event Maximum Velocity (ft/s)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 12.0
- 12.1 - 20.0
- > 20

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1 INCH = 5,000 FEET

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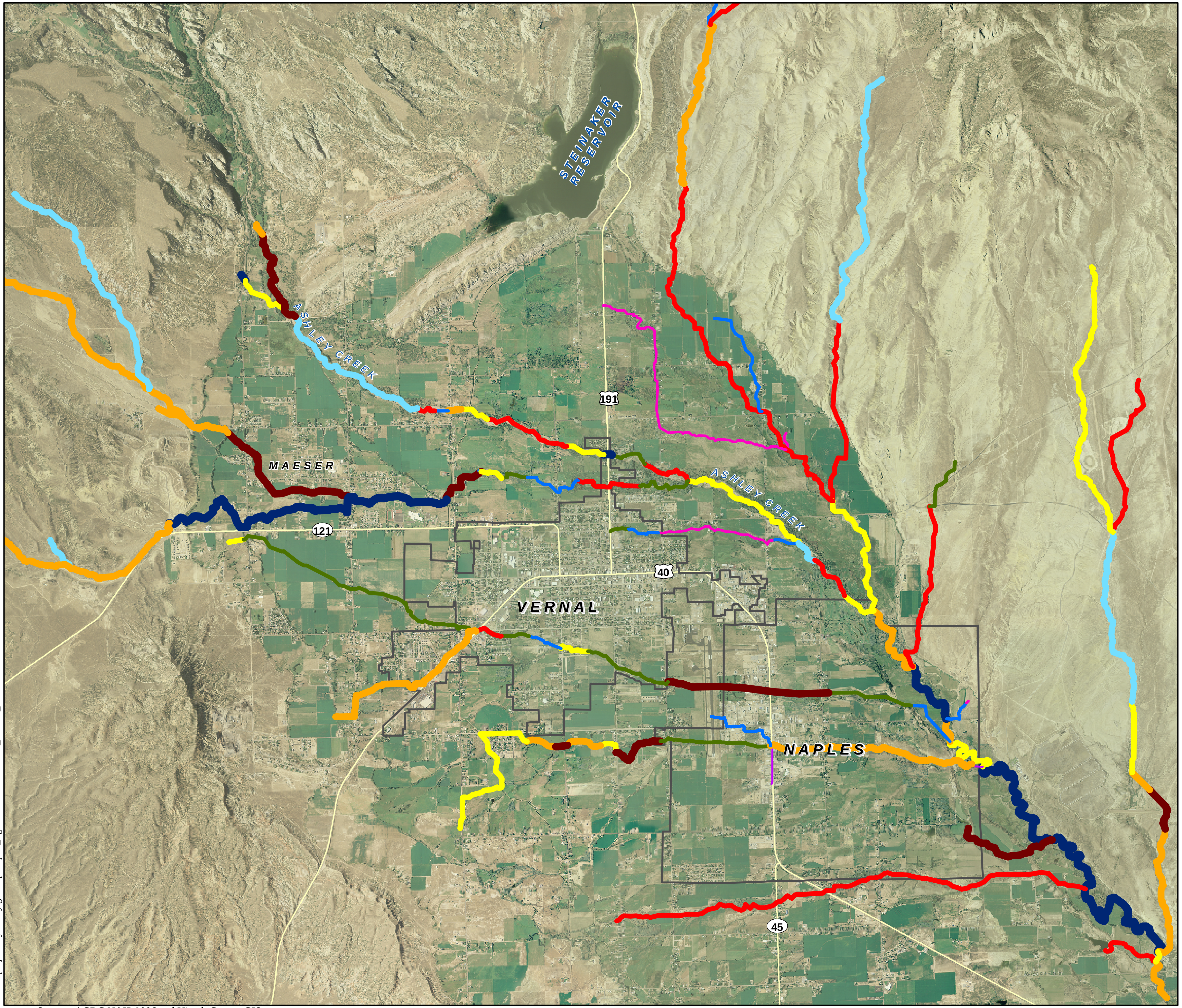
FIGURE 6-11
ESTIMATED FUTURE UNMODIFIED 500-YEAR CHANNEL VELOCITIES ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008



Legend

Major Road

Municipal Boundary

Storm Event Maximum Velocity (ft/s)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 12.0
- 12.1 - 20.0
- > 20

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1 INCH = 5,000 FEET

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Source: AGRC NAIP 2006 and Uintah County GIS.

6.2.3 CAPACITY OF EXISTING DRAINAGE FACILITIES

A number of concerns were identified in the previous chapter under the existing simulated conditions. Future simulation indicates that all of the existing problems will likely be exacerbated through development. Additionally, the future simulation indicates that additional problems will occur if modifications to the drainages are not properly managed. Areas throughout the Valley where roads and utilities cross drainage channels are of high concern. In the previous chapter, a number of culverts were identified as unable to pass the 10-year event. Under the future conditions model, it appears that most of the major crossings are ill-equipped to pass the 25-year or larger event. While some roadway flooding may be permissible during large flooding events, it is imperative that major utility corridors and evacuation routes remain operable during even the most extreme events. The necessary upgrades to correct both the existing and future flooding concerns are discussed in detail in the following chapter.

Chapter 7 RECOMMENDED UPGRADES

A number of existing and potential storm water concerns have been identified in the previous chapters. This chapter presents a series of recommendations to mitigate the existing and potential flooding concerns. The methodology behind the recommended capital improvements as well as the estimated costs for the improvements is also presented below.

7.1 IMPROVEMENT METHODOLOGY SELECTION

Identifying storm water problems is a complex process, but it is also one that relies on technical expertise and proven scientific methods. Identifying alternatives to mitigate the identified problems can be far more challenging. In addition to requiring sound engineering and technical knowledge to identify effective solutions, a number of factors must be evaluated, including:

- Cost / Fundability
- Effectiveness
- Sustainability
- Liability
- Community Impact
- Political Climate
- Water users /Water rights
- Environmental effects
- Community acceptance
- Property rights
- Future land uses

With few exceptions, the list above does not include technical or easily quantifiable items. Therefore, involvement of the political entities is required to effectively implement the recommended improvements. To that end, Epic Engineering staff attended numerous city and county meetings as well as meeting with governmental planning staff in an effort to understand the communities needs and desires as well as inform them of the flooding concerns and work collectively to develop the recommendations methodology herein. It is our hope that by including the governmental entities throughout the process, the recommendations will be implemented by the respective entities and the Valley protected from future flooding events.

The sections below detail three recommendation selection methodologies that were discussed throughout the process. Each of the methodologies has strengths and weaknesses and none of the methodologies provide a perfect solution to all of the problems. After numerous discussions, a hybrid of the three methodologies was selected to provide the most optimal list of recommended improvements.

7.1.1 DO NOTHING METHODOLOGY

The ‘do nothing’, or the ‘don’t do anything new’ methodology is founded on the basis that flooding is a natural process and structures within the flood plain are not necessary the responsibility of the government to protect. With this logic, new development is responsible for managing the storm water on-site, and the local entities will not be responsible for flooding in the future.

At first glance this alternative appears to be the least costly since it does not require major improvements. However, damage costs associated with the ‘do nothing’ methodology after a large storm event could far exceed the costs of the other alternatives.

7.1.2 Historic Drainage Restoration and Preservation

Methodology behind preserving (or restoring where necessary) the natural drainages throughout the basin is based on the concept that water has naturally established the most effective flow paths over time. Allowing the storm water to follow its natural course provides two primary benefits. First, the stream channels are already defined and will require little improvement. Second, since the flows are naturally occurring, governing entities can designate the channels as un-developable more easily than if flooding occurred through artificial diversions.

The primary shortfall of this methodology is that a number of drainages have already been filled, developed, or altered to the point that it is not feasible or economically possible to restore the channel to its natural condition.

7.1.3 Storm Water Basin Diversion and Storage

Divert, store and protect methodology is fundamentally opposite from the ‘do nothing’ strategy. The strategy behind diverting, storing and protecting is to construct artificial storm channels and detention or debris basins in an effort to minimize the floodplains throughout the Valley. Storm events of all sizes will be managed through a series of pipes, canals, and diversions.

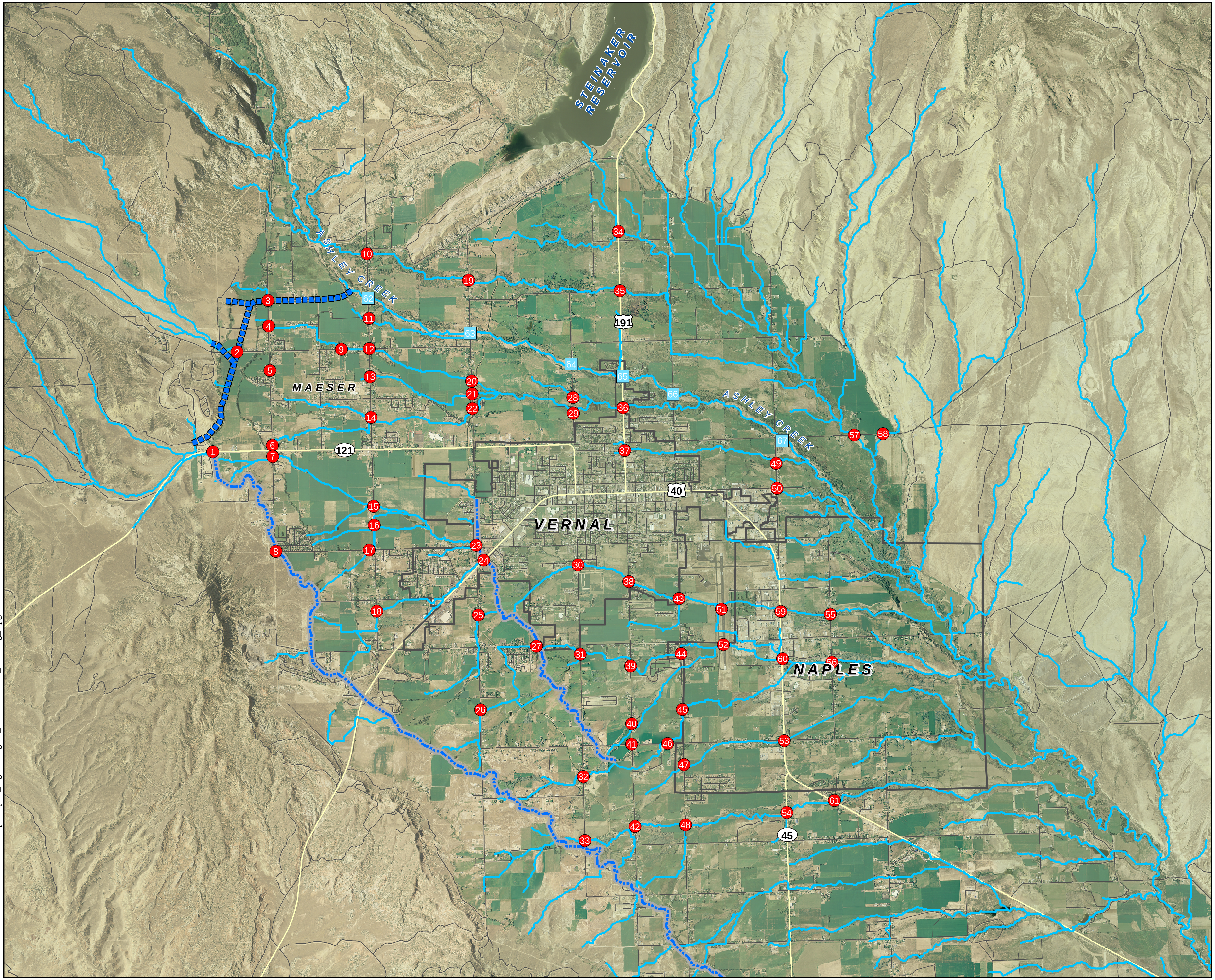
Applying this methodology to the entire basin would be extremely costly. Additionally, operation and maintenance of such a complex system would be labor intensive and the liability associated with a mechanical failure higher then with the other possible methodologies. The advantage to this methodology is that the floodplains would be minimized and could potentially allow for higher density developments closer to or within the low lying areas.

7.1.4 Recommended Methodology

After many discussions with the local municipalities it was determined that a hybrid of preservation and diversion methodologies was best suited for the Valley. The concept behind the recommended methodology is to preserve the natural drainage channels where possible, restore the natural channels when there are only minor encroachments and, finally, divert storm water from the highly developed areas where restoration of the natural channels is not feasible. This alternative is intended to minimize the cost and liability associated with implementation while providing adequate protection of the Valley. Additionally, preserving the natural drainages will provide open space for the community that can also serve as recreational corridors.

7.2 Recommended Upgrade Projects

The following sections describe the recommended alternatives based on the methodology described above. The upgrades have been classified into debris basins, detention basins to treat the storm water and remove storm water peaks, storm water canals to divert water away from developed areas, recommended road and utility crossing upgrades to ensure emergency ingress/egress is maintained, as well as the channels that should be protected and resorted to provide adequate capacity in the less developed areas. Proposed locations of these recommended improvement projects are shown in Figure 7-1 and Figure 7-2.



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Source: AGRC NAIP 2006 and Uintah County GIS.

FIGURE 7-1
RECOMMENDED CROSSING UPGRADES
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008

Legend

- Natural Stream Channel
- Major Road
- Minor Road
- New Channel
- Channel Improvement
- Municipal Boundary

Recommended Crossing Upgrade

- Culvert
- River Crossing Upgrade

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1 INCH = 5,000 FEET

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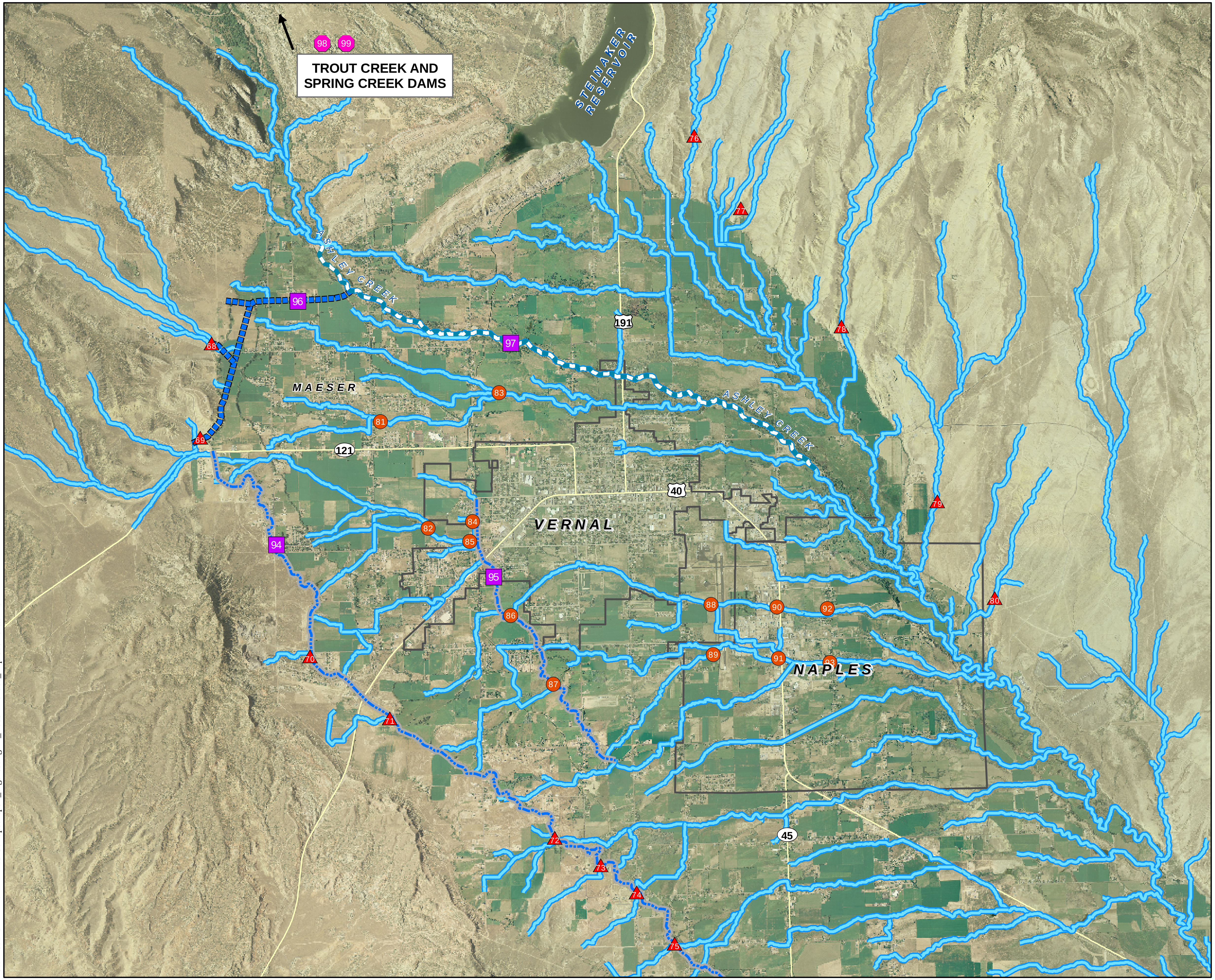

Source: AGRC NAIP 2006 and Uintah County GIS.

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FIGURE 7-2
RECOMMENDED IMPROVEMENTS
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008

Legend

Natural Stream Channel

Major Road

Municipal Boundary

Recommended Improvements

1 Debris Basin

1 Detention Pond

1 Dam

1 Channel Improvement

1 New Channel

Preserve and Protect

1 Restore Channel to Natural Conditions

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1 INCH = 5,000 FEET

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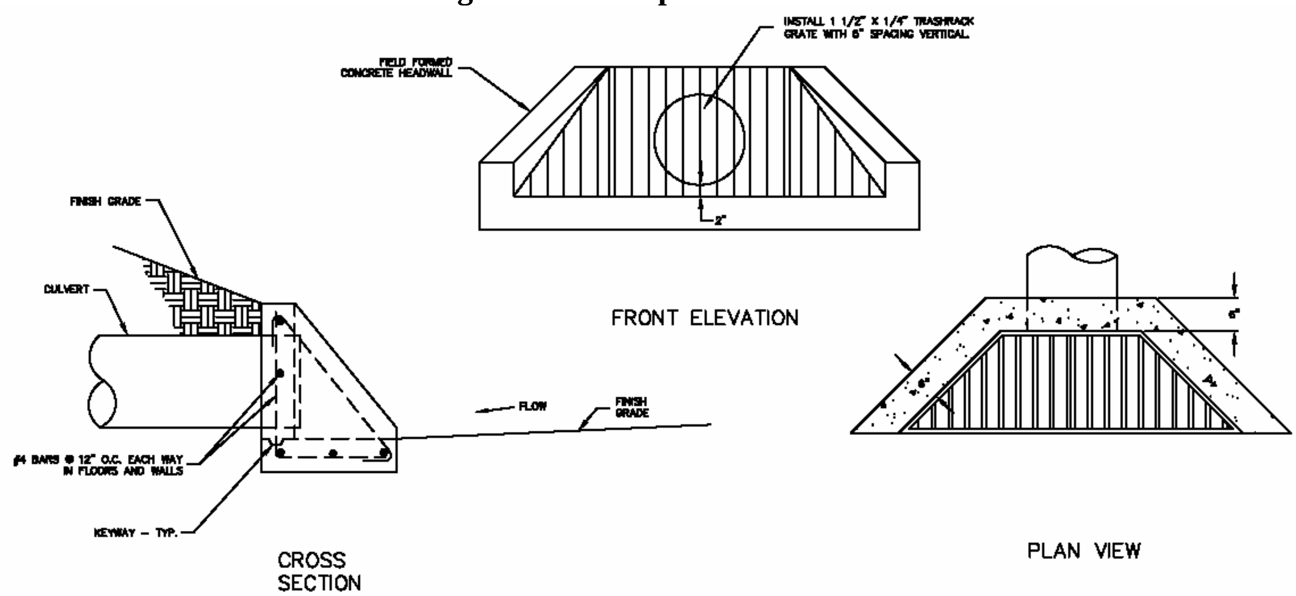
7.2.1 RECOMMENDED CROSSING UPGRADES

The following section describes the major recommended improvements that are required to divert flow around or reduce peak flow through developed areas of the Valley. A summary of the recommended improvements are listed in Table 7-1.

Analysis of numerous road and utility crossings throughout the basin indicates that many of the crossings are not currently equipped to be safely passable during the 10-year or larger event. During high flow events it is critical that key evacuation routes and utilities be maintained for the safety of the community. To that end, this report recommends that key crossings throughout the basin be improved to ensure they will remain operable. Additional road and utility corridor crossings should be upgraded to withstand a minimum of a 25-year or larger event to protect the Valley from frequent washouts and high replacement costs. It is recommended that the upgrades highlighted in Table 7-1 be constructed to ensure that utilities remain in operable condition and ingress / egress is maintained during extreme precipitation events. Note that that the recommended culvert crossing upgrades consistently recommend two or more parallel culverts.

During large storm events it is common for smaller crossings, such as culverts, to become blocked with debris even with well designed debris racks. Installing parallel culverts provides a level of redundancy to ensure that storm water will be conveyed even when partially blocked. ***It is recommended that multiple culverts with upstream trash racks, similar to Figure 7-3, be installed at all major existing and future crossings.***

Figure 7-3 Example Trash Rack



For the purposes of this report culverts were sized based on the flow and the nearest round culvert(s) that would provide the required capacity. While this concept provides an excellent idea of the required culvert size it is not intended to be all inclusive. When the crossing upgrades are designed ***it is recommended that site specific considerations be evaluated and a variety of culvert types considered including box culverts, squash pipe and bridges.***

Table 7-1 Recommended Crossing Upgrades

		Storm Event				Recommended Sizing and Barrels for Respective Storm Event							
		10	25	50	100	10		25		50		100	
Item	Location	Flow (cfs)				Size (in)	Barrels	Size (in)	Barrels	Size (in)	Barrels	Size (in)	Barrels
1	4105 W State 121 @ future canal	216	319	408	509	54	2	60	2	66	2	60	3
2	3850 W 1500 N @ future canal	386	562	693	829	66	2	66	3	66	3	66	4
3	2000 N 3500 W @ future canal	814	1190	1528	1821	60	5	72	5	78	5	78	5
4	1750 N 3500 W	17	24	31	39	24	2	24	2	24	2	30	2
5	1250 N 3500 W	1	2	3	4	18	2	18	2	18	2	18	2
6	550 N 3500 W	19	28	36	45	24	2	24	2	30	2	30	2
7	400 N 3500 W	78	113	145	179	36	2	42	2	48	2	48	2
8	500 S 3500 W	216	319	408	509	54	2	60	2	66	2	72	2
9	2750 W 1500 N	17	24	31	39	24	2	24	2	24	2	30	2
10	2450 N 2500 W	3	4	6	7	18	2	18	2	18	2	24	2
11	1800 N 2500 W	17	24	31	39	24	2	24	2	24	2	30	2
12	1500 N 2500 W	17	24	31	39	24	2	24	2	24	2	30	2
13	1200 N 2500 W	12	17	22	28	24	2	24	2	24	2	24	2
14	750 N 2500 W	20	30	39	49	24	2	24	2	30	2	30	2
15	100 S 2500 W	78	113	145	179	36	2	42	2	48	2	48	2
16	250 S 2500 W	78	113	145	179	36	2	42	2	48	2	48	2
17	500 S 2500 W	78	113	145	179	36	2	42	2	48	2	48	2
18	1100 S 2500 W	78	113	145	179	36	2	42	2	48	2	48	2
19	2200 N 1500 W	3	4	6	7	18	2	18	2	18	2	24	2
20	1200 N 1500 W	17	24	31	39	24	2	24	2	24	2	30	2
21	1000 N 1500 W	12	17	22	28	18	2	24	2	24	2	24	2
22	900 N 1500 W	19	30	39	49	24	2	24	2	30	2	30	2
23	450 S 1500 W	152	222	284	359	48	2	54	2	60	2	60	2
24	600 S 1400 W	147	213	259	299	48	2	54	2	54	2	60	2
25	1150 S 1500 W	84	126	162	203	36	2	42	2	48	2	48	2
26	2100 S 1500 W	84	126	162	203	36	2	42	2	48	2	48	2
27	900 W 1500 S	68	111	149	158	36	2	42	2	48	2	48	2
28	1000 N 500 W	3	4	6	8	18	2	18	2	18	2	18	2
29	750 N 500 W	45	67	86	108	30	2	36	2	36	2	42	2

		Storm Event				Recommended Sizing and Barrels for Respective Storm Event							
		10	25	50	100	10		25		50		100	
Item	Location	Flow (cfs)				Size (in)	Barrels	Size (in)	Barrels	Size (in)	Barrels	Size (in)	Barrels
30	700 S 500 W	141	176	200	222	42	2	48	2	48	2	54	2
31	1580 S 500 W	81	124	161	202	36	2	42	2	48	2	48	2
32	2800 S 500 W	110	163	208	260	42	2	48	2	54	2	54	2
33	3500 S 500 W	110	163	208	260	42	2	48	2	54	2	54	2
34	2600 N Vernal Ave	25	39	52	67	24	2	30	2	30	2	36	2
35	2000 N Vernal Ave	3	4	6	7	18	2	18	2	18	2	24	2
36	750 N Vernal Ave	48	71	92	115	30	2	36	2	36	2	42	2
37	400 N Vernal Ave	84	116	143	172	36	2	42	2	48	2	48	2
38	900 S Vernal Ave	140	174	198	221	42	2	48	2	48	2	54	2
39	1750 S Vernal Ave	90	138	180	224	36	2	42	2	48	2	54	2
40	2250 S Vernal Ave	110	163	208	260	42	2	48	2	54	2	54	2
41	2500 S Vernal Ave	110	163	208	260	42	2	48	2	54	2	54	2
42	3300 S Vernal Ave	110	163	208	260	42	2	48	2	54	2	54	2
43	1100 S 500 E	158	209	242	276	48	2	54	2	54	2	54	2
44	1580 S 500 E	110	166	215	272	42	2	48	2	54	2	54	2
45	2100 S 500 E	3	37	61	93	18	2	30	2	36	2	36	2
46	360 E 2500 S	3	37	61	93	18	2	30	2	36	2	36	2
47	2800 S 500 E	3	37	61	93	18	2	30	2	36	2	36	2
48	3300 S 500 E	110	163	208	260	42	2	48	2	54	2	54	2
49	250 N 1500 E	76	104	131	160	36	2	42	2	42	2	48	2
50	1500 E Main	25	35	44	53	24	2	30	2	30	2	30	2
51	1200 S Airport	127	180	211	248	42	2	48	2	54	2	54	2
52	1550 S Airport	86	147	192	236	36	2	48	2	48	2	54	2
53	US-40, 2500 S	3	37	61	93	18	2	30	2	36	2	36	2
54	3200 S 1500 E	110	163	208	260	42	2	48	2	54	2	54	2
55	1200 S 2000 E	120	160	199	238	42	2	48	2	48	2	54	2
56	1750 S 2000 E	89	185	254	329	36	2	48	2	54	2	60	2
57	2300 E State 121	578	822	1065	1262	66	3	66	4	72	4	72	5
58	2500 E State 121	176	250	307	375	48	2	54	2	60	2	66	2
59	HWY 40 and 1200 South	120	160	199	238	42	2	48	2	48	2	54	2
60	HWY 40 and 1700 South	89	185	254	329	36	2	48	2	54	2	60	2
61	HWY 40 and 3625 South	120	160	199	238	42	2	48	2	48	2	54	2

			Ashley Creek only		Ashley Creek & rainfall		Recommendation
Item	Location		100	500	100	500	
			Flow (cfs)				
62	2500 West and Ashley Creek		4,134	4,655	4,717.46	5,542.40	Bridge
63	1500 West and Ashley Creek		4,134	4,655	4,717.46	5,542.40	Bridge
64	500 West and Ashley Creek		4,134	4,655	4,767.13	5,625.10	Bridge
65	HWY 191 and Ashley Creek		4,134	4,655	4,767.13	5,625.10	Bridge
66	500 East and Ashley Creek		4,134	4,655	4,770.97	5,631.73	Bridge
67	500 North and Ashley Creek		4,134	4,655	6,838.95	8,658.80	Bridge

Table 7-1 provides recommended sizes for culverts to safely pass the 10- through 100-year event. On average it is recommend that these crossings be sized to pass a minimum of the 25-year event. However, at key locations such as primary roadways, the 50- and 100-year flows should be considered. Larger flows should also be considered in cases where backing up storm water would result in flooding. Where the impoundment of storm water could result in damage to structures the crossings should be designed to pass a minimum of the 100-year event. The crossing upgrades should be ranked as a medium priority.

7.2.2 Recommended Control and Diversion Improvements

The following table describes the major recommended control and diversion improvements that are required to divert flow around or reduce peak flow through developed areas of the Valley. A summary of the recommended improvements are listed in Table 7-2.

Table 7-2 Recommended Control and Diversion Improvements

Item	Approximate Location	Recommended Action	Units	Unit	Priority*
68	4000 West, 1500 North (Coalmine Basin)	Construct Large Debris Basin	160	AF	A
69	4000 West and 2000 North	Construct Large Debris Basin	112	AF	A
70	1500 South above Highline Canal	Construct Small Debris Basin	5	AF	B
71	3000 South above Highline Canal	Construct Small Debris Basin	5	AF	B
72	3300 South above Highline Canal	Construct Small Debris Basin	5	AF	B
73	3700 South above Highline Canal	Construct Small Debris Basin	5	AF	B
74	4000 South above Upper Ashley Canal	Construct Small Debris Basin	5	AF	B
75	5000 South above Upper Ashley Canal	Construct Small Debris Basin	5	AF	B
76	3300 North, 750 East	Construct Large Debris Basin	130	AF	B
77	1200 East, 2900 North	Construct Large Debris Basin	90	AF	B
78	2850 East, 1500 North	Construct Large Debris Basin	95	AF	B
79	500 South, 3200 East	Construct Large Debris Basin	120	AF	B
80	1400 South, 3900 East	Construct Large Debris Basin	75	AF	B
81	2400 West and 700 North	Construct Detention Pond	24	EA	B
82	1750 West and 350 South	Construct Detention Pond	25	EA	B
83	1200 West and 1000 North	Construct Detention Pond	20	EA	B
84	1580 West and 475 South	Construct Detention Pond	15	EA	B
85	1560 West and 300 South	Construct Detention Pond	20	EA	B
86	Ashley Central Canal at 1200 West and 1200 South	Construct Detention Pond	10	EA	B
87	Ashley Central Canal at 300 West and 2700 South	Construct Detention Pond	40	EA	B
88	800 East and 1100 South	Construct Detention Pond	50	EA	B
89	800 East and 1600 South	Construct Detention Pond	45	EA	B
90	HWY 40 and 1200 South	Construct Detention Pond	45	EA	B
91	HWY 40 and 1700 South	Construct Detention Pond	40	EA	B
92	2000 East and 1200 South	Construct Detention Pond	50	EA	B
93	2000 East and 1750 South	Construct Detention Pond	100	EA	B
94	Highline / Upper Ashley Canal from US-191 to ~4000 S	Construct Storm Water Canal	50,000	LF	C
95	Ashley Central Canal from 300 S to 2500 S	Construct Storm Water Canal	15,000	LF	C
96	US-191 & 4000 W to 3000 W & Ashley Creek	Construct Storm Water Canal	20,000	LF	C

Item	Approximate Location	Recommended Action	Units	Unit	Priority*
	Miscellaneous	Restore Natural Channel	10,000	LF	A

* Priority A: Short-term, B: Intermediate-term, C: Long-term

7.2.2.1 Debris Basins

Debris basins are recommended on the outskirts of the Valley where major drainages from the hillsides enter the Valley flats. As the name implies, the purpose of debris basins is to capture debris that flows down the mountain channels during high-flow events. Due to the nature of the local topology, the higher regions of the Valley are steep, resulting in high-energy storm water runoff which often mobilizes large debris such as rocks and tree limbs. When this debris enters the flat, lower energy Valley, the debris settles out and can potentially block key flow paths during flooding events. To ensure that the waterways remain free flowing during high-flow events, it is important that as much debris as possible be removed from the flow in a controlled manner. ***It is recommended that debris basins be constructed at the base of the major drainage basins.***

7.2.2.2 Detention Basins

Detention basins are recommended in numerous locations throughout the Valley. The purpose of the detention basin is to alter the storm water hydrograph. Existing flows generally result in high intensity, short duration peak flows that can cause large amounts of erosion and require a fairly large floodplain. Detention basins store the highest portion of the peak flow and instead release a smaller, controlled flow over a longer period of time. By constructing detention basins along the major drainages, the flows can be controlled to be less damaging, and allow for smaller, less costly downstream improvements to provide adequate protection. ***It is recommended that detention basins be constructed throughout the major channels within the Valley to minimize the peak flow and protect downstream channels and structures.***

7.2.2.3 Storm Water Canals

Construction of two major storm water canals is recommended in order to divert water around Vernal City and the community of Maeser. The first canal is located in the northwest corner of the Valley. The canal will divert water from the drainage near US-121 and from Coal Mine Basin north to Ashley Creek following an alignment generally between the Highline Canal and the Upper Ashley Canal. Working in tandem with debris basins, this canal will divert the majority of storm water that currently threatens Maeser and the northern portions of Vernal City.

The second recommended canal will follow the existing alignments of the Highline Canal and the Upper Ashley Canal beginning at US-121 and running south around the Valley and either diverting storm water into adjacent canals or carrying flow all the way to the Green River. This canal will collect the highest runoff of the Valley and serve to collect much of the debris that currently runs off the hillsides. The canal will also provide a means to divert some storm water away from channels that may be experiencing capacity limitations or have not yet been fully upgraded. ***It is recommended that two canals be constructed to divert storm water around the key development areas of Maeser and Vernal City.***

7.2.3 ASHLEY CREEK IMPROVEMENTS

As stated previously, the major drainage through the Valley is Ashley Creek. Over the years, portions of this drainage have been modified in an attempt to increase channel capacity, limit flooding, divert flows for irrigation and to provide transportation and utility crossings. [1]The largest single change to Ashley Creek occurred in the 1960's when the Army Corps channelized and straightened a reach of Ashley Creek from the Thornburgh Diversion to approximately the golf course. The intent of this project was to increase the capacity and reduce flooding of the main channel. Providing additional capacity in the main channel allowed the historic meanders of Ashley Creek (the north and south channels) to be developed for agricultural and urbanization. The project increased the bed slope by approximately 50%, removed the meanders and provided sufficient capacity for approximately the 50 year event. The increased main channel capacity resulted in increased erosion, and ultimately, stream instability.

A detailed study of the stability of Ashley Creek was conducted in 1998 and 2000 by Mussetter Engineering Incorporated (MEI). The study indicated that the increased sediment transport and subsequent downstream deposition will likely continue to modify the river channel and may result in increased flooding potential near and below the golf course. Additionally, excessive erosion between the Thornburgh Diversion and the golf course will eventually result in channel migration and threaten existing structures. The bridges across Ashley Creek are also noted as undersized, which results in local flooding and sediment deposition.

Also, in May 2000 MEI and Franson Noble & Assoicates, Inc published a Stabilization/Restoration Report based on the MEI analysis. The alternatives for stream rehabilitation ranged from no changes to complete restoration of the entire channel reach. Erosion control measures, debris basins, and dam construction were also evaluated as part of the study. The study also considered diverting high water flows into the irrigation canals to relieve the peak flow from Ashley Creek. The basin-wide flood analysis contained herein suggests that the canals will fill with storm water from sources other than Ashley Creek, and as development of the Valley continues, locations to turn out the water will become more limited. ***It is recommended that the irrigation canals not be used as part of the Ashley Creek flood control project so that they can be used to control other flooding concerns throughout the Valley.***

Each of the proposed alternatives in the May 2000 report was compared to the flood protection methodology recommended in this report, "to protect and restore drainages where possible, and divert where necessary." The Ashley Creek improvement project alternative that is most closely aligned with the recommended methodology is alternative 9. This alternative consists of the following parameters and specific major projects described in Table 7-3:

1) Creek management to develop a monitoring and maintenance program;

2) Bridge enlargement (discussed in the previous section);

3) Soft Bank Stabilization to control erosion;

[1] Historic information summarized from Hydraulic and Geomorphic Analyses May 2000 MEI

4) Riparian restoration to reduce stream velocities and provide numerous other desirable benefits;

5) Provide upstream storage to minimize peak flows and provide water to future riparian zones.

Table 7-3 Recommended Ashley Creek Improvements

Item	Approximate Location	Recommended Action	Units	Unit	Priority*
97	Ashley Creek from Thornburgh Diversion to Golf Course	Restore Natural Channel	330,000	LF	C
98	Trout Creek Dam	Construct Spring Creek (or equivalent) Dam	1	EA	C
99	Spring Creek Drainage above Ashley Creek	Construct Spring Creek (or equivalentl) Dam	1	EA	C
100	20% of area above Thornburg Diversion	Watershed management	30,000	AC	B

* Priority A: Short-term, B: Intermediate-term, C: Long-term

It is recommended that the modified version of alternative 9 be implemented to restore Ashley Creek and mitigate future flooding concerns and minimize sediment transport.

Providing additional storage reservoir(s) above the Valley may become a controversial and environmentally challenging project to obtain funding and the necessary permits. While it is the preferred alternative in this report it may not be a feasible flood protection alternative. In the event that upstream storage cannot be constructed, the next best alternative for Ashley Creek would be to provide a series of small in-stream debris basins and deepen the channel to provide additional capacity through the developed areas of the Valley.

7.2.4 IRRIGATION CANALS

As discussed previously in this document there are a number of locations throughout the Valley where storm water is directed into the irrigation network. As the cities grow this co-mingled water can cause diminished water quality. ***It is recommended that future construction projects be required to maintain separate conduits for irrigation and storm water, and that existing storm water discharge into irrigation channels be modified to maintain the required separation as future improvements are constructed throughout the region.***

7.3 OPINION OF PROBABLE IMPROVEMENT COST

The following section provides a cost estimate to construct the projects described in the sections above. These costs are based on estimates for excavation, engineered fill, storm water piping and other construction activities obtained from 2007 and 2008, in addition to engineering judgment. Additional detail describing the basis for these costs is provided in the Appendix. The costs provided are intended to provide an approximate funding price tag. These costs do not include property acquisition (with the exception of detention basins), replacement of other utilities, or costs not directly associated with the design and construction of the recommended improvement. The opinion of probable costs is presented in 2008 U.S. dollars, ENR cost index 8,184.94; no attempt to project the future cost of these improvements is presented herein. Table 7-4 below presents the estimated unit costs to construct the general types of improvements described above.

Table 7-4 Opinion of Probable Unit Construction Costs

Improvement	Base Cost Unit Cost	Base Cost Unit	Incremental Cost Unit Cost	Incremental Cost Unit
*Canal Construction / Reconstruction	$ 51.00	LF	$ 0.20	CFS-LF
*Concrete Levee Construction	$ 541.00	LF	$ -	-
*Earth Levee Construction	$ 393.00	LF	$ -	-
*Detention Basin Construction	$ 42,621.00	EA	$ 2,640.00	AF
*Debris Basin Construction	$ 282,710.00	EA	$ 2,640.00	AF
**Bridge Replacement	$ 320,000.00	EA	$ -	-
**Stream Rehabilitation	$ 120.00	LF	$ -	-
**Spring Creek Dam	$38,000,000.00	EA	$ -	-
**Watershed Management	$ 500.00	AC	$ -	-
Increase Culvert – 18 in.	$ 106.75	LF	$ -	-
Increase Culvert – 21 in.	$ 91.50	LF	$ -	-
Increase Culvert – 24 in.	$ 97.60	LF	$ -	-
Increase Culvert – 27 in.	$ 109.80	LF	$ -	-
Increase Culvert – 30 in.	$ 122.00	LF	$ -	-
Increase Culvert – 36 in.	$ 146.40	LF	$ -	-
Increase Culvert – 42 in.	$ 183.01	LF	$ -	-
Increase Culvert – 48 in.	$ 231.81	LF	$ -	-
Increase Culvert – 54 in.	$ 274.51	LF	$ -	-
Increase Culvert – 60 in.	$ 301.96	LF	$ -	-
Increase Culvert – 66 in.	$ 305.01	LF	$ -	-
Increase Culvert – 72 in.	$ 366.01	LF	$ -	-
Increase Culvert – 78 in.	$ 475.81	LF	$ -	-
Increase Culvert – 84 in.	$ 640.52	LF	$ -	-
Increase Culvert – 90 in.	$ 869.27	LF	$ -	-
Increase Culvert – 96 in.	$ 1,098.03	LF	$ -	-
Increase Culvert – 102 in.	$ 1,296.29	LF	$ -	-

* Costs do not include land acquisition
** Costs from Franson-Noble & Associates, Inc May 2000 report Table 4-1 Cost Estimates for Components plus 3% annual inflation

In addition to the estimated direct construction costs, the design, construction management, legal, and administrative costs must also be considered. This report assigns overhead costs as a percentage of the raw construction cost estimates as shown in Table 7-5.

Table 7-5 Administrative Fees

Item	Percent of Construction Cost
Engineering	8%
Construction Management and Survey	7%
Administration	2%
Legal	1%
Contingency	15%
Total	33%

Based on the unit costs described above, an estimated cost for each of the recommended construction projects are shown in Table 7-7, Table 7-6, and Table 7-8 below.

Table 7-6 Opinion of Probable Crossing Improvement Cost

		Storm Event			
Item	Location	10	25	50	100
1	4105 W State 121 @ future canal	$ 62,573.37	$ 82,872.33	$ 106,853.81	$ 124,308.49
2	3850 W 1500 N @ future canal	$ 106,853.81	$ 160,280.72	$ 160,280.72	$ 213,707.63
3	2000 N 3500 W @ future canal	$ 207,180.82	$ 336,898.86	$ 417,059.95	$ 417,059.95
4	1750 N 3500 W	$ 7,198.40	$ 7,198.40	$ 7,198.40	$ 13,051.57
5	1250 N 3500 W	$ 3,342.46	$ 3,342.46	$ 3,342.46	$ 3,342.46
6	550 N 3500 W	$ 7,198.40	$ 7,198.40	$ 13,051.57	$ 13,051.57
7	400 N 3500 W	$ 21,223.30	$ 32,013.83	$ 45,707.01	$ 45,707.01
8	500 S 3500 W	$ 62,573.37	$ 82,872.33	$ 106,853.81	$ 134,759.54
9	2750 W 1500 N	$ 7,198.40	$ 7,198.40	$ 7,198.40	$ 13,051.57
10	2450 N 2500 W	$ 3,342.46	$ 3,342.46	$ 3,342.46	$ 7,198.40
11	1800 N 2500 W	$ 7,198.40	$ 7,198.40	$ 7,198.40	$ 13,051.57
12	1500 N 2500 W	$ 7,198.40	$ 7,198.40	$ 7,198.40	$ 13,051.57
13	1200 N 2500 W	$ 7,198.40	$ 7,198.40	$ 7,198.40	$ 7,198.40
14	750 N 2500 W	$ 7,198.40	$ 7,198.40	$ 13,051.57	$ 13,051.57
15	100 S 2500 W	$ 21,223.30	$ 32,013.83	$ 45,707.01	$ 45,707.01
16	250 S 2500 W	$ 21,223.30	$ 32,013.83	$ 45,707.01	$ 45,707.01
17	500 S 2500 W	$ 21,223.30	$ 32,013.83	$ 45,707.01	$ 45,707.01
18	1100 S 2500 W	$ 21,223.30	$ 32,013.83	$ 45,707.01	$ 45,707.01
19	2200 N 1500 W	$ 3,342.46	$ 3,342.46	$ 3,342.46	$ 7,198.40
20	1200 N 1500 W	$ 7,198.40	$ 7,198.40	$ 7,198.40	$ 13,051.57
21	1000 N 1500 W	$ 3,342.46	$ 7,198.40	$ 7,198.40	$ 7,198.40
22	900 N 1500 W	$ 7,198.40	$ 7,198.40	$ 13,051.57	$ 13,051.57
23	450 S 1500 W	$ 45,707.01	$ 62,573.37	$ 82,872.33	$ 82,872.33
24	600 S 1400 W	$ 45,707.01	$ 62,573.37	$ 62,573.37	$ 82,872.33
25	1150 S 1500 W	$ 21,223.30	$ 32,013.83	$ 45,707.01	$ 45,707.01
26	2100 S 1500 W	$ 21,223.30	$ 32,013.83	$ 45,707.01	$ 45,707.01
27	900 W 1500 S	$ 21,223.30	$ 32,013.83	$ 45,707.01	$ 45,707.01
28	1000 N 500 W	$ 3,342.46	$ 3,342.46	$ 3,342.46	$ 3,342.46
29	750 N 500 W	$ 13,051.57	$ 21,223.30	$ 21,223.30	$ 32,013.83
30	700 S 500 W	$ 32,013.83	$ 45,707.01	$ 45,707.01	$ 62,573.37
31	1580 S 500 W	$ 21,223.30	$ 32,013.83	$ 45,707.01	$ 45,707.01
32	2800 S 500 W	$ 32,013.83	$ 45,707.01	$ 62,573.37	$ 62,573.37
33	3500 S 500 W	$ 32,013.83	$ 45,707.01	$ 62,573.37	$ 62,573.37
34	2600 N Vernal Ave	$ 7,198.40	$ 13,051.57	$ 13,051.57	$ 21,223.30
35	2000 N Vernal Ave	$ 3,342.46	$ 3,342.46	$ 3,342.46	$ 7,198.40
36	750 N Vernal Ave	$ 13,051.57	$ 21,223.30	$ 21,223.30	$ 32,013.83
37	400 N Vernal Ave	$ 21,223.30	$ 32,013.83	$ 45,707.01	$ 45,707.01
38	900 S Vernal Ave	$ 32,013.83	$ 45,707.01	$ 45,707.01	$ 62,573.37
39	1750 S Vernal Ave	$ 21,223.30	$ 32,013.83	$ 45,707.01	$ 62,573.37
40	2250 S Vernal Ave	$ 32,013.83	$ 45,707.01	$ 62,573.37	$ 62,573.37
41	2500 S Vernal Ave	$ 32,013.83	$ 45,707.01	$ 62,573.37	$ 62,573.37

		Storm Event			
Item	Location	10	25	50	100
42	3300 S Vernal Ave	$ 32,013.83	$ 45,707.01	$ 62,573.37	$ 62,573.37
43	1100 S 500 E	$ 45,707.01	$ 62,573.37	$ 62,573.37	$ 62,573.37
44	1580 S 500 E	$ 32,013.83	$ 45,707.01	$ 62,573.37	$ 62,573.37
45	2100 S 500 E	$ 3,342.46	$ 13,051.57	$ 21,223.30	$ 21,223.30
46	360 E 2500 S	$ 3,342.46	$ 13,051.57	$ 21,223.30	$ 21,223.30
47	2800 S 500 E	$ 3,342.46	$ 13,051.57	$ 21,223.30	$ 21,223.30
48	3300 S 500 E	$ 32,013.83	$ 45,707.01	$ 62,573.37	$ 62,573.37
49	250 N 1500 E	$ 21,223.30	$ 32,013.83	$ 32,013.83	$ 45,707.01
50	1500 E Main	$ 7,198.40	$ 13,051.57	$ 13,051.57	$ 13,051.57
51	1200 S Airport	$ 32,013.83	$ 45,707.01	$ 62,573.37	$ 62,573.37
52	1550 S Airport	$ 21,223.30	$ 45,707.01	$ 45,707.01	$ 62,573.37
53	US-40, 2500 S	$ 3,342.46	$ 13,051.57	$ 21,223.30	$ 21,223.30
54	3200 S 1500 E	$ 32,013.83	$ 45,707.01	$ 62,573.37	$ 62,573.37
55	1200 S 2000 E	$ 32,013.83	$ 45,707.01	$ 45,707.01	$ 62,573.37
56	1750 S 2000 E	$ 21,223.30	$ 45,707.01	$ 62,573.37	$ 82,872.33
57	2300 E State 121	$ 160,280.72	$ 213,707.63	$ 269,519.08	$ 336,898.86
58	2500 E State 121	$ 45,707.01	$ 62,573.37	$ 82,872.33	$ 106,853.81
59	HWY 40 and 1200 South	$ 32,013.83	$ 45,707.01	$ 45,707.01	$ 62,573.37
60	HWY 40 and 1700 South	$ 21,223.30	$ 45,707.01	$ 62,573.37	$ 82,872.33
61	HWY 40 and 3625 South	$ 32,013.83	$ 45,707.01	$ 45,707.01	$ 62,573.37
		Ashley Creek only		Ashley Creek & rainfall	
		Storm Event		Storm Event	
		100	500	100	500
62	2500 West and Ashley Creek	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 320,000.00
63	1500 West and Ashley Creek	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 320,000.00
64	500 West and Ashley Creek	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 320,000.00
65	HWY 191 and Ashley Creek	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 320,000.00
66	500 East and Ashley Creek	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 320,000.00
67	500 North and Ashley Creek	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 320,000.00
	Totals	**$ 3,607,643.44**	**$ 4,418,062.91**	**$ 5,028,597.71**	**$ 5,482,387.32**

Table 7-7 Opinion of Probable Control and Diversion Improvement Cost

Item	Approximate Location	Recommended Action	Estimated Cost
68	4000 West, 1500 North (Coalmine Basin)	Construct Large Debris Basin	$ 937,796.30
69	4000 West and 2000 North	Construct Large Debris Basin	$ 769,258.70
70	1500 South above Highline Canal	Construct Small Debris Basin	$ 31,727.48
71	3000 South above Highline Canal	Construct Small Debris Basin	$ 31,727.48
72	3300 South above Highline Canal	Construct Small Debris Basin	$ 31,727.48
73	3700 South above Highline Canal	Construct Small Debris Basin	$ 31,727.48
74	4000 South above Upper Ashley Canal	Construct Small Debris Basin	$ 31,727.48
75	5000 South above Upper Ashley Canal	Construct Small Debris Basin	$ 31,727.48
76	3300 North, 750 East	Construct Large Debris Basin	$ 832,460.30
77	1200 East, 2900 North	Construct Large Debris Basin	$ 692,012.30
78	2850 East, 1500 North	Construct Large Debris Basin	$ 709,568.30
79	500 South, 3200 East	Construct Large Debris Basin	$ 797,348.30
80	1400 South, 3900 East	Construct Large Debris Basin	$ 639,344.30
81	2400 West and 700 North	Construct Detention Pond	$ 140,954.73
82	1750 West and 350 South	Construct Detention Pond	$ 144,465.93
83	1200 West and 1000 North	Construct Detention Pond	$ 126,909.93
84	1580 West and 475 South	Construct Detention Pond	$ 109,353.93
85	1560 West and 300 South	Construct Detention Pond	$ 126,909.93
86	Ashley Central Canal at 1200 West and 1200 South	Construct Detention Pond	$ 91,797.93
87	Ashley Central Canal at 300 West and 2700 South	Construct Detention Pond	$ 197,133.93
88	800 East and 1100 South	Construct Detention Pond	$ 232,245.93
89	800 East and 1600 South	Construct Detention Pond	$ 214,689.93
90	HWY 40 and 1200 South	Construct Detention Pond	$ 214,689.93
91	HWY 40 and 1700 South	Construct Detention Pond	$ 197,133.93
92	2000 East and 1200 South	Construct Detention Pond	$ 232,245.93
93	2000 East and 1750 South	Construct Detention Pond	$ 407,805.93
94	Highline / Upper Ashley Canal from US191 to~ 4000 S	Construct Storm Water Canal	$ 3,391,766.00
95	Ashley Central Canal from 300 S to 2500 S	Construct Storm Water Canal	$ 1,017,556.40
96	US-191 & 4000 W to 3000 W & Ashley Creek	Construct Storm Water Canal	$ 1,356,999.00
	Misc.	*Restore Natural Channel	$ 1,596,000.00
		Total	**$ 15,366,812.69**

Table 7-8 Opinion of Probable Ashley Creek Improvement Cost

Item	Approximate Location	Recommended Action	Estimated Cost
97	Ashley Creek from Thornburgh Diversion to Golf Course	*Restore Natural Channel	$ 52,668,000.00
98	Trout Creek Dam	* Construct Spring Creek (or equivalent) Dam	$ 50,540,000.00
99	Spring Creek Drainage above Ashley Creek	* Construct Spring Creek (or equivalent) Dam	$ 66,500,000.00
100	20% of area above Thornburg Diversion	Watershed Management	$ 19,950,000.00
		Total	**$ 189,658,000.00**

7.4 RECOMMENDED STORM WATER POLICIES

A number of policy changes will be required to protect the Valley from flooding. The most important policy change is to require that all of the remaining natural drainages be preserved. Other policy issues that should be evaluated are the requirements for storm water management under conditions of new development. These policy issues are discussed in more detail below.

7.4.1 DESIGNATED FLOODWAY PROTECTION / RESTORATION

In addition to the recommended improvements discussed above, the key component to ensuring that both existing and future developments are protected from flooding is to ensure that the remaining natural channels be preserved. Currently, there are no clearly defined policies in place to prevent the development of a historic floodway. For the plan proposed herein it is imperative that each of the three major governing entities within the Valley adopt policies that do not allow development within or modification of natural floodways, and prohibit the rebuilding of existing structures within floodways. The major channels are highlighted in Table 7-2 above.

The second and potentially more difficult portion of the recommended methodology is to restore drainages where possible. There are a number of drainages throughout the basin that are largely intact and can be preserved for future flows. However, in one or two locations these channels have been modified and developed. It is recommended that the channels shown in Table 7-2 as preserve and protect be restored or reconstructed as required to maintain the historic channel capacity. One example of a floodway that has been developed is along the drainage channel south of Vernal near 500E. The channel in this location has been filled and the historic drainage capacity significantly diminished.

It is recommended that each governing adjacencies modify their zoning code and ordinances, etc., to reflect the following actions:

- ***Prohibit development within existing flood channels highlighted in Table 7-2;***
- ***Prohibit the modification, including piping, of major drainage channels;***
- ***Prohibit the reconstruction of developments currently within the existing flood channels.***

7.4.2 Future Development Requirements

In addition to preventing development in flood channels it is imperative that the flood channels are not obstructed or filled through future roadways or similar development.

7.4.2.1 Onsite Detention / Retention

One of the key assumptions throughout the modeling is that the local municipalities will continue to require detention or retention for each new development. Continuing to require local retention / detention will preserve the existing flow patterns which will keep the high water flows in the banks. of the existing channels. The regional detention basins described above are intended to reduce the peak flows and velocities through key areas. They are not intended to replace or diminish the requirements for local detention basins.

It is recommended that each municipality adopt or continue to include requirements on new development that:

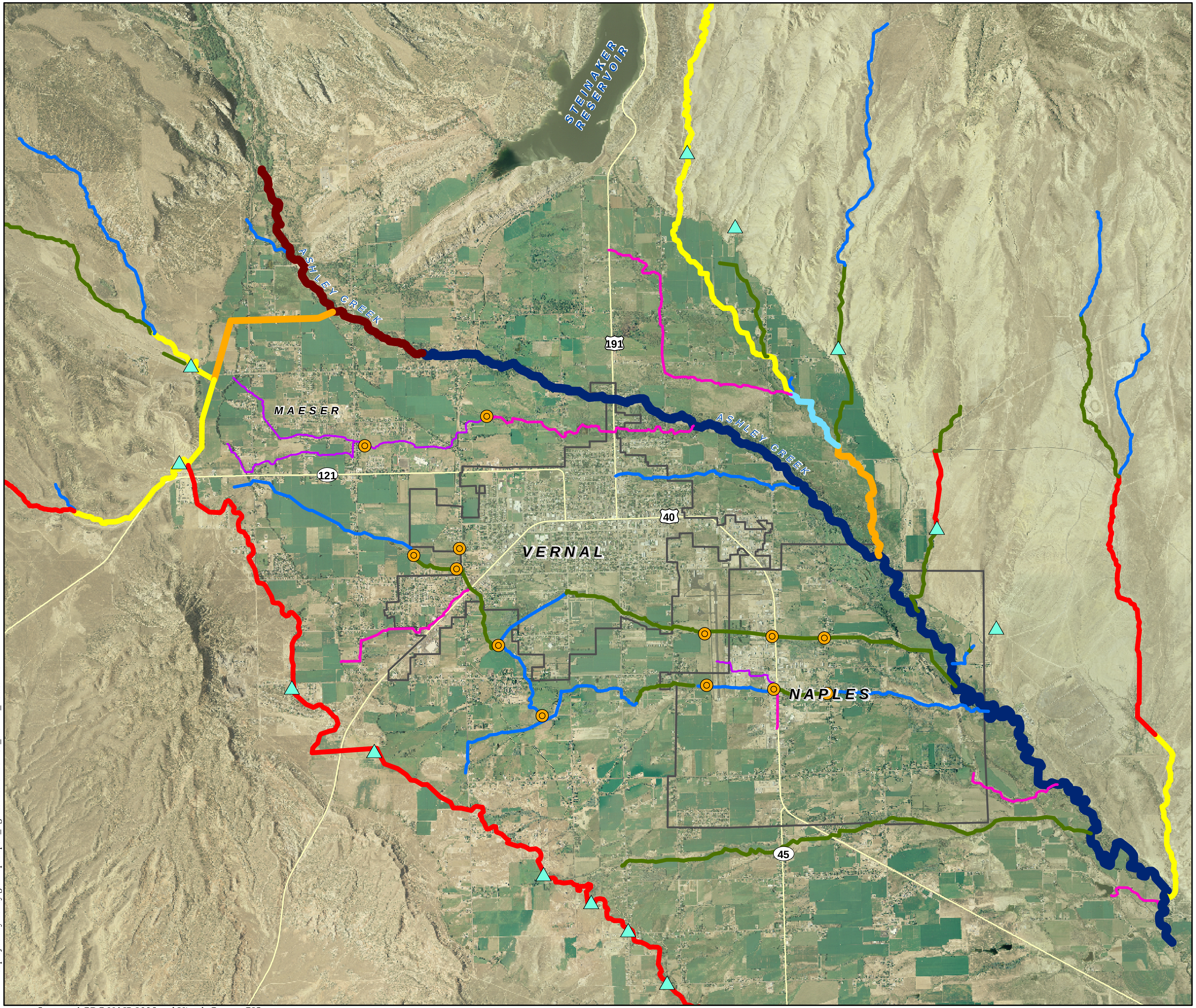
- ***Require local detention/ retention of storm water for all new development;***
- ***Require that each detention/ retention basin contain an overflow designed to safely discharge the 100-year flow into a natural stream channel;***
- ***That the basins be designed such that the final discharge is less then historical peak flows for the 10-, 50-, and 100-year storm events.***

7.4.2.2 Parks, Open Space and Trail System

To offset the costs, monetary and otherwise by requiring the flood channels be preserved, ***it is recommended that the preserved flood corridors be preserved through open space credits and to potentially provide trail corridors and parks.***

7.5 Simulated Peak Flows With Improvements

Once the recommended improvements were identified and conceptually designed, they were entered into the model to determine: 1) the size required for each improvement, 2) the downstream flows with the recommended system working and 3) to ensure that large storm events will pass through the communities without major flooding when the recommended improvements are in place. Figure 7-4, Figure 7-5, Figure 7-6, Figure 7-7 and Figure 7-8 below indicate the anticipated modified peak flows from the respective storm events utilizing the recommended improvements.



Source: AGRC NAIP 2006 and Uintah County GIS.

s:\proj\ashley-valley\gis\maps\report_figures\futuremodified_channel_flows.mxd

FIGURE 7-4
ESTIMATED FUTURE MODIFIED 10-YEAR CHANNEL FLOWS ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008

Legend

- Debris Basin
- Detention Pond
- Major Road
- Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

N
W E
S

0 5,000 10,000 Feet

1 INCH = 5,000 FEET

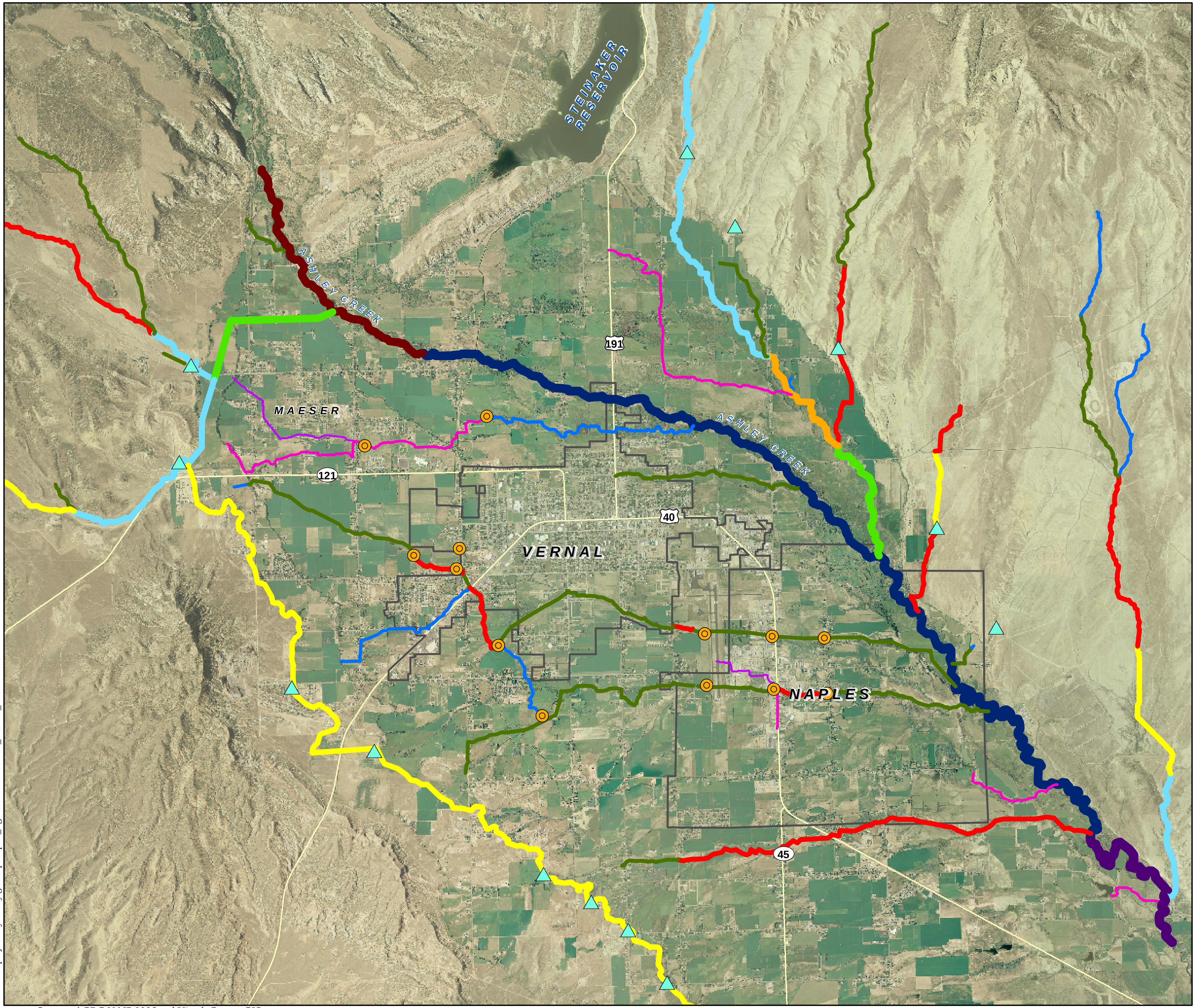
Epic Engineering

3341 SOUTH 4000 WEST
WEST VALLEY CITY, UTAH 84120
(801) 955-5605

50 EAST 100 SOUTH
HEBER CITY, UTAH 84032
(435) 654-6600

FIGURE 7-5
ESTIMATED FUTURE MODIFIED 25-YEAR CHANNEL FLOWS
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008



Legend

- Debris Basin
- Detention Pond
- Major Road
- Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

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0 5,000 10,000 Feet

1 INCH = 5,000 FEET

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HEBER CITY, UTAH 84032
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Source: AGRC NAIP 2006 and Uintah County GIS.

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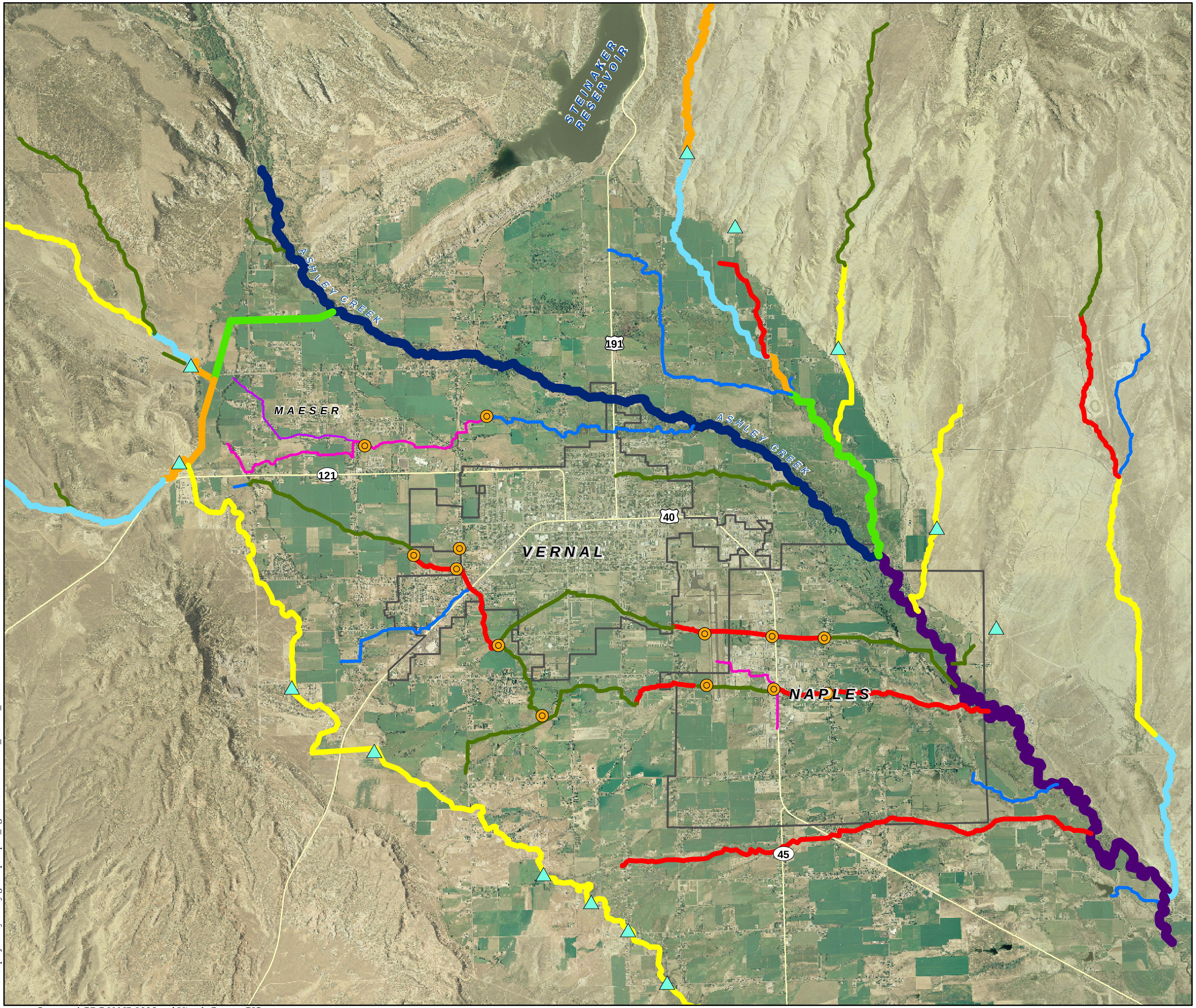
FIGURE 7-6
ESTIMATED FUTURE MODIFIED 50-YEAR CHANNEL FLOWS
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008



Source: AGRC NAIP 2006 and Uintah County GIS.

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Legend

- Debris Basin
- Detention Pond
- Major Road
- Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

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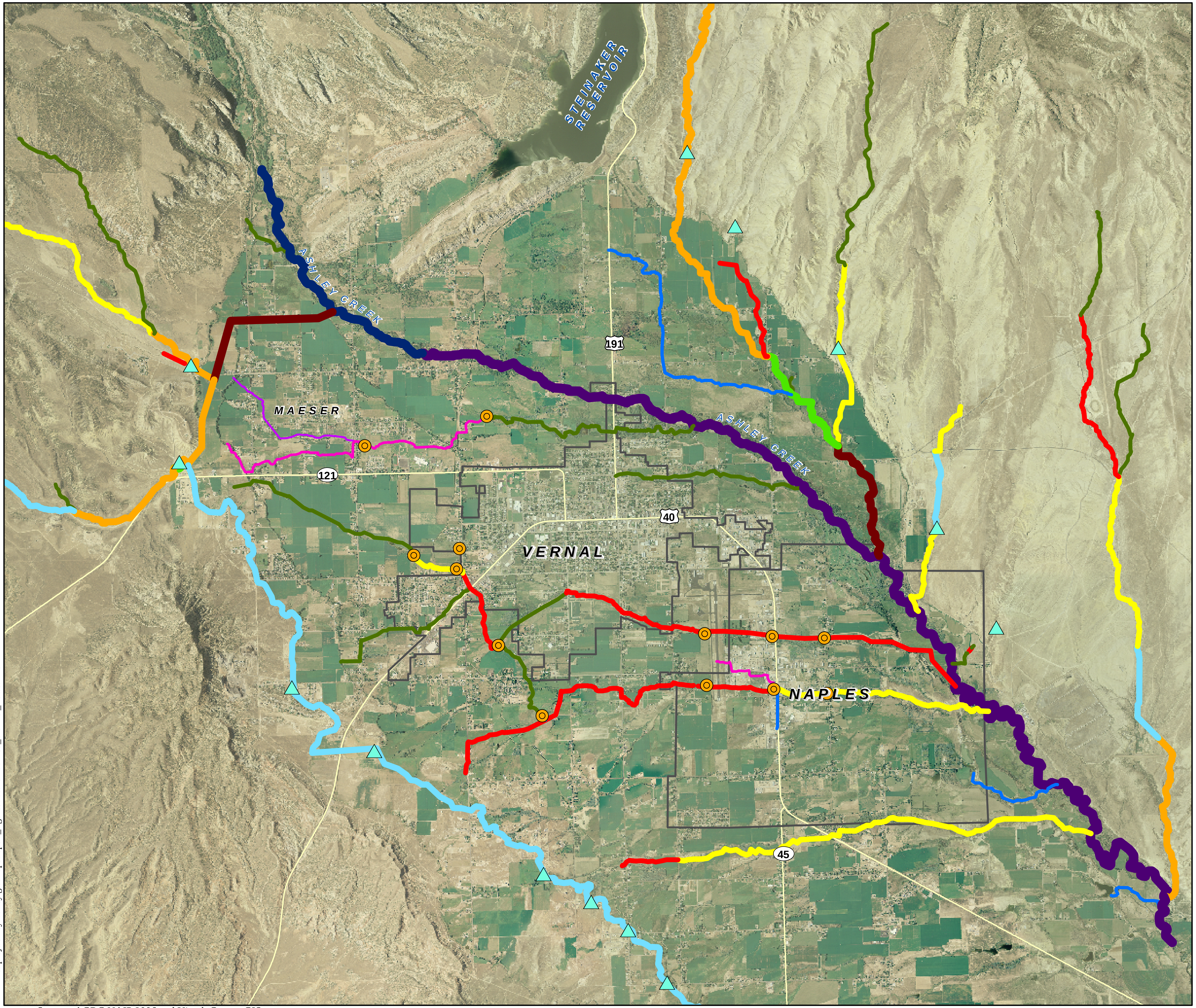

FIGURE 7-7
ESTIMATED FUTURE MODIFIED 100-YEAR CHANNEL FLOWS ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008

Legend

- Debris Basin
- Detention Pond
- Major Road
- Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

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1 INCH = 5,000 FEET

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Source: AGRC NAIP 2006 and Uintah County GIS.

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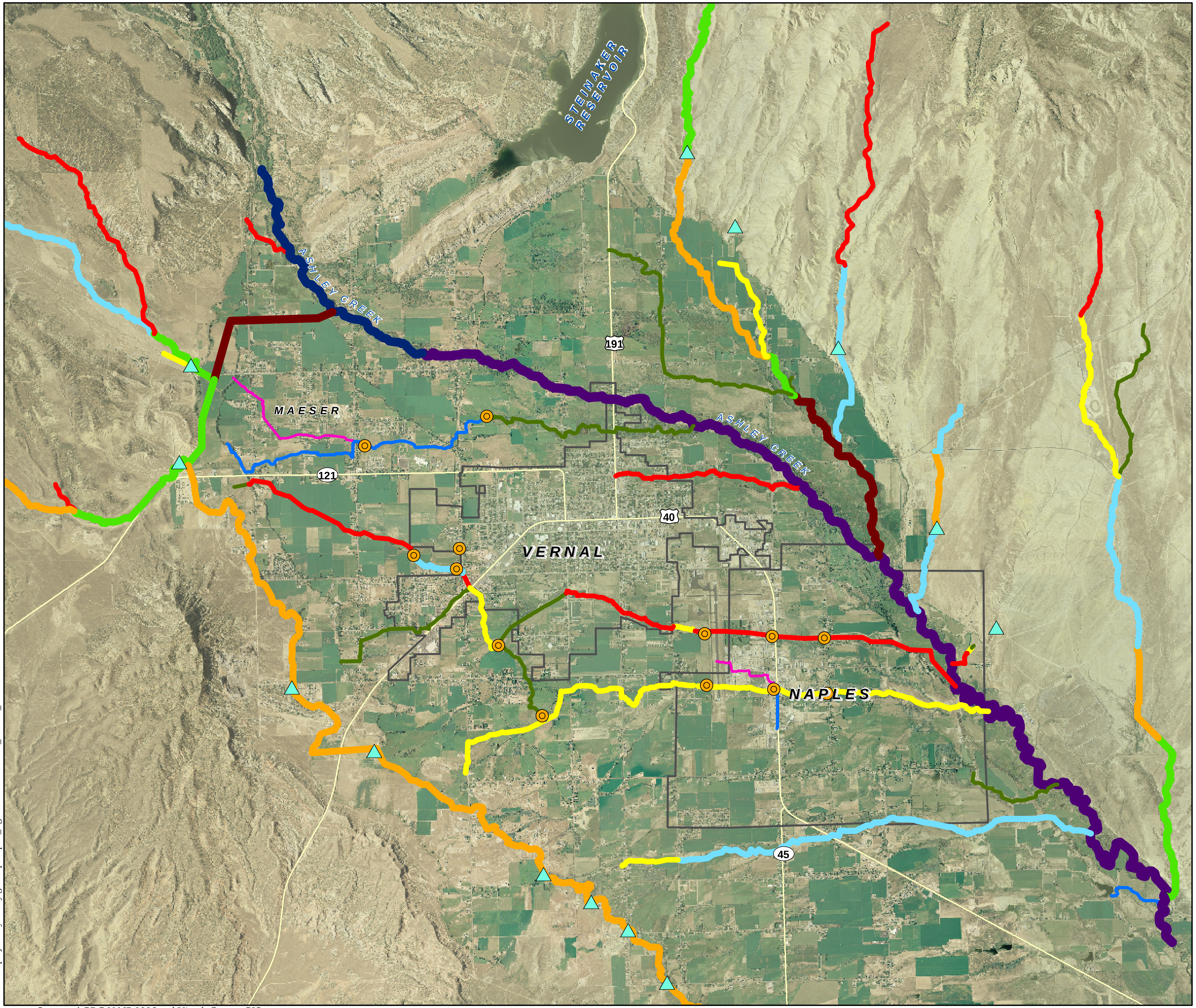
FIGURE 7-8
ESTIMATED FUTURE MODIFIED 500-YEAR CHANNEL FLOWS ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008



Legend

Debris Basin

Detention Pond

Major Road

Municipal Boundary

Storm Event Maximum Flow (cfs)

- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 700
- 701 - 1,000
- 1,001 - 1,500
- 1,501 - 3,000
- 3,001 - 6,000
- > 6,000

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1 INCH = 5,000 FEET

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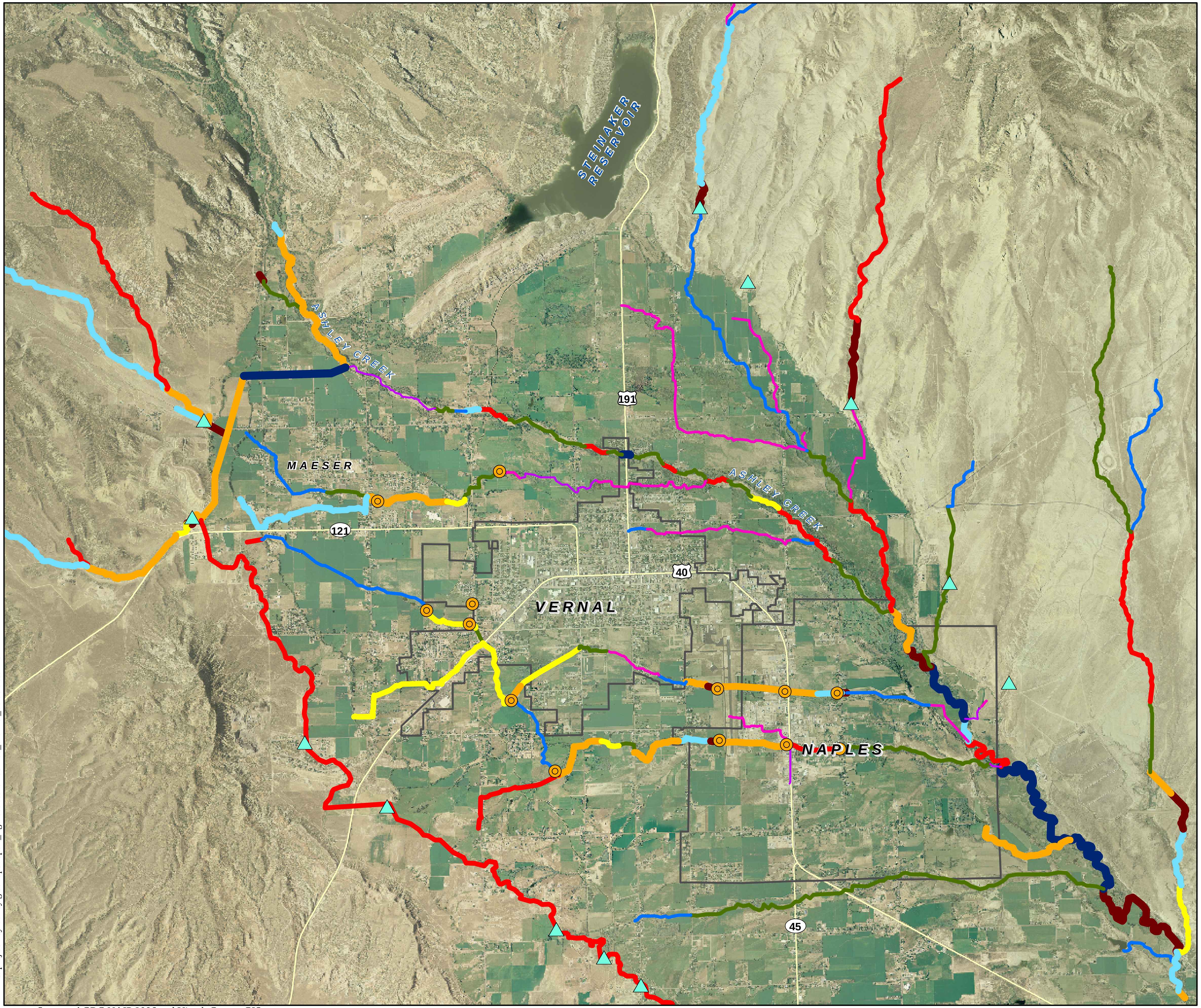
Source: AGRC NAIP 2006 and Uintah County GIS.

7.6 SIMULATED PEAK VELOCITIES WITH IMPROVEMENTS

As with the existing and future model output the peak velocities for each channel were once again computed with the major improvements integrated. Note that through the majority of the Valley the peak storm events, especially for the 10- year and 25- year storms the peak velocities are greatly reduced over existing conditions. The reduced velocities should improve channel stability. The improved channel stability will help maintain the current channel alignment in the future to aid their preservation. The peak channel velocities with the improvements are shown in Figure 7-9, Figure 7-10, Figure 7-11, Figure 7-12, and Figure 7-13, respectively.

FIGURE 7-9
ESTIMATED FUTURE MODIFIED 10-YEAR CHANNEL VELOCITIES
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008



Legend

- Debris Basin
- Detention Pond
- Major Road
- Municipal Boundary

Storm Event Maximum Velocity (ft/s)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 12.0
- 12.1 - 20.0
- > 20

N W E S

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1 INCH = 5,000 FEET

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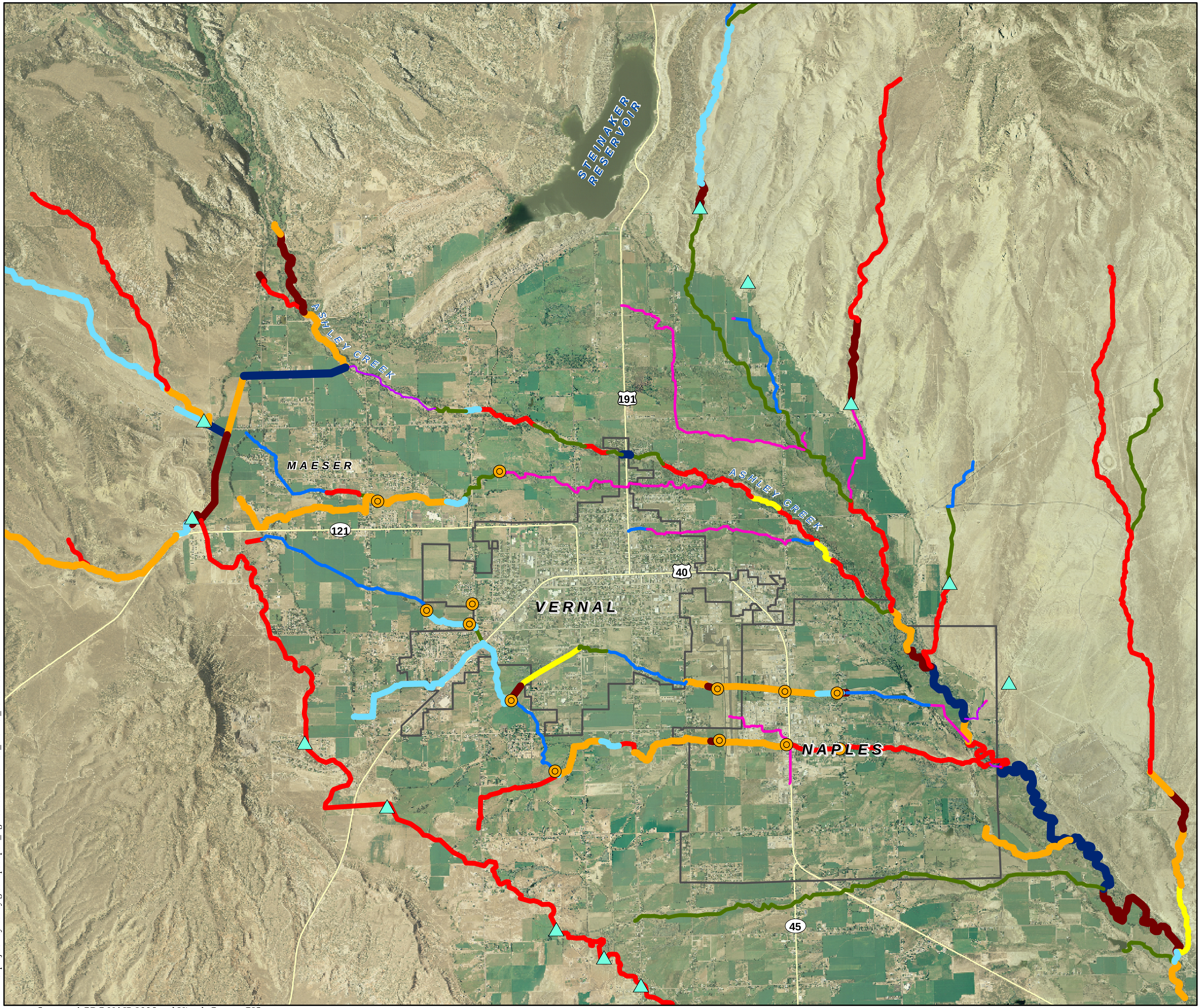
Source: AGRC NAIP 2006 and Uintah County GIS.

FIGURE 7-10
ESTIMATED FUTURE MODIFIED 25-YEAR CHANNEL VELOCITIES
ASHLEY VALLEY
UINTAH COUNTY, UTAH

JUNE 2008



Legend

- Debris Basin
- Detention Pond
- Major Road
- Municipal Boundary

Storm Event Maximum Velocity (ft/s)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 12.0
- 12.1 - 20.0
- > 20

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1 INCH = 5,000 FEET

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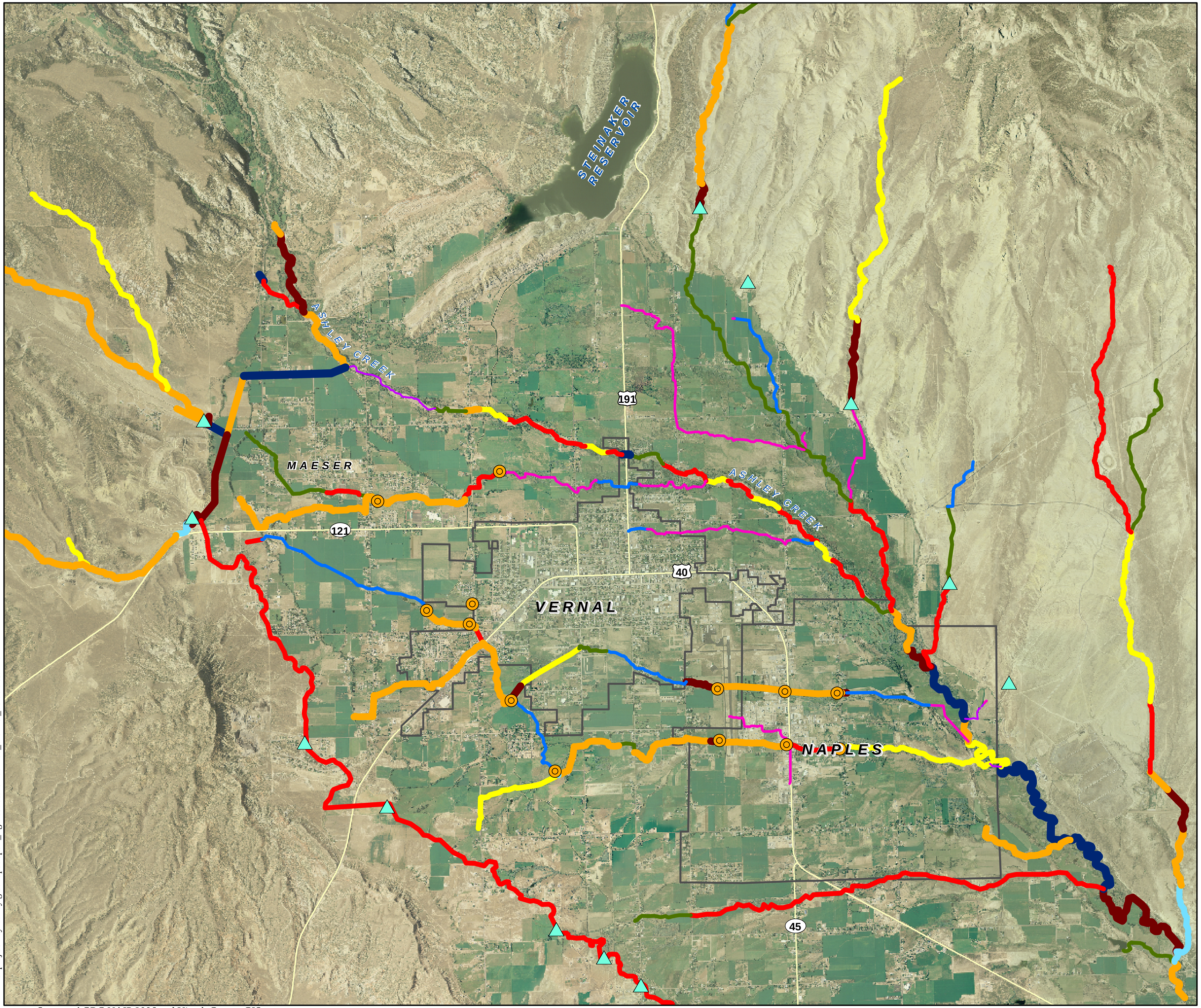
Source: AGRC NAIP 2006 and Uintah County GIS.

FIGURE 7-11
ESTIMATED FUTURE MODIFIED 50-YEAR CHANNEL VELOCITIES ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008



Legend

- Debris Basin
- Detention Pond
- Major Road
- Municipal Boundary

Storm Event Maximum Velocity (ft/s)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 12.0
- 12.1 - 20.0
- > 20

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1 INCH = 5,000 FEET

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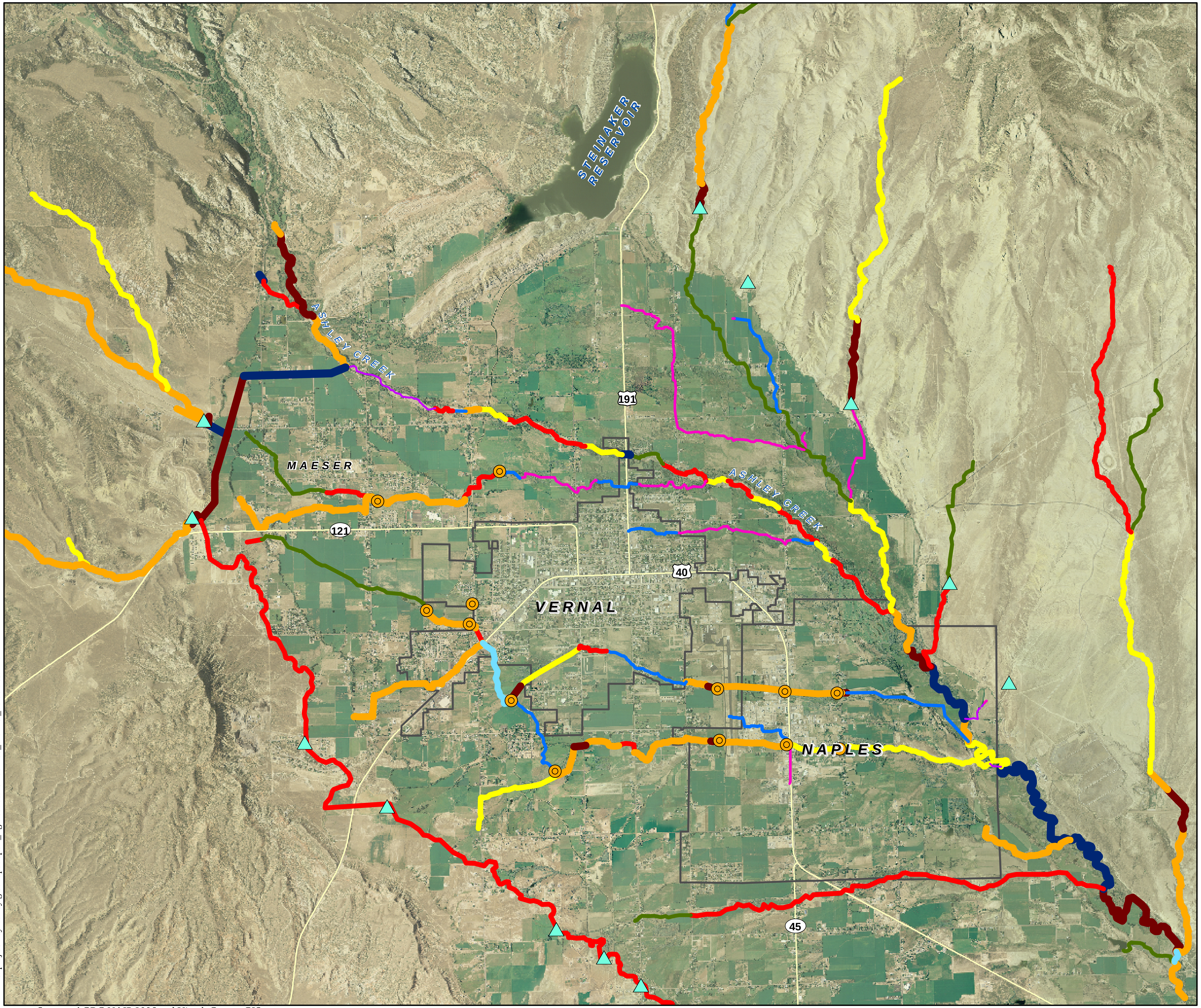
Source: AGRC NAIP 2006 and Uintah County GIS.



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Source: AGRC NAIP 2006 and Uintah County GIS.

FIGURE 7-12
ESTIMATED FUTURE MODIFIED 100-YEAR CHANNEL VELOCITIES ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008

Legend

- Debris Basin
- Detention Pond
- Major Road
- Municipal Boundary

Storm Event Maximum Velocity (ft/s)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 12.0
- 12.1 - 20.0
- > 20

N W E S

0 5,000 10,000 Feet

1 INCH = 5,000 FEET

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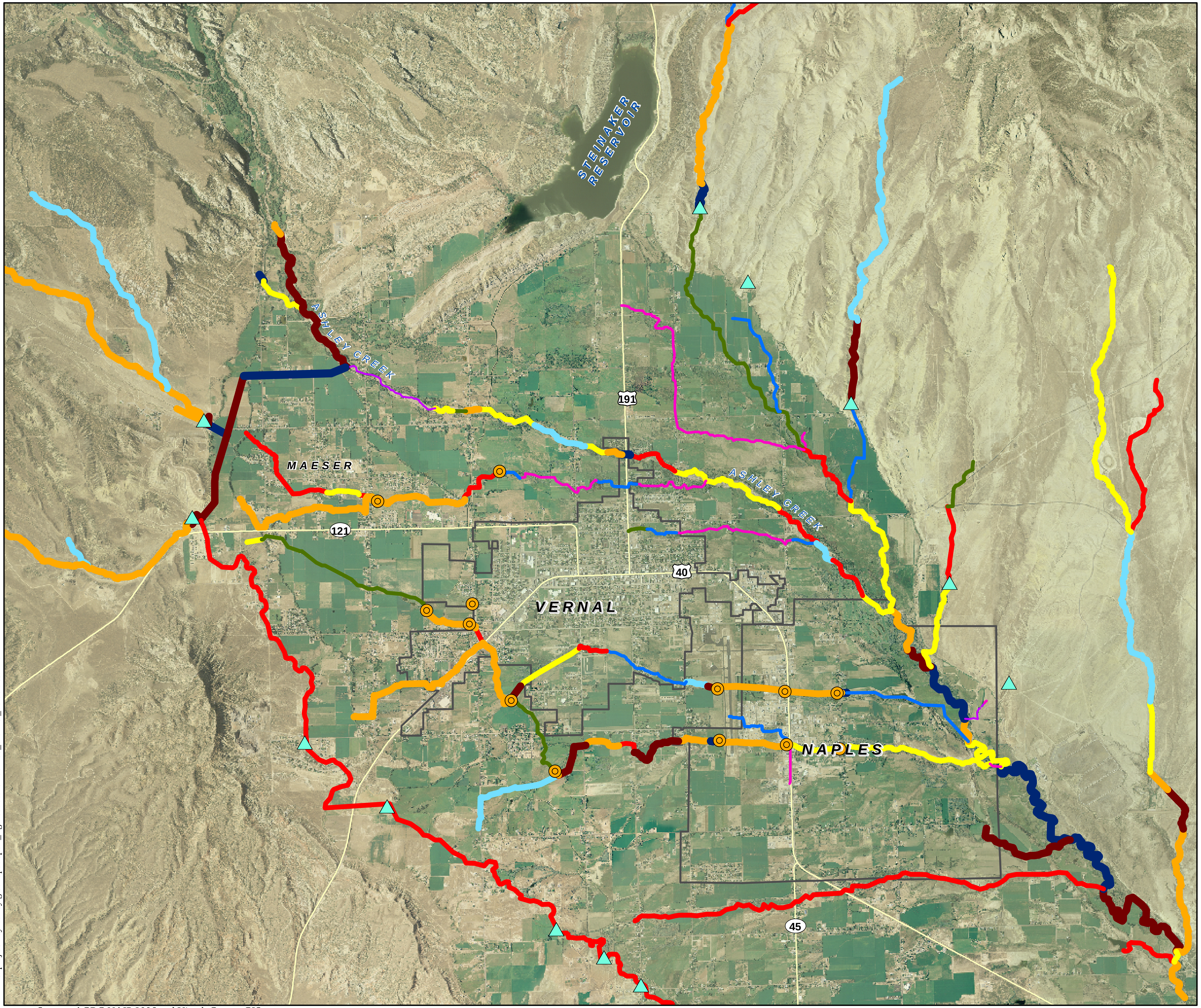
FIGURE 7-13
ESTIMATED FUTURE MODIFIED 500-YEAR CHANNEL VELOCITIES ASHLEY VALLEY UINTAH COUNTY, UTAH

JUNE 2008



Legend

- Debris Basin
- Detention Pond
- Major Road
- Municipal Boundary

Storm Event Maximum Velocity (ft/s)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 12.0
- 12.1 - 20.0
- > 20

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Source: AGRC NAIP 2006 and Uintah County GIS.

Chapter 8 PERMITTING REQUIREMENTS AND FUTURE REGULATIONS

8.1 STORM WATER PERMITTING

Storm water permitting dates back to 1972 when the federal Water Pollution Control Act (also known as the Clean Water Act [CWA]) was amended to provide that the discharge of pollutants to waters of the United States from any point source is unlawful unless the discharge is in compliance with a National Pollutant Discharge Elimination System (NPDES) permit. The 1987 amendments to the CWA added section 402(p), which established a framework for regulating storm water discharges under the NPDES Program. Subsequently, in 1990, the U.S. Environmental Protection Agency (EPA) promulgated regulations for permitting storm water discharges from industrial sites (including construction sites that disturb five acres or more) and from Municipal Separate Storm Sewer Systems (MS4s) serving a population of 100,000 people or more. These regulations, known as the Phase I regulations, require operators of medium and large MS4s to obtain storm water permits from the EPA or State, where equivalent State regulations are adopted. On December 8, 1999, the EPA promulgated regulations, known as Phase II, requiring similar permits for storm water discharges from Small MS4s and from construction sites disturbing between one and five acres of land.

An “MS4” is a conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains): (i) designed or used for collecting or conveying storm water; (ii) which is not a combined sewer; and (iii) which is not part of a Publicly Owned Treatment Works (POTW). [See Title 40, Code of Federal Regulations (40 CFR) §122.26(b)(8).]

A “Small MS4” is an MS4 that is not permitted under the municipal Phase I regulations, and which is “owned or operated by the United States, a State, City, Town, borough, County, Parish, District, association, or other public body (created by or pursuant to State law) having jurisdiction over disposal of sewage, industrial wastes, storm water, or other wastes, including special districts under State law such as a sewer district, flood control district or drainage district, or similar entity…” (40 CFR §122.26(b)(16)).

The State of Utah has adopted the NPDES permitting requirements through the ratification of the Utah Water Quality Act in 1994. This act created the Utah Pollutant Discharge Elimination System (UPDES) as an equivalent to the NPDES. The UPDES is operated by the State Division of Water Quality (DWQ) of the Department of Environmental Quality.

Federal and State regulations allow two permitting options for storm water discharges (individual permits and general permits). The State has elected to adopt a statewide general permit for Small MS4s in order to efficiently regulate numerous storm water discharges under a single permit. When governmental entities within the Valley conduct improvement projects involving storm drains and/or surface improvements that have the potential to affect State receiving waters, a Notice of Intent (NOI) to comply with the terms of this general permit should be submitted.

Activities involving storm drains within the Valley should fall under one of two types of permits: a construction permit or a Small Municipal Separate Storm Sewer Systems (MS4) General Permit.

8.1.1 CONSTRUCTION PERMIT

A construction permit must be secured prior to breaking ground on construction that will disturb more than one acre of land. The UPDES General Permit for Storm Water Discharges Associated with Construction Activity (General Construction Permit) requires all dischargers where construction activity disturbs one acre or more to:

1. Develop and implement a Storm Water Pollution Prevention Plan (SWPPP) which specifies Best Management Practices (BMPs) that will prevent all construction pollutants from contacting storm water and with the intent of keeping all products of erosion from moving off-site into receiving waters.
2. Eliminate or reduce non-storm water discharges to storm sewer systems and other waters of the U.S.
3. Develop and implement a monitoring program.
4. Perform inspections of all BMPs.

8.1.2 SMALL MS4 GENERAL PERMIT

According to the General Construction Permit, the SWPPP shall emphasize the use of appropriately selected, correctly installed and maintained pollution reduction BMPs. All dischargers are required to prepare and implement a SWPPP prior to disturbing a site, and the SWPPP shall remain on the site at all times and shall be implemented to protect water quality at all times throughout the life of the project.

The SWPPP has two major objectives: (1) to help identify the potential sources of sediment and other pollutants that affect the quality of storm water discharges and (2) to describe and ensure the implementation of BMPs to reduce or eliminate sediment and other pollutants from storm water, as well as non-storm water, discharges.

The SWPPP shall include BMPs which address source control and, if necessary, shall also include BMPs which address pollutant control.

The following elements are required in a SWPPP:
1. Site description addressing the elements and characteristics specific to the site;
2. Descriptions of BMPs for erosion and sediment controls;
3. BMPs for construction waste handling and disposal;
4. Implementation of approved local plans;
5. Proposed post-construction controls, including description of local post-construction erosion and sediment control requirements;
6. Non-storm water management.

8.1.3 MONITORING PROGRAM

The General Construction Permit requires development and implementation of a monitoring program. Dischargers are required to inspect the construction site prior to anticipated storm events and after actual storm events. During extended storm events, inspections must be made during each

24-hour period. Inspections will identify areas contributing to a storm water discharge and evaluate whether measures to reduce pollutant loadings identified in the SWPPP are adequate and properly installed and functioning in accordance with the terms of the General Permit. In addition, inspections will determine whether additional control practices or corrective maintenance activities are needed.

8.2 SMALL MS4 GENERAL PERMIT

Upon completion of development, or at an appropriate time as determined through communications with State DWQ staff, the local governing body will likely require a municipal permit. Small MS4s may be identified through the following methods:

1. Automatically designated by U.S. EPA pursuant to 40 CFR section 122.32(a)(1) because it is located within an urbanized area defined by the Bureau of the Census.
2. Traditional Small MS4s that serve Cities, Counties, and unincorporated areas that are designated by DWQ after consideration of the following factors:
   a. High population density – an area with greater than 1,000 residents per square mile, potentially created by a non-residential population, such as tourists or commuters.
   b. High growth or growth potential – Growth of more than 25 percent between 1990 and 2000, or anticipated growth of more than 25 percent over a 10-year period ending prior to the end of the first permit term.
   c. Significant contributor of pollutants to an interconnected permitted MS4.
   d. Discharge to sensitive water bodies.
   e. Significant contributor of pollutants to waters of the U.S.

Based on the above criteria, portions of the Valley are likely subject to MS4 permit regulations. As development occurs, additional portions of the Valley will also be expected to conform. It is recommended that all governing bodies adopt these criteria in the near future regardless of their current designation under the MS4 discharge permit.

The MS4 permit requires dischargers to develop and implement a Storm Water Management Program (SWMP) that describes the best management practices, measurable goals, and time schedules of implementation as well as assigns responsibility of each task. Also, as required by the Small MS4 General Permit, the SWMP must be available for public review and must be approved by the State prior to permit coverage commencing. This information is provided to facilitate the process of an MS4 obtaining Small MS4 General Permit coverage. The Storm Water Management Plan is completed as a separate document and can be obtained from the City by the public for review.

8.2.1 STORM WATER MANAGEMENT PLAN

The General Permit requires permittees to develop and implement a SWMP designed to reduce the discharge of pollutants through their MS4s to the Maximum Extent Practicable (MEP). The General Permit requires the SWMP to be fully implemented by the end of the permit term (or five years after designation for those designated subsequent to General Permit adoption). Once DWQ staff has reviewed a SWMP and, in light of meeting the MEP standard, recommends approval of coverage, the public may review the SWMP and request a public hearing if necessary. The SWMP will be made available for public review for a minimum of 60 days.

Federal and State regulations require operators of MS4s to develop a five-year work plan with associated performance measures and budgeting to address six Minimum Control Measures (MCMs). The MCMs to be addressed include:

1. Public Outreach and Education;
2. Public Participation and Involvement;
3. Illicit Discharge Elimination;
4. Construction Site BMPs Over One Acre;
5. Post-Construction BMPs; and
6. Municipal Activities.

For each MCM, measurable BMPs should be developed, and a schedule and budget provided for completion of the BMP.

8.2.2 STORM WATER POLLUTION PREVENTION REGULATION

To ensure BMPs are followed, each entity should implement a storm water pollution prevention ordinance. The ordinance should describe the BMPs described in this section and as well as other relevant BMPs as the entity deems necessary or prudent. The ordinances should be worded such that most of the physical BMPs for new construction are a requirement of approval to ensure they will be properly constructed and maintained.

8.3 BEST MANAGEMENT PRACTICES

The best management practices for the following types of potential contamination sources are described below. Additional detail on each of the proposed BMPs can be found in the Appendix of this report.

8.3.1 NEW CONSTRUCTION

All new construction projects in excess of one acre or those projects which pose a potential risk to storm water pollutants should be required to submit a Storm Water Pollution Prevention Plan (SWPPP). At a minimum, the SWPPP should include the following components:

1. Site description addressing the elements and characteristics specific to the site;
2. Descriptions of BMPs for erosion and sediment controls;
3. BMPs for construction waste handling and disposal;
4. Implementation of approved local plans;
5. Proposed post-construction controls, including description of local post-construction erosion and sediment control requirements;
6. Non-storm water management.

Examples of BMPs that may be part of a SWPPP include:

1) Straw bales or gravel bags around inlets and along new ditches.
2) Detention or settling ponds prior to discharge off-site.
3) Phased construction to minimize exposed sediment.

It is recommended that all new development and large construction projects be required to submit and follow a SWPPP plan prior to commencing work.

8.3.2 EXISTING DEVELOPMENT

Controlling the quality of storm water runoff from existing development generally requires public involvement and education. Informing the community of the importance of clean water and ways to avoid or minimize behaviors that typically cause polluted storm water is imperative to maintaining reasonably clean runoff from existing developments. Three typical sources of pollution are Oil and grease, fertilizer, and trash. Oil and grease as well as fertilizer often affect water quality throughout the region. Through education and proper management these contaminates can be minimized and the water quality of the region preserved. Trash can also affect water quality but more often than not it clogs key storm culverts and grates and diminishes capacity. Education and street cleaning to prevent trash from entering the storm water system can prevent or minimize flooding during major rainfall events.

Since not all pollution from existing developments can be eliminated through public education it is also important to provide treatment of storm water through detention basin, screening manholes, or oil water separators throughout existing communities whenever practical.

8.3.3 ROADWAY MAINTENANCE

Roadways in general have high potential to contribute large amount of pollutants into storm water for a variety of reasons, including:

1) Roadways cover a large portion of the land, and often are constructed through sensitive areas.
2) Curbs and gutters catch and store debris, fuel, oil and grease from automobiles.
3) Winter operations introduce salts and sands throughout the roadway network.
4) Pavement design creates high runoff volumes, while increasing contact time between storm water and contaminates.

As regions such as the Valley continue to develop, additional roadways and the associated storm water pollutant potential will increase. The pollutants generated from roadways can be mitigated by implementing best management practices. There are a series of best management practices to reduce roadway generated polluted storm water.

The following BMPs are recommended for use within the Valley:

- ***Develop roadway salting and sanding protocols to minimize the use of salt and sand on the roadways throughout the winter. Consider using alternative de-icing formulas throughout the Valley and especially near environmentally sensitive areas.***
- ***Site future O&M facilities, such as sand storage, away from natural water ways and storm channels.***
- ***Store winter salt and sand piles under cover to prevent contact with wind and precipitation. Construct evaporation ponds for storm water in and around these sites where possible.***
- ***Divert all existing storm water and require that future storm water runoff from roadways be treated prior to discharge into natural channels. Treatment may include grassy swales, settling ponds, and oil water separators.***

Chapter 9 REFERENCES

- SewerGEMs 8.1, Bentley Systems, Inc., 2007.
- Magna Water Company Water and Sewer Master Plan 1999, Hansen, Allen, Luce Inc. and Epic Engineering, P.C., August 1999
- Syracuse City Storm Drain Master Plan, Epic Engineering P.C., June 2007
- Introduction to Environmental Engineering third edition, McGraw-Hill ISBN 0-07-015918-1, 1998
- Summit County Storm Water Pollution & Erosion Control Ordinance 381-A, Adopted December 2004
- Urban Storm Water Management BMP Performance Monitoring, US EPA & American Society of Civil Engineers EPA-821-B-02-001, April 2002
- Ashley Creek Stabilization / Restoration Report, Franson Noble & Associates, Inc and Mussetter Engineering Inc. May 2000.
- Geotechnical / Geological Feasibility Evaluation Proposed Spring Creek Reservoir, Kleinfelder, Inc. May 2003.

Ashley Valley

Storm Water Master Plan

APPENDICES

June 2008

Prepared By:

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Uintah county

People Serving People
City of Naples

Vernal City

TABLE OF APPENDICES

Appendix A: CURVE NUMBER CALCULATIONS

Existing Conditions CN Basis

Pasture, Range, Meadow (well vegetated)

	1	*1.36	*1.5
Soil Type	<2%	2% to 10%	>10%
Clay	0.40	0.55	0.60
Clay loam	0.38	0.53	0.57
Silty clay loam	0.35	0.47	0.53
Silty clay	0.32	0.40	0.48
Silt loam	0.30	0.36	0.45
Loam	0.28	0.34	0.42
Loamy fine sand	0.24	0.30	0.35
Loamy sand	0.19	0.25	0.29
Sandy clay loam	0.15	0.21	0.22
Sandy loam	0.10	0.16	0.15
Fine sandy loam	0.09	0.14	0.13
Fine sand	0.07	0.12	0.11
Sand	0.06	0.10	0.09
Coarse sand	0.05	0.07	0.08

Cultivated / Bare

Soil Type	<2%	2% to 10%	>10%
Clay	0.60	0.75	0.80
Clay loam	0.58	0.73	0.77
Silty clay loam	0.55	0.67	0.73
Silty clay	0.52	0.60	0.68
Silt loam	0.50	0.56	0.65
Loam	0.48	0.54	0.62
Loamy fine sand	0.44	0.50	0.55
Loamy sand	0.39	0.45	0.49
Sandy clay loam	0.35	0.41	0.42
Sandy loam	0.30	0.36	0.35
Fine sandy loam	0.29	0.34	0.33
Fine sand	0.27	0.32	0.31
Sand	0.26	0.30	0.29
Coarse sand	0.25	0.30	0.28

SCS curve number proceedure

Soil	Soil Type
Clay	D
Clay loam	D
Silty clay loam	D
Silty clay	D
Silt loam	D
Loam	D
Loamy fine sand	C
Loamy sand	C
Sandy clay loam	C
Sandy loam	C
Fine sandy loam	B
Fine sand	B
Sand	B
Coarse sand	B
Water	A
Rock	D
Cobbly loam	D

Soil Type	Good	Poor
D	80	89
C	74	86
B	61	79
A	68	39

$$\boxed{CN = A\left[39(V_a) + 68(1 - V_a)\right] + B\left[61(V_b) + 79(1 - V_b)\right] + C\left[74(V_c) + 86(1 - V_c)\right] + D\left[80(V_d) + 89(1 - V_d)\right]}$$

Where

CN	Composite SCS Curve Number
A,B,C,D	%(decimal) area of each soil type
V	%(decimal) area of vegetation in each soil type

*CN values base on pasture/range type land use

			Data from GIS					
Basin ID	Area (Acres)	avg slope (ft/ft)	Length of water course (ft)		% veg	K	**Tc (hr)**	Average Velocity (ft/s)
Max	1505.73661	0.128246	172471.4566		100%	10	50.00	1.66
Min	102.493531	0.000154007	6685.695536		0%	7	2.74	0.27
Average	490.712735	0.032382817	31032.10071		37%	8.904303	12.03	0.85
Basin ID	AREA (AC)	SLOPE	FLOW LENGTH FT	FLOW LENGTH MI	Veg			
1	896	8.26%	22594	4.28	0%	10.00	3.78	1.66
2	837	10.14%	20210	3.83	0%	10.00	3.39	1.66
3	764	11.30%	18567	3.52	0%	10.00	3.18	1.62
4	865	8.01%	15911	3.01	0%	10.00	3.44	1.29
5	391	6.66%	8821	1.67	0%	10.00	3.24	0.76
6	146	1.30%	31701	6.00	0%	10.00	10.16	0.87
7	865	4.01%	18550	3.51	0%	10.00	4.65	1.11
8	1473	4.62%	24784	4.69	0%	10.00	4.83	1.43
9	934	11.41%	16506	3.13	0%	10.00	3.06	1.50
10	717	5.04%	15737	2.98	0%	10.00	4.06	1.08
13	353	2.70%	25320	4.80	0%	10.00	6.64	1.06
14	498	9.09%	11761	2.23	0%	10.00	3.05	1.07
15	723	2.13%	42419	8.03	0%	10.00	9.53	1.24
16	845	8.03%	15627	2.96	0%	10.00	3.42	1.27
17	311	9.83%	10913	2.07	0%	10.00	2.92	1.04
18	351	2.51%	19101	3.62	0%	10.00	6.12	0.87
19	754	6.11%	15997	3.03	0%	10.00	3.80	1.17
20	272	6.50%	6686	1.27	0%	10.00	3.14	0.59
23	345	6.25%	8721	1.65	0%	10.00	3.31	0.73
25	269	3.43%	11051	2.09	0%	10.00	4.56	0.67
26	102	2.83%	20485	3.88	0%	10.00	5.98	0.95
27	285	0.85%	28540	5.41	0%	10.00	11.62	0.68
29	859	4.36%	20122	3.81	0%	10.00	4.61	1.21
31	536	1.21%	38789	7.35	0%	10.00	11.65	0.93
32	792	2.69%	17378	3.29	0%	10.00	5.75	0.84
33	384	9.96%	10536	2.00	0%	10.00	2.89	1.01
34	290	10.12%	8099	1.53	0%	10.00	2.74	0.82
35	1057	2.73%	27359	5.18	0%	10.00	6.84	1.11
36	941	10.00%	20250	3.84	0%	10.00	3.41	1.65
37	459	5.35%	11691	2.21	0%	10.00	3.71	0.88
38	784	12.08%	15781	2.99	0%	10.00	2.96	1.48
39	460	5.63%	13168	2.49	0%	10.00	3.73	0.98
40	849	5.12%	19931	3.77	1%	9.97	4.32	1.28
41	539	4.32%	20149	3.82	4%	9.89	4.63	1.21
43	428	5.13%	14811	2.81	0%	10.00	3.97	1.04
44	614	5.36%	12424	2.35	37%	8.88	3.75	0.92
45	337	9.40%	9008	1.71	0%	10.00	2.86	0.87
46	659	6.51%	21255	4.03	0%	10.00	4.03	1.46
47	329	8.08%	12222	2.31	0%	10.00	3.21	1.06
48	444	0.63%	54166	10.26	50%	8.51	19.23	0.78
49	429	5.29%	10688	2.02	0%	10.00	3.66	0.81
50	522	4.35%	14067	2.66	12%	9.65	4.18	0.93
51	553	4.17%	17249	3.27	2%	9.93	4.48	1.07
52	337	1.25%	18723	3.55	0%	10.00	8.18	0.64
53	282	0.39%	53369	10.11	0%	10.00	23.64	0.63
54	211	0.83%	24997	4.73	0%	10.00	10.98	0.63
55	1076	2.81%	40208	7.62	0%	10.00	8.18	1.37
56	1234	3.38%	27390	5.19	0%	10.00	6.24	1.22
57	706	2.02%	16387	3.10	34%	8.99	6.36	0.72
61	208	0.94%	25661	4.86	88%	7.37	10.57	0.67
62	268	7.61%	15560	2.95	0%	10.00	3.48	1.24
63	979	5.15%	24976	4.73	0%	10.00	4.64	1.49
64	260	8.07%	9524	1.80	0%	10.00	3.06	0.87
65	523	3.55%	13222	2.50	15%	9.55	4.71	0.78
66	263	6.45%	10860	2.06	4%	9.88	3.41	0.89
67	377	4.10%	21791	4.13	0%	10.00	4.85	1.25
68	402	6.86%	7297	1.38	64%	8.07	3.11	0.65
69	368	6.45%	10041	1.90	4%	9.89	3.35	0.83
71	347	3.29%	12243	2.32	10%	9.70	4.76	0.71
72	755	5.90%	23915	4.53	0%	10.00	4.35	1.53
74	1062	3.56%	19066	3.61	0%	10.00	5.28	1.00

75	818	11.57%	15282	2.89	0%	10.00	2.98	1.43
77	666	3.21%	15191	2.88	77%	7.70	5.12	0.82
78	987	0.98%	50008	9.47	92%	7.24	14.89	0.93
80	349	0.97%	38244	7.24	22%	9.34	12.78	0.83
81	382	0.61%	65605	12.43	84%	7.48	22.20	0.82
82	203	0.81%	27237	5.16	79%	7.63	11.60	0.65
83	486	12.82%	13763	2.61	0%	10.00	2.79	1.37
84	342	3.72%	13829	2.62	6%	9.83	4.68	0.82
85	575	4.98%	23907	4.53	0%	10.00	4.63	1.43
86	267	4.52%	9766	1.85	0%	10.00	3.82	0.71
87	260	4.11%	9867	1.87	0%	10.00	3.97	0.69
88	259	4.29%	13027	2.47	0%	10.00	4.13	0.88
89	723	1.40%	32309	6.12	0%	10.00	9.91	0.91
90	644	2.56%	19934	3.78	66%	8.01	6.17	0.90
91	469	3.38%	21923	4.15	59%	8.24	5.68	1.07
92	630	4.58%	18992	3.60	0%	10.00	4.44	1.19
93	519	1.38%	23333	4.42	0%	10.00	8.56	0.76
94	376	1.70%	15488	2.93	100%	7.00	6.71	0.64
96	302	5.68%	9133	1.73	0%	10.00	3.46	0.73
97	290	0.69%	31504	5.97	100%	7.00	13.36	0.66
99	271	3.65%	12068	2.29	35%	8.96	4.55	0.74
100	200	0.19%	58141	11.01	100%	7.00	35.32	0.46
102	416	1.09%	11554	2.19	100%	7.00	7.39	0.43
103	486	1.86%	23084	4.37	83%	7.50	7.49	0.86
104	493	0.40%	54715	10.36	98%	7.07	23.78	0.64
105	212	0.21%	76100	14.41	100%	7.00	40.30	0.52
107	727	2.75%	16738	3.17	0%	10.00	5.63	0.83
109	761	4.10%	14653	2.78	0%	10.00	4.33	0.94
110	140	0.22%	37274	7.06	100%	7.00	24.44	0.42
113	448	1.60%	20848	3.95	99%	7.02	7.68	0.75
114	539	0.33%	80719	15.29	95%	7.14	33.33	0.67
115	175	0.21%	70170	13.29	100%	7.00	38.49	0.51
116	266	1.49%	13233	2.51	100%	7.00	6.76	0.54
117	274	0.16%	85428	16.18	100%	7.00	47.88	0.50
118	269	10.31%	10339	1.96	0%	10.00	2.84	1.01
119	339	0.26%	77524	14.68	79%	7.62	36.82	0.58
120	202	0.21%	63704	12.07	100%	7.00	35.81	0.49
121	264	3.45%	10600	2.01	37%	8.90	4.51	0.65
122	331	4.60%	9504	1.80	0%	10.00	3.78	0.70
124	642	1.81%	21723	4.11	0%	10.00	7.40	0.82
126	653	0.80%	39159	7.42	15%	9.55	14.10	0.77
127	250	0.36%	54714	10.36	100%	7.00	25.05	0.61
128	368	8.64%	10803	2.05	0%	10.00	3.06	0.98
129	686	0.37%	88800	16.82	76%	7.73	33.09	0.75
131	888	1.39%	21498	4.07	36%	8.92	8.25	0.72
132	239	0.99%	33015	6.25	0%	10.00	11.69	0.78
133	491	0.44%	43189	8.18	0%	10.00	19.61	0.61
134	295	4.20%	14216	2.69	0%	10.00	4.25	0.93
135	583	6.03%	17162	3.25	6%	9.83	3.89	1.23
136	143	0.70%	39518	7.48	0%	10.00	15.11	0.73
137	979	4.30%	28879	5.47	80%	7.60	5.26	1.53
138	151	1.91%	20950	3.97	0%	10.00	7.13	0.82
139	293	10.39%	9779	1.85	44%	8.68	2.80	0.97
140	845	1.85%	17156	3.25	0%	10.00	6.71	0.71
141	410	1.35%	20655	3.91	67%	7.98	8.21	0.70
142	400	1.31%	18804	3.56	60%	8.21	8.03	0.65
143	340	0.36%	31211	5.91	25%	9.26	17.80	0.49
144	833	1.39%	17219	3.26	66%	8.01	7.58	0.63
145	429	6.85%	17443	3.30	56%	8.33	3.73	1.30
147	204	0.18%	94798	17.95	73%	7.80	47.53	0.55
148	538	1.95%	14206	2.69	0%	10.00	6.17	0.64
149	298	0.35%	32140	6.09	87%	7.38	18.21	0.49
151	329	1.19%	24812	4.70	63%	8.11	9.38	0.73
152	367	2.94%	14149	2.68	40%	8.81	5.19	0.76
153	194	0.54%	38750	7.34	22%	9.33	16.79	0.64
154	799	0.34%	45537	8.62	54%	8.38	22.80	0.55
155	1023	1.90%	21768	4.12	85%	7.44	7.26	0.83
156	574	1.33%	20535	3.89	34%	8.97	8.25	0.69
159	269	0.66%	13861	2.63	0%	10.00	9.61	0.40
160	141	0.07%	49421	9.36	67%	7.98	49.28	0.28

162	317	0.23%	101385	19.20	56%	8.33	43.94	0.64
163	350	1.66%	13286	2.52	97%	7.09	6.46	0.57
164	470	1.87%	12623	2.39	0%	10.00	6.06	0.58
165	290	10.48%	9742	1.85	22%	9.35	2.79	0.97
166	323	6.85%	13690	2.59	42%	8.75	3.50	1.09
167	239	0.11%	53984	10.22	1%	9.97	43.36	0.35
170	777	0.73%	39248	7.43	100%	7.00	14.74	0.74
171	566	0.34%	50019	9.47	86%	7.43	24.15	0.58
174	672	1.38%	15547	2.94	97%	7.08	7.34	0.59
175	527	1.56%	21318	4.04	90%	7.29	7.81	0.76
176	683	0.42%	66506	12.60	86%	7.41	26.69	0.69
178	226	0.15%	107535	20.37	36%	8.93	50.00	0.60
179	301	2.58%	9767	1.85	100%	7.00	4.98	0.55
180	586	3.99%	19820	3.75	83%	7.50	5.10	1.08
181	659	1.29%	11589	2.19	0%	10.00	6.90	0.47
182	497	0.16%	116782	22.12	71%	7.87	50.00	0.65
183	188	0.07%	48302	9.15	0%	10.00	49.01	0.27
184	316	2.08%	10754	2.04	0%	10.00	5.56	0.54
185	486	1.28%	15416	2.92	100%	7.00	7.55	0.57
187	151	0.29%	50923	9.64	0%	10.00	26.53	0.53
188	328	2.45%	10638	2.01	0%	10.00	5.19	0.57
189	399	1.61%	12511	2.37	100%	7.00	6.44	0.54
190	961	4.22%	21565	4.08	25%	9.24	4.78	1.25
191	264	6.16%	9494	1.80	39%	8.83	3.38	0.78
192	242	0.29%	54578	10.34	0%	10.00	27.45	0.55
193	353	0.15%	122497	23.20	32%	9.03	50.00	0.68
194	178	1.10%	21572	4.09	100%	7.00	9.15	0.66
195	1152	1.13%	45997	8.71	100%	7.00	13.26	0.96
196	287	2.57%	12148	2.30	0%	10.00	5.26	0.64
197	265	0.43%	59251	11.22	2%	9.95	24.41	0.67
198	382	0.15%	132203	25.04	69%	7.92	50.00	0.73
199	385	1.63%	14908	2.82	100%	7.00	6.76	0.61
201	604	5.32%	18261	3.46	62%	8.13	4.15	1.22
202	496	5.81%	15158	2.87	24%	9.29	3.81	1.10
203	974	4.50%	17717	3.36	62%	8.13	4.38	1.12
204	489	2.76%	13634	2.58	12%	9.65	5.27	0.72
205	537	1.62%	16723	3.17	100%	7.00	7.03	0.66
206	230	0.81%	18832	3.57	100%	7.00	9.84	0.53
207	368	1.81%	11697	2.22	100%	7.00	6.02	0.54
209	483	0.82%	30756	5.83	100%	7.00	12.25	0.70
211	147	0.37%	34929	6.62	100%	7.00	18.76	0.52
212	538	0.72%	46053	8.72	100%	7.00	16.27	0.79
213	832	5.77%	17622	3.34	62%	8.15	3.98	1.23
214	427	5.90%	17018	3.22	38%	8.86	3.91	1.21
215	869	2.09%	23243	4.40	99%	7.02	7.15	0.90
218	391	1.90%	16669	3.16	100%	7.00	6.57	0.70
219	163	0.09%	141733	26.84	100%	7.00	50.00	0.79
220	524	3.42%	11581	2.19	13%	9.62	4.62	0.70
221	287	3.23%	11991	2.27	34%	8.98	4.77	0.70
222	676	1.94%	21101	4.00	75%	7.75	7.09	0.83
223	200	0.14%	144086	27.29	100%	7.00	50.00	0.80
224	398	2.81%	10971	2.08	29%	9.13	4.94	0.62
225	1107	3.60%	35657	6.75	44%	8.68	6.88	1.44
229	354	0.58%	45951	8.70	57%	8.28	17.99	0.71
230	118	0.49%	35348	6.69	5%	9.86	16.55	0.59
231	870	1.11%	31872	6.04	44%	8.67	10.91	0.81
232	488	2.27%	13106	2.48	0%	9.99	5.66	0.64
233	361	6.50%	13798	2.61	28%	9.17	3.58	1.07
234	459	3.27%	10912	2.07	34%	8.99	4.64	0.65
235	315	0.15%	152002	28.79	91%	7.26	50.00	0.84
236	396	6.05%	12408	2.35	28%	9.17	3.58	0.96
237	613	2.15%	18022	3.41	17%	9.48	6.40	0.78
238	144	0.08%	154357	29.23	94%	7.17	50.00	0.86
240	146	0.10%	160303	30.36	59%	8.23	50.00	0.89
241	1506	1.69%	30251	5.73	8%	9.77	8.83	0.95
242	893	1.64%	21645	4.10	18%	9.47	7.70	0.78
243	326	1.50%	12063	2.28	80%	7.60	6.56	0.51
244	109	0.02%	172471	32.67	98%	7.05	50.00	0.96
246	551	1.23%	15901	3.01	64%	8.08	7.77	0.57

Future Conditions CN Basis

		Soil Type			
Land uses	Classes	A	B	C	D
C2	Commercial	89	92	94	95
CC1	Commercial	89	92	94	95
CP2	Commercial	89	92	94	95
F1	Commercial	89	92	94	95
HC1	Commercial	89	92	94	95
I1	Commercial	89	92	94	95
R1	Residential <1/8 acre lots	77	85	90	92
R2	Residential 1/3 acre lots	61	75	83	87
R3	Residential 1/3 acre lots	57	72	81	86
R4	Residential 1/2 acre lots	54	70	80	85
RA1	Residential 1 acre lots	51	68	79	84
RA2	Residential >1 acre lots	51	68	79	84

		Soil Type			
% impervio	Group	A	B	C	D
85	Commercial	89	92	94	95
0	Open Spaces	49	69	79	84
65	Residential <1/8 acre lots	77	85	90	92
30	Residential 1/3 acre lots	57	72	81	86
25	Residential 1/2 acre lots	54	70	80	85
20	Residential >1 acre lots	51	68	79	84

		Soil Group A						Soil Group B						
		A-Commercial	A-Open Spaces	A-Residential <1/8 acre lots	A-Residential 1/3 acre lots	A-Residential 1/2 acre lots	A-Residential >1 acre lots	B-Commercial	B-Open Spaces	B-Residential <1/8 acre lots	B-Residential 1/3 acre lots	B-Residential 1/2 acre lots	B-Residential >1 acre lots	C-Commercial
Cn Value		89	49	77	57	54	51	92	69	85	72	70	68	94
Future Cn	Basin													
88	1	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%	0%	3%	0%
84	2	0%	0%	0%	0%	0%	0%	0%	22%	0%	0%	0%	25%	0%
81	3	0%	0%	0%	0%	0%	0%	0%	82%	0%	0%	0%	0%	0%
87	4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	22%	0%
89	5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
86	6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	27%	0%
89	7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
82	9	0%	0%	0%	0%	0%	0%	0%	73%	0%	0%	0%	0%	0%
89	10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
86	13	0%	0%	0%	0%	0%	0%	0%	26%	0%	0%	0%	4%	0%
89	14	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	15	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	25%	0%
88	16	0%	0%	0%	0%	0%	0%	0%	8%	0%	0%	0%	1%	0%
89	17	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	18	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	19	0%	0%	0%	0%	0%	0%	0%	6%	0%	0%	0%	0%	0%
89	20	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	23	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	25	0%	0%	0%	0%	0%	0%	0%	8%	0%	0%	0%	0%	0%
89	26	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
86	27	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	28%	0%
87	29	0%	0%	0%	0%	0%	0%	0%	7%	0%	0%	0%	13%	0%
89	31	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
80	32	0%	0%	0%	0%	0%	41%	0%	0%	0%	0%	0%	0%	0%
88	33	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	34	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	35	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	36	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	37	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	38	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	39	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	17%	0%
88	40	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%
89	41	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	43	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
82	44	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	18%	2%	0%
88	45	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	46	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	47	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
84	48	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	49	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	50	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%
89	51	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
83	52	0%	0%	0%	0%	0%	28%	0%	0%	0%	0%	0%	2%	0%
73	53	0%	0%	0%	0%	0%	74%	0%	0%	0%	0%	0%	0%	0%
76	54	0%	0%	0%	0%	0%	62%	0%	0%	0%	0%	0%	1%	0%
89	55	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	56	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
83	57	0%	0%	0%	0%	0%	8%	0%	0%	0%	0%	2%	0%	0%
78	61	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	34%	0%	0%
89	62	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	64	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
84	65	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	25%	0%
89	66	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	67	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
86	68	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	69	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	71	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	72	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	74	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	75	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
82	77	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	8%	0%	1%
76	78	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	42%	0%	0%
87	80	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
83	81	0%	0%	0%	0%	0%	3%	0%	0%	0%	1%	1%	0%	3%
85	82	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	83	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	84	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	85	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	86	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	87	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	88	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	89	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
83	90	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%	0%
82	91	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	0%	0%	0%
89	92	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	93	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
79	94	0%	0%	0%	0%	0%	0%	0%	0%	0%	23%	8%	0%	0%
88	96	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
76	97	0%	0%	0%	0%	0%	0%	0%	0%	3%	65%	0%	0%	0%

		Soil Group A						Soil Group B						
		A-Commercial	A-Open Spaces	A-Residential <1/8 acre lots	A-Residential 1/3 acre lots	A-Residential 1/2 acre lots	A-Residential >1 acre lots	B-Commercial	B-Open Spaces	B-Residential <1/8 acre lots	B-Residential 1/3 acre lots	B-Residential 1/2 acre lots	B-Residential >1 acre lots	C-Commercial
Cn Value		89	49	77	57	54	51	92	69	85	72	70	68	94
Future Cn	Basin													
86	99	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
83	100	0%	0%	0%	0%	0%	0%	0%	0%	0%	19%	0%	0%	0%
81	102	0%	0%	0%	1%	0%	0%	0%	0%	1%	16%	0%	0%	1%
83	103	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	0%	0%	0%
85	104	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
83	105	0%	0%	0%	0%	0%	0%	2%	0%	0%	18%	0%	0%	1%
89	107	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	109	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
82	110	0%	0%	0%	0%	0%	0%	2%	0%	3%	38%	0%	0%	21%
86	113	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
85	114	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%
81	115	0%	0%	0%	0%	0%	0%	0%	0%	0%	34%	0%	0%	0%
80	116	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	0%	0%	0%
80	117	0%	0%	0%	0%	0%	0%	0%	0%	0%	42%	0%	0%	0%
88	118	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
82	119	0%	0%	0%	1%	0%	0%	2%	0%	7%	36%	0%	0%	1%
88	120	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
86	121	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	122	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	124	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	126	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	127	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	128	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
84	129	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	0%	0%	0%
89	131	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%
89	132	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	133	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	134	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	135	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	11%	0%
88	136	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%
85	137	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	138	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
85	139	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	140	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
90	141	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
89	142	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%
90	143	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%
88	144	0%	0%	0%	0%	0%	0%	0%	1%	0%	5%	0%	0%	2%
86	145	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
85	147	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	148	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	149	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	151	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	13%
87	152	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
91	153	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	8%
87	154	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	155	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
90	156	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	14%
89	159	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	19%
87	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
85	162	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
86	163	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	164	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
86	165	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	4%	0%
82	166	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	0%	11%	0%
94	167	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%
86	170	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	171	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%
90	174	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	15%
87	175	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%
87	176	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%
85	178	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
86	179	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
84	180	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	0%
85	181	0%	0%	0%	0%	0%	16%	0%	0%	0%	0%	0%	0%	0%
84	182	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
82	183	0%	0%	0%	0%	0%	34%	0%	0%	0%	0%	0%	0%	0%
88	184	0%	0%	0%	0%	0%	4%	0%	0%	0%	0%	0%	0%	0%
86	185	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	2%
88	187	0%	0%	0%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%
88	188	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	189	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	8%
86	190	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	1%	1%
84	191	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	0%	0%
89	192	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
83	193	0%	0%	0%	0%	0%	9%	0%	0%	0%	0%	0%	0%	0%
85	194	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
85	195	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	1%
89	196	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	197	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
84	198	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

		Soil Group A						Soil Group B						
		A-Commercial	A-Open Spaces	A-Residential <1/8 acre lots	A-Residential 1/3 acre lots	A-Residential 1/2 acre lots	A-Residential >1 acre lots	B-Commercial	B-Open Spaces	B-Residential <1/8 acre lots	B-Residential 1/3 acre lots	B-Residential 1/2 acre lots	B-Residential >1 acre lots	C-Commercial
Cn Value		89	49	77	57	54	51	92	69	85	72	70	68	94
Future Cn	Basin													
85	199	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	4%
86	201	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	202	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
85	203	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	204	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
84	205	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	2%
84	206	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
85	207	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	3%	0%	5%
85	209	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
89	211	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	23%
83	212	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	3%
84	213	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
85	214	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	215	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
86	218	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	2%
90	219	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%
88	220	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
86	221	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
89	222	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	19%
92	223	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	42%
86	224	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
85	225	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%
91	229	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	18%
88	230	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%
84	231	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	232	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
86	233	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%
86	234	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
86	235	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
82	236	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	35%	0%
87	237	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
85	238	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
85	240	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
88	241	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
87	242	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
85	243	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
85	244	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
85	246	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

		Soil Group C					Soil Group D					
		C-Open Spaces	C-Residential <1/8 acre lots	C-Residential 1/3 acre lots	C-Residential 1/2 acre lots	C-Residential >1 acre lots	D-Dommercial	D-Open Spaces	D-Residential <1/8 acre lots	D-Residential 1/3 acre lots	D-Residential 1/2 acre lots	D-Residential >1 acre lots
Cn Value		79	90	81	80	79	95	84	92	86	85	84
Future Cn	Basin											
88	1	0%	0%	0%	0%	0%	0%	17%	0%	0%	0%	77%
84	2	0%	0%	0%	0%	0%	0%	15%	0%	0%	0%	38%
81	3	0%	0%	0%	0%	0%	0%	15%	0%	0%	0%	3%
87	4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	78%
89	5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
86	6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	73%
89	7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
89	8	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	98%
82	9	0%	0%	0%	0%	0%	0%	27%	0%	0%	0%	0%
89	10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
86	13	0%	0%	0%	0%	0%	0%	63%	0%	0%	0%	7%
89	14	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	90%
87	15	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	75%
88	16	0%	0%	0%	0%	0%	0%	91%	0%	0%	0%	1%
89	17	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	99%
89	18	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
88	19	4%	0%	0%	0%	0%	0%	85%	0%	0%	0%	4%
89	20	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
89	23	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
88	25	1%	0%	0%	0%	13%	0%	10%	0%	0%	0%	68%
89	26	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
86	27	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	72%
87	29	0%	0%	0%	0%	5%	0%	18%	0%	0%	0%	56%
89	31	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	99%
80	32	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	59%
88	33	0%	0%	0%	0%	26%	0%	0%	0%	0%	0%	74%
88	34	0%	0%	0%	0%	33%	0%	0%	0%	0%	0%	67%
89	35	0%	0%	0%	0%	11%	0%	0%	0%	0%	0%	89%
87	36	76%	0%	0%	0%	0%	0%	23%	0%	0%	0%	0%
89	37	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
87	38	53%	0%	0%	0%	0%	0%	47%	0%	0%	0%	0%
87	39	0%	0%	0%	0%	9%	0%	0%	0%	0%	0%	74%
88	40	42%	0%	0%	0%	0%	0%	55%	0%	0%	0%	2%
89	41	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	95%
88	43	0%	0%	0%	0%	22%	0%	0%	0%	0%	0%	78%
82	44	1%	0%	0%	14%	0%	0%	30%	0%	0%	7%	27%
88	45	28%	0%	0%	0%	0%	0%	72%	0%	0%	0%	0%
88	46	0%	0%	0%	0%	40%	0%	0%	0%	0%	0%	60%
89	47	3%	0%	0%	0%	0%	0%	97%	0%	0%	0%	0%
84	48	0%	0%	7%	0%	22%	0%	0%	0%	5%	38%	29%
89	49	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	95%
88	50	0%	0%	0%	6%	0%	0%	0%	0%	0%	10%	84%
89	51	0%	0%	0%	0%	2%	0%	0%	0%	0%	3%	95%
83	52	0%	0%	0%	0%	13%	0%	0%	0%	0%	0%	57%
73	53	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	26%
76	54	0%	0%	0%	0%	3%	0%	0%	0%	0%	0%	34%
89	55	1%	0%	0%	0%	5%	0%	20%	0%	0%	0%	75%
87	56	36%	0%	0%	0%	41%	0%	15%	0%	0%	0%	9%
83	57	0%	0%	0%	25%	1%	0%	0%	0%	0%	36%	29%
78	61	0%	0%	0%	40%	0%	0%	0%	0%	0%	13%	13%
89	62	0%	0%	0%	0%	12%	0%	0%	0%	0%	0%	88%
88	63	0%	0%	0%	0%	17%	0%	0%	0%	0%	0%	83%
89	64	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
84	65	0%	0%	0%	7%	1%	0%	0%	0%	0%	11%	49%
89	66	0%	0%	0%	0%	0%	0%	29%	0%	0%	1%	69%
89	67	0%	0%	0%	0%	14%	0%	0%	0%	0%	0%	86%
86	68	0%	0%	0%	5%	0%	9%	0%	0%	0%	58%	28%
88	69	0%	0%	0%	1%	22%	0%	0%	0%	0%	0%	77%
88	71	0%	0%	0%	0%	0%	0%	0%	0%	0%	13%	87%
89	72	0%	0%	0%	0%	2%	0%	3%	0%	0%	0%	94%
89	74	0%	0%	0%	0%	4%	0%	0%	0%	0%	0%	96%
88	75	19%	0%	0%	0%	11%	0%	8%	0%	0%	0%	62%
82	77	0%	0%	0%	49%	1%	1%	0%	0%	0%	20%	20%
76	78	0%	0%	15%	28%	0%	0%	0%	0%	0%	7%	4%
87	80	0%	0%	0%	0%	2%	0%	0%	0%	21%	0%	76%
83	81	0%	0%	1%	40%	0%	1%	0%	0%	0%	35%	16%
85	82	0%	0%	7%	0%	0%	0%	0%	0%	19%	55%	19%
88	83	0%	0%	0%	0%	37%	0%	0%	0%	0%	0%	63%
89	84	0%	0%	0%	0%	0%	0%	0%	0%	5%	0%	95%
89	85	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	98%
89	86	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	98%
89	87	0%	0%	0%	0%	13%	0%	0%	0%	0%	0%	87%
88	88	0%	0%	0%	0%	18%	0%	0%	0%	0%	0%	82%
89	89	0%	0%	0%	0%	6%	0%	0%	0%	0%	0%	94%
83	90	0%	0%	21%	10%	7%	3%	0%	0%	4%	36%	16%
82	91	0%	0%	35%	0%	29%	0%	0%	0%	17%	0%	13%
89	92	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	99%
89	93	0%	0%	0%	0%	5%	0%	0%	0%	0%	0%	95%
79	94	0%	0%	47%	7%	0%	0%	0%	0%	15%	0%	0%
88	96	0%	0%	2%	0%	36%	0%	0%	0%	13%	1%	47%
76	97	0%	0%	31%	0%	0%	0%	0%	0%	1%	0%	0%

		Soil Group C					Soil Group D					
		C-Open Spaces	C-Residential <1/8 acre lots	C-Residential 1/3 acre lots	C-Residential 1/2 acre lots	C-Residential >1 acre lots	D-Dommercial	D-Open Spaces	D-Residential <1/8 acre lots	D-Residential 1/3 acre lots	D-Residential 1/2 acre lots	D-Residential >1 acre lots
Cn Value		79	90	81	80	79	95	84	92	86	85	84
Future Cn	Basin											
86	99	0%	0%	1%	0%	0%	0%	0%	0%	34%	0%	65%
83	100	0%	0%	22%	0%	0%	0%	0%	0%	60%	0%	0%
81	102	0%	2%	55%	0%	0%	0%	0%	0%	24%	0%	0%
83	103	0%	0%	21%	0%	20%	0%	0%	0%	55%	0%	0%
85	104	0%	0%	11%	0%	8%	0%	0%	0%	73%	0%	8%
83	105	0%	0%	26%	0%	0%	3%	0%	0%	50%	0%	0%
89	107	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
89	109	0%	0%	0%	1%	10%	0%	0%	0%	0%	33%	56%
82	110	0%	1%	29%	0%	0%	2%	0%	1%	4%	0%	0%
86	113	0%	0%	4%	0%	2%	0%	0%	1%	92%	0%	0%
85	114	0%	0%	38%	0%	0%	2%	0%	0%	53%	0%	5%
81	115	0%	0%	14%	0%	0%	0%	0%	0%	51%	0%	0%
80	116	0%	0%	70%	0%	0%	0%	0%	0%	10%	0%	0%
80	117	0%	0%	16%	0%	0%	0%	0%	0%	43%	0%	0%
88	118	0%	0%	0%	0%	22%	0%	0%	0%	0%	0%	78%
82	119	0%	4%	4%	0%	0%	2%	0%	7%	37%	0%	0%
88	120	0%	0%	0%	0%	0%	0%	0%	20%	80%	0%	0%
86	121	0%	0%	0%	0%	0%	0%	0%	0%	94%	6%	1%
89	122	0%	0%	0%	5%	11%	0%	0%	0%	38%	45%	1%
89	124	0%	0%	0%	5%	2%	0%	0%	0%	0%	11%	81%
87	126	0%	0%	0%	1%	6%	0%	0%	0%	4%	11%	78%
87	127	0%	0%	0%	0%	0%	1%	0%	0%	99%	0%	0%
88	128	0%	0%	0%	0%	32%	0%	0%	0%	0%	0%	68%
84	129	1%	0%	30%	0%	1%	0%	1%	0%	39%	0%	25%
89	131	0%	8%	3%	0%	0%	9%	3%	25%	44%	0%	0%
89	132	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
89	133	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
89	134	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
87	135	0%	0%	0%	0%	0%	0%	0%	0%	4%	0%	84%
88	136	0%	0%	0%	0%	11%	0%	0%	0%	0%	14%	73%
85	137	0%	0%	8%	0%	6%	0%	0%	0%	72%	0%	14%
89	138	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
85	139	0%	0%	0%	0%	0%	0%	0%	0%	40%	0%	60%
89	140	0%	0%	0%	0%	3%	0%	0%	0%	0%	0%	96%
90	141	0%	3%	1%	0%	0%	6%	0%	48%	42%	0%	0%
89	142	0%	0%	0%	0%	0%	13%	0%	15%	70%	0%	0%
90	143	0%	0%	2%	0%	0%	7%	0%	42%	42%	0%	0%
88	144	2%	0%	7%	0%	0%	33%	15%	1%	29%	5%	0%
86	145	0%	0%	6%	0%	1%	0%	0%	0%	66%	0%	26%
85	147	0%	0%	2%	1%	6%	0%	1%	0%	26%	15%	49%
89	148	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
87	149	0%	0%	0%	0%	0%	0%	0%	17%	83%	0%	0%
89	151	0%	1%	4%	0%	0%	18%	0%	2%	62%	0%	0%
87	152	0%	0%	3%	0%	0%	2%	0%	14%	81%	0%	0%
91	153	0%	3%	3%	0%	0%	24%	0%	30%	33%	0%	0%
87	154	0%	0%	17%	0%	0%	2%	0%	21%	60%	0%	0%
87	155	0%	0%	10%	0%	0%	10%	0%	3%	76%	0%	0%
90	156	1%	0%	13%	1%	0%	42%	1%	0%	22%	6%	0%
89	159	11%	8%	1%	0%	0%	11%	1%	13%	36%	0%	0%
87	160	0%	6%	12%	0%	0%	3%	0%	7%	72%	0%	0%
85	162	0%	0%	0%	6%	3%	0%	0%	0%	0%	78%	13%
86	163	0%	0%	8%	7%	0%	7%	0%	0%	60%	18%	0%
89	164	0%	0%	0%	0%	3%	0%	0%	0%	0%	0%	97%
86	165	0%	0%	9%	0%	2%	0%	0%	0%	46%	0%	39%
82	166	0%	0%	21%	0%	0%	0%	0%	0%	38%	0%	26%
94	167	0%	0%	1%	0%	0%	81%	0%	1%	14%	0%	0%
86	170	0%	3%	11%	0%	0%	0%	0%	2%	79%	4%	0%
87	171	0%	2%	27%	0%	0%	15%	0%	0%	52%	0%	0%
90	174	0%	1%	9%	0%	0%	14%	0%	23%	38%	0%	0%
87	175	0%	0%	11%	0%	0%	13%	0%	0%	59%	14%	0%
87	176	2%	1%	17%	7%	0%	15%	3%	6%	35%	12%	0%
85	178	0%	0%	0%	3%	10%	0%	0%	0%	0%	33%	54%
86	179	0%	0%	11%	3%	0%	0%	0%	10%	59%	17%	0%
84	180	0%	0%	19%	11%	0%	0%	0%	0%	16%	49%	4%
85	181	0%	0%	0%	0%	6%	0%	0%	0%	0%	0%	78%
84	182	0%	0%	0%	9%	12%	0%	0%	0%	0%	62%	18%
82	183	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	66%
88	184	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	86%
86	185	0%	0%	6%	9%	0%	5%	0%	0%	32%	44%	0%
88	187	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	92%
88	188	0%	0%	0%	0%	20%	0%	0%	0%	0%	0%	80%
87	189	0%	0%	7%	2%	0%	15%	0%	0%	38%	29%	0%
86	190	0%	1%	8%	3%	1%	13%	0%	5%	23%	16%	26%
84	191	0%	0%	0%	6%	0%	0%	0%	0%	1%	50%	37%
89	192	0%	0%	0%	0%	12%	0%	0%	0%	0%	1%	88%
83	193	0%	0%	0%	12%	9%	0%	0%	0%	0%	43%	27%
85	194	0%	0%	0%	15%	0%	0%	0%	0%	0%	85%	0%
85	195	0%	0%	19%	11%	0%	3%	0%	0%	42%	24%	0%
89	196	0%	0%	0%	0%	3%	0%	0%	0%	0%	0%	97%
88	197	0%	0%	0%	2%	12%	0%	0%	0%	0%	16%	70%
84	198	0%	0%	0%	26%	4%	0%	0%	0%	0%	61%	9%

		Soil Group C					Soil Group D					
		C-Open Spaces	C-Residential <1/8 acre lots	C-Residential 1/3 acre lots	C-Residential 1/2 acre lots	C-Residential >1 acre lots	D-Dommercial	D-Open Spaces	D-Residential <1/8 acre lots	D-Residential 1/3 acre lots	D-Residential 1/2 acre lots	D-Residential >1 acre lots
Cn Value		79	90	81	80	79	95	84	92	86	85	84
Future Cn	Basin											
85	199	0%	0%	0%	11%	0%	5%	0%	0%	0%	79%	0%
86	201	0%	0%	2%	1%	0%	0%	0%	0%	38%	43%	16%
87	202	0%	0%	0%	8%	0%	0%	0%	0%	11%	52%	28%
85	203	0%	0%	0%	3%	2%	0%	0%	0%	3%	71%	21%
87	204	0%	0%	0%	0%	16%	0%	0%	0%	0%	13%	71%
84	205	0%	0%	41%	5%	0%	1%	0%	0%	44%	6%	0%
84	206	0%	0%	0%	24%	0%	0%	0%	0%	0%	76%	0%
85	207	0%	0%	0%	33%	0%	11%	0%	0%	0%	46%	0%
85	209	0%	0%	0%	23%	0%	1%	0%	0%	28%	46%	0%
89	211	0%	0%	0%	10%	9%	31%	0%	0%	0%	8%	18%
83	212	0%	0%	0%	25%	6%	0%	0%	0%	0%	59%	5%
84	213	0%	0%	0%	23%	2%	0%	0%	0%	0%	35%	40%
85	214	0%	0%	0%	17%	0%	0%	0%	0%	0%	23%	60%
87	215	0%	0%	0%	8%	0%	17%	0%	0%	0%	72%	1%
86	218	0%	0%	0%	10%	5%	10%	0%	0%	0%	67%	4%
90	219	0%	0%	0%	3%	0%	38%	0%	0%	0%	54%	0%
88	220	0%	0%	0%	2%	0%	1%	0%	0%	0%	15%	82%
86	221	0%	0%	0%	0%	2%	3%	0%	0%	0%	32%	64%
89	222	0%	0%	0%	6%	5%	23%	0%	0%	0%	40%	7%
92	223	0%	0%	0%	10%	0%	32%	0%	0%	0%	16%	0%
86	224	0%	0%	0%	0%	0%	0%	0%	0%	0%	26%	73%
85	225	0%	0%	0%	11%	0%	5%	0%	0%	0%	62%	19%
91	229	0%	0%	0%	1%	8%	46%	0%	0%	0%	5%	21%
88	230	0%	0%	0%	7%	25%	19%	0%	0%	0%	12%	35%
84	231	0%	0%	0%	21%	13%	0%	0%	0%	0%	41%	26%
88	232	0%	0%	0%	7%	21%	0%	0%	0%	0%	8%	64%
86	233	0%	0%	0%	5%	5%	0%	0%	0%	0%	18%	71%
86	234	0%	0%	0%	0%	0%	0%	0%	0%	0%	55%	45%
86	235	0%	0%	0%	0%	0%	12%	0%	0%	0%	9%	79%
82	236	0%	0%	0%	8%	2%	0%	0%	0%	0%	7%	48%
87	237	0%	0%	0%	0%	17%	0%	0%	0%	0%	0%	83%
85	238	0%	0%	0%	0%	0%	0%	0%	0%	0%	45%	55%
85	240	0%	0%	0%	13%	0%	0%	0%	0%	0%	87%	0%
88	241	0%	0%	0%	2%	14%	0%	0%	0%	0%	4%	80%
87	242	0%	0%	0%	4%	13%	0%	0%	0%	0%	20%	63%
85	243	0%	0%	0%	3%	0%	0%	0%	0%	0%	96%	0%
85	244	0%	0%	0%	0%	0%	0%	0%	0%	0%	99%	0%
85	246	0%	0%	0%	15%	0%	0%	0%	0%	0%	85%	0%

Appendix B: TIME TO CONCENTRATION CALCULATIONS

```
Function tc(L, S, K) ' Based on USBR modified Kirpich method for overland flow plus Chezy for channel
and stream flow

LOmax = 1500
LchMax = 75000
Kch = 15
Kst = 25

If L <= LOmax Then ' Assume flow is all overland flow
     tc = (11.9 * (L / 5280) ^ 2 / S) ^ 0.385 '(hours)
End If

If L > LOmax And L <= LchMax Then 'need overland and channel flows
    'overland flow
        ov = (11.9 * (LOmax / 5280) ^ 2 / S) ^ 0.385 '(hours)
    'channel flow
        If S <= 0.04 Then ' shallow slope equation applies
            ch = ((L - LOmax) / (Kch * S ^ 0.5)) * 1 / 60 ^ 2 ' (hours)
        End If

        If S > 0.04 Then ' steep slope equation applies
            ch = (L - LOmax) / (Kch * (0.05247 + 0.6363 * S - 0.182 * Exp(-62.38 * S)) ^ 0.5) * (1 / 6
0 ^ 2) '(sec)
        End If
    tc = (ov + ch)  '(hours)
End If

If L > LchMax Then 'need overland + Channel + stream flow
    'overland flow
        ov = (11.9 * (LOmax / 5280) ^ 2 / S) ^ 0.385 '(hours)
    'channel flow
        If S <= 0.04 Then ' shallow slope equation applies
            ch = ((LchMax - LOmax) / (Kch * S ^ 0.5)) * 1 / 60 ^ 2 ' (hours)
        End If

        If S > 0.04 Then ' steep slope equation applies
            ch = (LchMax - LOmax) / (Kch * (0.05247 + 0.6363 * S - 0.182 * Exp(-62.38 * S)) ^ 0.5) * (
1 / 60 ^ 2) '(sec)
        End If
     'stream flow
        If S <= 0.04 Then ' shallow slope equation applies
            st = ((L - LchMax - LOmax) / (Kst * S ^ 0.5)) * 1 / 60 ^ 2 ' (hours)
        End If

        If S > 0.04 Then ' steep slope equation applies
            st = (L - LchMax - LOmax) / (Kst * (0.05247 + 0.6363 * S - 0.182 * Exp(-62.38 * S)) ^ 0.5)
 * (1 / 60 ^ 2) '(sec)
        End If

    tc = (ov + ch + st) '(hours)
End If
End Function
```

Data from GIS

Basin ID	Area (Acres)	avg slope (ft/ft)	Length of water course (ft)		% veg	K	**Tc (hr)**	Average Velocity (ft/s)
Max	1505.73661	0.128246	172471.4566		100%	10	50.00	1.66
Min	102.493531	0.000154007	6685.695536		0%	7	2.74	0.27
Average	490.712735	0.032382817	31032.10071		37%	8.904303	12.03	0.85
Basin ID	AREA (AC)	SLOPE	FLOW LENGTH FT	FLOW LENGTH MI	Veg			
1	896	8.26%	22594	4.28	0%	10.00	3.78	1.66
2	837	10.14%	20210	3.83	0%	10.00	3.39	1.66
3	764	11.30%	18567	3.52	0%	10.00	3.18	1.62
4	865	8.01%	15911	3.01	0%	10.00	3.44	1.29
5	391	6.66%	8821	1.67	0%	10.00	3.24	0.76
6	146	1.30%	31701	6.00	0%	10.00	10.16	0.87
7	865	4.01%	18550	3.51	0%	10.00	4.65	1.11
8	1473	4.62%	24784	4.69	0%	10.00	4.83	1.43
9	934	11.41%	16506	3.13	0%	10.00	3.06	1.50
10	717	5.04%	15737	2.98	0%	10.00	4.06	1.08
13	353	2.70%	25320	4.80	0%	10.00	6.64	1.06
14	498	9.09%	11761	2.23	0%	10.00	3.05	1.07
15	723	2.13%	42419	8.03	0%	10.00	9.53	1.24
16	845	8.03%	15627	2.96	0%	10.00	3.42	1.27
17	311	9.83%	10913	2.07	0%	10.00	2.92	1.04
18	351	2.51%	19101	3.62	0%	10.00	6.12	0.87
19	754	6.11%	15997	3.03	0%	10.00	3.80	1.17
20	272	6.50%	6686	1.27	0%	10.00	3.14	0.59
23	345	6.25%	8721	1.65	0%	10.00	3.31	0.73
25	269	3.43%	11051	2.09	0%	10.00	4.56	0.67
26	102	2.83%	20485	3.88	0%	10.00	5.98	0.95
27	285	0.85%	28540	5.41	0%	10.00	11.62	0.68
29	859	4.36%	20122	3.81	0%	10.00	4.61	1.21
31	536	1.21%	38789	7.35	0%	10.00	11.65	0.93
32	792	2.69%	17378	3.29	0%	10.00	5.75	0.84
33	384	9.96%	10536	2.00	0%	10.00	2.89	1.01
34	290	10.12%	8099	1.53	0%	10.00	2.74	0.82
35	1057	2.73%	27359	5.18	0%	10.00	6.84	1.11
36	941	10.00%	20250	3.84	0%	10.00	3.41	1.65
37	459	5.35%	11691	2.21	0%	10.00	3.71	0.88
38	784	12.08%	15781	2.99	0%	10.00	2.96	1.48
39	460	5.63%	13168	2.49	0%	10.00	3.73	0.98
40	849	5.12%	19931	3.77	1%	9.97	4.32	1.28
41	539	4.32%	20149	3.82	4%	9.89	4.63	1.21
43	428	5.13%	14811	2.81	0%	10.00	3.97	1.04
44	614	5.36%	12424	2.35	37%	8.88	3.75	0.92
45	337	9.40%	9008	1.71	0%	10.00	2.86	0.87
46	659	6.51%	21255	4.03	0%	10.00	4.03	1.46
47	329	8.08%	12222	2.31	0%	10.00	3.21	1.06
48	444	0.63%	54166	10.26	50%	8.51	19.23	0.78
49	429	5.29%	10688	2.02	0%	10.00	3.66	0.81
50	522	4.35%	14067	2.66	12%	9.65	4.18	0.93
51	553	4.17%	17249	3.27	2%	9.93	4.48	1.07
52	337	1.25%	18723	3.55	0%	10.00	8.18	0.64
53	282	0.39%	53369	10.11	0%	10.00	23.64	0.63
54	211	0.83%	24997	4.73	0%	10.00	10.98	0.63
55	1076	2.81%	40208	7.62	0%	10.00	8.18	1.37
56	1234	3.38%	27390	5.19	0%	10.00	6.24	1.22
57	706	2.02%	16387	3.10	34%	8.99	6.36	0.72
61	208	0.94%	25661	4.86	88%	7.37	10.57	0.67
62	268	7.61%	15560	2.95	0%	10.00	3.48	1.24
63	979	5.15%	24976	4.73	0%	10.00	4.64	1.49
64	260	8.07%	9524	1.80	0%	10.00	3.06	0.87
65	523	3.55%	13222	2.50	15%	9.55	4.71	0.78
66	263	6.45%	10860	2.06	4%	9.88	3.41	0.89
67	377	4.10%	21791	4.13	0%	10.00	4.85	1.25
68	402	6.86%	7297	1.38	64%	8.07	3.11	0.65
69	368	6.45%	10041	1.90	4%	9.89	3.35	0.83
71	347	3.29%	12243	2.32	10%	9.70	4.76	0.71
72	755	5.90%	23915	4.53	0%	10.00	4.35	1.53
74	1062	3.56%	19066	3.61	0%	10.00	5.28	1.00

75	818	11.57%	15282	2.89	0%	10.00	2.98	1.43
77	666	3.21%	15191	2.88	77%	7.70	5.12	0.82
78	987	0.98%	50008	9.47	92%	7.24	14.89	0.93
80	349	0.97%	38244	7.24	22%	9.34	12.78	0.83
81	382	0.61%	65605	12.43	84%	7.48	22.20	0.82
82	203	0.81%	27237	5.16	79%	7.63	11.60	0.65
83	486	12.82%	13763	2.61	0%	10.00	2.79	1.37
84	342	3.72%	13829	2.62	6%	9.83	4.68	0.82
85	575	4.98%	23907	4.53	0%	10.00	4.63	1.43
86	267	4.52%	9766	1.85	0%	10.00	3.82	0.71
87	260	4.11%	9867	1.87	0%	10.00	3.97	0.69
88	259	4.29%	13027	2.47	0%	10.00	4.13	0.88
89	723	1.40%	32309	6.12	0%	10.00	9.91	0.91
90	644	2.56%	19934	3.78	66%	8.01	6.17	0.90
91	469	3.38%	21923	4.15	59%	8.24	5.68	1.07
92	630	4.58%	18992	3.60	0%	10.00	4.44	1.19
93	519	1.38%	23333	4.42	0%	10.00	8.56	0.76
94	376	1.70%	15488	2.93	100%	7.00	6.71	0.64
96	302	5.68%	9133	1.73	0%	10.00	3.46	0.73
97	290	0.69%	31504	5.97	100%	7.00	13.36	0.66
99	271	3.65%	12068	2.29	35%	8.96	4.55	0.74
100	200	0.19%	58141	11.01	100%	7.00	35.32	0.46
102	416	1.09%	11554	2.19	100%	7.00	7.39	0.43
103	486	1.86%	23084	4.37	83%	7.50	7.49	0.86
104	493	0.40%	54715	10.36	98%	7.07	23.78	0.64
105	212	0.21%	76100	14.41	100%	7.00	40.30	0.52
107	727	2.75%	16738	3.17	0%	10.00	5.63	0.83
109	761	4.10%	14653	2.78	0%	10.00	4.33	0.94
110	140	0.22%	37274	7.06	100%	7.00	24.44	0.42
113	448	1.60%	20848	3.95	99%	7.02	7.68	0.75
114	539	0.33%	80719	15.29	95%	7.14	33.33	0.67
115	175	0.21%	70170	13.29	100%	7.00	38.49	0.51
116	266	1.49%	13233	2.51	100%	7.00	6.76	0.54
117	274	0.16%	85428	16.18	100%	7.00	47.88	0.50
118	269	10.31%	10339	1.96	0%	10.00	2.84	1.01
119	339	0.26%	77524	14.68	79%	7.62	36.82	0.58
120	202	0.21%	63704	12.07	100%	7.00	35.81	0.49
121	264	3.45%	10600	2.01	37%	8.90	4.51	0.65
122	331	4.60%	9504	1.80	0%	10.00	3.78	0.70
124	642	1.81%	21723	4.11	0%	10.00	7.40	0.82
126	653	0.80%	39159	7.42	15%	9.55	14.10	0.77
127	250	0.36%	54714	10.36	100%	7.00	25.05	0.61
128	368	8.64%	10803	2.05	0%	10.00	3.06	0.98
129	686	0.37%	88800	16.82	76%	7.73	33.09	0.75
131	888	1.39%	21498	4.07	36%	8.92	8.25	0.72
132	239	0.99%	33015	6.25	0%	10.00	11.69	0.78
133	491	0.44%	43189	8.18	0%	10.00	19.61	0.61
134	295	4.20%	14216	2.69	0%	10.00	4.25	0.93
135	583	6.03%	17162	3.25	6%	9.83	3.89	1.23
136	143	0.70%	39518	7.48	0%	10.00	15.11	0.73
137	979	4.30%	28879	5.47	80%	7.60	5.26	1.53
138	151	1.91%	20950	3.97	0%	10.00	7.13	0.82
139	293	10.39%	9779	1.85	44%	8.68	2.80	0.97
140	845	1.85%	17156	3.25	0%	10.00	6.71	0.71
141	410	1.35%	20655	3.91	67%	7.98	8.21	0.70
142	400	1.31%	18804	3.56	60%	8.21	8.03	0.65
143	340	0.36%	31211	5.91	25%	9.26	17.80	0.49
144	833	1.39%	17219	3.26	66%	8.01	7.58	0.63
145	429	6.85%	17443	3.30	56%	8.33	3.73	1.30
147	204	0.18%	94798	17.95	73%	7.80	47.53	0.55
148	538	1.95%	14206	2.69	0%	10.00	6.17	0.64
149	298	0.35%	32140	6.09	87%	7.38	18.21	0.49
151	329	1.19%	24812	4.70	63%	8.11	9.38	0.73
152	367	2.94%	14149	2.68	40%	8.81	5.19	0.76
153	194	0.54%	38750	7.34	22%	9.33	16.79	0.64
154	799	0.34%	45537	8.62	54%	8.38	22.80	0.55
155	1023	1.90%	21768	4.12	85%	7.44	7.26	0.83
156	574	1.33%	20535	3.89	34%	8.97	8.25	0.69
159	269	0.66%	13861	2.63	0%	10.00	9.61	0.40
160	141	0.07%	49421	9.36	67%	7.98	49.28	0.28

162	317	0.23%	101385	19.20	56%	8.33	43.94	0.64
163	350	1.66%	13286	2.52	97%	7.09	6.46	0.57
164	470	1.87%	12623	2.39	0%	10.00	6.06	0.58
165	290	10.48%	9742	1.85	22%	9.35	2.79	0.97
166	323	6.85%	13690	2.59	42%	8.75	3.50	1.09
167	239	0.11%	53984	10.22	1%	9.97	43.36	0.35
170	777	0.73%	39248	7.43	100%	7.00	14.74	0.74
171	566	0.34%	50019	9.47	86%	7.43	24.15	0.58
174	672	1.38%	15547	2.94	97%	7.08	7.34	0.59
175	527	1.56%	21318	4.04	90%	7.29	7.81	0.76
176	683	0.42%	66506	12.60	86%	7.41	26.69	0.69
178	226	0.15%	107535	20.37	36%	8.93	50.00	0.60
179	301	2.58%	9767	1.85	100%	7.00	4.98	0.55
180	586	3.99%	19820	3.75	83%	7.50	5.10	1.08
181	659	1.29%	11589	2.19	0%	10.00	6.90	0.47
182	497	0.16%	116782	22.12	71%	7.87	50.00	0.65
183	188	0.07%	48302	9.15	0%	10.00	49.01	0.27
184	316	2.08%	10754	2.04	0%	10.00	5.56	0.54
185	486	1.28%	15416	2.92	100%	7.00	7.55	0.57
187	151	0.29%	50923	9.64	0%	10.00	26.53	0.53
188	328	2.45%	10638	2.01	0%	10.00	5.19	0.57
189	399	1.61%	12511	2.37	100%	7.00	6.44	0.54
190	961	4.22%	21565	4.08	25%	9.24	4.78	1.25
191	264	6.16%	9494	1.80	39%	8.83	3.38	0.78
192	242	0.29%	54578	10.34	0%	10.00	27.45	0.55
193	353	0.15%	122497	23.20	32%	9.03	50.00	0.68
194	178	1.10%	21572	4.09	100%	7.00	9.15	0.66
195	1152	1.13%	45997	8.71	100%	7.00	13.26	0.96
196	287	2.57%	12148	2.30	0%	10.00	5.26	0.64
197	265	0.43%	59251	11.22	2%	9.95	24.41	0.67
198	382	0.15%	132203	25.04	69%	7.92	50.00	0.73
199	385	1.63%	14908	2.82	100%	7.00	6.76	0.61
201	604	5.32%	18261	3.46	62%	8.13	4.15	1.22
202	496	5.81%	15158	2.87	24%	9.29	3.81	1.10
203	974	4.50%	17717	3.36	62%	8.13	4.38	1.12
204	489	2.76%	13634	2.58	12%	9.65	5.27	0.72
205	537	1.62%	16723	3.17	100%	7.00	7.03	0.66
206	230	0.81%	18832	3.57	100%	7.00	9.84	0.53
207	368	1.81%	11697	2.22	100%	7.00	6.02	0.54
209	483	0.82%	30756	5.83	100%	7.00	12.25	0.70
211	147	0.37%	34929	6.62	100%	7.00	18.76	0.52
212	538	0.72%	46053	8.72	100%	7.00	16.27	0.79
213	832	5.77%	17622	3.34	62%	8.15	3.98	1.23
214	427	5.90%	17018	3.22	38%	8.86	3.91	1.21
215	869	2.09%	23243	4.40	99%	7.02	7.15	0.90
218	391	1.90%	16669	3.16	100%	7.00	6.57	0.70
219	163	0.09%	141733	26.84	100%	7.00	50.00	0.79
220	524	3.42%	11581	2.19	13%	9.62	4.62	0.70
221	287	3.23%	11991	2.27	34%	8.98	4.77	0.70
222	676	1.94%	21101	4.00	75%	7.75	7.09	0.83
223	200	0.14%	144086	27.29	100%	7.00	50.00	0.80
224	398	2.81%	10971	2.08	29%	9.13	4.94	0.62
225	1107	3.60%	35657	6.75	44%	8.68	6.88	1.44
229	354	0.58%	45951	8.70	57%	8.28	17.99	0.71
230	118	0.49%	35348	6.69	5%	9.86	16.55	0.59
231	870	1.11%	31872	6.04	44%	8.67	10.91	0.81
232	488	2.27%	13106	2.48	0%	9.99	5.66	0.64
233	361	6.50%	13798	2.61	28%	9.17	3.58	1.07
234	459	3.27%	10912	2.07	34%	8.99	4.64	0.65
235	315	0.15%	152002	28.79	91%	7.26	50.00	0.84
236	396	6.05%	12408	2.35	28%	9.17	3.58	0.96
237	613	2.15%	18022	3.41	17%	9.48	6.40	0.78
238	144	0.08%	154357	29.23	94%	7.17	50.00	0.86
240	146	0.10%	160303	30.36	59%	8.23	50.00	0.89
241	1506	1.69%	30251	5.73	8%	9.77	8.83	0.95
242	893	1.64%	21645	4.10	18%	9.47	7.70	0.78
243	326	1.50%	12063	2.28	80%	7.60	6.56	0.51
244	109	0.02%	172471	32.67	98%	7.05	50.00	0.96
246	551	1.23%	15901	3.01	64%	8.08	7.77	0.57

Future model Tc Values

Basin ID	Tc (hours)	Basin ID	Tc (hours)	Basin ID	Tc (hours)	Basin ID	Tc (hours)	Basin ID	Tc (hours)
1	3.9	50	4.3	100	52.3	151	14.5	202	3.9
2	3.5	51	4.6	102	17.0	152	5.4	203	4.5
3	3.3	52	8.5	103	9.0	153	19.0	206	14.5
4	3.6	53	24.4	104	31.5	154	26.0	207	10.3
5	3.3	54	11.3	105	60.2	155	11.2		
6	10.5	55	8.5	107	5.8	156	8.5		
7	4.8	56	6.5	109	4.5	159	9.9		
8	5.0	57	6.6	110	58.4	160	59.2		
9	3.2	61	15.1	113	13.2	162	45.4		
10	4.2	62	3.6	114	45.6	163	12.5		
13	6.9	63	4.8	115	60.2	164	6.3		
14	3.2	64	3.2	116	15.6	165	2.9		
15	9.9	65	4.9	117	85.3	166	3.6		
16	3.5	66	3.5	118	2.9	167	49.2		
17	3.0	67	5.0	119	65.3	170	24.5		
18	6.3	68	4.0	120	52.2	171	35.6		
19	3.9	69	3.5	121	4.7	174	17.9		
20	3.2	71	4.9	122	3.9	175	13.5		
23	3.4	72	4.5	124	7.6	176	37.1		
25	4.7	74	5.5	126	14.6	178	51.7		
26	6.2	75	3.1	127	34.2	179	9.6		
27	12.0	77	6.4	128	3.2	180	8.1		
29	4.8	78	24.5	129	38.2	181	7.1		
31	12.0	80	13.2	131	8.1	182	51.7		
32	5.9	81	27.7	132	12.1	183	50.7		
33	3.0	82	13.0	133	20.3	184	5.7		
34	2.8	83	2.9	134	4.4	185	11.6		
35	7.1	84	4.8	135	4.0	187	27.4		
36	3.5	85	4.8	136	15.6	188	5.4		
37	3.8	86	3.9	137	6.3	189	11.1		
38	3.1	87	4.1	138	7.4	190	4.9		
39	3.9	88	4.3	139	2.9	191	3.5		
40	4.5	89	10.2	140	6.9	192	28.4		
41	4.8	90	6.4	141	11.9	193	51.7		
43	4.1	91	5.9	142	10.1	194	13.6		
44	3.9	92	4.6	143	20.0	195	20.7		
45	3.0	93	8.8	144	10.5	196	5.4		
46	4.2	94	14.5	145	3.9	197	25.2		
47	3.3	96	3.6	147	49.1	198	52.0		
48	19.9	97	38.5	148	6.4	199	11.0		
49	3.8	99	4.7	149	23.5	201	4.5		

Appendix C: IMPROVEMENT COST ESTIMATES

Improvement	Base Cost		Incremental Cost	
	Unit Cost	Unit	Unit Cost	Unit
Canal Improvement Construction	$ 51.00	LF	$ -	
Adding capacity to an existing canal	$ 51.00	LF	$ 0.20	CFS-LF
Concrete Levee Construction	$ 541.00	LF	$ -	
Earth Levee Construction	$ 393.00	LF	$ -	
Detention Basin Construction	$ 42,621.00	ea	$ 2,640.00	AF
Debris Basin Construction	$ 282,710.00	Ea	$ 2,640.00	AF

*Cost Justification plus 25% for engineering, CM, Legal and admin

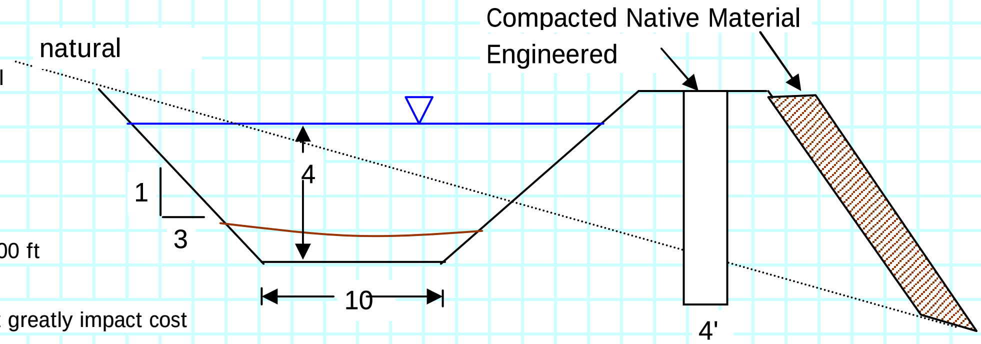
Piping / Culvert Improvement Costs				
Pipe Size	2006 Unit Cost	2007 Unit Cost	2008 unit costs	2008 Vernal
18	$ 87.50	$ 90.13	$ 92.83	$ 106.75
21	$ 75.00	$ 77.25	$ 79.57	$ 91.50
24	$ 80.00	$ 82.40	$ 84.87	$ 97.60
27	$ 90.00	$ 92.70	$ 95.48	$ 109.80
30	$ 100.00	$ 103.00	$ 106.09	$ 122.00
36	$ 120.00	$ 123.60	$ 127.31	$ 146.40
42	$ 150.00	$ 154.50	$ 159.14	$ 183.01
48	$ 190.00	$ 195.70	$ 201.57	$ 231.81
54	$ 225.00	$ 231.75	$ 238.70	$ 274.51
60	$ 250.00	$ 257.50	$ 265.23	$ 301.96
66	$ 247.50	$ 254.93	$ 262.57	$ 305.01
72	$ 300.00	$ 309.00	$ 318.27	$ 366.01
78	$ 390.00	$ 401.70	$ 413.75	$ 475.81
84	$ 525.00	$ 540.75	$ 556.97	$ 640.52
90	$ 712.50	$ 733.88	$ 755.89	$ 869.27
96	$ 900.00	$ 927.00	$ 954.81	$1,098.03
102	$ 1,062.50	$ 1,094.38	$ 1,127.21	$1,296.29

* Assumes 3% annual cost increase + 15% location adjustment

Canal Improvement Construction

Assumptions

Sections are Earth lined trapezoidal
3:1 side slopes
No upstream bank
Average of 1.5' of silt in bottom
Average depth of engineered fill 6'
Crossing or turn out structure ~1000 ft
1 overflow structure per 7500 ft
Variations in canal capacity will not greatly impact cost



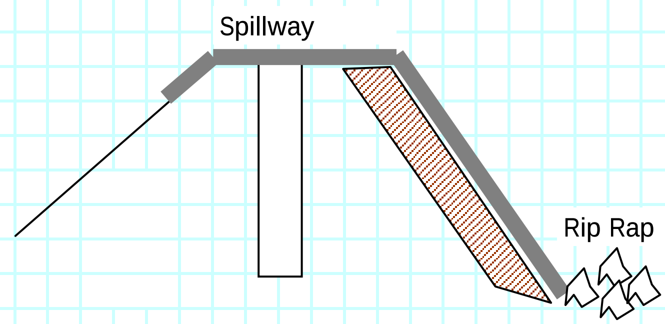
Unit Cost Estimates

Excavate & recompact material = 5$/yd
Import & Compact Engineered Fill = 25 $/yd
Turn out / crossing structure improvement cost = 25,000 $/each
Concrete in place = 150 $/yd
Rip Rap = 5 $/SF

Calculations

Silt removal	10* 1.5'=15cf/lf
Bank Excavation	4x6=10 cf/LF
Total Excavation	25 cf
Engineered Fill	4x6=10 cf/LF

Concrete Overflow Structure
Average width = 20'
Average Length =30'
Concrete Thickness 1'
Energy Dissipation = 20 x 15 = 300SF of riprap
Total Concrete
20'x30'x1'=600 CF =~23 yd



Estimated Improvement Cost

Excavation & recompaction	=	25	CF	*	9	$/yd			=	$	8.61	LF
Engineered Fill	=	10	CF	*	44	$/yd			=	$	16.30	LF
Structure cost = 25,000 $/1000 lf * 1000lf = 25/lf									=	$	25.00	LF
Concrete Cost	=	23	YD	*	230	$/yd	/	7500	=	$	0.71	LF
Rip Rap cost	=	300	SF	*	9	$/sf	/	7500	=	$	0.36	LF
Total Improvement Cost									=	$	50.97	

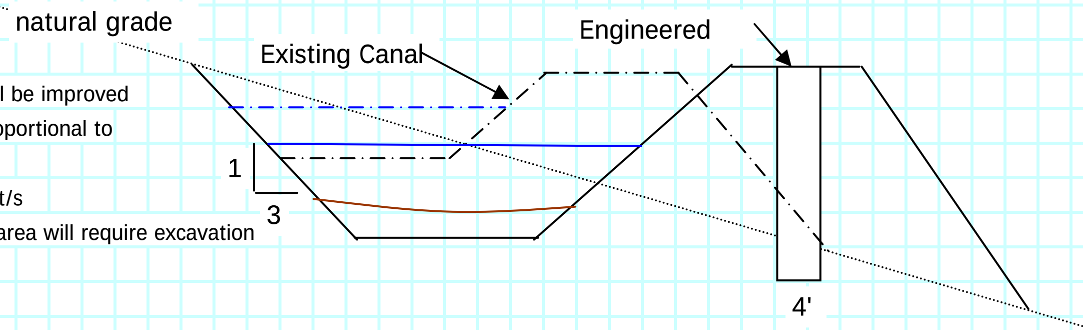
Epic Engineering, P.C.

CIVIL MUNICIPAL PROJECT MANAGEMENT WATER RESOURCES

Date: April 3, 2008

By: GRT
Subject: Ashley Valley Storm Water Master Plan Improvement Justification

Adding capacity to an existing canal



Assumptions
All enlarged canals will be improved
Capacity is directly proportional to
Area of flow
Average velocity is 3 ft/s
75% of the new flow area will require excavation

Costs:

Base Cleaning cost = $ 50.97 LF

Additional CFS Calculations

3 ft/s *1 cf / 0.75 = 4 CFS of capacity per 1 CF of soil excavated

or

1 CY/LF = 108 CFS

1CY per 108 CFS * 5 $/YD = 0.05 $/CFS

Additional cost for canal crossing and turnouts as a result of larger capacities

= 0.15 $/CFS

Total Cost:

Base Cleaning Cost = $ 50.97 LF

Enlargements Cost = $ 0.15 LF/CFS

For New canals assume existing capacity is 0 CFS plus right of way costs

new canals are lined w/ rip rap

Property value: $ 100,000.00 per acre

Typical width : 100 ft

Rip Rap cost

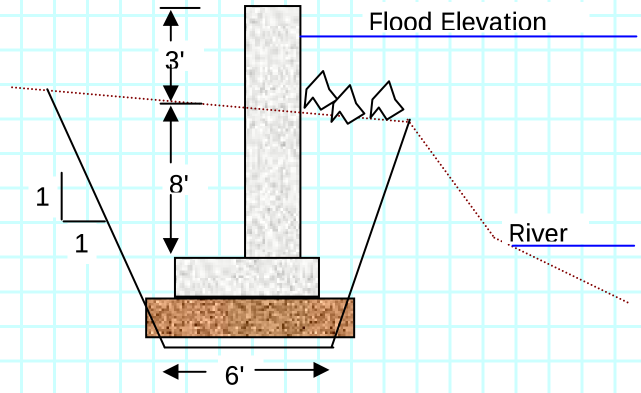
$5.00/sf ~75 sf/lf >>> $375/LF

Total new canal cost w/ rip rap $644.43/LF + $0.15/lf-cfs

Concrete Levee Construction

Assumptions

Average Height of Levee = 3'
Concrete Width = 2'
Concrete in place cost = 150 $/yd
Excavation & haul off Cost = 15 $/yd
Engineered Fill = 25 $/ yd



Calculations

Concrete Volume 2' x (3'+8') + 6x2 = 34 CF/LF
Excavation Volume 6' x 8' + 2(6x8/2) = 96 CF/LF
Engineered Fill 6'x2'=12 CF/LF

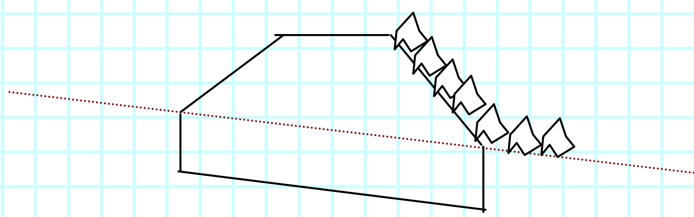
Costs

Concrete Volume	34	CF	*	$	233.00	$/CY	=	$	293.41	
Excavation Volume	96	CF	*	$	44.00	$/CY	=	$	156.44	
Engineered Fill	25	CF	*	$	44.00	$/CY	=	$	40.74	
Rip Rap	5	SF/	*	$	9.00	$/SF	=	$	45.00	
Permitting							=	$	5.00	
Total								$	540.59	$/LF

Earth Levee Construction

Assumptions

Average Height of Levee = 3'
Engineered Fill = 25 $/ yd
Side Slopes 3:1
Top width 12'



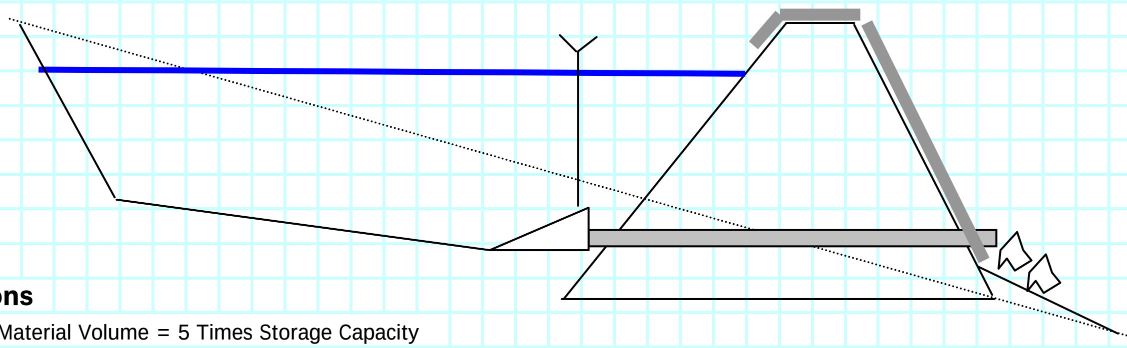
Calculations

Fill Volume Required 12*3+((3*3)*3/2)*2 + (12+6)*3= 117 CF/LF
Earth removal 12+(3*2)*3= 54
Rip Rap 3*3 +4=13 SF/LF

Costs

Fill Volume Required	117	cf	*	$ 44.00	=	$	190.67	
Earth removal	54	cf		$ 44.00	=	$	88.00	
Rip Rap	13	SF	*	$ 8.00	=	$	104.00	
Permitting				$ 5.00	=	$	10.00	
Total						$	392.67	$/LF

Debris / detention Basin Construction



Assumptions

Excavated Material Volume = 5 Times Storage Capacity
Excavated Material is suitable to be used for berm

Debris Basin		Detention Basin
Typical Spillway	1'x50'x200' concrete	1'x20'x50'
Typical outlet works	36" RCP ~300' long	24" RCP ~100 ft
	Inlet & outlet structure w/ orifice	Rip Rap 20x30
	Air tube 18" RCP ~10' high	
	Rip Rap 50' x 200'	

Unit Cost Estimates

Excavate & recompact material = 8$/yd
Import & Compact Engineered Fill = 44 $/yd
Turn out / crossing structure improvement cost = 25,000 $/each
Concrete in place = 230 $/yd
Rip Rap = 8 $/SF

Estimated Debris Basin Improvement Cost

Fixed Costs									
Concrete	1'x50'x200'=	370	yd	x	233	$/yd	=	$	86,210.00
Rip Rap	50'x200'=	10,000	sf	x	8	$/sf	=	$	80,000.00
RCP pipe	300	ft		x	300	$/ft	=	$	90,000.00
Inlet structure							=	$	25,000.00
Airway	18" CMP x 10'			x	200	$/ft	=	$	1,500.00
Total							=	**$**	**282,710.00**

Estimated Detention Basin Improvement Cost

Fixed Costs									
Concrete	1'x20'x50'=	37	yd	x	233	$/yd	=	$	8,621.00
Rip Rap	20x30=	500	sf	x	8	$/sf	=	$	4,000.00
RCP pipe	100	ft		x	200	$/ft	=	$	20,000.00
Inlet structure							=	$	10,000.00
							=	$	-
Total							=	**$**	**42,621.00**

Storage sizing costs
excavated & recompacted soil @ 8 $/yd
Every 1 yd of soil = 5 yd of storage
$1.00 per yd of storage or ~2,640 $/AF

Appendix D: URBAN STORM WATER BMP PERFORMANCE MONITORING (EPA PUBLICATION)

United States
Environmental Protection
Agency

American Society of Civil Engineers

Urban Stormwater BMP Performance Monitoring

A Guidance Manual for Meeting the National Stormwater BMP Database Requirements

April 2002

Urban Stormwater BMP Performance Monitoring

A Guidance Manual for Meeting the National Stormwater BMP Database Requirements

Prepared by

GeoSyntec Consultants
Urban Drainage and Flood Control District

and

Urban Water Resources Research Council (UWRRC) of ASCE

In cooperation with

Office of Water (4303T)
US Environmental Protection Agency
Washington, DC 20460

April 2002

EPA-821-B-02-001

American Society of Civil Engineers

United States Environmental Protection Agency

TABLE OF CONTENTS

List of Tables

List of Figures

Acknowledgements and Disclaimer

The authors, Eric Strecker, P.E. of GeoSyntec Consultants, Ben Urbonas, P.E. Urban Drainage and Flood Control District, Denver, Marcus Quigley, P.E., Jim Howell, and Todd Hesse of GeoSyntec Consultants would like to thank Jesse Pritts, P.E. and Eric Strassler of the Environmental Protection Agency and Tom McLane and Lorena Diaz of the American Society of Civil Engineers (ASCE) for their support for and participation in the ASCE/EPA National Stormwater Best Management Practices Database Project and the development of this guidance. The authors would also like to thank the following members of ASCE's Urban Water Resources Research Council for their thorough review and contributions to this guidance:

Robert Pitt, P.E., Ph.D. (University of Alabama, Birmingham)
Eugene Driscoll, P.E.
Roger Bannerman, P.E. (Wisconsin Department of Natural Resources)
Shaw Yu, P.E., Ph.D. (University of Virginia)
Betty Rushton (Southwest Florida Water Management District)
Richard Field (EPA), P.E.
Jonathan Jones, P.E. (Wright Water Engineers)
Jane Clary (Wright Water Engineers)
Tom Langan (Wright Water Engineers)

Sections of this manual were developed by the authors concurrently with the Federal Highway Administration's (FHWA) "Guidance Manual For Monitoring Highway Runoff Water Quality." Although the focus of the FHWA manual is on highway runoff monitoring, much of the information on equipment selection, use, and installation is applicable to best management practice monitoring and thus was adapted for this guidance.

In addition, portions of this document were adapted from work originally conducted for the Washington State Department of Ecology's (DOE) November 1995, "Stormwater Monitoring Guidance Manual" by an author of this document (Eric Strecker) and Mike Milne (URS Group, Inc.), Terry Cook (URS Group, Inc.), Gail Boyd (URS Group, Inc.), Christa Reininga (URS Group, Inc.), and Lynn Krasnow. The thoroughness and specific insight provided in the DOE Manual were useful in assembling this guidance.

The authors would also like to thank Joan LeBlanc, and Kathy Staffier (GeoSyntec Consultants) for editorial review and edits of the final document.

Disclaimer:
Mention of trade names or commercial products does not constitute endorsement by EPA or ASCE, or recommendation for use.

1 Introduction

1.1 Scope

Existing guidance is available for assessing the effectiveness of stormwater best management practices (EPA 1997; FHWA 2000). However, few existing documents provide targeted practical assistance in conducting and reporting data from a water quality based monitoring program that results in data that are useful for assessing BMP effectiveness on a broader scale.

This guidance has been developed by integrating experience gleaned from field monitoring activities conducted by members of ASCE's Urban Water Resource Research Council and through the development of the ASCE/EPA National Stormwater Best Management Practices Database. The manual is intended to help achieve stormwater BMP monitoring project goals through the collection of more useful and representative rainfall, flow, and water quality information. Many of the recommended protocols (particularly those for reporting monitoring, watershed, and design information) are directly related to requirements of the National Stormwater Best Management Practices Database.

This manual is intended to improve the state of the practice by providing a recommended set of protocols and standards for collecting, storing, analyzing, and reporting BMP monitoring data that will lead to better understanding of the function, efficiency, and design of urban stormwater BMPs. This manual provides insight into and guidance for strategies, approaches, and techniques that are appropriate and useful for monitoring BMPs.

This document addresses methods that were in use at the time it was written. As the state of the practice and the design of monitoring equipment progress, new monitoring approaches and techniques, more sensitive devices, and equipment based on new technologies will likely be employed. Although the technology may change somewhat from that described herein, most of the basic flow and water quality monitoring methods discussed in this document have a long history of use and will most likely remain viable even as new and different technologies emerge.

This manual focuses primarily on the collection, reporting, and analysis of water quantity and quality measurements at the heart of quantitative BMP efficiency projects. It does not address, in detail, sediment sampling methods and techniques, biological assessment, monitoring of receiving waters, monitoring of groundwater, streambank erosion, channel instability, channel morphology, or other activities that in many circumstances may be as, or more, useful for measuring and monitoring water quality for assessing BMP efficiency.

1.1.1 State of the Practice

Many studies have assessed the ability of stormwater treatment BMPs (e.g., wet ponds, grass swales, stormwater wetlands, sand filters, dry detention, etc.) to reduce pollutant concentrations and loadings in stormwater. Although some of these monitoring projects conducted to date have done an excellent job of describing the effectiveness of specific BMPs and BMP systems, there is a lack of standards and protocols for conducting BMP assessment and monitoring work. These problems become readily apparent for persons seeking to summarize the information gathered from a number of individual BMP evaluations. Inconsistent study methods, lack of associated design information, and reporting protocols make wide-scale assessments difficult, if not impossible. (Strecker et al. 2001; Urbonas 1998) For example, individual studies often include the analysis of different constituents and utilize different methods for data collection and analysis, as well as report varying degrees of information on BMP design and flow characteristics. The differences in monitoring strategies and data evaluation alone contribute significantly to the range of BMP "efficiency" that has been reported in literature to date.

1.1.2 The Need for Guidance

Municipal separate storm sewer system owners and operators need to identify effective BMPs for improving stormwater runoff water quality. Because of the current state of the practice, however, very little sound scientific data are available for making decisions about which structural and non-structural management practices function most effectively under what conditions; and, within a specific category of BMPs, to what degree design and environmental static and state variables directly affect BMP efficiency. This guidance addresses this need by helping to establish a standard basis for collecting water quality, flow, and precipitation data as part of a BMP monitoring program. The collection, storage, and analysis of this data will ultimately improve BMP selection and design.

1.1.3 National Stormwater Best Management Practices Database

The National Stormwater BMP Database (Database) serves two key purposes: (1) to define a standard set of data reporting protocols for use with BMP monitoring efforts; and (2) to assemble and summarize historical and future BMP study data in a standardized format. The software consists of a data entry module for reporting data on new BMP studies and a search engine module to allow users to retrieve data. The Database is a user-friendly, menu-driven software program developed in a run-time version of Microsoft® Access 97 and Access 2000. The software has been distributed on CD-ROM and is now also accessible via the Internet at www.bmpdatabase.org.

1.2 Format and Content of This Document

This document is broken down into two main sections following this introduction:

Section 2 provides an overview of BMP monitoring. Discussion is provided on the context of BMP monitoring, difficulties in assessing BMP performance, and understanding the relationship between BMP study design and the attainment of monitoring program goals. Useful analysis of data collected from BMP monitoring studies is essential for understanding and comparing BMP monitoring study results. A summary of historical and recommended approaches for data analysis is provided in this section to elucidate the relationship between the details and subtleties of each analysis approach and the assessment of performance.

Section 3 discusses the specifics of developing a monitoring program, selecting monitoring methods and equipment, installing and using equipment, implementing sampling approaches and techniques, and reporting information consistent with the National Stormwater Best Management Practices Database.

In addition, four appendices have been included in this guidance document. The first appendix describes methods for calculating expected errors in field measurements. The second provides detailed information about the number of samples required to obtain statically significant monitoring data. The third appendix includes charts for estimating the number of samples required to observe a statically significant difference between two populations for a various levels of confidence and power. The final appendix is a table for estimating arithmetic descriptive statistics based on descriptive statistics of log-transformed data.

2 BMP Monitoring Overview

This section provides an overview of BMP monitoring program context and execution, including a discussion of approaches used for quantifying BMP efficiency.

2.1 Context of BMP Monitoring in the Regulatory Environment

BMP monitoring is conducted by researchers, public entities, and private companies for meeting both regulatory and non-regulatory needs. This section briefly discusses some of the regulatory programs that drive BMP monitoring programs.

A number of environmental laws exist for implementation of stormwater and BMP monitoring programs including:

- The Clean Water Act (CWA) of 1972:

  Section 208 of 1972 CWA requires every state to establish effective BMPs to control nonpoint source pollution. The 1987 Water Quality Act (WQA) added section 402(p) to the CWA, which requires that urban and industrial stormwater be controlled through the National Pollutant Discharge Elimination System (NPDES) permit program.

  Section 303(d) of WQA requires the states to list those water bodies that are not attaining water quality standards including designated uses and identification of relative priorities among the impaired water bodies. States must also develop TMDLs (Total Maximum Daily Loads) that quantify the pollutant load or the impairing pollutants that will bring the waterbody back into attainment.

- The Endangered Species Act:

  The Endangered Species Act of 1973 protects animal and plant species currently in danger of extinction (endangered) and those that may become endangered in the foreseeable future (threatened). It provides for the conservation of ecosystems upon which threatened and endangered species of fish, wildlife, and plants depend, both through Federal action and by encouraging the establishment of state programs.

- Coastal Zone Act Reauthorization Amendments (CZARA) of 1990:

  CZARA was passed to help address nonpoint source pollution in coastal waters. Each state with an approved coastal zone management program must develop and submit to the EPA and National Oceanic and Atmospheric Administration (NOAA) a Coastal Nonpoint Pollution Control Program (CNPCP), which provides for the implementation of the most economically achievable management measures and BMPs to control the addition of pollutants to coastal waters.

CZARA does not specifically require that states monitor implementation of management measures and BMPs. They must, however, provide technical assistance to local governments and the public in the implementation of the management measures and BMPs, which may include assistance to predict and assess the effectiveness of such measures.

CZARA also states that the EPA and NOAA shall provide technical assistance to the states in developing and implementing the CNPCP, including methods to predict and assess the effects of coastal land use management measures on coastal water quality and designated uses:

1. Protection of stream and water body designated use (meet fishable and swimmable goals)

2. Antidegradation policies designated to protect water quality when the water quality already is higher than existing standards

3. Other state, county, and local regulations or ordinances

As regulations and the application and enforcement thereof change over time, details about the above environmental laws and their implications for specific sites and watersheds are best obtained from current EPA, state, county, and local resources.

2.2 BMP Monitoring Goals

BMP monitoring projects are initiated to address a broad range of programmatic, management, regulatory, and research goals. Goal attainment is often focused on the achievement of water quality objectives downstream of the BMP. However, there are many other objectives that have been established as part of BMP implementation projects that cannot be measured using a water quality monitoring approach alone. Table 2.1 below describes the relationship between BMP implementation objectives and the ability of water quality monitoring studies to address the attainment of these objectives.

Studies directed at addressing the efficiency of BMPs in attaining water quality goals are usually conducted to obtain information to help answer one or more of the following questions:

- What degree of pollution control or effluent quality does the BMP provide under normal conditions?

- How does this efficiency vary from pollutant to pollutant?

- How does this normal efficiency vary with large or small storm events?
- How does this normal efficiency vary with rainfall intensity?
- How do design variables affect efficiency?
- How does efficiency vary with different operational and/or maintenance approaches?
- Does efficiency improve, decay, or remain stable over time?
- How does this BMP's efficiency compare with the efficiency of other BMPs?

The ability of a specific BMP monitoring program to answer these questions and ultimately address the desire to measure goal attainment is a vital planning stage component of setting up a meaningful BMP monitoring program.

Table 2.1: Objectives of BMP implementation projects and the ability of comprehensive water quality monitoring studies to provide information useful for determining performance and effectiveness

Category	**Goals of BMP Projects**	**Ability to Evaluate Performance and Effectiveness**
Hydraulics	• Improve flow characteristics upstream and/or downstream of BMP	-
Hydrology	• Flood mitigation, improve runoff characteristics (peak shaving)	✓
Water Quality	• Reduce downstream pollutant loads and concentrations of pollutants	✓
	• Improve/minimize downstream temperature impact	✓
	• Achieves desired pollutant concentration in outflow	✓
	• Removal of litter and debris	-
Toxicity	• Reduce acute toxicity of runoff	✓
	• Reduce chronic toxicity of runoff	✓
Regulatory	• Compliance with NPDES permit	-
	• Meet local, state, or federal water quality criteria	✓[1]
Implementation Feasibility	• For non-structural BMPs, ability to function within management and oversight structure	-
Cost	• Capital, operation, and maintenance costs	-
Aesthetic	• Improve appearance of site	-
Maintenance	• Operate within maintenance, and repair schedule and requirements	-
	• Ability of system to be retrofit, modified or expanded	-
Longevity	• Long-term functionality	✓
Resources	• Improve downstream aquatic environment/erosion control	-
	• Improve wildlife habitat	-
	• Multiple use functionality	-
Safety, Risk and Liability	• Function without significant risk or liability	-
	• Ability to function with minimal environmental risk downstream	-
Public Perception	• Information is available to clarify public understanding of runoff quality, quantity and impacts on receiving waters	✓

✓ can be evaluated using water quality monitoring as primary source of information
✓[1] can be evaluated using water quality monitoring as the primary source of information combined with a secondary source of comparative data
- cannot be directly evaluated using water quality monitoring, but in some cases may be supported by work associated with collecting water quality information (i.e., detailed flow data)

2.3 Physical and Chemical Characteristics of Stormwater Runoff

In this guidance manual, the term "stormwater" refers to more than just storm-driven surface runoff. Here the term is expanded to cover water and other substances that are transported through stormwater conveyance systems during, after, and between storm events. In addition to the runoff from rainfall or snowmelt, a typical stormwater sample may contain materials that were dumped, leaked, spilled, or otherwise discharged into the conveyance system. The sample may also contain materials that settled out in the system toward the end of previous storms and were flushed out by high flows during the event being sampled. Stormwater also can include dry weather flows such as pavement washing, pavement cutting wash water, or irrigation. Loads from dry weather flows, in some cases, can greatly exceed wet weather loads over the course of a year and must be taken into account.

Stormwater quality tends to be extremely variable (EPA 1983; Driscoll et al. 1990). The intensity (volume or mass of precipitation per unit time) of rainfall often varies irregularly and dramatically. These variations in rainfall intensity affect runoff rate, pollutant washoff rate, in-channel flow rate, pollutant transport, sediment deposition and re-suspension, channel scour, and numerous other phenomena that collectively determine the pollutant concentrations, pollutant forms, and stormwater flow rate observed at a given monitoring location at any given moment. In addition, the transitory and unpredictable nature of many pollutant sources and release mechanisms (e.g., spills, leaks, dumping, construction activity, landscape irrigation runoff, vehicle washing runoff), and differences in the time interval between storm events also contribute to inter-storm variability. As a result, pollutant concentrations and other stormwater characteristics at a given location should be expected to fluctuate greatly during a single storm runoff event and from event to event.

In addition, the complexity of introducing a structural management practice can greatly affect hydraulics and constituent concentrations in complex ways. For example, flows from detention facilities are often not confined only to the period of wet weather, as drain time can be significant.

Numerous studies conducted during the late 1970s and early 1980s show that stormwater runoff from urban and industrial areas are a potentially significant source of pollution (EPA 1983; Driscoll et al. 1990). As a result, federal, state and local regulations have been promulgated to address stormwater quality (see Section 2.1 above).

The impacts of hydrologic and hydraulic (physical as opposed to chemical) changes in watersheds are increasingly being recognized as significant contributors to receiving waters not meeting beneficial criteria. These impacts include stream channel changes (erosion, sedimentation, temperature changes) as well as wetland water level fluctuations.

2.4 Stormwater Quality Monitoring Challenges

Information collected on the efficiency and design of BMPs serves a variety of goals and objectives as discussed in Section 2.2. The principal challenge facing persons implementing BMP monitoring programs is the great temporal and spatial variability of stormwater flows and pollutant concentrations. Stormwater quality at a given location varies greatly both between storms and during a single storm event, and thus a small number of samples are not likely to provide a reliable indication of stormwater quality at a given site or the effect of a given BMP. Therefore, collection of numerous samples is generally needed in order to accurately characterize stormwater quality at a site and BMP efficiency (see Section 3.2.2).

Collecting enough stormwater samples to answer with a high level of statistical confidence many of the common questions regarding BMP efficiency is generally expensive and time-consuming. A poorly-designed monitoring program could lead to erroneous conclusions and poor management decisions, resulting in misdirected or wasted resources (e.g., staff time, funds, credibility, and political support). Therefore, before one begins a BMP monitoring program, it is critical to clearly identify and prioritize the goals of the project, determine the type and quality of information needed to attain those goals, and then compare this list of needs to the resources available for monitoring. If the available resources cannot support the scale of monitoring needed to provide the quality of information deemed necessary, then consider the following options to obtain useful results within your resource limitations (e.g., funds, personnel, time):

- A phased approach wherein you address only a subset of the overall geographic area, or only the most important stormwater questions.

- Limiting the number of constituents evaluated as an alternative to reducing the number of samples collected.

- Utilizing available data from other locations to support decision-making.

The key question should be: "Will the information provided from the monitoring program I am considering (and would be able to implement) significantly improve my understanding of the effectiveness of the BMP being monitored?" If the answer is no, reconsider the monitoring program.

2.5 Complexities Specific to BMP Monitoring

Monitoring BMPs introduces a number of specific difficulties into the already complex task of monitoring stormwater runoff water quality.

In many ways a structural BMP system is best viewed as an environmental unit process with a large number of static and state variables affecting functionality of the process. For example, static variables that can directly affect BMP system function include:

- BMP design (e.g., length, width, height, storage volume, outlet design, upstream bypass, model number, etc.)
- Geographical location.
- Watershed size.
- Percent imperviousness.
- Vegetative canopy.
- Soil type.
- Watershed slopes.
- Compaction of soils.

State variables that directly affect BMP function may include:

- Rainfall intensity.
- Flow rate.
- Season.
- Vegetation.
- Upstream non-structural controls.
- Inter-event timing.
- Settings for control structures such as gates, valves, and pumps.
- Maintenance of the BMP.

The inconsistent use of language in reporting BMP information can compound the difficult task of assessing physically complex systems. In order to provide a consistent context for discussion of monitoring approaches in this guidance, the following definitions are provided:

- Best Management Practice (BMP) - A device, practice, or method for removing, reducing, retarding, or preventing targeted stormwater runoff constituents, pollutants, and contaminants from reaching receiving waters.

- BMP System - A BMP system includes the BMP and any related bypass or overflow. For example, the efficiency (see below) can be determined for an offline retention (Wet) Pond either by itself (as a BMP) or for the BMP system (BMP including bypass).

- Performance - measure of how well a BMP meets its goals for stormwater that the BMP is designed to treat.

- Effectiveness - measure of how well a BMP system meets its goals in relation to all stormwater flows.

- Efficiency - measure of how well a BMP or BMP system removes or controls pollutants.

Researchers often want to determine efficiency of BMPs and BMP systems and to elucidate relationships between design and efficiency. Efficiency has typically been quantified by "percent removal". As is discussed in the following sections, "percent removal" alone is not a valid measure of the functional efficiency of a BMP (Strecker et al. 2001). As a result the definition of "efficiency" in this manual can mean any measure of how well a BMP or BMP system removes or controls pollutants and is not restricted by the historical use of the term referring to "percent removal."

2.5.1 Considerations for Evaluating BMP Effectiveness

Load Versus Water Quality Status Monitoring

The choice between monitoring either (a) the status or condition of the water resource or (b) the pollutant load and event mean concentrations discharged to the water resource should be made with care (Coffey and Smolen 1990). Monitoring of loads and event mean concentrations is focused on obtaining quantitative information about the amount of pollutants transported to the receiving water from overland, channel and pipe, tributary, or groundwater flow. Load and concentration monitoring can be used to evaluate pollutant export at a stormwater BMP.

Water Quality Status Monitoring

Water quality status can be evaluated in a number of ways, including:

- Evaluating "designated use" attainment[1].
- Evaluating Water Quality Standards violations.
- Assessing ecological integrity.
- Monitoring an indicator parameter.

Monitoring water quality status includes measuring a physical attribute, chemical concentration, or biological condition, and may be used to assess baseline conditions, trends, or the impact of treatment on the receiving water. Monitoring water quality status may be the most effective method to evaluate the impact of the management measure implemented, but sensitivity may be low (Coffey and Smolen 1990). When the probability of detecting a trend in water quality status is low, load monitoring may be necessary.

When deciding between measuring load or water quality status (i.e., it is not clear whether abatement can be detected in the receiving resource), a pollutant budget may help to make the decision (Coffey and Smolen 1990). The budget should account for mass balance of pollutant input by source, all output, and changes in storage. Sources of error in the budget should also be evaluated (EPA 1993a).

Pollutant Load and Event Mean Concentration Monitoring

Load monitoring requires considerable effort and should include the protocols that are the primary intent of this document. Because of potentially high variability of discharge and pollutant concentrations in watersheds impacted by both point and non-point sources, collecting accurate and sufficient data from a significant number of storm events and base flows over a range of conditions (e.g., season, land cover) is important. This manual describes several methods for collecting and analyzing meaningful pollutant loading and event concentration data. Most of these methods are also applicable to water quality status monitoring where specific chemical concentrations must be monitored.

Monitoring for designated use attainment or standards violations should focus on those parameters or criteria specified in state water quality standards. Where the monitoring objective includes relating improvements in water quality to the pollution control activities, it is important that the parameters monitored are connected to the management

[1] See Clean Water Act, Section 303(c)(2)

measures implemented. For violations of standards, the choice of variable is specified by the state water quality standard (EPA 1993a).

Consideration of Parameters for Monitoring

Many studies have been conducted to assess the effectiveness of stormwater treatment BMPs to reduce pollutant concentrations and loads in stormwater runoff. Unfortunately, inconsistent study methods and reporting make assessment and comparison of BMP efficiency studies difficult. The studies often analyze different constituents with varying methods for data collection and analysis. These differences can contribute considerably to the range of BMP effectiveness observed (Strecker 1994).

Several protocols for parameter selection have been used in the past. The most widely applied was developed as a part of the Nationwide Urban Runoff Program (NURP). NURP adopted consistent data collection techniques and analytical parameters so that meaningful comparisons of gathered data could be made. NURP adopted the following constituents as "standard pollutants characterizing urban runoff" (EPA 1983):

- SSC – Suspended Solids Concentration
- BOD – Biochemical Oxygen Demand
- COD – Chemical Oxygen Demand
- CU – Copper
- Pb – Lead
- Zn – Zinc
- TP – Total Phosphorous
- SP – Soluble Phosphorous
- TKN – Total Kjeldahl Nitrogen
- NO_2 + NO_3 – Nitrate + Nitrite

The following factors were considered for including a parameter in the list of recommended monitoring constituents (Strecker 1994):

- The pollutant has been identified as prevalent in typical urban stormwater at concentrations that could cause water quality impairment.

- The analytical test used can be related back to potential water quality impairment.

- Sampling methods for the pollutant are straight forward and reliable for a moderately careful investigator.

- Analysis of the pollutant is economical on a widespread basis.

- Treatment is a viable option for reducing the load of the pollutant.

Similar considerations should go into the planning of water quality constituents and analytical methods to be used in monitoring the effectiveness of stormwater BMPs. The NURP parameters are a starting point and may or may not represent constituents of concern for discharges from specific BMPs. As mentioned previously, there is often a tradeoff between the breadth and depth of a monitoring program given a fixed cost and, as a result, narrowing the list of constituents monitored can dramatically improve the ability to quantify the efficiency of the BMP.

Large volumes of data have been collected over the past 20 years on the performance of many structural stormwater BMPs, with most of the data relating to the performance of detention basins, retention ponds, and wetlands. Less data are available on the effectiveness of other types of BMPs (Urbonas 1994). Many of the reported results do not demonstrate a clear relationship between the efficiency of similar BMPs among the sites in which they were investigated. Sufficient parametric data has generally not been reported with the performance data to permit a systematic analysis of the data collected (Urbonas 1994).

There are a number of important parameters that need to be measured and reported whenever BMP performance is monitored (Urbonas 1994). A detailed discussion on this subject is provided in Section 3.4 of this manual.

2.6 BMP Types and Implications for Calculation of Efficiency

The issues involved in selecting methods for quantifying efficiency, performance, and effectiveness are complex. It would be difficult, at best, to find one method that would cover the data analysis requirements for the widely varied collection of BMP types and designs available. When analyzing efficiency, it is convenient to classify BMPs according to one of the following four distinct categories:

- BMPs with well-defined inlets and outlets whose primary treatment depends upon extended detention storage of stormwater, (e.g., retention (wet) and detention (dry) ponds, wetland basins, underground vaults).

- BMPs with well-defined inlets and outlets that do not depend upon significant storage of water, (e.g., sand filters, swales, buffers, structural “flow-through” systems).

- BMPs that do not have a well-defined inlet and/or outlet (e.g., full retention, infiltration, porous pavement, grass swales where inflow is overland flow along the length of the swale).

- Widely distributed (scattered) BMPs where studies of efficiency use reference watersheds to evaluate effectiveness, (e.g., catch basin retrofits, education programs, source control programs).

Any of the above can also include evaluations where the BMP's efficiency was measured using before and after or paired watershed comparisons of water quality.

The difficulty in selecting measures of efficiency stems not only from the desire to compare a wide range of BMPs, but also from the large number of methods currently in use. There is much variation and disagreement in the literature about what measure of efficiency is best applied in specific situations, however it is generally accepted that event mean concentrations and long-term loading provide the best means for observing the effects of the BMP respectively on acute and chronic pollution.

It has been suggested that intra-storm monitoring could be used to establish paired inflow/outflow samples during the storm based upon average travel times. However, this method would only be valid if a BMP were functioning as a perfect plug-flow reactor, which is rarely the case.

2.7 Relationship Between Monitoring Study Objectives and Data Analysis

In selecting a specific method for quantifying BMP efficiency, it is helpful to look at the objectives of previous studies seeking such a goal. BMP studies are usually conducted to obtain information regarding one or more of the following objectives:

- What degree of pollution control does the BMP provide under typical operating conditions?

- How does effectiveness vary from pollutant to pollutant?

- How does effectiveness vary with various input concentrations?

- How does effectiveness vary with storm characteristics such as rainfall amount, rainfall density, and antecedent weather conditions?

- How do design variables affect performance?

- How does effectiveness vary with different operational and/or maintenance approaches?

- Does effectiveness improve, decay, or remain stable over time?

- How does the BMP's efficiency, performance, and effectiveness compare to other BMPs?

- Does the BMP reduce toxicity to acceptable levels?

- Does the BMP cause an improvement in or protect downstream biotic communities?

- Does the BMP have potential downstream negative impacts?

The monitoring efforts implemented most typically seek to answer a small subset of the above questions. This approach often leaves larger questions about the efficiency, performance and effectiveness of the BMP, and the relationship between design and efficiency, unanswered. This document recommends monitoring approaches consistent with protocols established as part of the National Stormwater Best Management Practices Database project and useful for evaluating BMP data such that some or all of the above questions about BMP efficiency can be assessed.

2.8 Physical Layout and Its Effect on Efficiency and Its Measure

The estimation of the efficiency of BMPs is often approached in different ways based on the goals of the researcher. A BMP can be evaluated by itself or as part of an overall BMP system. The efficiency of a BMP when bypass or overflow are not considered may be dramatically different than the efficiency of an overall system. Bypasses and overflows can have significant effects on the ability of a BMP to remove constituents and appreciably reduce the efficiency of the system as a whole. Researchers who are interested in comparing the efficiency of an offline wet pond and an offline wetland may not be concerned with the effects of bypass on a receiving water. On the other hand, another researcher who is comparing offline wet ponds with online wet ponds would be very interested in the effects of the bypass. Often in past study reports detailed information about the bypass flows is not available. In some cases, comprehensive inflow and outflow measurements allow for the calculation of a mass balance that can be used to estimate bypass flow volumes. Estimations of efficiency of a BMP system can be based on these mass balance calculations coupled with sampling data.

The effect of devices in series is often neglected in the analyses of BMPs. BMPs are often used in conjunction with a variety of upstream controls. For example detention ponds often precede wetlands, and sand filters typically have upstream controls for sediment removal such as a forebay or a structural separator or settling device. Depending on the approach used to quantify BMP efficiency, the effects resulting from upstream controls can have a sizable impact on the level of treatment observed.

The efficiency of a BMP system or a BMP can be directly affected by the way in which an operator chooses to physically manage the system. This is the case where parameters of a design can be adjusted (e.g., adjustments to the height of an overflow/bypass weir or gate). These adjustments can vary the efficiency considerably. In order to analyze a BMP or BMP system thoroughly, all static and state variables of the system must be known and documented for each monitoring period. The protocols established for the National Stormwater Best Management Practices Database (Database) provide a framework for reporting the static and state variables thought to most strongly contribute to BMP efficiency and provide flexibility for non-standard situations.

2.9 Relevant Period of Impact

The period of analysis used in carrying out a monitoring program is important. The period used should take into account how the parameter of interest varies with time. This allows for observation of relevant changes in the efficiency of the BMP on the time scale in which these changes occur. For example, in a wetland it is often observed that during the growing season effluent quality for nutrients improves. The opposite effect may be observed during the winter months or during any period where decaying litter and plant material may contribute significantly to export of nutrients and, potentially, other contaminants. Therefore, monitoring observations may need to be analyzed differently during different seasons. This variation of performance and more specifically efficiency on a temporal scale is extremely important in understanding how a specific BMP functions.

In addition to observing how factors such as climate affect BMP efficiency as a function of time, it is important to relate the monitoring period to the potential impact a given constituent would have on the receiving water. For example, it may not be useful to study the removal of some heavy metals (e.g., mercury) for a short period of record when the negative impacts of such a contaminant are generally expressed over a long time scale (accumulation in sediments and biota). Likewise, some parameters (e.g., temperature, BOD, DO, pH, TSS and metals) may have a significant impact in the near term.

Toxicity plays a major role in evaluating the type of monitoring conducted at a site as well as the time period that should be used to analyze efficiency. Specific constituents that are acutely toxic may require a short-term analysis on an “intra-storm” basis. Where dilution is significant and/or a constituent is toxic on a chronic basis, long-term analysis that demonstrates removal of materials on a sum of loads or average EMC basis may be more appropriate. Many contaminants may have both acute and chronic effects in the aquatic environment. These contaminants should be evaluated over both periods of time. Similarly, hydraulic conditions merit both short and long-term examination. Event peak flows are examples of short-term data, while seasonal variations of the hydrologic budget due to the weather patterns are examples of long-term data. Examples of water quality parameters and their relationship to the time scale over which they are most relevant are given in Table 2.2.

Table 2.2: Examples of water quality parameters and relevant monitoring period

Time Scale for Analysis	**Water Quality Parameter**
Short-term	BOD, DO
Long-term	Organics, Carcinogens
Both Short- and Long-term	Metals, TSS, Nitrogen, Phosphorous, Temperature, pH, Pesticides

2.9.1 Concentrations, Loads, and Event Mean Concentrations

A variety of tools are available for assessing and quantifying the amount of pollutant conveyed to and from a BMP. Three primary measures are used most commonly: concentrations of stormwater at some point in time, the total load conveyed over a specified duration, or the event mean concentration (EMC).

2.9.1.1 Concentrations

Concentrations measured at a point in time can be useful for BMP efficiency evaluation in a number of circumstances. Concentrations resulting from samples collected at specific times during an event allow the generation of a pollutograph (i.e., a plot of the concentration of pollutants as a function of time). The generation of pollutographs facilitates the analysis of intra-event temporal variations in runoff concentration. For example, pollutographs can be used to determine if the “first-flush” phenomenon was observed for a specific event. Detailed concentration data is one of the approaches for assessing concentrations of pollutants that have acutely toxic effects, particularly where runoff from storm events constitutes a significant proportion of downstream flow. Under some circumstances, reduction of peak effluent concentrations may be more important than event mean concentration reduction. The cost of implementing a monitoring program that collects sufficient data to evaluate the temporal variation in runoff and BMP effluent concentration can be high. The trade-off between collecting data from a larger number of events versus collecting detailed concentration data from intra-storm periods often limits the utility of studies that collect detailed concentration data. This type of detailed monitoring is best focused on outflow monitoring rather than inflow and outflow.

2.9.1.2 Loads

Loads are typically calculated by the physical or mathematical combination of a number of individual concentration measurements, which have been assigned by some means an associated flow volume. A variety of methods are available for estimation of loads. The method employed is dependent on the sampling and flow measurement techniques used. Sampling approaches include collection of either timed samples, flow weighted samples, or some combination of both. Likewise, flow can be collected continuously, intermittently, or modeled from other hydrologic information such as rain gauge information, or gauging conducted in a nearby watershed. Many BMP monitoring studies focus efforts on water quality sample collection and neglect flow measurement. *Accurate flow measurement or well-calibrated flow modeling is essential for loading determination.*

Loads are often most useful for assessing the impact of a BMP where receiving waters are lakes or estuaries where long-term loadings can cause water quality problems outside of storms. Where the effluent flow rate from a particular BMP is small compared to the flow rate of the receiving water body, potential downstream impairments are typically not dependent on concentrations, but the absolute load of pollutant reaching the receiving water. For example, loads are the central issue in BMP studies that have direct links to receiving water bodies that are regulated under the Total Maximum Daily Load (TMDL) program, particularly where the concern is pollutants deposited in slow moving systems.

Dry weather flows can also contribute substantially to long-term loading. In addition, "on-line" BMPs (ponds and possibly filters) that have appreciable dry weather flows passing through them, may have reduced "capacity" for storage of wet weather pollutants. For example, pond performance may also be affected by the amount of water in the pond before the event, and filters may have some of their adsorption capacity consumed by pollutants and other constituents during dry weather flows.

2.9.1.3 Event Mean Concentrations

The term event mean concentration (EMC) is a statistical parameter used to represent the flow-proportional average concentration of a given parameter during a storm event. It is defined as the total constituent mass divided by the total runoff volume. The calculation of EMCs from discrete observations is discussed in detail in Section 2.5.3. When combined with flow measurement data, the EMC can be used to estimate the pollutant loading from a given storm. The EMC approach to understanding BMP efficiency is primarily aimed at wet weather flows.

Under most circumstances, the EMC provides the most useful means for quantifying the level of pollution resulting from a runoff event. Collection of EMC data has been the primary focus of the National Stormwater Best Management Practices Database Project.

2.9.2 Measures of BMP Efficiency

The efficiency of stormwater BMPs (how well a BMP or BMP system removes pollutants or results in acceptable effluent quality) can be evaluated in a number of ways. An understanding of how BMP monitoring data will be analyzed and evaluated is essential to establishing a useful BMP monitoring study. The different methods used to date are explained in this section to illustrate historical approaches and provide context for the method recommended in this manual (Effluent Probability Method), which is presented at the end of this section. The following table (Table 2.3) summarizes all of the methods examined by this guidance.

Table 2.3: Summary of historical, alternative, and recommended methods for BMP water quality monitoring data analysis

Category	Method Name	Recommendation	Comments
Historical Methods	Efficiency Ratio (ER)	Not recommended as a stand-alone assessment of BMP performance. More meaningful when statistical approach is used.	Most commonly used method to date. Most researchers assume this is the meaning of "percent removal". Typical approach does not consider statistical significance of result.
	Summation of Loads (SOL)	Not recommended as a stand-alone assessment of BMP performance. More meaningful when statistical approach is used.	Utilizes total loads over entire study. May be dominated by a small number of large events. Results are typically similar to ER method. Typical approach does not consider statistical significance of result.
	Regression of loads (ROL)	Do not use	Very rarely are assumptions of the method valid. Cannot be universally applied to monitoring data.
	Mean Concentration	Do not use	Difficult to "track" slug of water through BMP without extensive tracer data and hydraulic study. Results are only for one portion of the pollutograph.
	Efficiency of Individual Storm Loads	Do not use	Storage of pollutants is not taken into account. Gives equal weight to all storm event efficiencies
Alternative Methods	Percent Removal Exceeding Irreducible Concentration or Relative to WQ Standards/Criteria	Not recommended – May be useful in some circumstances	Typically only applicable only for individual events to demonstrate compliance with standards.
	Relative Efficiency	Not recommended – May be useful in some circumstances	Typically only applicable only for individual events to demonstrate how well a BMP perfoms relative to how well it would perform if it
	"Lines of Comparative Performance©"	Do not use	Spurious self-correlation. Method is not valid.
	Multi-Variate and Non-Linear Models	Possible future use	Additional development of methodology based on more complete data sets than are currently available.
Recommended Method	**Effluent Probability Method**	**Recommended Method**	**Provides a statistical view of influent and effluent quality. This is the method recommended in this guidance manual. Benefits over other approaches that are described in this section of the Guidance.**

2.9.2.1 Historical Approaches

A variety of pollutant removal methods have been utilized in BMP monitoring studies to evaluate efficiency. This section describes and gives examples of methods employed by different investigators. Historically, one of six methods has been used by investigators to calculate BMP efficiency:

- Efficiency ratio
- Summation of loads
- Regression of loads
- Mean concentration
- Efficiency of individual storm loads
- Reference watersheds and before/after studies

Although use of each of these methods provides a single number that summarizes efficiency of the BMP in removing a particular pollutant, they are not designed to look at removal statistically, and thus, do not provide enough information to determine if the differences in inflow and outflow water quality measures are statistically significant.

Efficiency Ratio

Definition

The efficiency ratio is defined in terms of the average event mean concentration (EMC) of pollutants over some time period:

$$ER = 1 - \frac{\text{average outlet EMC}}{\text{average inlet EMC}} = \frac{\text{average inlet EMC - average outlet EMC}}{\text{average inlet EMC}}$$

EMCs can be either collected as flow weighted composite samples in the field or calculated from discrete measurements. The EMC for an individual event or set of field measurements, where discrete samples have been collected, is defined as:

$$EMC = \frac{\sum_{i=1}^{n} V_i C_i}{\sum_{i=1}^{n} V_i}$$

where,

V: volume of flow during period i
C: average concentration associated with period i
n: total number of measurements taken during event

The arithmetic average EMC is defined as:

$$\text{average EMC} = \frac{\sum_{j=1}^{m} EMC_j}{m}$$

where,

m: number of events measured

In addition, the log mean EMC can be calculated using the logarithmic transformation of each EMC. This transformation allows for normalization of the data for statistical purposes.

$$\text{Mean of the Log EMCs} = \frac{\sum_{j=1}^{m} Log\left(EMC_j\right)}{m}$$

Estimates of the arithmetic summary statistics of the population (mean, median, standard deviation, and coefficient of variation) should be based on their theoretical relationships (Appendix A) with the mean and standard deviation of the transformed data. Computing the mean and standard deviation of log transforms of the sample EMC data and then converting them to an arithmetic estimate often obtains a better estimate of the mean of the population due to the more typical distributional characteristics of water quality data. This value will not match that produced by the simple arithmetic average of the data. Both provide an estimate of the population mean, but the approach utilizing the log-transformed data tends to provide a better estimator, as it has been shown in various investigations that pollutant, contaminant, and constituent concentration levels tend to be well described by a log-normal distribution (EPA 1983). As the sample size increases, the two values converge.

Assumptions

This method:

- Weights EMCs from all storms equally regardless of relative magnitude of storm. For example, a high concentration/high volume event has equal weight in the average EMC as a low concentration/low volume event. The logarithmic data transformation approach tends to minimize the difference between the EMC and mass balance calculations.

- Is most useful when loads are directly proportional to storm volume. For work conducted on nonpoint pollution (i.e., inflows), the EMC has been shown to not vary significantly with storm volume. Accuracy of this method will vary based on the BMP type.

- Minimizes the potential impacts of smaller/"cleaner" storm events on actual performance calculations. For example, in a storm by storm efficiency approach, a low removal value for such an event is weighted equally to a larger value.

- Allows for the use of data where portions of the inflow or outflow data are missing, based on the assumption that the inclusion of the missing data points would not significantly impact the calculated average EMC.

Comments

- This method is taken directly from non-point pollution studies and does a good job characterizing inflows to BMPs but fails to take into account some of the complexities of BMP design. For example, some BMPs may not have outflow EMCs that are normally distributed (e.g., media filters and other BMPs that treat to a relatively constant level that is independent of inflow concentrations).

- This method also assumes that if all storms at the site had been monitored, the average inlet and outlet EMCs would be similar to those that were monitored.

- Under all circumstances this method should be supplemented with an appropriate non-parametric (or if applicable parametric) statistical test indicating if the differences in mean EMCs are statistically significant (it is better to show the actual level of significance found, than just noting if the result was significant, assuming a 0.05 level).

Example

The example calculations given below are for the Tampa Office Pond using arithmetic average EMCs in the efficiency ratio method.

Table 2.4: Example of ER Method results for TSS in the Tampa Office Pond

Period of Record	Average EMC In	Average EMC Out	Efficiency Ratio
1990	27.60	11.18	59%
1993-1994	34.48	12.24	64%
1994-1995	131.43	6.79	95%
ER is rounded, but the other numbers were not (to prevent introduction of any rounding errors in the calculations)			

Summation of Loads

Definition

The summation of loads method defines the efficiency based on the ratio of the summation of all incoming loads to the summation of all outlet loads, or:

$$\text{SOL} = 1 - \frac{\text{sum of outlet loads}}{\text{sum of inlet loads}}$$

The sum of outlet loads are calculated as follows:

$$\text{sum of loads} = \sum_{j=1}^{m}\left(\sum_{i=1}^{n} C_i V_i\right) = \sum_{j=1}^{m} EMC_j \cdot V_j$$

Assumptions

- Removal of material is most relevant over entire period of analysis.
- Monitoring data accurately represents the actual entire total loads in and out of the BMP for a period long enough to overshadow any temporary storage or export of pollutants.
- Any significant storms that were not monitored had a ratio of inlet to outlet loads similar to the storms that were monitored.

- No materials were exported during dry periods, or if they were, the ratio of inlet to outlet loads during these periods was similar to the ratio of the loads during the monitored storms.

Comments

- A small number of large storms typically dominate efficiency.

- If toxics are a concern then this method does not account for day-to-day releases, unless dry weather loads in and out are also accounted for. In many cases long-term dry weather loads can exceed those resulting from wet weather flows.

- Under all circumstances this method should be supplemented with an appropriate non-parametric (or if applicable parametric) statistical test indicating if the differences in loads are statistically significant (it would be better to show the actual level of significance found, rather than just noting if the result was significant, assuming a 0.05 level).

Example

The example calculations given in Table 2.5 are for the Tampa Office Pond using a mass balance based on the summation of loads.

Table 2.5: Example of SOL Method results for TSS in the Tampa Office Pond.

Period of Record	**Sum of Loads In (kg)**	**Sum of Loads Out (kg)**	**SOL Efficiency**
1990	134.60	39.67	71%
1993-1994	404.19	138.44	66%
1994-1995	2060.51	130.20	94%
SOL Efficiency is rounded, but the other numbers were not (to prevent introduction of any rounding errors in the calculations)			

<u>**Regression of Loads (ROL)**</u>

Definition

The regression of loads method as described by Martin and Smoot (1986) defines the regression efficiency as the slope (*b*) of a least squares linear regression of inlet loads and outlet loads of pollutants, with the intercept constrained to zero. The zero intercept is specified as an "engineering approximation that allows calculation of an overall efficiency and meets the general physical condition of zero loads-in (zero rainfall) yield zero loads-out". The equation for the ROL efficiency is:

$$\text{Loads out} = b \bullet \text{Loads in} = b - \frac{\text{Loads out}}{\text{Loads in}}$$

The percent reduction in loads across the BMP is estimated as:

$$\text{Percent Removal} = 1 - b = 1 - \frac{\text{Loads out}}{\text{Loads in}}$$

Due to the nature of stormwater event monitoring, it is rare that all of the assumptions for this method are valid, particularly requirements for regression analysis. The example calculations and plots provided in this section are from one of the better studies available at the time this manual was written, and as can be seen from the ROL plots, the data does not meet the requirements for proper simple linear regression analysis.

Assumptions

- Any significant storms that were not monitored had a ratio of inlet to outlet loads similar to the storms that were monitored. The slope of the regression line would not significantly change with additional data.

- No materials were exported during dry periods, or if they were, the ratio of inlet to outlet loads during these periods was similar to the ratio of the loads during the monitored storms.

- The data is well represented by a least squares linear regression, that is:

    - The data is “evenly” spaced along the x-axis.

    - Using an analysis of variance on the regression, the slope coefficient is significantly different from zero (the p value for the coefficient should typically be less than 0.05, for example).

    - A check of the residuals shows that the data meets regression requirements. The residuals should be random (a straight line on probability paper) and the residuals should not form any trend with predicted value or with time (i.e., they form a band of random scatter when plotted).

Comments

- A few data points often control the slope of the line due to clustering of loads about the mean storm size. Regressions are best used where data is equally populous through the range to be examined. This is readily observed in the examples that follow (See Figures 2.1 through 2.3).

- The process of constraining the intercept of the regression line to the origin is questionable and in some cases could significantly misrepresent the data. It may be more useful to apply the *Regression of Loads* method over some subset of the data without requiring that the intercept be constrained to the origin. The problem with this alternative approach is that a large number of data points are required in order to get a good fit of the data. Often a meaningful regression cannot be made using the data that was collected. This is well illustrated by the very low R^2 values in the table below. Forcing the line through the origin, in these cases, provides a regression line even where no useful trend is present.

- There is sufficient evidence that this first order polynomial (straight line) fit is not appropriate over a large range of loadings. Very small events are much more likely to demonstrate low efficiency where larger events may demonstrate better overall efficiency depending on the design of the BMP.

Table 2.6: Example of ROL Method results for TSS in the Tampa Office Pond.

Period of Record	**Slope of Regression Line**	**R^2**	**Percent Removal**
1990	0.21	0.06	79%
1993-1994	0.18	-0.06	82%
1994-1995	0.05	0.46	95%
Percent Removal is rounded, but the other numbers were not (to prevent introduction of any rounding errors in the calculations)			

The regressions used to arrive at the above slopes are given in Figures 2.1-2.3.

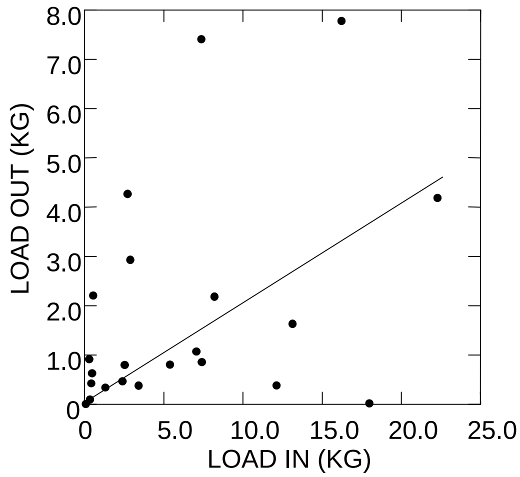


Figure 2.1: ROL Plot for use in Calculating Efficiency for TSS using the Tampa Office Pond (1990) (Slope = 0.2135, R^2 = 0.0563, Standard Error in Estimate = 2.176, one point is considered an outlier with a Studentized Residual of 3.304). All points were used for regression. Method is not valid due to failure of simple linear regression assumptions.

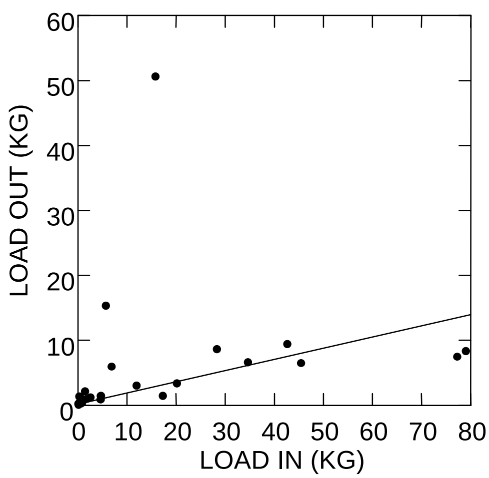


Figure 2.2: ROL Plot for use in Calculating Efficiency for TSS using the Tampa Office Pond (1993-1994) (Slope = 0.1801, R^2 = -0.0562, Standard Error in Estimate = 10.440, one point is considered an outlier with a Studentized Residual of 13.206 and one point has a high Leverage of 0.323). All points were used for regression. Method is not valid due to failure of simple linear regression assumptions.

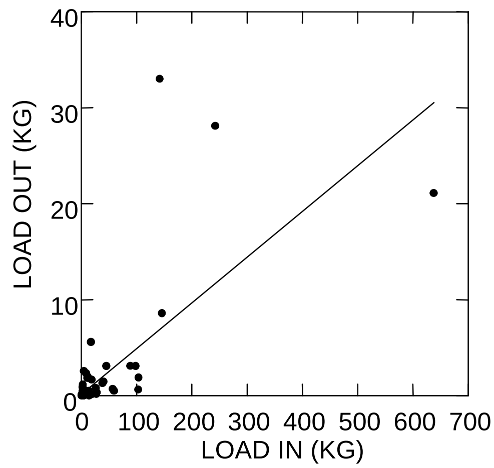


Figure 2.3: ROL Plot for use in Calculating Efficiency for TSS using the Tampa Office Pond (1994-1995) (Slope = 0.0492, R^2 = 0.4581, Standard Error in Estimate = 5.260, three points are considered outliers (Studentized Residuals of 3.724, 8.074, and –4.505, the point to the far right on the graph has large Leverage (0.724) and Influence, Cook Distance = 36.144). All points were used for regression. Method is not valid due to failure of simple linear regression assumptions.

Mean Concentration

Definition

The mean concentration method defines the efficiency as unity minus the ratio of the average outlet to average inlet concentrations. The equation using this method is:

$$\text{Mean Concentration} = 1 - \frac{\text{average outlet concentration}}{\text{average inlet concentration}}$$

This method does not require that concentrations be flow weighted. This method might have some value for evaluating grab samples where no flow weighted data is available or where the period of record does not include the storm volume.

Assumptions

- The flows from which the samples were taken are indicative of the overall event.

Comments

- This method might be useful for calculating BMP's effectiveness in reducing acute toxicity immediately downstream of the BMP. This is due to the fact that acute toxicity is measured as a threshold concentration value of a specific constituent in the effluent at or near the point of discharge.

- This methods weights individual samples equally. Biases could occur due to variations in sampling protocols or sporadic sampling (i.e., collecting many samples close in time and others less frequently). The sample collection program specifics are not accounted for in the method and estimated efficiencies are often not comparable between studies.

- There is appreciable lag time for most BMPs between when a slug of water enters a BMP and when the slug leaves the BMP. Unless this lag time is estimated (e.g., through tracer studies) results from this approach can be quite inaccurate. Results of this method may be particularly difficult to interpret where lag time is ignored or not aggressively documented.

- This method does not account for storage capacity. Typically BMPs will have an equal or lesser volume of outflow than of inflow. On a mass basis this affects removal, since volume (or flow) is used with concentration to determine mass for a storm event,

$$1 - \frac{C_{out} V_{out}}{C_{in} V_{in}} \geq 1 - \frac{\text{average outlet concentration}}{\text{average inlet concentration}}$$

where,

C_{in}: Concentration In
C_{out}: Concentration Out
V_{in}: Volume In
V_{out}: Volume Out

In this respect, it is often more conservative (i.e., lower removal efficiency stated) to use a concentration rather than mass-based removal approach.

<u>**Efficiency of Individual Storm Loads**</u>

Definition

The Efficiency of Individual Storm Loads (ISL) method calculates a BMP's efficiency for each storm event based on the loads in and the loads out. The mean value of these individual efficiencies can be taken as the overall efficiency of the BMP. The efficiency of the BMP for a single storm is given by:

$$\text{Storm Efficiency} = 1 - \frac{Load_{out}}{Load_{in}}$$

The average efficiency for all monitored storms is:

$$\text{Average Efficiency} = \frac{\sum_{j=1}^{m} \text{Storm Efficiency}_j}{m}$$

where,

m: number of storms

Assumptions

- Storm size or other storm factors do not play central roles in the computation of average efficiency of a BMP.

- Storage and later release of constituents from one storm to the next is negligible.

- The selection of storms monitored does not significantly skew the performance calculation.

Comments

- The weight of all storms is equal. Large storms do not dominate the efficiency in this scenario. The efficiency is viewed as an average performance regardless of storm size.

- Some data points cannot be used due to the fact that there is not a corresponding measurement at either the inflow or the outflow for a particular storm, and thus efficiency cannot always be calculated on a storm-by-storm basis. This is not true for the ER method, however it is a limitation of the Summation of Load Method.

- Storm by storm analysis neglects the fact that the outflow being measured may have a limited relationship to inflow in BMPs that have a permanent pool. For example, if a permanent pool is sized to store a volume equal to the average storm, about 60 to 70 percent of storms would be less than this volume [from studies conducted using SYNOP (EPA 1989)].

Table 2.7: Example of Individual Storm Loads Method results for TSS in the Tampa Office Pond.

Period of Record	Efficiency
1990	29%
1993-1994	-2%
1994-1995	89%

Summary and Comparison of Historical Methods

The table below shows the results of the various historical methods shown above for calculating efficiency for the Tampa Office Pond. The four methods demonstrated (mean concentration method was not applicable to data available from the Tampa Office Pond study) vary widely in their estimates of percent removal depending on the assumptions of each method as discussed above.

Table 2.8: Comparison of BMP efficiency methods.

	Method			
Design	**Efficiency Ratio (ER)**	**Summation of Loads (SOL)**	**Regression of Loads (ROL)**	**Efficiency of Individual Storms**
1990	59%	71%	79%	29%
1993-1994	64%	66%	82%	-2%
1994-1995	95%	94%	95%	89%

2.9.2.2 Other Methods and Techniques

"Irreducible Concentration" and "Achievable Efficiency"

As treatment occurs and pollutants in stormwater become less concentrated, they become increasingly hard to remove. There appears to be a practical limit to the effluent quality that any BMP can be observed to achieve for the stormwater it treats. This limit is dictated by the chemical and physical nature of the pollutant of concern, the treatment mechanisms and processes within the BMP, and the sensitivity of laboratory analysis techniques to measure the pollutant. This concept of "irreducible concentration" has significant implications for how BMP efficiency estimates are interpreted. However, it is possible to get concentrations as low as desired, but in most cases achieving extremely low effluent concentrations may not be practical (i.e., would require treatment trains or exotic methods). For example, colloids are typically viewed as "never" being able to be removed in a pond (settling is the primary mechanism for treatment in ponds), despite the fact that they could be further removed through chemical addition.

The term "irreducible concentration" (C*) has been used in stormwater literature (Schueler 2000) to represent the lowest effluent concentration for a given parameter that can be achieved by a specific type of stormwater management practice. Schueler examined the effluent concentrations achieved by stormwater management practices from published studies for several parameters. From this research, the following estimates of "irreducible concentrations" for TSS, Total Phosphorous, Total Nitrogen, Nitrate-Nitrogen, and TKN for all stormwater management practices were proposed:

Table 2.9: "Irreducible concentrations" as reported by Scheuler, 2000.

Contaminant	Irreducible Concentration
TSS	20 to 40 mg/L
Total Phosphorous	0.15 to 0.2 mg/L
Total Nitrogen	1.9 mg/L
Nitrate-Nitrogen	0.7 mg/L
TKN	1.2 mg/L

Recent research (ASCE 2000) indicates that achievable effluent concentrations vary appreciably between BMP types. For example, in many cases, well-designed sand filters can achieve lower effluent concentrations of TSS than well-designed detention facilities or grassed swales. However, sand filters have issues with long-term maintenance of flow treatment volumes.

The typical approach to reporting the ability of a BMP to remove pollutants from stormwater entails comparing the amount of pollutant removed by the BMP to the total quantity of that pollutant. The concept of irreducible concentration, however, suggests that in some cases it may be more useful to report the efficiency of the BMP relative to some achievable level of treatment (i.e. express efficiency as the ability of the BMP to remove the fraction of pollutant which is able to be removed by a particular practice.)

The following example illustrates this approach. Suppose that two similar BMPs have been monitored and generated the following results for TSS:

Table 2.10: Example TSS results for typical ER Method

Percent TSS Removal Using Absolute Scale		
	BMP A	**BMP B**
Influent Concentration	200 mg/L	60 mg/L
Effluent Concentration	100 mg/L	30 mg/L
Efficiency Ratio	50%	50 %

Clearly, the effluent from BMP B is higher quality than that from BMP A, however comparing percent removals between BMPs alone would indicate that both BMPs have an equal efficiency. Methods have been suggested for quantifying the dependence of BMP efficiency on influent concentration. The following section presents one such method advanced by Minton (1998).

In order to account for the dependence of BMP efficiency on influent concentration, Minton (1998) suggests a method of evaluating BMP efficiency that would recognize the relationship between influent concentration and efficiency. The relationship is summarized as follows:

$$\text{Achievable Efficiency} = (C_{influent} - C_{limit}) / C_{influent}$$

where,

$C_{influent}$: Influent Concentration of Pollutant; and
C_{limit} : The lower attainable limit concentration of the BMP (e.g., "irreducible concentration" or value obtained from previous monitoring of effluent quality)

For example, if a BMP had a lower treatment limit of TSS at 20mg/L concentration, then at an influent TSS concentration of 100 mg/L, it would be assigned an equivalent performance of 80%, while at an influent TSS concentration of 50 mg/L the equivalent performance would be 60%.

This method relies on the ability to determine the lower attainable limit concentration, which is analogous to the "irreducible concentration" for a specific BMP, however effluent quality is best described not as a single value, but from a statistical point of view (See the Effluent Probability Method).

The Achievable Efficiency may be useful in better understanding the results of the ER method in cases where the influent concentration is lower than is typically observed.

Alternately, a single factor (dubbed the Relative Efficiency here) can be used to report how well a BMP is functioning during some period relative to what that BMP is theoretically or empirically able to achieve (as defined by the Achievable Efficiency).

As shown below, the Relative Efficiency can be found by dividing the Efficiency Ratio by the Achievable Efficiency, thus yielding an estimate of how well the BMP performed relative to what is "achievable".

$$\text{Relative Efficiency} =$$

$$\frac{\text{Efficiency Ratio}}{\text{Achievable Efficiency}} = \frac{[(C_{influent} - C_{effluent})/C_{influent}]}{[(C_{influent} - C_{limit})/ C_{influent}]}$$

Or simplifying:

$$\text{Relative Efficiency} = (C_{influent} - C_{effluent})/(C_{influent} - C_{limit})$$

If applied to the example presented earlier in this section, the following results are obtained:

Table 2.11: Example TSS results for demonstration of Relative Efficiency approach.

	BMP A	**BMP B**
Influent Concentration	200 mg/L	60 mg/L
C_{limit}	20 mg/L	20 mg/L
Effluent Concentration	100 mg/L	30 mg/L
Relative Efficiency	56%	75 %

For this example, the results indicate that BMP B is achieving a higher level of treatment than BMP A and this approach may be more useful as a comparative tool than the Efficiency Ratio for some data sets. The Relative Efficiency for a BMP's effectiveness is still influenced by influent concentration but less so than is the Efficiency Ratio.

As $C_{influent}$ approaches C_{limit} the Relative Efficiency goes to infinity, which is not a very meaningful descriptor. However, if the influent concentration is near the "irreducible concentration" for a particular pollutant, very little treatment should occur and $C_{influent} - C_{effluent}$ should approach zero. $C_{effluent}$, at least theoretically, should always be higher than C_{limit} and the numerator of the equation should approach zero faster than the denominator. If $C_{influent}$ is less than C_{limit}, the Relative Efficiency approach should not be used. As is always the case, any of the percent removal efficiency approaches (including the Efficiency Ratio Method) should not be employed if there is not a statistically significant difference between the average influent and effluent concentrations.

If this method is used to represent data from more than one event (i.e., mean EMCs are calculated) it should be supplemented with an appropriate non-parametric (or if applicable parametric) statistical test indicating if the differences are statistically significant (it would be preferred to show the actual level of significance found, instead of just noting if the result was significant, assuming a 0.05 level).

Percent Removal Relative to Water Quality Standards

From a practical or programmatic perspective, it may be more useful to substitute the water quality limit for the "irreducible concentration" as a measure of how well the BMP is meeting specific water quality objectives. A measure of efficiency can be calculated to quantify the degree to which stormwater BMPs employed are meeting or exceeding state or federal water quality criteria or standards for the runoff they treat.

Standards are enforceable regulations established within the context of an NPDES permit or a TMDL and are usually specific to the receiving water. Water quality criteria are more general guidelines expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular beneficial use.

By showing that stormwater is being treated to a level that is higher than standards require or criteria recommend, a permitee may be able to demonstrate to regulators or stakeholders that their current stormwater management practices are adequate for a particular constituent of concern. The equation to calculate the Percent Removal Relative to Receiving Water Quality Limits is as follows:

Percent Removal Relative to Receiving Water Quality Limits =

$$(C_{\text{influent}} - C_{\text{effluent}})/(C_{\text{influent}} - C_{\text{standard/criterion}})$$

The following example illustrates the application of this approach for reporting efficiency:

Table 2.12: Example of percent removal relative to receiving water quality limits approach.

	BMP A
Influent Concentration (EMC)	1.65 ug/l
$C_{\text{standard/criterion}}$	0.889 ug/l
Effluent Concentration (EMC)	0.635 ug/l
Percent Removed Relative to Established WQ Limits	133 %

The results indicate that the BMP for the given event is meeting the water quality standard or criterion for dissolved lead. In fact the BMP is functioning to remove in excess of the amount needed to bring the influent concentration below the water quality limit (as indicated in the example by a value greater than 100%). Use of this method is only recommended for specific event analysis. As mentioned for previous analyses, if this approach is taken for a series of events it should be supplemented with an appropriate non-parametric (or if applicable parametric) statistical test indicating if the differences are statistically significant (it would be better to show the actual level of significance found, than just noting if the result was significant, assuming a 0.05 level)

<u>"Lines of Comparative Performance©"</u>

For many stormwater treatment BMPs, the efficiency of the BMP decreases as a function of the influent concentration. Methods have been recommended that integrate this concept into efficiency evaluations. The "Lines of Comparative Performance©" (Minton 1999) is one such method.

In this method, plots of percent removal as a function of the influent concentration for each storm are generated for each pollutant monitored. The results of these plots are overlain on plots of data collected from studies of similar BMPs within a region.

"Lines of Comparative Performance©" are generated for the data from similar BMPs based on best professional judgment by examining the likely "irreducible concentration" for a particular pollutant, the detection limit for that pollutant, and knowledge of expected maximum achievable efficiency for a BMP type.

This method has primarily been suggested as an approach to evaluate the efficiency of innovative and "unapproved" stormwater technologies. "To be accepted, the performance data points of an unapproved treatment technology must fall above and to the left of the 'Line of Comparative Performance©'."

This approach has several major problems. The most significant flaw is the use of "spurious" self-correlation. Plots such as those shown in Figures 2.4 through 2.6 can be generated using random, normally distributed influent and effluent concentrations as seen below in Figure 2.7. As such, **it is strongly recommended that this approach not be employed** in BMP monitoring evaluation studies. This approach may lead to overly complicated analysis methodologies without providing additional useable information on BMP functionality.

Figures 2.4-2.6 below show work conducted by Minton in the development of the Achievable Efficiency approach.

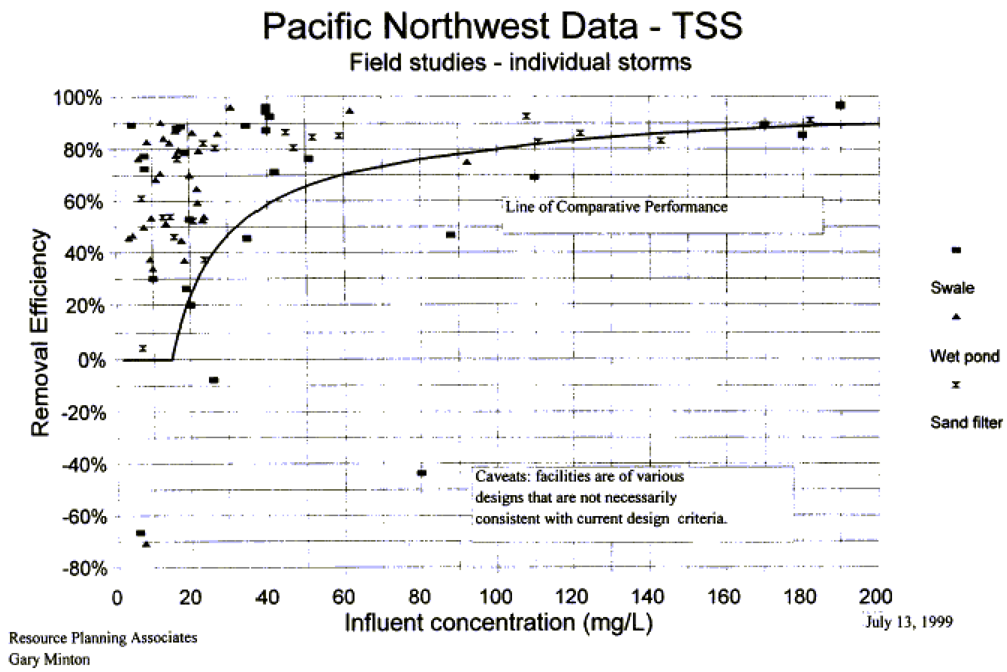


Figure 2.4: Removal Efficiency (ER Method) of TSS as a Function of Influent Concentration (Minton 1999)

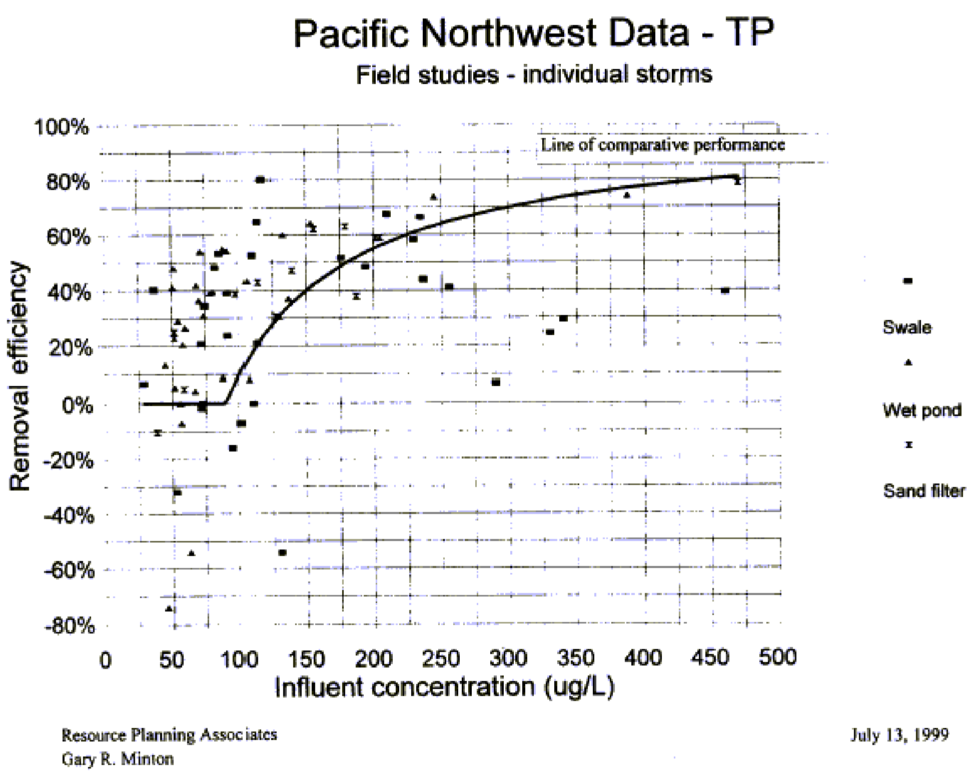


Figure 2.5: Removal Efficiency (ER Method) of Total Phosphorous as a function of influent concentration (Minton 1999)

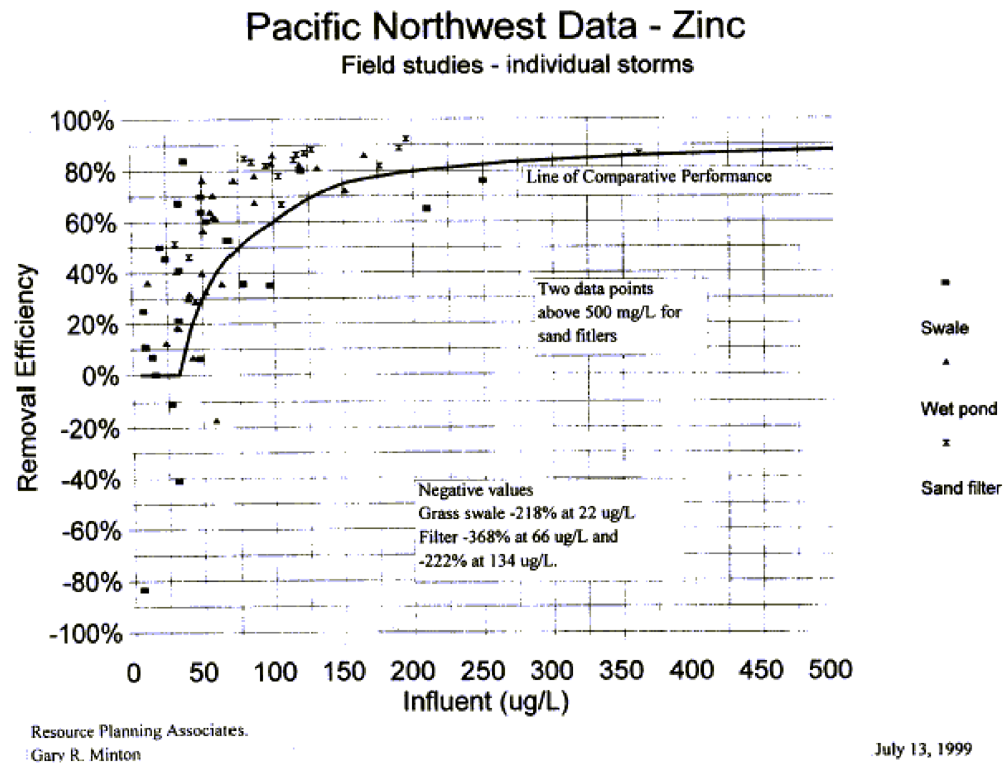


Figure 2.6: Removal Efficiency (ER Method) of Total Zinc as a Function of Influent Concentration (Minton 1999)

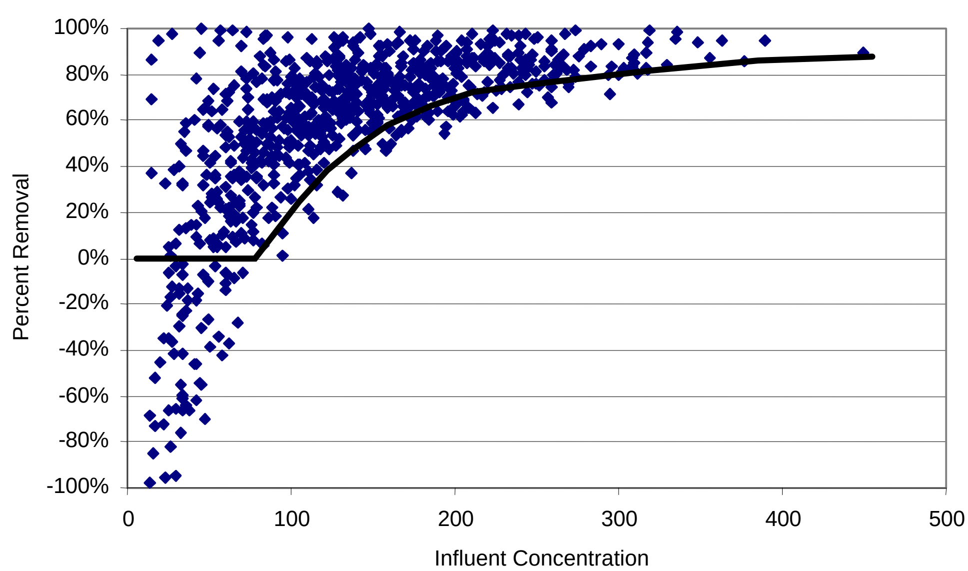


Figure 2.7: Percent removal as a function of influent concentration for randomly generated, normally distributed influent and effluent concentrations. Any number of similar charts can be generated from randomized data.

An alternate method which does not include the serious problems associated with the "Lines of Comparative Performance©", but presents relatively the same information can be generated using a simple plot of effluent concentration as a function of influent concentration with "rays" (or curves on a log plot) originating from the plot origin for several levels of control (e.g., 0, 25, 50, 75, and 90%). The plot may need to be a log-log plot for data with a large range of values typical of stormwater monitoring data.

Multi-Variate and Non-Linear Models

Reporting efficiency as a percent removal that is calculated based on the difference between influent and effluent concentrations will always make a BMP that treats higher strength influents appear to be more efficient than one treating weaker influents if both are achieving the same effluent quality. A more useful descriptor of efficiency would take into consideration that weaker influents are more difficult to treat than concentrated ones. A multi-variate equation that includes corrections to compensate for this phenomena or a non-linear model may be worth considering for reporting efficiency.

A model that approaches pollutant removal in a manner similar to the reaction rates for complex physical and chemical batch and plug-flow processes may be useful. To date calibration of such a model for all but the most elementary situations (e.g., settling of solids in relatively simplistic flow regimes) is difficult given the complexity of the real-world problem. As more high quality data becomes available, other approaches to evaluating BMP efficiency may become apparent.

Currently, effluent quality, as discussed below, is the best indicator of overall BMP performance.

2.9.2.3 Recommended Method

The following method is recommended for use in analyzing new and existing monitoring studies.

Effluent Probability Method

The most useful approach to quantifying BMP efficiency is to determine first if the BMP is providing treatment (that the influent and effluent mean EMCs are statistically different from one another) and then examine either a cumulative distribution function of influent and effluent quality or a standard parallel probability plot.

Before any efficiency plots are generated, appropriate non-parametric (or if applicable parametric) statistical tests should be conducted to indicate if any perceived differences in influent and effluent mean event mean concentrations are statistically significant (the level of significance should be provided, instead of just noting if the result was significant, assume a 95% confidence level).

Effluent probability method is straightforward and directly provides a clear picture of the ultimate measure of BMP effectiveness, effluent water quality. Curves of this type are the single most instructive piece of information that can result from a BMP evaluation study. The authors of this manual strongly recommend that the stormwater industry accept this approach as a standard “rating curve” for BMP evaluation studies.

The most useful approach for examining these curves is to plot the results on a standard parallel probability plot (see Figures 2.8-2.10). A normal probability plot should be generated showing the log transform of both inflow and outflow EMCs for all storms for the BMP. If the log transformed data deviates significantly from normality, other transformations can be explored to determine if a better distributional fit exists. Figures 2.8-2.10 show three types of results that can be observed when plotting pollutant reduction observations on probability plots. The data was taken from the Monroe St. wet detention pond study in Madison, WI, collected by the USGS and the WI DNR. Figure 2.8 for suspended solids (particulate residue) shows that SS are highly removed over influent concentrations ranging from 20 to over 1,000 mg/L. A simple calculation of “percent removal” (ER Method) would not show this consistent removal over the full range of observations. In contrast, Figure 2.9 for total dissolved solids (filtered residue) shows poor removal of TDS for all concentration conditions, as expected for this wet detention pond. The “percent removal” (ER Method) for TDS would be close to zero and no additional surprises are indicated on this plot. Figure 2.10, however, shows a wealth of information that would not be available from simple statistical numerical summaries, including the historical analysis approaches described in this manual. In this plot, filtered COD is seen to be poorly removed for low concentrations (less than about 20 mg/L), but the removal increases substantially for higher concentrations. Although not indicated on these plots, the rank order of concentrations was similar for both influent and effluent distributions for all three pollutants (Burton and Pitt 2001).

Water quality observations do not generally form a straight line on normal probability paper, but do (at least from about the 10th to 90th percentile level) on log-normal probability plots. This indicates that the samples generally have a log-normal distribution as described previously in this document and many parametric statistical tests can often be used (e.g., analysis of variance), but only after the data is log-transformed. These plots indicate the central tendency (median) of the data, along with their possible distribution type and variance (the steeper the plot, the smaller the COV and the flatter the slope of the plot, the larger the COV for the data). Multiple data sets can also be plotted on the same plot (such as for different sites, different seasons, different habitats, etc.) to indicate obvious similarities (or differences) in the data sets. Most statistical methods used to compare different data sets require that the sets have the same variances, and many require normal distributions. Similar variances are indicated by generally parallel plots of the data on the probability paper, while normal distributions would be reflected by the data plotted in a straight line on normal probability paper. (Burton and Pitt 2001)

Probability plots should be supplemented with standard statistical tests that determine if the data is normally distributed. These tests, at least some available in most software packages, include the Kolmogorov-Smirnov one-sample test, the chi-square goodness of fit test, and the Lilliefors variation of the Kolmogorov-Smironov test. They are paired tests comparing data points from the best-fitted normal curve to the observed data. The statistical tests may be visualized by imagining the best-fit normal curve data (a straight line) and the observed data plotted on normal probability paper. If the observed data crosses the fitted curve data numerous times, it is much more likely to be normally distributed than if it only crosses the fitted curve a small number of times (Burton and Pitt 2001).

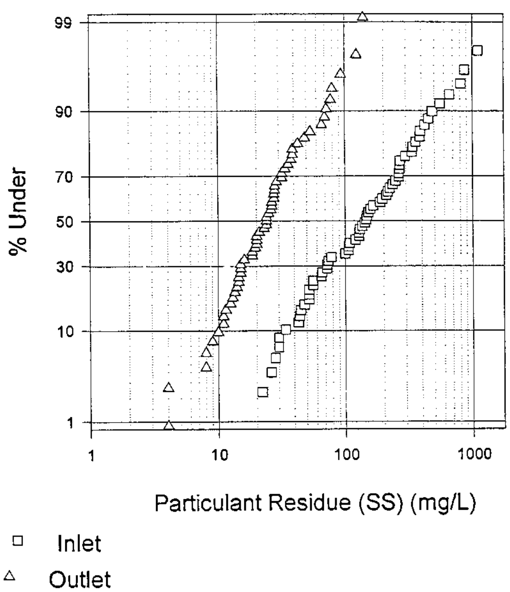


Figure: 2.8: Probability plot for Suspended Solids

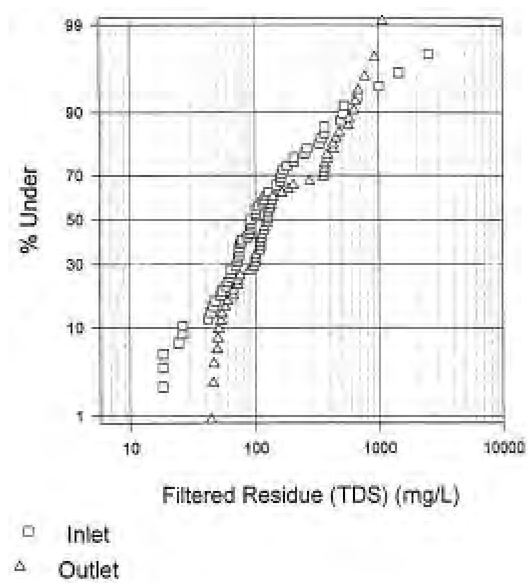


Figure: 2.9 Probability plot for Total Dissolved Solids

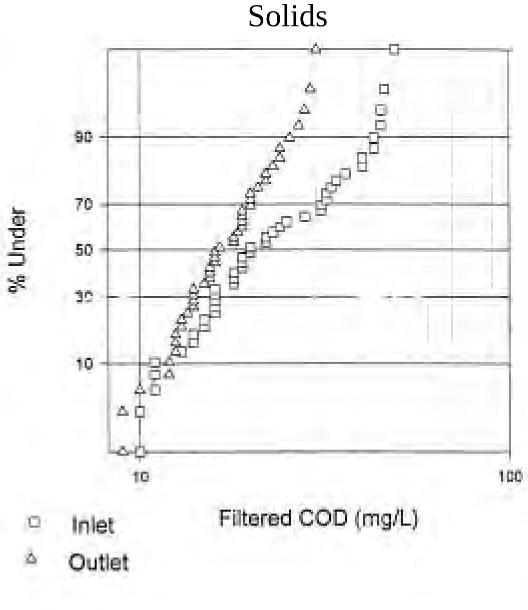


Figure: 2.10: Probability plot for Chemical Oxygen Demand

(Originally by Burton and Pitt 2001)

2.9.2.4 Reference Watershed Methods

Many BMPs do not allow for comparison between inlet and outlet water quality parameters. In addition, it is often difficult or costly, where there are many BMPs being installed in a watershed (e.g., retrofit of all catch basins), to monitor a large number of specific locations. A reference watershed is often used to evaluate the effectiveness of a given BMP or multiple BMPs of the same type. The database allows for a watershed and all associated data to be identified for use as a reference watershed. One of the primary reasons for using a reference watershed is that for some BMPs there is no clearly defined inlet or outlet point at which to monitor water quality. Such is the case with many non-structural BMPs, porous pavements, and infiltration practices.

The difficulty in determining the effectiveness of a BMP using a reference watershed approach stems from the large number of variables typically involved. When setting up a BMP monitoring study, it is advantageous to keep the watershed characteristics of the reference watershed and the test watershed as similar as possible. Unfortunately, finding two watersheds that are similar is often quite difficult, and the usefulness of the data can be compromised as a result. In order to determine the effectiveness of a BMP based on a reference watershed, an accurate accounting of the variations between the watersheds, and operational and environmental conditions is needed. The Database explicitly stores some of the key parameters required for normalization of watershed and environmental conditions.

The most obvious parameter used to normalize watershed characteristics is area. If the ratio of land uses and activities within each watershed is identical in both watersheds then the watershed area can be scaled linearly. The loads found at each downstream monitoring station for each event can be scaled linearly with area as well. Difficulty arises when land use in the reference watershed is not found in the same ratio. In this case, either the effects of land use must be ignored or a portion of the load found for each event must be allocated to a land use and then scaled linearly as a function of the area covered by that land use. In many cases, the differences in land use can be ignored, (e.g., between parking lots with relatively small, but different unpaved areas). The effect of the total impervious area is relevant and should always be reported in monitoring studies. The ratio of the total impervious areas can be used to scale event loads. Scaling the loads based on impervious areas would be best used where the majority of pollutants are from runoff from the impervious areas (e.g., parking lots), or the contaminant of interest results primarily from deposition on impervious surfaces, (e.g., TSS in a highly urban area). Methods that attempt to determine BMP performance from poorly matched watersheds yield poor results at best. As the characteristics of the two watersheds diverge, the effect of the BMP is masked by the large number of variables in the system; the noise in the data becomes greater than the signal.

The analysis of BMPs utilizing reference watersheds also requires incorporation of operational details of the system, (e.g., frequency of street sweeping, type of device used, device setup). Monitoring studies should always provide the frequency, extent, and other operational parameters for nonstructural BMPs. If the BMP is an alteration of the frequency of a certain practice, the system can be viewed in two ways, (1) as a control/test system, or (2) as a series of data aimed at quantifying the continuous effect of increasing or decreasing BMP frequency. In the first case, the BMP can be analyzed in a manner similar to other BMPs with reference watersheds. In the second case, the loads realized at the monitoring stations need to be correlated with the frequency using some model for the effectiveness of the practice per occurrence.

2.9.3 BMPs and BMP Systems

Overflow and bypassing of treatment BMPs affect the long-term performance of the pollution control measure. Many types of BMP structures, such as detention or filtration basins, are designed to treat specific volumes of stormwater runoff. Runoff volumes (or flows) exceeding the designed storage volume or maximum flow rate are bypassed untreated or partially treated. In order to accurately assess the long-term efficiency of the BMP system, the bypass flow needs to be taken into consideration. Ideally, a third flow monitor should be installed to measure by-passed flow directly (Oswald and Mattison 1994).

If monitoring data is not cost effective or physically difficult to collect, estimates of bypass can be made using inflow / outflow water balance calculations or modeled from local rainfall data, watershed hydrology, and BMP system hydraulics. The volume treated by a BMP for each event can be compared to a measured or modeled runoff volume yielding the volume of bypass.

Estimates of BMP system efficiency should always be calculated for the entire BMP system (in addition to the BMP). Mass balance checks should be performed in all cases to help verify monitoring data and/or modeled flow rates.

3 Developing a BMP Monitoring Program

This chapter describes the steps involved in developing and implementing a monitoring program to evaluate BMP effectiveness. Regardless of the scope and objectives, designing a monitoring plan generally involves four phases:

Phase 1: Determine the objectives and scope of your monitoring program
Phase 2: Develop the monitoring plan in view of your objectives
Phase 3: Implement the monitoring plan
Phase 4: Evaluate and report the results of monitoring

The activities associated with each phase are listed below.

<u>Phase 1: Determine Objectives and Scope</u>

- Identify permit requirements and/or information needs
- Compile and review existing information (maps, drawings, results from prior sampling, etc.) relevant to permit requirements and/or information needs
- Develop monitoring program objectives and scope

<u>Phase 2: Develop Monitoring Plan</u>

- Select monitoring locations
- Select monitoring frequency
- Select parameters and analytical methods
- Select monitoring methods and equipment
- Select storm criteria (i.e., size, duration, season)
- Develop mobilization procedures
- Prepare a quality assurance/quality control plan
- Prepare a health and safety plan
- Prepare a data management plan

<u>Phase 3: Implement Monitoring Plan</u>

- Install equipment (and modify channels, if applicable)
- Test and calibrate equipment
- Conduct training
- Conduct monitoring (collect samples)
- Conduct analyses (field and/or laboratory)

Phase 4: Evaluate and Report Results

- Validate chemical data quality
- Evaluate results
- Report the results

Several of the steps in developing a monitoring program are dependent on one another. Consequently, earlier steps may need to be revisited and refined throughout the planning process. For example, if it is determined in Phases 2 or 4 that monitoring more storms is needed to achieve objectives, revisiting the "select monitoring location" task and selecting a lower number of sampling locations and/or a different analytical scheme may be needed to keep within the schedule and budget.

Determine Key Study Parameters

Key parameters of the monitoring project are determined using the information gathered in the previous steps of the systematic planning process. Key study parameters include site selection, number of monitored storm events and their temporal distribution, characteristics of target storm events, types of samples (composite, grab, etc.), and analytical constituents. The better these characteristics are understood, the more efficiently the monitoring data can be collected (Caltrans 1997).

The planned number of sites and monitoring events are often constrained by fiscal factors, such as the cost of sample collection and analysis. For this reason, the list of analytical constituents is often considered in the early stages of project planning (see Section 3.2.3), so that costs of the appropriate sample collection and analysis can be factored into the expected cost per monitoring event. The analytical constituents are often prescribed by regulatory or legal mandate.

3.1 Phase I – Determine Objectives and Scope of BMP Water Quality Monitoring Program

It is particularly important that the objectives of a BMP monitoring program be clearly stated and recorded. The process of writing them down generally results in careful consideration being given to the possible options. Written objectives help avoid misunderstandings by project participants, are an effective way of communicating with sponsors, and provide assurance that the monitoring program has been systematically planned.

Studies of BMP performance are usually conducted to obtain information regarding one or more of the following questions:

- What degree of pollution control or effluent quality does the BMP provide under normal conditions?
- How does this performance vary from pollutant to pollutant?
- How does this normal performance vary with large or small storm events?
- How does this normal performance vary with rainfall intensity?
- How do design variables affect performance?
- How does performance vary with different operational and/or maintenance approaches?
- Does performance improve, decay, or remain stable over time?
- How does this BMP's performance compare with the performance of other BMPs?
- Does this BMP help achieve compliance with water quality standards?

Many BMP monitoring programs have been established to satisfy requirements prescribed by permits to monitor the effectiveness of BMPs, but often the wording of such requirements is vague. Local program-specific objectives are likely to provide the soundest basis for planning a BMP monitoring study.

A well-designed BMP monitoring program may help address specific monitoring questions, thereby enabling better decisions regarding allocation of resources to address stormwater quality issues. The ultimate use of the monitoring results should be kept in mind throughout the monitoring program planning process.

3.1.1 Monitoring and Literature Review to Assess BMP Performance

Typically, structural BMPs have well-defined boundaries and are relatively easy to monitor. Other types of BMPs, especially non-structural BMPs (e.g., street sweeping, catch basin cleaning, sewer cleaning, illicit discharge elimination), are more difficult to monitor partly because they tend to be geographically interspersed with many pollutant sources and can be influenced by many factors that cannot be "controlled" in an experimental sense. Some non-structural BMPs, such as public education programs, oil recycling programs, and litter control programs are virtually impossible to monitor or at best can be evaluated using trend monitoring.

It is assumed that many stormwater quality management programs will consider the possibility of implementing some structural BMPs by experimenting with them on a pilot-scale by testing and demonstrating their performance, their costs, and their practical implications before committing to larger-scale implementation. Programs that already have structural BMPs in place may also test their performance for a variety of reasons.

Before obtaining BMP performance data or establishing the objectives and scope of the BMP monitoring program, it is useful to investigate other regional BMP monitoring programs to learn from their successes and/or failures in implementing the BMP, establishing their objectives and scope of their BMP monitoring program, and obtaining meaningful results. This research will also provide some level of foresight in developing a meaningful monitoring program that will produce results that will be useful in achieving project goals and comparable to other programs.

Nationally, many stormwater programs need BMP performance data, and many are planning or conducting performance monitoring. The concept of sharing monitoring results is very appealing but could be seriously constrained if pre-planning to maximize the chances of yielding comparable/compatible monitoring approaches, analytical protocols, and data management are not implemented. Some of the guidance provided in this manual and referred to in literature citations is intended to facilitate exchanges of more transferable data among programs.

As an example, in a review of the use of wetlands for stormwater pollution control (Strecker et al. 1992), a summary of the literature was prepared regarding the performance of wetland systems and the factors that are believed to affect pollutant removals. The studies reported in the reviewed literature were inconsistent with respect to the constituents analyzed and the methods used to gather and analyze data. Several pieces of information were improperly collected and recorded, which decreased their usefulness for evaluating the effectiveness of stormwater wetlands. Furthermore, the lack of such basic information limits the transferability of the studies' findings into better design practices.

The technical literature has many reports of monitoring programs to evaluate BMP performance. Those that address conceptual and strategic aspects of monitoring (e.g., Strecker 1994; Urbonas 1993) could be of particular value during the planning stage. In addition, EPA and ASCE’s Urban Water Resources Research Council have compiled a National Stormwater Best Management Practices Database (ASCE 1999) (on the world wide web at http://www.bmpdatabase.org/). The purpose of this effort is to develop a more useful set of data on the effectiveness of individual BMPs used to reduce pollutant discharges from urban development. Review of the protocols established for the database is useful in determining what and how information should be collected.

It is also valuable to review the monitoring methods and findings of other reported programs because they may contain transferable concepts (or even data). In considering the use of data collected elsewhere, critical attention must be given to differences that might lead to erroneous conclusions (e.g., weather, soil types, role of specific sources of pollutants). Particular care should be taken to avoid errors that are often introduced by assuming (rather than determining) that certain pollutants are associated with certain sediment fractions.

These associations of pollutants with particles are very important (in fact they are the reason why most BMPs are effective), but they vary dramatically from place to place and must be determined based on careful local studies of relevant factors. When reviewing data from relatively early studies, it is important to remember that state of the art of analyses has advanced considerably in the past decade or so. For example, many data entries that report "non-detect" may not be relevant.

3.1.2 Monitoring to Assess Compliance with Surface Water quality criteria

A main objective of BMP monitoring is to determine if the BMP helps reduce concentrations of constituents of concern and therefore achieves compliance with water quality criteria set forth by state and federal regulations.

Water quality standards may include bacteria, dissolved oxygen, temperature, pH, turbidity, and toxic organic and inorganic compounds in marine and freshwater bodies. The water quality standards for toxic compounds (e.g., metals, pesticides) are intended to protect aquatic organisms, terrestrial animals, and humans who drink the water and/or consume shellfish and fish from the waterbody. In addition, the water quality bacterial standards are intended to guard against human health risks associated with recreational activities such as swimming, wading, boating, fishing, and shellfish consumption.

State water quality standards often include the federal water quality criteria for the protection of human health and aquatic life (40 CFR 131.36). Federal water quality criteria may include a number of additional compounds not listed in state water q
uality standards.

Note that water quality criteria are guidelines, whereas water quality standards are enforceable regulations. In this section, water quality criteria are used to encompass both state standards and the federal guidelines.

There are two general categories of water quality criteria: aquatic (or marine) criteria, and human health criteria. These are summarized below.

3.1.3 Criteria for the Protection of Aquatic/Marine Life

Criteria for the protection of aquatic and marine life were developed based on laboratory toxicity tests of representative organisms using test solutions spiked with pollutants to simulate exposure. In order to apply the results of these tests, EPA has classified aquatic life standards as either "acute" or "chronic" based on the length of time the organisms are exposed to the listed concentrations.

Criterion maximum concentrations (CMC - acute) are intended to protect against short-term exposure. Criterion continuous concentrations (CCC - chronic) are designed to protect against long-term exposure. In deriving the acute criteria, the laboratory organisms were exposed to pollutant concentrations for 24 to 48 hours. EPA suggests one hour as the shortest exposure period, which may cause acute effects and recommends the criteria be applied to one-hour average concentrations. That is, to protect against acute effects, the one-hour average exposure should not exceed the acute criteria. EPA derives chronic criteria from longer term (often greater than 28-day) tests that measure survival, growth, reproduction, or in some cases, bioconcentration. For chronic criteria, EPA recommends the criteria be applied to an averaging period of 4 days. That is, the 4-day average exposure should not exceed the chronic criteria.

water quality criteria for aquatic life were developed based on an allowable exceedance frequency of once every three years, based on the theory that an ecosystem is likely to recover from a brief water quality exceedance, provided it does not occur too often.

3.1.4 Human Health

Water quality standards for the protection of human health contain only a single concentration value and are intended to protect against long-term (chronic) exposure. For carcinogenic compounds, a lifetime exposure over 70 years is generally used to calculate the criteria. For non-carcinogens, exposure periods are more chemical specific and depend on the particular endpoint and toxic effect.

EPA has defined two levels of protection for human health criteria. The first criteria were derived based on cumulative risks associated with drinking water and eating organisms that live in the water. The criteria for carcinogenic compounds are the calculated water-column concentrations that would produce a one in a million (10^{-6}) lifetime cancer risk if water were consumed by humans and a given amount of organisms, like fish or shellfish, living in that water was eaten every day. The second set of criteria is based on consumption of organisms alone (the water is not consumed by humans). These standards apply to saltwater or other water that is not a drinking water source but does support a fishery, and that is used as food. The standard for carcinogenic compounds in the consumption of organisms only criteria is the calculated water concentration that would produce a one in a million (10^{-6}) lifetime cancer risk if a person were to consume a given amount of fish or shellfish from that waterbody (without drinking the water).

3.1.5 Application of Water quality criteria to Stormwater

The water quality criteria are intended to protect the beneficial uses of streams, lakes, and other receiving water bodies. Most of the man-made conveyances within a near-highway stormwater drainage system do not support these beneficial uses. Thus, monitoring to assess compliance with water quality criteria is usually conducted in a receiving water body (rather than in the stormwater conveyance system that discharges into it) in order to provide a direct measure of whether the beneficial uses of the waterbody are impaired or in jeopardy.

Direct comparisons between stormwater quality and the water quality criteria should be interpreted with caution because the effects of receiving water hardness levels do not account for mixing and dilution in the receiving waters or for such comparisons on heavy metals. This is especially true when the stormwater discharge is very small relative to the receiving waterbody.

The variable nature of stormwater quality further complicates comparison to water quality standards. Stormwater quality varies both between and during storm events, so it is very difficult to extrapolate data from one storm to another or to generate statistically representative data for all types and combinations of storms.

In spite of the limitations mentioned above, comparisons between stormwater quality and water quality standards can provide valuable information for stormwater management. Water quality standards can be used as screening criteria, or "benchmarks," for assessing stormwater quality problems and establishing management priorities. Direct comparisons with the water quality criteria can over-estimate the potential impact of the stormwater discharges on the receiving water bodies because mixing and dilution are not taken into account. However, the relative frequency and magnitude of water quality standards exceedances within storm sewer systems can help prioritize additional investigations and/or implementation of control measures. Frequent large exceedances are a clear indication that further investigation and control measures are warranted. Marginal or occasional exceedances are more typical and more difficult to interpret.

3.1.6 Groundwater and Sediment Standards

In addition to surface water quality standards, stormwater discharges may affect compliance with standards for groundwater quality and/or marine sediment quality. However, stormwater monitoring is typically of limited value with regard to assessing compliance with groundwater and/or sediment quality standards. Compliance with the groundwater standards is generally assessed through groundwater monitoring (rather than stormwater monitoring) because stormwater quality is likely to change substantially while percolating through soils, and the extent of the change is very difficult to predict without a great deal of site-specific information. Similarly, compliance with sediment quality standards is generally assessed through sediment monitoring within receiving water bodies. This is because numerous storms would need to be monitored in order to develop useful estimates of total annual sediment loads, and the particulate portion of each sample would need to be divided into particle size fractions prior to chemical analysis to allow even a qualitative evaluation of potential sediment transport/deposition. For these reasons, this manual does not address stormwater monitoring to assess compliance with groundwater or sediment quality standards.

3.1.7 Scope of Work for BMP Monitoring Program

Once monitoring objectives have been defined, the scope of the monitoring program must be determined. It is important to balance information needs with the resources available, and to consider alternative means for obtaining information. To that end, consider the following:

- How accurate or representative do the monitoring results need to be in order to support forthcoming management decisions?

If objectives include determination of stormwater quality trends or evaluation of BMP effectiveness, numerous storms may need to be monitored in order to account for the variability inherent in stormwater quality data. It can be difficult and expensive to obtain truly definitive stormwater data. For example, one of the City of Fresno's monitoring programs (15 storms per year) has a 20% probability of detecting a 20% change in stormwater quality at a confidence level of 95%. This monitoring program was expected to cost about $1.55 million over 10 years, which was about 21% of Fresno's total budget for stormwater management during that period. To attain an 80% probability of detecting a 20% change at a 95% confidence limit, the monitoring cost would have risen to about $5.84 million, or 41% of the total stormwater management budget (Harrison 1994).

Note that the BMPs necessary to reduce stormwater contamination from built-out areas by 20% would probably be costly and challenging to implement. Cave and Roesner (1994) estimated that typical non-structural BMPs are likely to result in stormwater pollutant reductions on the order of 5%-10%, while structural measures may reduce some stormwater pollutants by 50%-90%. They suggested that a fully implemented municipal stormwater management program is likely to result in pollutant load reductions of 25% or less for built-out areas. This number, however, has been cited by others to be closer to 40% (Bannerman 2001).

Devoting large amounts of time and money to achieve a high level of accuracy may not be the best use of stormwater program resources. It might be more cost effective to spend less on trend monitoring and more on source identification, sediment monitoring, and/or control measures. In some cases, a simple, screening-type monitoring program may be sufficient to meet needs.

- Are sufficient staff and financial resources available to obtain the needed information at the desired level of accuracy? If not, can additional resources be obtained?

This is a critical consideration. BMP monitoring is generally expensive and time-consuming. This question can be addressed by developing an overview of monitoring required and reviewing general cost information of other programs.

In assessing personnel resources, consider staff size, technical background, physical condition, and ability (and willingness) to respond to storm events with little advance notice. These factors are discussed below.

<u>Staff Size</u>. Few organizations can afford to have many personnel whose sole responsibility is stormwater monitoring. In most cases, monitoring duties are assigned to

certain people in addition to their regular responsibilities. Back-ups are needed in case the designated personnel are sick, on vacation, or otherwise unavailable when a storm monitoring event occurs. The assigned people must be able and willing to drop what they are doing and mobilize for a storm event on short notice. In some organizations, personnel are not allowed to perform work that is not specified in their job descriptions. Insurance and liability may also be considerations. Because of these staffing issues, some agencies elect to hire contractors to perform monitoring.

Technical Expertise. Some technical expertise is needed to properly conduct monitoring, especially if automated equipment is used. Special training is required for any personnel that enter confined spaces, such as manholes, to collect samples. In addition, the person directing a monitoring program should be familiar with how the results will be used, so that effective decisions are made regarding storm selection, when to cancel a monitoring event, etc.

Physical Condition/Health. Stormwater monitoring can be physically demanding. Monitoring personnel may be required to work in slippery or otherwise challenging conditions at night.

Ability to Respond to Storm Events. Storms often occur outside of normal working hours when it is more difficult to contact and mobilize monitoring personnel.

If resources are not sufficient to sample enough storms and/or enough locations to meet tentatively identified program objectives, monitoring program objectives and scope should be scaled back until they are commensurate with resources. This can sometimes be accomplished by using a phased approach where only one or two areas or questions are addressed at a time so that useful results can be obtained within budget limitations. Supplementing existing resources should also be considered. It may be worthwhile to contact neighboring municipalities or facilities to find out if they are willing to pool their resources in order to fund a joint BMP monitoring program. If objectives cannot be met with the available resources, possible alternatives to stormwater monitoring should be considered (discussed below), or monitoring resources should be allocated to additional pollution control measures.

- Can some of the information needed be obtained without conducting BMP monitoring?

Because of the typically high cost of BMP monitoring, it may be desirable to evaluate alternative means for addressing some information needs (assuming that BMP monitoring is not required to comply with a permit). Depending on the situation, sediment sampling, biological sampling, and/or visual surveys of the stormwater conveyance system may be cost-effective alternatives to stormwater quality monitoring. Literature reviews may also help address some stormwater management issues.

- Who is going to use the monitoring data and what is the intended use?

Develop specific monitoring objectives and scope based on answers to these questions. At this point, the objectives should still be considered flexible because they may need to be re-considered and revised as the monitoring program is developed.

3.1.8 Information Needs to Meet Established Goals of BMP Monitoring

Generally, the more information that is available, the easier it is to design a practical monitoring program. For BMP monitoring programs, compile and review the following information, if available:

- Results from prior surface water and groundwater quality studies, other BMP monitoring studies in the local area, sediment quality studies, aquatic ecology surveys, dry weather reconnaissance, etc.
- Drainage system maps.
- Land use maps (or general plan or zoning maps).
- Aerial photographs.
- Precipitation and streamflow records.
- Reported spills and leaks.
- Interviews with public works staff.
- Literature on design of structural BMPs to understand functionality and pollutant removal processes.

For BMPs monitored in industrial areas, the following information may also be relevant:

- BMP performance data for similar industries in region.
- Facility map(s) showing locations of key activities or materials that could be exposed to stormwater.
- Lists of materials likely to be exposed to stormwater.
- Reported spills and leaks.
- Interviews with facility staff and others who are knowledgeable about the facility.

In addition to gathering information about the study area and BMP design, some forethought should be given to the expected data characteristics and subsequent data analysis methods in order to optimize collection of data within the limitations of the proposed study and ensure that useful results will be provided to fulfill study objectives (Caltrans 1997).

Essential data characteristics include the type of data to be collected (e.g., constituents and concentrations), the variables affecting the data (e.g., antecedent conditions, rainfall intensity, site type and location) and the expected variability of the data (derived from previous studies when available). Statistical techniques such as power analysis can then be used to determine key study parameters, such as the number of monitoring locations and storm events to be monitored (Caltrans 1997).

Prior to the initiation of environmental sampling, a strategy should be developed for analysis of the data, directed to answering the specific study questions. The selected data analyses technique(s) may influence the types and quantities of data required to satisfy study objectives. The analysis methods applied to data collected for BMP evaluations or characterization studies typically involve straight-forward statistical operations.

3.2 Phase II – Develop BMP Monitoring Plan

3.2.1 Recommendation and Discussion of Monitoring Locations

The number of locations to be monitored depends on program objectives, permit requirements (if applicable), the size and complexity of the drainage basin(s), and the resources (time, personnel, funds) allocated to monitoring. In addition, the frequency of sampling at each location must be considered. Depending on objectives, resources, and logistical considerations, many locations may be sampled infrequently, or fewer locations more frequently. The former approach is generally better for evaluating place-to-place variability; the latter approach is generally better for evaluating storm-to-storm variability and for characterizing the monitoring location more accurately. If the effectiveness of a specific structural BMP needs to be evaluated, monitoring locations should be located immediately upstream and downstream of the structure.

In general, choose monitoring sites that facilitate representative sampling and flow measurement. Consider the criteria listed below in the selection of monitoring sites:

- The contributing (upgradient) catchment should be completely served by a separate storm drain system or, if it is served by a combined sewer system, carefully consider the possibility that stormwater samples would be contaminated by sanitary sewage.

- The storm drain system should be sufficiently well understood to allow a reliable delineation and description of the catchment area (e.g., geographic extent, topography, land uses).

- For monitoring stations that will be used to measure flow in open channels, the flow measurement facilities need to be located where there is suitable hydraulic control so that reliable rating curves (i.e., stage-discharge relationships) can be developed. In other words, the upstream and downstream conditions must meet the assumptions on which the measurement method is based.

- Where possible, stations should be located in reaches of a conveyance where flows tend to be relatively "stable" and "uniform" for some distance upstream (approximately 6 channel widths or 12 pipe diameters), to better approach "uniform" flow conditions. Thus, avoid steep slopes, pipe diameter changes, junctions, and areas of irregular channel shape due to breaks, repairs, roots, debris, etc.

- Locations likely to be affected by backwater and tidal conditions should be avoided since these factors can complicate the reliable measurement of flow and the interpretation of data.

- Stations in pipes, culverts, or tunnels should be located to avoid surcharging (pressure flow) over the normal range of precipitation.

- Stations should be located sufficiently downstream from inflows to the drainage system to better achieve well-mixed conditions across the channel and to favor the likelihood of "uniform" flow conditions.

- Stations should be located where field personnel can be as safe as possible (i.e., where surface visibility is good and traffic hazards are minimal, and where monitoring personnel are unlikely to be exposed to explosive or toxic atmospheres).

- Stations should be located where access and security are good, and vandalism of sampling equipment is unlikely.

- Stations should be located where the channel or storm drain is soundly constructed.

- If an automated sampler with a peristaltic pump is to be used, and the access point is a manhole, the water surface elevation should not be excessively deep (i.e., it should be less than 6 meters, or 20 feet, below the elevation of the pump in the sampler, and preferably less than 4.5 meters or 15 feet deep).

- If automated equipment is to be used, the site configuration should be such that confined space entry (for equipment installation, routine servicing, and operation) can be performed safely and in compliance with applicable regulations.

Each potential sampling station should be visited, preferably during or after a storm to observe the discharge. A wet-weather visit can provide valuable information regarding logistical constraints that may not be readily apparent during dry weather.

Integration of BMP Monitoring into a Municipal Monitoring Program

In most cases, it is not practical to monitor water quality at every BMP within a municipality. Therefore, most municipal monitoring programs are designed to yield estimates of effluent water quality for other similar BMPs by extrapolating data collected at a small number of locations.

Many municipal stormwater monitoring programs use stations that monitor relatively small, homogeneous land use catchments (so called "single land use" or upland stations). Data from a study site may then be extrapolated to other catchments within the project area that are thought to have similar sources and pollutant-generating mechanisms. This approach may also be useful for BMP monitoring studies. However, extrapolations should be interpreted with caution because it is difficult to ascertain the degree to which catchments and BMP functionality are truly similar. Also, previous studies have shown that stormwater quality within a given land use category can vary considerably; thus, the correlation between land use and stormwater quality, and thus the utility of a particular BMP, may not be as strong as is typically assumed.

Other municipal programs use stations that sample relatively large catchments representing a composite of land uses. These stations are typically located in streams or other stormwater conveyances at the lower end of a watershed and are sometimes referred to as "mixed land use" stations or "stream stations." If possible, choose stream stations that receive runoff from catchments with a land use composition similar to that of the project area as a whole. This will make it easier to apply BMP monitoring results to similar watersheds. A geographic information system (GIS) can be very helpful in characterizing land uses and identifying stormwater monitoring locations.

Care must be taken to locate flow measurement and sampling sites in places that are likely to yield good data over diverse operational conditions. For performance monitoring approaches that are intended to compare changes in pollutant loads (i.e., “loads in” versus “loads out” of the BMP), it is especially important to use accurate flow measurement methods and to site the points of measurement at locations that maximize the attainment of credible data (see Section 3.2.1). The added cost of a weir or flume, as opposed to less sophisticated flow measurement methods, is almost always worthwhile because measurement errors propagate through various aspects of the analysis. Propagation of errors due to inaccurate measurement is discussed in detail in Section 3.2.4.3.

It is often difficult to identify large, homogeneous land use catchments that satisfy all of the above criteria. As a result, compromises will typically need to be made. Refer to basic texts on hydraulics and flow measurement and the instructions provided by monitoring equipment manufacturers to guide judgment.

Sampling from a Well Mixed Location

The location of a permanent sampling station is probably the most critical factor in a monitoring network that collects water quality data. If the samples collected are not representative of the water mass, the frequency of sampling as well as the mode of data interpretation and presentation becomes inconsequential. The following paragraphs describe the theory of mixing within a river cross-section, which is applicable to stormwater flows within stormwater conveyance systems. Typically these calculations are not needed for stormwater monitoring design, but they are presented here to bring attention to the need to be aware of mixing problems, particularly in wide conveyances. (Saunders 1983)

The representativeness of a water quality sample is a function of the uniformity of the sample concentrations in a river’s cross sectional area. Wherever the concentration of a water quality variable is independent of depth and lateral location in a river's cross section, the river at that point is completely mixed and could serve as a desirable sampling location (Saunders 1983).

Well mixed zones in a river for representative water quality sampling can be defined, given that several assumptions will apply. By assuming that a pollutant distribution from an instantaneous point source is normally distributed on both the lateral and vertical transect and applying classical image theory, a theoretical distance from an outfall to a well mixed zone in a straight uniform river channel is a function of 1) mean stream velocity, 2) location of the point source and 3) the mean lateral and vertical turbulent diffusion coefficients (Saunders 1983).

There are several models available that are functions of the mixing coefficients, which have been shown to apply for predicting a zone of relatively complete mixing. Ruthven (1971) derived an expression for a mixing distance utilizing the solution to the steady-state, two-dimensional advection and dispersion equation. Assuming that complete vertical mixing is assured in a relatively short distance, he established a relationship from the two-dimensional solution to predict the mixing distance to a point where the concentration variation in the cross section does not exceed ten percent. The approach taken by Ruthven is shown in the following equation:

$$L \geq 0.075 \frac{w^2 u}{D_y} \qquad \text{Equation 3.1}$$

where,

- L: mixing distance
- w: width of channel
- u: mean stream velocity
- D_y: lateral turbulent diffusion coefficient

The distance needed for complete mixing using the above approach results in great distances for most situations. In addition, many upstream discharges normally exist and it is rarely possible to get far enough below all of them. Because of the distance required for complete mixing, there is often a need to composite samples across wide streams.

Extensive discussion on this subject can be found in Fischer et al. (1979).

3.2.1.1 Upstream

Monitoring stations established upstream of a BMP can give results that reveal the influent concentration or load of pollutants before they flow through the BMP. Upstream water quality is indicative of concentrations and pollutant loads that would be observed downstream if no BMP were implemented. It is important to monitor only waters that flow into the BMP to be able to use the resultant data to compare upstream water quality with downstream locations. Upstream monitoring locations can also be useful to determine bypass water quality. Where bypass is present, accurate flow measurement is highly important. Where sufficient funds are available and the physical layout of the control structures allow, bypass and flow to the BMP should be monitored directly. In situations where direct measurement is not practical, modeling of bypass flows can be substituted, particularly where the hydraulics of the bypass structure are well known or can be calibrated to flow rates. Typically a mass balance approach is used to model bypass flow rates and volumes.

Upstream monitoring stations should be located far enough away from the BMP to ensure that samples are independent of the BMP. Immediately upstream from a BMP, contributing runoff could be affected by backflow, slope, vegetation, etc. Upstream monitoring should be representative of conditions that existed before the BMP was implemented.

3.2.1.2 Downstream

Monitoring stations established downstream of a BMP can indicate water quality of flows that are treated by the BMP. Downstream monitoring is essential for establishing:

- That the BMP provides a measurable and statistically significant change in water quality.
- That the BMP provides effluent of sufficient quality to meet water quality criteria.
- A comparison of effluent concentrations with similar BMPs to determine if the BMP is achieving typical effluent water quality.

Monitoring stations should be located immediately downstream so that BMP effluent is sampled before it is introduced into the receiving waters or is exposed to factors that may affect constituent concentrations. Where bypass is present and one wants to understand the efficiency of the BMP in addition to the BMP system, it is important to monitor water quality of the bypass flows and the effluent separately. In some cases where influent water quality is not expected to be appreciably different than bypass water quality, upstream data may be used to determine water quality. This approach does not, however, obviate the need for accurate estimates of bypass flow rates and/or volumes from monitoring or flow modeling. In some cases, bypass flows may be very difficult to separate from treated effluent (e.g., in hydrodynamic devices).

3.2.1.3 Intermediate Locations

BMPs are often designed as a group of devices or chambers that target specific processes. For example, a filter might have a settling chamber to quickly remove large settlable solids before flowing into the filter media chamber. A treatment train approach is sometimes taken to combine various BMPs in order to maximize removal of specific constituents. Intermediate monitoring locations in the interior of the BMP are useful for investigating how various sections of the BMP are working and establishing mid-BMP concentrations. Monitoring stations are also useful in between treatment train BMPs to assess effectiveness of each individual BMP in addition to monitoring upstream/downstream stations to determine overall BMP efficiency.

Intermediate monitoring locations should be located either interior to the BMP or in between BMPs linked in a treatment train. For interior monitoring, such as in the middle of a wetland or detention pond, stations should be established in a location that is representative of the BMP. For example, monitoring within a wetland should be done in the middle section, where the slopes, vegetation, channel width, etc., are uniform and similar to the rest of the wetland, avoiding any microcosms of unique vegetation, basins, or slopes. To monitor in between treatment train BMPs, stations should be established to capture effluent from the upstream BMP or inflow to the downstream BMP, or both. Monitoring should not be conducted in a place where backflow or mixing is occurring, as these processes do not allow for isolated sampling of direct BMP discharge or inflow. During high flow conditions, this may be difficult because many BMPs overflow, reducing the distinction and separation between BMPs. Intermediate treatment train BMP monitoring stations need to be carefully evaluated to determine if samples taken during high flows are representative of water quality of flow between the BMPs and not backflow or some other phenomena.

3.2.1.4 Rainfall

Rainfall monitoring can be an essential piece of the monitoring puzzle. Rainfall data may help determine when to start sampling as well as provide information to calculate rainfall characteristics such as intensities. The importance of accurate rainfall data, however, decreases as the accuracy and reliability of flow information is improved. Rainfall data are relatively inexpensive to collect and therefore, even in cases where rainfall data may not be required for a detailed analysis of BMP efficiency, it is usually worthwhile to monitor for validation of flow monitoring results.

Site Proximity

Rainfall gauges should be established as close as possible to the monitoring stations. In many regions, rainfall is highly variable within a small area due to orographic effects, elevation, and proximity to water bodies. The US Geological Survey, National Weather Service, and many municipalities have networks of rain gauges, some with real-time rain data available over the Internet. These established stations are convenient to use if they are in close proximity to the monitoring site, or as a general estimate of rainfall if they are not in close proximity to the monitoring site.

Rain gauges may need to be installed near the site to obtain accurate rainfall data where established gauges are not available. Proper installation and maintenance of the rain gauge is as important as gauge proximity to the monitoring site. Installation of rain gauges is often a straightforward matter. Manufacturers provide guidelines on the appropriate mounting of the devices. The main concerns during installation are:

- Leveling the device.
- Making sure that vegetation (trees) or structures are not obstructing rainfall.
- Providing enough height above the ground to prevent vandalism.
- Locating the rain gauge in close proximity to other monitoring equipment to provide required connections for recording of rainfall depths and/or representative records.

Number of Gauges

The number of precipitation gauges installed in a system directly affects the quality of precipitation data. Generally, the higher the number of precipitation gauges, the better the estimate of precipitation amounts. Locating a gauge at each monitoring site for small catchments is imperative, because local variations in total rainfall and rainfall intensity can have significant effects on runoff when the watershed is minimal in size. Nearby locations may not be useful in estimating rainfall at the actual site.

In addition to the network of rain gauges accessed for monitoring, it is also useful to install manual rain gauges at the monitoring site to check accuracy, consistency and proper functioning among different gages. It is not difficult to discover a gauge that produces different rainfall data than that observed at the site due to the location of the gauge at a different elevation or microclimate, improper installation or placement, or natural interferences (birds resting on the gauge, for example).

3.2.1.5 Groundwater

Although most BMPs are designed to treat surface water runoff, some BMPs also promote groundwater infiltration. BMPs incorporating infiltration should not process large quantities of certain constituents (petroleum products, pesticides, solvents, etc.) that could be mobilized in groundwater or pose a drinking water hazard to those who rely on downstream wells.

Groundwater monitoring wells should be established if contamination of groundwater is suspected. Groundwater flow, direction and elevation as well as soil types should be established before monitoring sites are chosen. Monitoring stations should be located sufficiently down gradient from the BMP where infiltrated water from the BMP is accessible. A series of monitoring stations could be established: a station upstream of the BMP, one a short distance downstream from the BMP, another a longer distance downstream, and another even further downstream from the BMP. This will indicate if there is any contribution of constituents to the groundwater from the BMP, and where there is a contribution, if the concentrations decrease with increasing distance from the BMP.

3.2.1.6 Sediment Sampling

Many constituents either settle out of the water column or prefer not to be in the water column (due to hydrophobicity) and become incorporated in the sediment. Sediment can store significant amounts of certain constituents, such as BTEX, PCBs, metals, and microbes. During high flows, these sediments are stirred up and can release their potentially high concentrations of accumulated constituents. Many BMPs are designed to remove the sediment from runoff, theoretically removing the associated constituents as well.

Sediment sampling can determine concentrations of constituents not necessarily found through water column monitoring. Sediments can be sampled upstream and downstream of BMPs as well as internal to the BMP to assess removal and effluent efficiencies as well as internal accumulation of sediment and associated constituents.

When sampling for suspended sediments in the water column, it is important to take the sample well below the surface of the water, ideally in the middle portion of the water column where the average concentration of suspended sediment is found. When sampling sediment from the creek bed or internal to the BMP (e.g., sampling the filter media or detention pond bottom sediments) sediments should be collected minimizing disturbance or resuspension of the sediment bed so that the original settled material is captured in the sample apparatus. Depth of sediment sample should also be noted as constituent concentrations can vary with depth.

3.2.1.7 Dry Deposition

Many constituents are quite volatile, including mercury, BTEX, PCBs, and some pesticides. Atmospheric deposition has been pointed to as a significant source of certain constituents to water bodies in some areas. These constituents are continuously being deposited out of the atmosphere either by coming into contact with the surface and sorbing to it, settling out of the air, or through rainfall. Constituents are deposited onto surfaces, such as roads, rooftops, and driveways and then incorporated into runoff during storm or low flow events. Therefore, atmospheric deposition may contribute some material to those BMPs that are exposed to the atmosphere, such as detention ponds and wetlands.

In order to assess the contribution of atmospheric deposition to constituent concentrations and to isolate influent and effluent concentrations, dry deposition can be monitored in conjunction with BMP monitoring. Pans can be set out near BMPs to capture dry deposition of these volatile constituents much in the same way that rainfall gauges are installed to capture rainfall. After a period of time the deposited material can be analyzed to determine constituent concentrations. It is recommended that dry deposition sampling should only be conducted as a follow-up investigation where sufficient evidence indicates that dry deposition may be contributing appreciably to stormwater pollution.

It is important to note that very little of the total watershed dry deposition actually contributes to stormwater runoff. The only contributions to water quality impairment that currently can be directly attributed to dry deposition fall on the receiving waters themselves (such as PCBs and DDT measurements for the Great Lakes) (Pitt 2001). Otherwise, most is incorporated in soils or may not wash off paved areas during rains. Fugitive dust from nearby sources is usually comprised of relatively large material that is poorly washed off, while particulates from regional air pollution sources (particularly power generation and autos) are mostly very small and are typically incorporated in soils; however, these smaller particles are much more easily washed off from pavements and might be a quantifiable source of pollutants where depositional rates are relatively large compared to other sources.

3.2.1.8 Modeling Methods

When monitoring is not feasible due to a limited budget or lack of sampling staff, estimates of water quality parameters, flow, and rainfall can be made using various models and assumptions. The use of modeling to estimate these parameters may limit usability of the data depending on the validity of the assumptions made, the accuracy of the model itself, and accuracy of the information input into the model.

Estimates of Water Quality Parameters

Certain water quality parameters can be estimated by monitoring instead for related parameters that are simpler or less expensive. These related or surrogate parameters are statistically correlated to the more complicated or expensive parameters. Some common surrogate parameters and represented parameters are:

Surrogate Parameter	Parameter Represented by Surrogate
Turbidity	TSS
Fecal Coliform	Pathogens
Chemical oxygen Demand (COD)	Biological Oxygen Demand (BOD)

In addition to monitoring for surrogate parameters at each monitoring site, water quality models can be used to estimate constituent concentrations at monitoring sites using available monitoring data, upstream land use, hydrology, geology, and history to calculate a mass balance for each constituent. Water quality models are a tool for simulating the movement of precipitation and pollutants from the ground surface through pipe and channel networks, storage treatment units, and finally to receiving waters. Both single-event and continuous simulation may be performed on catchments having storm sewers and natural drainage for prediction of flows, stages and pollutant concentrations. Each water quality model has its own unique purpose and simulation characteristics. It is advisable to thoroughly review downloading and data input instructions for each model.

The applicability and usefulness of these models is dependent upon a number of assumptions. The degree of accuracy of these assumptions determines the usefulness of the output data. For example, one assumption could be based on certain types of land use contributing certain constituents to the catchment runoff. The constituents associated with each land use have been well studied by many monitoring programs, but are still highly variable, depending on specific activities on each parcel, history of spills, age of infrastructure, climate, and many other factors. Although modeling of water quality parameters is a useful tool to estimate parameter concentrations, model results should not be interpreted as exact data. Confirmation of water quality model results should be done by monitoring a few storms and/or a few sites, then running the model with the observed conditions as input variables and comparing the results.

A variety of modeling tools are available for modeling water quality these include, but are not limited to, the following:

- Enhanced Stream Water Quality Model, Windows (QUAL2E)

Simulates the major reactions of nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric reaeration and their effects on the dissolved oxygen balance. It is intended as a water quality planning tool for developing total maximum daily loads (TMDLs) and can also be used in conjunction with field sampling for identifying the magnitude and quality characteristics of nonpoint sources.

- AQUATOX: A Simulation Model for Aquatic Ecosystems

AQUATOX is a freshwater ecosystem simulation model. It predicts the fate of various pollutants, such as nutrients and organic toxicants, and their effects on the ecosystem, including fish, invertebrates, and aquatic plants. AQUATOX is a valuable tool for ecologists, water quality modelers, and anyone involved in performing ecological risk assessments for aquatic ecosystems.

- SWMM: Storm Water Management Model

The EPA's Storm Water Management Model (SWMM) is a large, complex model capable of simulating the movement of precipitation and pollutants from the ground surface through pipe and channel networks, storage/treatment units, and finally to receiving water. Both single-event and continuous simulation may be performed on catchments having storm sewers, combined sewers, and natural drainage for prediction of flows, stages and pollutant concentrations (EPA 1995). See http://www.ccee.orst.edu/swmm/ for more information on this model.

- HSPF: Hydrologic Simulation Program – Fortran

The HSPF Model is an EPA developed application for simulation of watershed hydrology and water quality. The HSPF model uses historical rainfall, temperature and solar radiation data; land surface characteristics such as land use patterns; and land management practices to simulate the processes that occur in watersheds. The result of this simulation is a continuous recreation of the quantity and quality of runoff from urban or agricultural watersheds. Flow rate, sediment load, and nutrient and pesticide concentrations are predicted. The HSPF model incorporates the watershed-scale Agricultural Runoff Model (ARM) and Non-Point Source (NPS) models into a basin-scale analysis framework that includes pollutant transport and transformation in stream channels.

- WASP5: Water Quality Analysis Simulation Program

The Water Quality Analysis Simulation Program (WASP) is a generalized framework for modeling contaminant fate and transport in surface waters. WASP5 is the latest of a series of WASP programs. Based on the flexible compartment modeling approach, WASP can be applied in one, two, or three dimensions. WASP is designed to permit easy substitution of user-written routines into the program structure. Problems that have been studied using the WASP framework include biochemical oxygen demand and dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination, and organic chemical and heavy metal contamination (James 2001).

- SLAMM: Source Loading and Management Model

The Source Loading and Management Model (SLAMM) was developed to assist water and land resources planners in evaluating the effects of alternative control practices and development characteristics on urban runoff quality and quantity. SLAMM only evaluates runoff characteristics at the source areas In the watershed and at the discharge outfall; it does not directly evaluate receiving water responses. However, earlier versions of SLAMM have been used in conjunction with receiving water models (HSPF) to examine the ultimate effects of urban runoff.

SLAMM is different from other urban runoff models. Beside examining land development practices and many source area and outfall control practices, it contains two major areas of improvements. These are corrected algorithms for the washoff of street dirt and the incorporation of small storm hydrology. Without these corrections, it is not possible to appropriately predict the outfall responses associated with source area controls and development practices. (James 2001)

Estimates of Flow

Flows entering and leaving a BMP may be useful to model if actual monitoring is prohibitive. Flow can be estimated at varying levels of detail using approaches ranging from simple spreadsheets to complex hydraulic simulations of extensive urban drainage networks. Many of the water quality models presented in the previous section are also the best choices for modeling flows.

The simplest approach is to use the volumetric runoff coefficient approach described below.

- Volumetric Runoff Coefficient

The Volumetric Runoff Coefficient is an empirical relationship that provides an estimate of total volume of runoff based on total volume of rainfall according to the following equation:

$$\text{Volume of Runoff} = \text{Volume of Rainfall} \times Rv - \text{Depression Storage}$$

where,

Rv: Volumetric Runoff Coefficients

This method is usually applied to smaller catchments such as parking lots, rather than entire watershed areas.

Where monitoring data have been collected for some calibration period such that an accurate estimate of the volumetric runoff coefficient and depression storage for the watershed can be made, this approach coupled with accurate rainfall data may provide one of the least expensive methods for determining total volume of flow from a watershed on a storm-by-storm basis.

Estimates of Rainfall

If a nearby rainfall gauge is not available, rainfall at the monitoring site can be approximated using available gauges that are located as close as possible and at similar elevation. A network of gauges in an area can be analyzed to relate latitude, longitude, and elevation to rainfall. The grid of gauges can be expanded and extrapolated to an area lacking any gauges, provided that enough rainfall gauges exist.

Although raw rainfall data are often sufficient for monitoring needs, statistical evaluation of the data is often more useful. For example, if rainfall is needed to estimate runoff, most of the rainfall less than 0.1 inch will infiltrate into the ground and not produce any runoff. These small events could be eliminated from the data set to allow for a more accurate account of actual runoff. Two statistical analysis tools used extensively in separating and filtering continuous rainfall records, include:

- SYNOP

SYNOP is a statistical rainfall analysis program that converts hourly data into descriptive statistics for individual storm events and provides annual rainfall statistics. The program takes an hourly precipitation record from a station, organizes the data into rainfall events, and computes the statistics of the storm event parameters. When a complete hourly record has been organized into a sequence of individual storm events, the mean and standard deviation may be determined for each of the event parameters (EPA 1989).

- SWMM

The SWMM model will conduct a complete statistical analysis almost identical to the SYNOP tool. In most cases, SWMM is the preferred analysis tool as it is based on the same basic approach as SYNOP and it lacks some minor bugs present in SYNOP.

3.2.2 Recommendation and Discussion of Monitoring Frequency

The number of storms to be monitored each year (i.e., monitoring frequency) is an important consideration in planning your monitoring program. Budget and staff constraints generally limit the number of storms, locations, and parameters to be monitored. Program objectives should be weighed in light of available resources to determine the best mix of monitoring frequency, locations, and parameters.

The cost of learning more (i.e., conducting more intensive monitoring) should be compared to the cost implications of moving forward too far and implementing extensive controls before having learned enough to guide planning, stormwater management commitments, and/or negotiations with regulatory agencies. The cost of controlling unimportant pollutants and/or unimportant sources, or implementing ineffective BMPs could easily exceed the cost of monitoring to learn more about actual BMPs' performance under the conditions that prevail in the system. Clearly, there is a need for balance here, because endless studies should not be substituted for control actions.

In general, however, many measurements (i.e., many samples during many events) are necessary to obtain enough data to be confident that actual BMP performance not just “noisy data” (e.g., variability artifacts caused by external factors, equipment and operator errors). Consequently, BMP effectiveness studies can be expensive and time-consuming.

3.2.2.1 Statistical Underpinnings of Study Design

Four factors influence the probability of identifying a significant temporal and/or spatial change in water quality:

1) Overall variability in the water quality data.

2) Minimum detectable change in water quality (difference in mean concentration).

3) Number of samples collected.

4) Desired confidence level from which to draw conclusions.

Statistical analysis may be conducted to estimate how many events need to be monitored to achieve a desired confidence in a conclusion (i.e., power analysis). Performing a power analysis requires that the magnitude of detectable change, the confidence level, and the statistical power or probability of detecting a difference are defined. Typically, the confidence level and power are at least 95% and 80%, respectively, meaning that there is a 5% probability of drawing an incorrect conclusion from the analysis and a 20% probability that a significant change will be overlooked.

The power analysis often shows that many samples are needed to yield a power of 80% to 90% (i.e., discern a small change). In fact, Loftis et al. (2001) report that achieving a power of 80% requires double the data required for a power of 50%, and a power of 90% requires triple the data required for a power of 50%. The exponential increase in data required to achieve higher statistical power reinforces the need for careful consideration of the minimum detectable change required (and amount of data required) to achieve project objectives. In some cases, project objectives require quantification of small changes in concentration (e.g., inefficient BMPs or BMPs receiving relatively clean influent), which may call for larger power, but in many cases, less power (i.e., few samples) may be sufficient. If available resources prohibit the frequent monitoring of all locations, then reducing the number of locations or parameters tested may provide sufficient data to resolve slight differences in concentration at a more reasonable cost. Statistical confidence in the results of the monitoring program(collecting samples from a significant number of events) should be assigned a higher importance than collecting information from a larger number of locations or testing a multitude of water quality parameters.

3.2.2.2 Factors Affecting Study Design

Based on a review of existing studies, it is apparent that much BMP research in the past has not considered several key factors. The most frequently overlooked factor is the number of samples required to obtain a statistically valid assessment of water quality. This section focuses on estimating the number of samples required prior to beginning monitoring activities.

Number of Samples

Stormwater quality may vary dramatically from storm to storm. Therefore, monitoring a large number of storms is required if the objective of the program is to obtain accurate estimates of stormwater pollution in a given catchment (e.g., to determine whether water quality is changing over time or whether a given BMP is effective). However, staff and budget constraints typically limit monitoring to either a limited sampling methodology incorporating a smaller set of parameters for many storms, or a more detailed monitoring approach including a larger set of parameters for a few storms.

Determining the Number of Observations Needed

Typically a large portion of the costs associated with conducting a BMP monitoring program are related to collection and analysis of water quality samples. It is imperative that samples are not only collected in a manner consistent with the guidelines, but also that an adequate number of samples are collected for statistical validation. Estimates of the number of samples required to yield statistically valid monitoring results are also useful for making decisions about the nature and extent of monitoring efforts prior to implementation. Often goals for a monitoring effort (e.g., to demonstrate that a specific BMP is achieving a given level of removal of a constituent) may not be consistent with fiscal limitations of the project. This section provides a method for estimating the number of samples required for obtaining a statistically valid estimate of both the mean event mean concentration at a single sampling station and the percent difference observed at two stations.

As mentioned above, four factors affect predictions as to whether a sampling program will collect an adequate number of samples to provide a useful estimate of the mean station EMC:

1) Allowable level of error in estimates of mean (i.e., variance)

2) Level of statistical confidence in estimates of the mean

3) Number of samples collected

4) Variability in population trends

A variety of methods are available for estimating the number of observations required to predict the range surrounding a sample mean that contains the population mean. EPA (1993b) presents a nomograph relating the coefficient of variation (COV, defined as the ratio of the sample standard deviation to the sample mean) to the allowable error in the estimate of the population mean as a fraction of the sample mean. This nomograph is given in Figure 3.1 for normally distributed data and a statistical confidence of 95%.

Figure 3.1 can be generated using Equation 3.2 below. The number of samples required (n) is a function of the allowable error in the data mean (E) and the standard deviation (s), (or in the case of Figure 3.1, the COV) (Cochran 1963).

$$n = \frac{4(s)^2}{(E)^2}$$ Equation 3.2

where,

n: number of samples
s: sample standard deviation
E: allowable error in the data mean

This approach is useful for estimating the number of samples required when sampling at a single location where an acceptable upper bound for the error is known. However, Equation 3.2 does not provide an estimate of the number of samples required to determine if the mean concentrations from two sample sets are statistically significantly different.

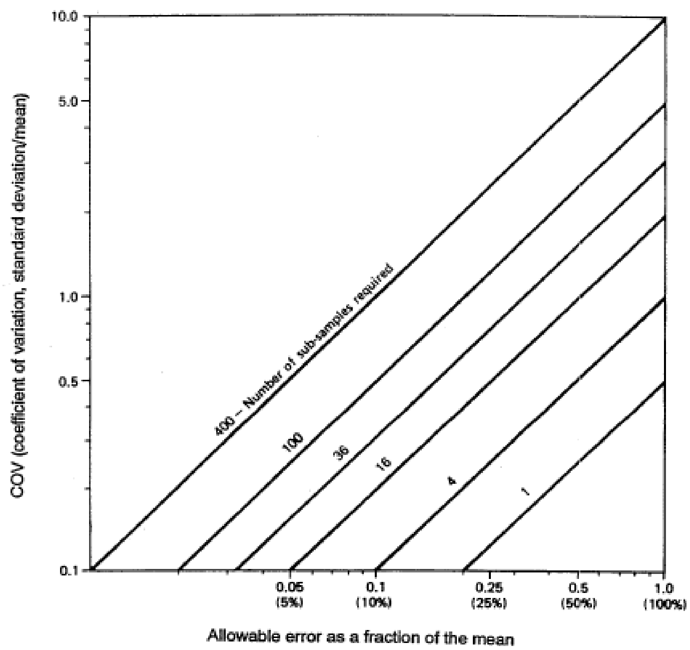


Figure 3.1: Nomograph relating coefficient of variation of a sample set to the allowable error in the estimate of the population mean (Pitt 1979).

Consideration of the number of samples required to draw statistically significant conclusions from data is often ignored until after monitoring work has been completed. However, there is great benefit to performing this analysis before initiating a monitoring program, particularly where the variability of the data is expected to be quite high because resources may be better spent on control measures than verification of BMP efficiency.

Appendix C expands the approach described in EPA (1993b) to the analysis of the number of samples required to conclude that there is a statistically significant difference between means calculated from sample data selected at random from two populations.

Appendix C provides a straightforward method for estimating the number of samples required to determine, with some degree of confidence, that observed means (such as the EMCs resulting from a BMP monitoring program) are statistically significant.

One assumption of the approach provided in Appendix C is that measured influent and effluent concentrations are normally distributed having a mean equal to the EMC.

Collection of water quality sample data at the inflow and outflow of a structural BMP allows for the determination of a mean EMC and the variance of the data (or log-mean and log-variance for log-normally distributed data). The mean and variance (square of the standard deviation) are the first and second moments of the distribution, respectively. These moments completely describe a normal distribution; thus, using the mean and variance of the distribution corresponding to any probability can be determined. Additionally, probabilities are additive so that confidence intervals between any two probabilities can be determined simply by calculating values of the distribution corresponding to the upper and lower probabilities of the confidence interval (i.e., confidence limits). The most common application is to determine the range of values surrounding the mean that falls within a specified 95% confidence interval (i.e., probabilities of 2.5% and 97.5%, which are the mean plus/minus 1.96 times the standard deviation).

One test that can be used to evaluate whether the means of two data sets (e.g., influent and effluent) are statistically different is a hypothesis test (e.g., student t-test), which is basically a test that quantifies the overlap of two confidence intervals surrounding the mean. The mean values will be considered different if there is little (as defined by the t-statistic distribution) overlap between the confidence intervals. This document presents hypothesis testing with the assumption that data sets are large (i.e., are composed of 30 or more values). Given this assumption, the Z-statistic can be used in place of the t-statistic, which eliminates the need to incorporate the degrees of freedom of a data set into hypothesis analysis. However, for analysis of small data sets, users should use the t-statistic in place of the Z-statistic (and refer to the student t-test in a standard statistics text). An iterative solution is required to determine the number of samples needed if the t-statistic, due to its dependence on the number of measurements, is used in place of the Z-statistic (Gilbert 1987).

The confidence interval about the mean for normally distributed data is defined as:

$$\left(\overline{C} - Z_{\alpha/2}\frac{s}{\sqrt{n}}, \quad \overline{C} + Z_{\alpha/2}\frac{s}{\sqrt{n}}\right) \qquad \text{Equation 3.3}$$

where,

$\overline{C}$ = mean concentration

σ = standard deviation for the population of the concentrations

$Z_{\alpha/2}$ = Z-statistic obtained from a standard normal distribution table n = number of measurements

The confidence interval corresponds to a significance level (α), where $(1 - \alpha)$x100% is the probability that $\overline{C}$ will fall within the confidence interval. As α increases, the confidence interval will become larger (all other variables remaining the same). If the population standard deviation (σ) is unknown, which is typically the case, then σ can be estimated using the sample standard deviation (s). Prior to the collection of field data, the standard deviation typically is estimated from existing data sets either from local or nationally published data on expected quality of stormwater runoff.

The confidence interval is often used to show the likely range containing the population mean, and for comparing the means for two populations (i.e., influent and effluent). However, the confidence interval formula contains the number of samples in the data sets, and therefore the equation can be solved for the number of samples needed to achieve a desired confidence interval for an expected difference in population means. The derivation of this formula is provided in Appendix C. As Appendix C shows, the resulting equation is (see the appendix for variable definitions):

$$n = \left[\frac{\left(Z_{a/2} + Z_{b/2} \right) \times COV \times \left(2 - \%removal \right)}{\%removal} \right]^2 \qquad \text{Equation 3.4}$$

$$n = 2\,[(Z_{1-\alpha} + Z_{1-\beta})/(\mu_1 - \mu_2)]^2 \sigma^2 \qquad \text{Equation 3.5}$$

This assumes that the sample sets have identical n, COV, $Z_{\alpha/2}$, and $Z_{1-\beta}$. Assuming the COVs of the sample sets are equal is a significant assumption because it mandates that s_{in}/s_{out} equals $\overline{C}_{in}/\overline{C}_{out}$. This assumption allows for the generation of a simple nomograph showing iso-sample number lines on a plot of COV versus percent difference in the means (see Figure 3.2). If the influent and effluent COVs are not assumed to be equal, *n* can be found from Equation 3.6 below:

$$n = Z_{a/2} \left[\frac{COV_{in} + COV_{out} \left(1 - \%removal \right)}{\%removal} \right]^2 \qquad \text{Equation 3.6}$$

Where COV is defined for influent and effluent data sets.

$Z_{\alpha/2}$ is a function of the desired level of certainty. For example, to determine a confidence interval with 95% certainty (significance level $\alpha = 0.05$), $Z_{\alpha/2}$ equals 1.96. Values for $Z_{\alpha/2}$ are tabulated in most statistical texts.

As an example of the application of the confidence interval, consider the case where the researcher wants to determine if a mean influent concentration is greater than a mean effluent concentration (assuming effluent concentrations are lower than influent concentrations). To do this, the 95% confidence interval of the influent and effluent EMCs are calculated. If the upper confidence limit (i.e., 97.5 percentile) of the effluent is less than the lower confidence limit of the influent (2.5 percentile), then the mean influent concentration is not equal to the mean effluent concentration, with 95% confidence.

As mentioned above, the Equation s derived in Appendix C allow for the solution of the COV, percent removal, or *n* in terms of the other two variables. Solving for the required COV for an estimated percent removal and *n* is shown in Figure 3.2 (for 95% confidence limits and a power of 80%). The primary use of Figure 3.2 is to estimate the *n* required to have 95% confidence in a hypothesis test given estimates of COV and percent removal. It is recommended that Figure 3.2 be used to provide a reasonable estimate of the number of samples (i.e., events) needed to quantify whether or not a BMP achieves an anticipated level of performance (i.e., measured by percent removal). It can be seen from Figure 3.2 that as the relative difference between influent and effluent mean event mean concentrations becomes small, the number of required monitored events becomes quite large.

Variations of the plot presented in Figure 3.2 are provided in Appendix B for a variety of different confidence intervals, powers, and percent differences. These plots were developed by Pitt and Parmer (1995).

Many commonly used statistical tests (e.g., parametric analysis of variance) are based on the assumption that the data are sampled at random from a normally distributed population. Thus, prior to applying the methods outlined in this section, the limitations imposed by assumed normality of sample data sets should be fully understood. Several methods can be used to determine the normality of a data set (or of data that is transformed to be normally distributed). Some of these tests are the W-test, Probability Plot Correlation Coefficient (PPCC), and graphical methods; all are useful for the analysis of stormwater quality data.

As mentioned previously, researchers have found that stormwater quality data is generally best fit by a log-normal distribution (EPA 1983; Driscoll et al. 1990; Harremoes 1988; Van Buren et al. 1996) and theoretical justification for using a log-normal distribution is provided by Chow (1954). Although, Van Buren et al. (1997) and Watt et al. (1989) found that pond effluent and/or soluble constituents in stormwater may be better fit using a normal distribution.

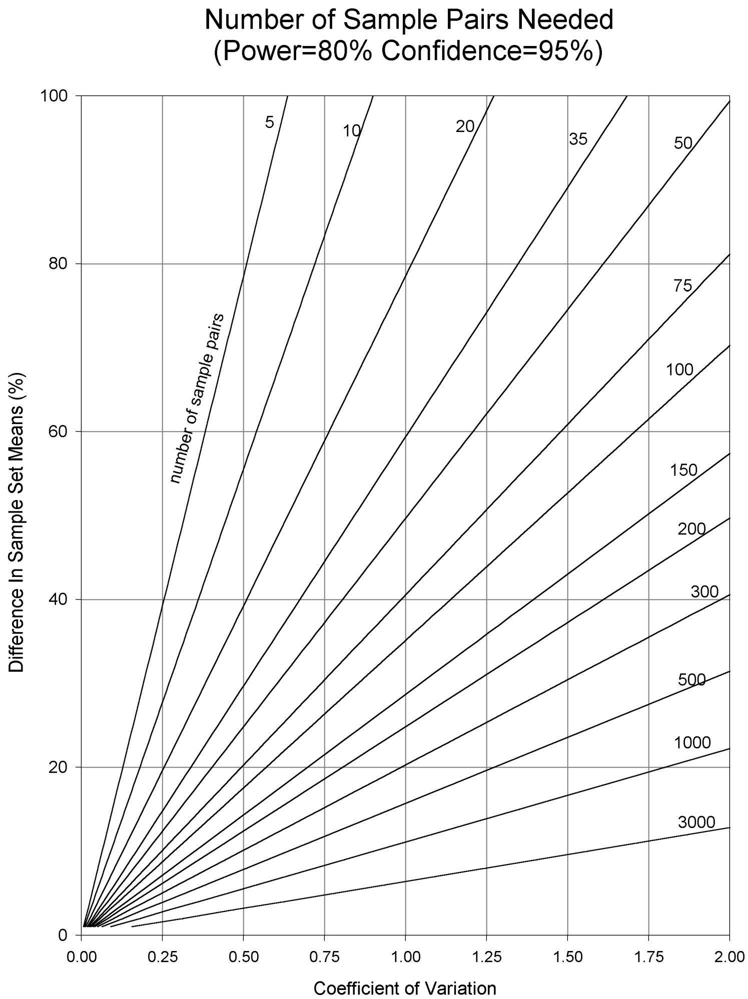


Figure 3.2 Number of samples required using a paired sampling approach to observe a statistically significant percent difference in mean concentration as a function of the coefficient of variation (power of 80% and confidence of 95%)

The following are some properties of the lognormal distribution. If a sample (a data set of N observations) is drawn from an underlying population that has a lognormal distribution, the following apply:

1. The natural logarithm of log-normally distributed data is normally distributed with a log-mean (μ_{lnK}) and log-standard deviation (σ_{lnK}) computed from the natural log-transformed data.

2. The arithmetic statistical parameters of the population (mean, median, standard deviation, coefficient of variation) should be determined from the theoretical relationships (see Appendix D) between these values and the mean and standard deviation of the transformed data.

A few mathematical formulas based on probability theory summarize the pertinent statistical relationships for log-normal probability distributions. These formulas provide the basis for forward and reverse conversions between arithmetic properties of untransformed data (such as measurements of concentration, flow, and load) and properties of transformed data (values that fall on a normal distribution so that statistical moments and probabilities can be defined). Appendix D, presents these formulas.

3.2.3 Recommendation and Discussion of Water Quality Parameters and Analytical Methods

3.2.3.1 Selecting Parameters

Stormwater runoff may contain a variety of substances that can adversely affect the beneficial uses of receiving water bodies. To select the parameters to be analyzed for a given monitoring location, consider the following:

- Permit requirements (if any). Monitoring to comply with a permit may specify the parameters that must be measured in stormwater discharges. However, monitoring for additional parameters may help attain overall program objectives.

- Land uses in the catchment area. Land use is a major factor affecting stormwater quality. Developing a list of the pollutants commonly associated with various land uses is helpful for deciding what to look for when monitoring.

- Existing monitoring data (if any) for the catchment area. Previous monitoring data can be helpful in refining the parameter list. However, if there is uncertainty about the monitoring methods and/or analytical data quality, or if the existing data pertain to baseflow conditions or only one or two storms, caution should be used in ruling out potential pollutants. For example, an earlier study may have used outdated analytical methods which had higher detection limits than current methods.

- Beneficial uses of the receiving water. Information on water quality within a stormwater drainage system often is used to indicate whether discharges from the system are likely to adversely affect the receiving water body. For example, if a stormwater system discharges to a lake, consider analyzing for nitrogen and phosphorus because those constituents may promote eutrophication.

- Overall program objectives and resources. The parameter list should be adjusted to match resources (personnel, funds, time). If program objectives require assessing a large number of parameters (based on a review of land uses, prior monitoring data, etc.), consider a screening approach where samples collected during the first one or two storms are analyzed for a broad range of parameters of potential concern. Parameters that are not detected, or are measured at levels well below concern, can then be dropped from some or all subsequent monitoring events. To increase the probability of detecting the full range of pollutants, the initial screening samples should be collected from storms that occur after prolonged dry periods.

A recommended list of constituents (along with recommended method detection limits for comparing stormwater samples to water quality criteria) for BMP monitoring has been developed and is presented in Table 3.1 below. Refer to Strecker (1994), Urbonas and Stahre (1993), and the ASCE Database website (http://www.bmpdatabase.org/) for more information on BMP monitoring parameters. The choice of which constituents to include as standard parameters is subjective. The following factors were considered in developing the recommended list of monitoring parameters:

- The pollutant has been identified as prevalent in typical urban stormwater at concentrations that could cause water quality impairment (NURP 1983; FHWA 1990; and recent Municipal NPDES data).

- The analytical result can be related back to potential water quality impairment.

- Sampling methods for the pollutant are straightforward and reliable for a moderately careful investigator.

- Analysis of the pollutant is economical on a widespread basis.

- Controlling the pollutant through practical BMPs, rather than trying to eliminate the source of the pollutant (e.g., treating to remove pesticide downstream instead of eliminating pesticide use).

Although not all of the pollutants recommended here fully meet all of the factors listed above, the factors were considered in making the recommendations. When developing a list of parameters to monitor for a given BMP evaluation, it is important to consider the upstream land uses and activities.

The base list represents the most basic arrangement of parameters. There may be appropriate applications where other parameters should be included. For a discussion of why some parameters were not included, see Strecker (1994).

Table 3.1: Typical urban stormwater runoff constituents and recommended detection limits

Parameter	Units	Target Detection Limit
Conventional		
PH	pH	N/A
Turbidity	mg/L	4
Total Suspended Solids	mg/L	4
Total Hardness	mg/L	5
Chloride	mg/L	1
Bacteria		
Fecal Coliform	MPN/100ml	2
Total Coliform	MPN/100ml	2
Enterococci	MPN/100ml	2
Nutrients		
Orthophosphate	mg/L	0.05
Phosphorus – Total	mg/L	0.05
Total Kjeldahl Nitrogen (TKN)	mg/L	0.3
Nitrate – N	mg/L	0.1
Metals-Total Recoverable		
Total Recoverable Digestion	µg/L	0.2
Cadmium	µg /L	1
Copper	µg /L	1
Lead	µg /L	5
Zinc		
Metals-Dissolved		
Filtration/Digestion	µg /L	0.2
Cadmium	µg /L	1
Copper	µg /L	1
Lead	µg /L	5
Zinc		
Organics		

Organophosphate Pesticides (scan)	μg /L	0.05 - .2

Note: This list includes constituents found in typical urban stormwater runoff. Additional parameters may be needed to address site specific concerns.

3.2.3.2 Dissolved vs. Total Metals

Different metal forms (species) show different levels of toxic effects. In general, metals are most toxic in their dissolved, or free ionic form. Specifically, EPA developed revised criteria for the following dissolved metals: arsenic, cadmium, chromium, copper, lead, mercury (acute only), nickel, silver, and zinc. Chronic criteria for dissolved mercury were not proposed because the criteria were developed based on mercury residuals in aquatic organisms (food chain effects) rather than based on toxicity. For comparisons with water quality criteria, it is advised that the dissolved metals fraction be determined. If selenium or mercury is of concern, total concentrations should also be measured to enable comparison with criteria based on bioaccumulation by organisms.

The distribution of pollutants between the dissolved and particulate phases will depend on where in the system the sample is collected. Runoff collected in pipes with little sediment will generally have a higher percentage of pollutants present in the dissolved form. Runoff collected in receiving waters will generally have a higher percentage of pollutants present in particulate form due to higher concentrations of suspended solids that acts as adsorption sites for pollutants to attach to. It is difficult to determine how much of the dissolved pollutants found in storm system pipes will remain in the dissolved form when they are mixed with suspended sediments in receiving waters. As a result, it is difficult to determine the ecological significance of moderate levels of dissolved pollutants present within the conveyance system. In addition, hardness values for receiving waters are often different than those for stormwater. Hardness affects the bio-availability of heavy metals, further complicating the ecological impact of dissolved heavy metals.

If loads to the receiving waters are of concern (e.g., discharge to a lake known to be a water quality limited water body) it may be desirable to determine total recoverable metals in addition to dissolved metals to assess the relative load from different sources. Finally, total recoverable metals data together with dissolved metals data can be used to assess potential metals sediment issues.

3.2.3.3 Measurements of Sediment Concentration

A variety of methods have been employed in stormwater quality studies for quantifying sediment concentration. The most frequently cited parameter is “TSS” or total suspended solids. The “TSS” label is used, however, to refer to more than one sample collection and sample analysis method. The “TSS” analytical method originated in wastewater analysis as promulgated by the American Public Health Association.

The USGS employs the suspended-sediment concentration (SSC) method (ASTM 2000), which was originally developed for the Federal Interagency Sedimentation Project (USGS 2001). SSC data is often described as TSS data, when in many cases results from the two methods may be significantly different. The difference between methods is sample size – the SSC method analyzes the entire sample while the TSS method uses a sub-sample. The process of collecting a representative sub-sample containing larger sediment particles is problematic as large sediment particles (e.g., sand) often settle quickly. Differences between the results obtained from SSC and TSS analytical methods become apparent when sand-sized particles exceed 25% of the sample sediment mass (Gray et al. 2000). Gray demonstrates that at similar flow rates, sediment discharge values from SSC data can be more than an order of magnitude larger than those from TSS data (USGS 2001) due primarily to larger particles that are often missed in the TSS method. “The USGS policy on the collection and use of TSS data establishes that TSS concentrations and resulting load calculations of suspended material in water samples collected from open channel flow are not appropriate” (USGS 2001).

It is recommended that both TSS (for comparison to existing data sets) and SSC be measured.

The discrepancies in sampling methodologies currently employed in the field highlight the importance of particle size distribution (PSD) analysis as an essential component of any BMP monitoring study. PSD data provide the information necessary to meaningfully interpret the ability of a BMP to remove suspended materials. However, PSD methods are varied and include (USGS 2001):

- Dry sieve.
- Wet sieve.
- Visual accumulation tube (VA).
- Bottom withdrawal tube.
- Pipet.
- Microscopy.
- Coulter counter.
- Sedigraph (x-ray sedimentation).
- Brinkman particle pize analyzer.
- Laser diffraction spectroscopy.

- Light-based image analysis.

The investigator must select and use a consistent and appropriate method.

Specific gravity (SG) of sediments is also an important component in determining the settleability of sediments and is recommended for sediment analysis by ASTM (1997). For BMP studies where PSD data are being collected, SG provides additional useful information about the ability of a particular BMP to remove sediment.

In addition, settling velocities of sediments are highly important and can be either measured directly or calculated theoretically from SG and PSD data. Settling velocities give the most useful information for quantifying BMP sediment removal efficiency.

The difficulty of collecting accurate sediment samples underscores the need to fully understand the conditions under which sediment data were collected and analyzed. Regardless of the analytical methods used, the sampling methodology often introduces the largest bias to sediment data.

3.2.3.4 Analytical Methods

After the parameters have been selected, the analytical methods to be used to measure them must be chosen. Select analytical methods that will provide results of sufficient quality to support the intended uses of the data. To determine the quality of data necessary for a program, consider the following:

- Appropriate analytical levels. EPA guidance suggests tailoring the analytical level to the intended use of the data. EPA has defined five analytical levels:

  I. Field screening and analysis using portable instruments

  II. Field analysis using more sophisticated portable analytical instruments, possibly set up in a portable laboratory at the site

  III. Analysis performed at an off-site analytical laboratory using EPA Contract Laboratory Program (CLP) or equivalent methods, but without the validation or documentation procedures required for CLP

  IV. CLP routine analytical services and complete data reporting packages

  V. Analysis by non-standard methods (to achieve very low detection limits or measure a specific parameter not included in standard methods)

  Stormwater samples are generally analyzed using Levels I, II, or III. Levels IV and V are not used very often for stormwater projects because these levels are intended for situations requiring low detection limits and high confidence, such as human or ecological risk assessments or Superfund/MTCA investigations.

- Appropriate methods should be selected for the chemicals of concern. These are the most significant contributors to human health or environmental risk at the site. Chenicals of concern are generally the most toxic, mobile, persistent, and/or frequently occurring chemicals found at the site. Commonly occurring chemicals of concern in stormwater runoff include metals (cadmium, copper, lead, and zinc), polycyclic aromatic hydrocarbons (PAHs), and organo-phosphate insecticides (e.g., diazinon and chloropyrifos). The latter are included because recent studies in the San Francisco Bay area found that diazinon accounted for much of the observed aquatic toxicity in urban runoff (Cooke and Lee 1993). Other chemicals (e.g., organochlorine pesticides and PCBs) should be included if there is reason to believe they are present. Note that the potential toxicity of some metals in freshwater systems is affected by the hardness of the water; thus, water quality standards for cadmium, copper, chromium, lead, nickel, silver, and zinc are calculated based on water hardness. For this reason, total hardness should be measured if metals are measured at sites where fresh water quality standards may apply.

- Level of concern. This term refers to the chemical concentration that is of concern. Typically, state or federal water quality criteria for protection of aquatic life or human health are used as the default level of concern for water sample results, and sediment quality criteria are used as the level of concern for sediment sample results. For pollutants that do not have state or federal water or sediment quality standards, the Risk-based Concentration Table developed by EPA Region III (EPA 1994a,b) can be used as levels of concern for water and soil sample results.

- Required detection limit/practical quantitation limit. The level of concern directly affects the data quality requirements because the sampling and analysis methods used must be accurate at the level of concern. Sampling variability is often difficult to control, especially in stormwater. The relative accuracy of most laboratory methods decreases as concentrations approach the detection limits. For these reasons, the practical quantitation limit (5 to 10 times the detection limit) should be below the level of concern, if possible.

If the objective is to conduct a screening study to identify chemicals that appear to be present at levels of concern, consider analyzing for a wide range of constituents using analytical methods with low detection limits. An initial screening analysis can generally reduce the number of chemicals analyzed in subsequent studies by eliminating those that were detected below their corresponding levels of concern.

In cases where it is known that there is a high degree of correlation between the concentration of the target pollutant(s) and some other parameter (e.g., fine particles, TSS, total organic carbon), then it may be possible to use less costly monitoring approaches to track the substitute, or “proxy” parameter(s). Although this approach can introduce some uncertainty because it does not track the target pollutants, it is still worthy of consideration. If the correlations are known to be strong and the cost differences pronounced, this strategy may provide a way to obtain much more data (i.e., more frequent observations during more storm events and/or at more locations). Such improvements in data quantity could more than offset the uncertainties introduced by imperfect correlations.

There are many precedents for using proxy parameters as indicators. For example, fecal coliform are bacteria often used as proxies for pathogens and as an indicator of fecal contamination. Total organic carbon and COD are sometimes used as proxies for BOD. Turbidity is commonly used as a proxy for suspended solids, which in turn, is sometimes used as a proxy for other pollutants of concern (e.g., metals, PAHs). The important consideration is that other factors could also account for observed changes in the proxy parameter relationship to other pollutants.

In many BMP monitoring programs, there are opportunities to obtain additional information at little or no incremental cost (e.g., temperature or pH data). Such information may turn out to be valuable to the overall stormwater program at some time in the future and/or to others programs.

3.2.4 Recommendation and Discussion of Monitoring Equipment and Methods

BMP monitoring can be done using a variety of equipment and methods. The type of equipment and methods used often directly affect the usability of the data collected. Both options and recommended approaches for monitoring are provided in this section.

3.2.4.1 Equipment

Equipment used to monitor BMPs includes a variety of data loggers, primary devices (e.g., flumes, weirs, and nozzles), secondary devices (e.g., bubblers, pressure transducers, and ultrasonic devices), automatic samplers, manual sampling devices, and rain gauges. These devices and their uses are described below.

Data Loggers

Data loggers are used to monitor signals from various pieces of equipment and store the impulses that they generate. When data loggers are combined with software to measure and route signals between instruments and analyze data, they are referred to as "data acquisition systems" and are often used as the execution center of a monitoring station. Most data loggers have several input ports and can accommodate a variety of sensory devices, such as a probe or transducer (e.g., flow meters, rain gauges, etc.). While specific design characteristics vary between instruments, overall data logger design is relatively standard. Some water quality samples have data loggers built into them; however, they are usually more limited in capabilities (e.g., programmability, communication options, etc.) than independent data loggers.

Data loggers suitable for stormwater monitoring applications are typically constructed of weather-resistant materials capable of protecting their internal circuitry from water and dust hazards. They are designed to operate at extreme temperatures, from as low as -55^{o}C to as high as 85^{o}C (-67^{o}F to 185^{o}F). In addition, most models can be securely mounted in remote locations, providing protection from wind and rain, wildlife, and vandalism.

Figure 3.3: Data Logger with Weatherproof Housing (Handar)

Typical data loggers for field use consist of the following components: a weatherproof external housing (a "case"), a central processing unit (CPU) or microprocessor, a quantity of random-access memory (RAM) for recording data, one or several data input ports, a data output port, at least one power source, and an internal telephone modem. In addition, most data loggers have an input panel or keyboard and a display screen for field programming. The CPU processes the input data for storage in RAM, which usually has a backup power source (such as a lithium battery) to ensure that data are not lost in the event of a failure of the primary power. Data stored in RAM may be retrieved by downloading to a portable personal computer (PC), or to a host PC via modem.

Figure 3.4: Data Logger Without Housing (Campbell Scientific)

Data loggers vary in size from 0.2 to 9 kilograms (0.5 to 20 pounds) or more. Both portable and fixed data-logging systems are available. For long-term, unattended monitoring projects, a fixed instrument capable of serving as a remote transmitting unit (RTU) may be preferable to a portable one. Manufacturers of data loggers suitable for stormwater monitoring include: Campbell Scientific, Logan, Utah; Global Water Instrumentation, Fair Oaks, California; Handar, Inc., Sunnyvale, California; In-Situ, Inc., Laramie, Wyoming; ISCO, Inc., Lincoln, Nebraska; Logic Beach, Inc., La Mesa, California; and Sutron Corporation, Sterling, Virginia.

Programmability

Most data loggers can be programmed to record data at user-selected intervals. For example, a particular model may be designed to permit a user to select a data recording frequency from once every two seconds to once every 48 hours, with the choice of frequencies varying by two-second intervals. The minimum and maximum intervals vary from vendor to vendor, and often vary among models offered by the same vendor. In addition, some data loggers have the ability to record event-related data, such as minimum and maximum flow rates and event timing and duration. Data loggers can also record data simultaneously for several different intervals (15 minutes, storm event, daily).

Most data loggers are field programmable, meaning that the software is equipped with an interface that permits on-site manipulation. However, some less expensive models may only be programmed at the factory. These models provide the advantage of cost savings but provide limited versatility, especially if project requirements change over time.

In addition, most data loggers possess the capability of remote programming via telephone modem. These models offer a significant advantage over factory programmed and field programmable data loggers because they allow the user to manipulate the program or monitor its effectiveness remotely. A network of data loggers used in a multi-site monitoring effort can be reprogrammed more efficiently than by traveling from site to site. An example where this functionality would be useful is if a predicted storm rainfall depth changes after sites are set up, the sampling interval could be adjusted remotely.

Although many vendors offer data loggers with the capability of remote manipulation via modem and PC, the user-friendliness of the various models may vary greatly between vendors. Most vendors have developed software packages that are provided free of charge with the purchase of their data logging systems. These software packages allow for remote data logger programming, and provide for data manipulation, analysis, and presentation at the host PC location. The interface environments used by these packages varies from DOS-like command lines to menu-driven point-and-click environments.

Most data loggers that are provided with vendor-developed software packages require an IBM-compatible PC with Windows™ to run the packages. Therefore, this additional cost should be considered when evaluating a particular model. Another point of consideration is the format in which a particular model logs the data it receives. Some models log data in a format that can be converted from ASCII files to any of several commonly available spreadsheet or word processing files, while others require the use of their particular vendor-developed software for data analysis and manipulation.

Data Capacity

Memory type and capacity vary greatly between instruments. Standard capacity varies between models and vendors from 8K or less, to more than 200K. In general, one data point uses 2 bytes of information; therefore, a data logger with 64K of memory could be expected to have a maximum data point capacity of 32,000 data points before data downloading or additional memory would be required. However, some types of data require as much as 4 bytes of memory per point. It should be noted that when recording sets of data related to storm events, memory may be exhausted more quickly than expected.

The type of memory used by a particular model is also an important consideration. Most data loggers use non-volatile RAM, (i.e., memory that is not lost in case of a power failure). Although this provides insurance that essential data will not be lost, the use of non-volatile memory may not be necessary if the data logger is equipped with a backup power source. A backup power source is automatically activated when the primary power source is lost. Typically, backup power is supplied by a lithium battery, with protection varying from 1 to 10 years.

Most models are programmed to stop recording data upon exhaustion of available memory ("stop when full"). However, some models are equipped with wraparound or rotary memory, which rewrites over the oldest data when available memory becomes exhausted. When using rotary memory, it is important to realize that data may be lost if it is not downloaded before it is written over.

Data loggers separate from water quality samplers increase the flexibility of the system because of their increased programmability over those loggers on samplers. Memory capacity is often an issue (even with the current inexpensive memory) and requires that careful attention be paid to downloading data before it is overwritten.

Communications

Models vary in their ability to accept input from more than one source. Some data loggers are designed with a single analog input channel, while others are designed with up to 16 channels. In addition, some of the newer models accept digital input data. The choice of a particular model should be based upon the number of sensors or probes from which the instrument will be required to accept data.

Data loggers can accept information from many different types of sensors and transducers. This allows for versatile use of most data logging systems. Some vendors offer probes and transducers with built-in data loggers; however, these systems typically cannot accept input data from other sensory devices, and their ability to communicate output data is often limited.

With regard to output communications, all data loggers interface with the standard RS-232 interface type, and some possess the capability to communicate with other interface types. In most cases, data can be downloaded on-site to a laptop PC or a unit may be transported to a lab or office so that the data can be downloaded to a desktop PC. As indicated earlier, data loggers can be equipped with an internal modem for telecommunications, allowing a user to download data from a remote host PC without having to visit the field site.

In most cases, use of a telephone modem requires an IBM-compatible PC as the host and the vendor's software. Typically, baud rates can be selected by the user. However, some models are capable of only a few baud rates, a limitation that should be considered when choosing a specific model. Some machines also possess the capability to transmit data via line-of-sight, UHF/VHF, or satellite radio. These options also allow for remote manipulation of programming and downloading of data.

Power Requirements

In general, data loggers are energy efficient devices. Most are powered by an internal battery, with the option of using external electrical power, if available. Some can also be equipped to use solar power.

Data loggers powered by internal batteries often offer a choice of cell type. Some models offer the choice of rechargeable cells or standard 12 volt alkaline cells, while others offer either alkaline or lithium batteries. The choice of power source and model selection, depends upon several factors, including site accessibility, distance, and amount of data to be recorded.

Alkaline cells are less expensive than lithium or rechargeable batteries, but they have a shorter life and must be replaced more often. While alkaline cells offer a potential power life of several months, lithium cells offer a potential power life of several years. However, since lithium batteries are considered a hazardous material, data loggers using lithium batteries are subject to more stringent shipping requirements than models using standard alkaline cells. In addition, since alkaline batteries must be replaced and discarded frequently, the use of alkaline batteries may actually be more expensive than using rechargeable batteries. Although rechargeable batteries offer less battery waste and potential cost savings, the time and cost required to recharge the batteries should be considered when evaluating power options.

Operating temperature range is another important factor to consider when choosing a power supply. Lithium expands both the minimum and maximum temperatures at which power can be used by the data logger. Under extreme conditions, it may not be feasible to use a data logger powered by alkaline batteries.

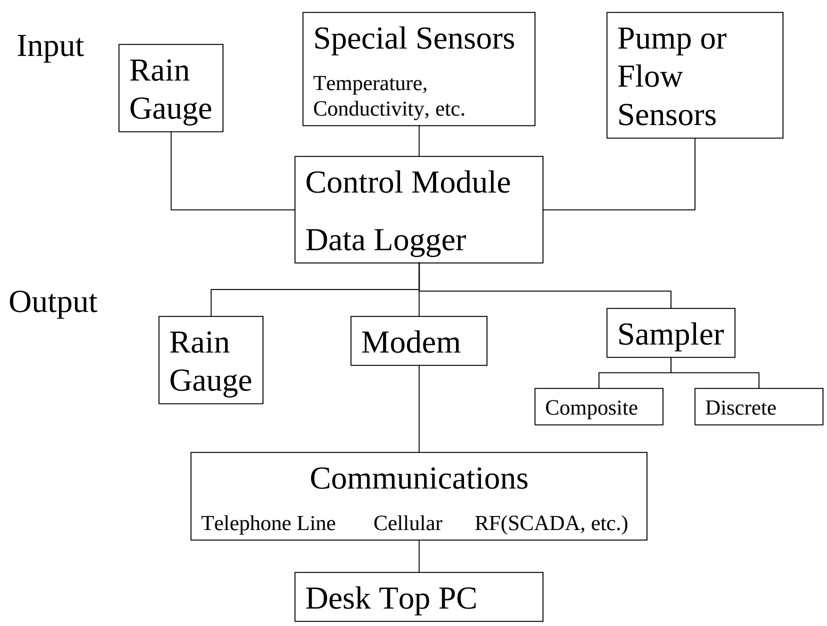


Figure 3.5: Data Logger Summary

Flow

Natural channels, engineered open channels, and pipes are used as stormwater conveyances. In each case, hydraulic considerations dictate the mathematical relationships that can be used to describe the flow rate at a given point in time. One of the primary hydraulic considerations is whether the flow configuration represents an "open" or "closed" channel. Open channel flow has a free water surface, and because the flow is driven by gravity, it varies with depth. Closed channel flow, in which the flow fills a conduit, is caused by and increases with the hydraulic pressure gradient. Some stormwater conveyance system pipes may function as open channels during periods of low storm runoff and as closed channels when the runoff volume becomes sufficiently large or when water is backed up due to downstream flow conditions (e.g., tide, river flooding, etc).

In general, the flow rate in an open channel depends on the depth of flow and several other factors (Chow 1959) including:

- Geometric shape and changes in shape and slope along the length of the channel (affects potential for development of turbulence and/or varied flow and therefore the choice of methods and instruments used for measurement of flow).
- Hydraulic roughness of the conveyance surface, whether natural or manmade (affects the energy losses of the flow).
- Rate at which the depth of flow changes over time (steady vs. unsteady flow).
- Spatial scale over which the flow rate changes (uniform vs. varied flow).

The measurement of the flow rate in an open channel is more difficult to obtain than that of a full pipe, because the free surface will change with respect to time.

Typically, stormwater flow through BMPs will fit the open channel flow configuration. However, some BMPs are drained by pipe systems, which may be flowing, full at times. Therefore, methods used for measuring flow in full pipes will also be discussed.

Table 3.2 summarizes available flow measurement methods, the requirements for their use, typical BMP use, and required equipment. Each of these methods is discussed in more detail in the following sections.

Table 3.2: Flow Measurement Methods

Method	Major Requirements For Use	Typical BMP Use	Required Equipment
Volume-Based	▪ Low flow rates	▪ Calibrating equipment ▪ Manual sampling	Container and stopwatch
Stage-Based Empirical Equations	▪ Open flow ▪ Known channel/pipe slope ▪ Channel slope, geometry, roughness consistent upstream	▪ Manual or automatic sampling	Depth Measurer
Stage-Based Weir/Flume	▪ Open flow ▪ Constraint will not cause flooding	▪ Manual or automatic sampling	Weir/flume and depth measurer
Stage-Based Variable Gate Meter	▪ 4-, 6-, or 8-inch pipes only	▪ Not typically used for BMPs	ISCO Variable Gate Meter
Velocity-Based	▪ None	▪ Automatic sampling	Depth measurer and velocity meter
Tracer Dilution	▪ Adequate turbulence and mixing length	▪ Typically used for calibrating equipment	Tracer and concentration meter
Pump-Discharge	▪ All runoff into one pond	▪ Not typically used for BMPs	Pump

Volume-Based Methods

The concept behind volume-based flow measurement is simple: one collects all the flow over a short period of time, measures the volume, and divides the collected volume by the length of the time period:

$$Q = V/T \qquad \text{Equation 3.7}$$

where,

Q: flow, m^3/s (ft^3/s)
V: volume, m^3 (ft^3)
T: time, s

A stopwatch can be used to measure the period required to fill a receptacle of known quantity to a predetermined level. The receptacle must be large enough that it requires some accurately measurable period of time to fill. The receptacle could be a bucket, a drum, or a larger container such as a catch basin, holding tank, or some other device that will hold water without leakage until the measurement is made.

This method is easy to understand, requires relatively simple equipment, and can be very accurate at low rates of flow. At higher rates of flow, collection of all the runoff from typical BMP conveyances (an essential component of the method) will probably become infeasible. This method is most useful for conducting limited research and for calibrating equipment.

Stage-Based Methods

Flow rate can be estimated from the depth of flow (i.e., water level or stage) using well-understood, empirically derived mathematical relationships. That is, for a set hydraulic configuration, the relationship between stage and flow is known. The most commonly used empirical relationship, the Manning Equation, is appropriate for open channels in which flow is steady-state (i.e., the flow rate does not vary rapidly over time) and uniform (the depth of flow does not vary over the length of the channel) (Gupta 1989). In automated stormwater sampling the Manning Equation is commonly used to estimate the flow rate of the flow stream.

Manning's Equation

The variables required for the Manning Equation (Equations 3.8 and 3.9) are the slope of the energy grade line (usually assumed to be the slope of the channel bottom), the cross-sectional area of the flow, the wetted perimeter, and an empirical roughness coefficient, which takes into account channel material, age, and physical condition.

Equation 3.8	Equation 3.9
$Q = \frac{1}{n} AR^{2/3}S^{1/2}$	$Q = \frac{1.486}{n} AR^{2/3}S^{1/2}$
where, Q: flow, m^3/s n: Manning roughness coefficient (dimensionless) A: cross sectional area, m^2 R: hydraulic radius, m = A/(wetted perimeter) S: slope of the channel, m/m	where, Q: flow, ft^3/s n: Manning roughness coefficient (dimensionless) A: cross sectional area, ft^2 R: hydraulic radius, ft =A/(wetted perimeter) S: slope of the channel, ft/ft

The Manning Equation truly applies only to steady and uniform flow but can provide a fairly accurate estimate of flow rates if certain conditions are met. The channel slope and cross-sectional geometry must be constant for some distance upstream of the site, the exact distance varying with overall system hydraulics (a rule of thumb is a length of twenty channel diameters upstream). Flow conditions at the site should not be affected by downstream features (i.e., no backflow effects). The cross-sectional area and wetted perimeter are both geometric functions of the channel shape and the depth of flow. The "roughness" of the conveyance walls can be described by a roughness coefficient. Additional information on applicability and values for Manning's roughness coefficients for common channel types are provided in most hydraulics texts (Chow 1959; Gupta 1989).

Use of the Manning Equation assumes that the slope of the channel bottom is accurately known. Monitoring studies using this technique to estimate flow rates often rely on as-built drawings to determine channel slope. Because these drawings vary in accuracy, direct measurement of the slope of the channel bottom and verification of hydraulic conditions is recommended.

The flow rate of stormwater runoff tends to be unsteady. This is due to changes in the intensity of precipitation and the dynamic nature of overland flow, which causes the flow rate to vary with time, either gradually or rapidly. Depending on the frequency with which the depth of flow is measured, rapid fluctuations in flow rate will be missed and the total runoff volume from a storm event will be miscalculated.

Other Empirical Stage-Flow Relationships

Another empirical relationship used to estimate flow is the Chézy Equation (Gupta 1989):

$$Q / A = C\sqrt{RS} \qquad \text{Equation 3.10}$$

where,

Q: flow, m^3/s (ft^3/s)
A: cross-sectional area, m^2 (ft^2)
R: hydraulic radius, m (ft)
S: slope of the energy grade line, m/m (ft/ft)
C: flow coefficient, $m^{1/2}/s$ ($ft^{1/2}/s$)

Under open channel flow, the coefficient "C" can be defined as:

$$C = \frac{R^{1/6}}{n} \qquad \text{Equation 3.11}$$

where,

n: Manning's Roughness Coefficient

When "C" is substituted into Chézy's Equation, the resulting Equation is identical to the Manning Equation.

A failure of both the Manning and Chézy Equations is that they imply that the Manning "n" value is constant for a given channel. However, it is known that for natural channels "n" may vary greatly with respect to flow (Ponce 1989). Therefore, when considering applying these equations to a natural channel, one should first evaluate the alluvial material in the channel and the magnitude of flows expected. It may be desirable to select another flow measurement approach for natural channels with highly varied surfaces and flow rates.

Stage Based Method Using Weirs and Flumes

The accuracy with which flow is estimated can be improved by using a weir or flume to create an area of the channel where the hydraulics is controlled (control section). Each type of weir or flume is calibrated (i.e., in the laboratory or by the manufacturer) such that the stage at a predetermined point in the control section is related to the flow rate using a known empirical equation (for examples, see Stevens 1991).

Stage-Based Variable Gate Meters

A relatively new development in flow metering technology is ISCO Inc.'s (Lincoln, NE) Variable Gate Metering Insert. Discharge flows through the insert and under a pivoting gate, creating an elevated upstream level that is measured with a bubbler system. The meter uses an empirical relationship to calculate the discharge rate based on the angle of the gate and the depth of flow upstream of the gate. This approach can be used only under conditions of open channel flow in circular pipes. Currently the system is only available for pipe diameters of 10.16, 15.24, and 20.32 cm (4, 6, and 8 inches). The Variable Gate Metering Insert was designed to measure the flow rate under fluctuating flows and should be effective at both very high and very low flow rates. Its main limitation is the size of the conveyance for which it is designed. The insert may be useful for sampling very small catchment areas. Again, problems with debris accumulation can occur.

Velocity-Based Methods

The continuity method is a velocity-based technique for estimating flow rate. Each determination requires the simultaneous measurement of velocity and depth of flow.

Flow rate is calculated as the sum of the products of the velocity and the cross-sectional area of the flow at various points across the width of the channel:

$$Q = A_i * V_i \qquad \text{Equation 3.12}$$

where,

- Q: flow, m^3/s (ft^3/s)
- A_i: cross-sectional area of the flow at section i, m^2 (ft^2)
- V_i: mean velocity of the flow at section i, m/s (ft/s)

The sections i = 1-n are planar segments of a cross-section of the flow where n is the number of points across the width of the channel. In stormwater runoff applications, the conveyance is small enough that a single cross-sectional area and estimate of average velocity is typically used to estimate flow rate. That is, it is not necessary to segment the cross-sectional area of the flow. The accuracy of this method is dependent on the ability of a sensor to measure velocity over a range of flow.

Although this method is useful for calibrating equipment, it is more sophisticated and expensive than the stage-flow relationships previously discussed. In addition, this method is suitable only for conditions of steady flow. That is, water level must remain essentially constant over the period required for obtaining velocity measurements. This is not generally a problem in small conveyance systems when instruments that make measurements rapidly are employed.

Additional relationships, developed for pipes that are flowing full, are the Darcy-Weisbach equation and the Hazen-Williams equation. These equations are used in systems where pressurized flow (i.e., pipes flowing full; no free water surface) is present and can be found in Gupta (1989).

Tracer Dilution Methods

Tracer dilution methods can be used where the flow stream turbulence and the mixing length are sufficient to ensure that an injected tracer is completely mixed throughout the flow stream (USGS 1980; Gupta 1989). Tracers are chosen so that they can be distinguished from other substances in the flow. For example, chloride ion can be injected into fresh water, and dyes or fluorescent material can be used if turbidity is not too high.

Dilution studies are well suited for short-term measurements of turbulent flow in natural channels and in many manmade structures such as pipes and canals. However, these methods are better suited to equipment calibration than to continuous monitoring during a storm event. Two dilution methods can be used to determine flow rate as described below.

Constant Injection Rate Tracer Dilution Studies

A known concentration of tracer is injected at a constant rate into a channel. The concentration of the tracer in the flow is measured at a downstream point over time. After some time period has passed, the tracer becomes completely mixed in the flow so that the downstream concentration reaches steady state. Flow is calculated from the initial tracer concentration, the tracer injection rate, and the steady-state downstream concentration.

Total Recovery Tracer Dilution Studies

A discrete "slug" of tracer is injected into the channel. Near-continuous measurements of tracer concentration in the flow are taken at a downstream point until the plume has entirely passed. Flow is calculated from the volume and concentration of injected tracer and the total area under the concentration-time curve.

Pump Discharge Method

In some cases, the overall discharge rate for a catchment may be measured as the volume of water that is pumped out of a basin per unit time while holding the water level in the basin constant. This method can be applied at sites where flow runs into a natural or manmade basin from several directions or as overland flow. If the pump is precalibrated, the number of revolutions per minute, or the electrical energy needed to pump a given volume, may be used as a surrogate for measuring the pumped volume during a stormwater runoff event. Application of this method requires considerable knowledge of the installed pump's performance. Because this setup (i.e., all of the runoff from a catchment flows into one pond or basin which can be pumped out) is not usually encountered in the field as the only available monitoring method, pumps are not discussed further in this manual.

3.2.4.2 Automatic Sampling Techniques

Selection of Primary Flow Measurement Device

This section provides an overview of the process of selecting a primary flow measurement device.

Changes to surface hydrology due to urbanization result primarily from the increases in impervious areas (roofs, streets, parking lots, etc.) and the increased hydraulic conveyance of the flow channels. The naturally occurring channels are often straightened, deepened, and lined in addition to the installation of storm sewers, drains, and gutters. Without detention storage, the resulting hydrograph has a higher peak discharge and shorter duration. This necessitates the ability of a primary flow device to accurately measure large discharge rates for storm events with high precipitation intensities. Due to the highly variable nature of storm events, low runoff rates will result from the smaller storm events. Analysis of long-term rainfall records indicates that smaller storm events generally account for the majority of stormwater runoff and resulting pollutant loads. Therefore it is essential that the primary device selected is also capable of accurately measuring the lower range of the expected flows. The potential for a wide range of flow rates resulting from stormwater runoff makes the assessment of the required range of discharge rates an important consideration for selection of a flow measurement device.

Flow measurements are critical to monitoring stormwater BMPs. Accurate flow measurements are necessary for accurate composting of samples used to characterize storm runoff and for the estimation of volumes (including pollutant loads) treated in the BMP. Many methods are available to estimate the flow in open channels: volume-based methods, velocity-based methods, empirical equations, and tracer-dilution methods. While these methods are all valid ways to measure the flow in open channels, they are not potentially as accurate as the use of a primary flow measurement device. Researchers monitoring flows pertaining to stormwater BMP effectiveness are encouraged to use primary flow devices where possible.

Types of Primary Flow Measurement Devices

Primary flow measurement devices fall into the general categories of flumes and weirs. Primary flow measurement devices allow for accurate measurement of discharge rates by creating a channel geometry in which the hydraulics are controlled (control section). Primary devices are calibrated (i.e., in the laboratory or by the manufacturer) to relate the stage at a predetermined point in the control section to the discharge rate using a known empirical equation (for examples, see Stevens 1998). These types of measurement devices are called depth (or stage) based methods because the discharge through the device is directly related to the depth (stage or head) of the flow. The relationship between the depth of flow and the discharge is called the rating. Tables referred to as rating curves are available for all standard flumes and weirs.

Weirs

A weir is an obstruction (usually a vertical plane) built or placed across an open channel (or within a pipe under open channel flow) so that water flows over the weir's top edge or through a well-defined opening in the plane. Many types of weirs can be used to measure discharge; the three most common are the rectangular, trapezoidal (or Cipolletti weir), and triangular weirs. The weir opening (i.e., the rectangular, trapezoidal, or triangular opening) is called the "notch." Each type of weir has a specific discharge equation for determining the flow rate through the weir.

Weirs are generally low in cost, easy to install (relative to flumes), and can be quite accurate when used correctly. A weir can be used to regulate flow in a natural channel with irregular geometry, a situation where Manning's Equation, for example, would not provide reliable estimates for the flow rate. However, a weir will back water up in channels by creating a partial dam. Weirs are generally used for flow measurements with relatively large head available to establish free-flow conditions over the weir. A weir is intended to back up water by creating a partial dam. During large storm events, backed-up water could cause or worsen flooding upstream, particularly in a closed conduit. Some jurisdictions prohibit the use of weirs for this reason. When evaluating the suitability of a monitoring site for a weir, it is important to determine whether the system was "over designed." That is, will the conveyance be able to move the design capacity after weir installation. In the case where the downstream depth of flow is greater than the crest of the weir, a different stage-flow relationship for the weir will apply.

Sediments and debris that accumulate behind a weir can alter the hydraulic conditions, changing the empirical relationship between flow depth and discharge rate. Weirs are often not a good choice where representative suspended sediment samples are desired. Weirs should be inspected regularly and accumulated sediment or debris removed. If high amounts of sediment or debris occur in the flow, then use of a flume may be more appropriate as they generally avoid sedimentation problems.

Flumes

A flume is a specially built reach of channel (sometimes a prefabricated insert) with a converging entrance section, a throat section, and diverging exit section.

Because the velocity of water accelerates as it passes through a flume, the problem of sedimentation associated with weirs (see below) is avoided; however, problems with debris accumulation may still occur. Another benefit is that flumes introduce a lower headloss than weirs, resulting in a reduced backwater effect. A flume may be more expensive and difficult to install than a weir due to its more complex design; however, where applicable, flumes can provide accurate results and significantly reduced maintenance.

The most common types of flumes are the Parshall, the Palmer-Bowlus, the HS, H, and HL flumes and the trapezoidal flume.

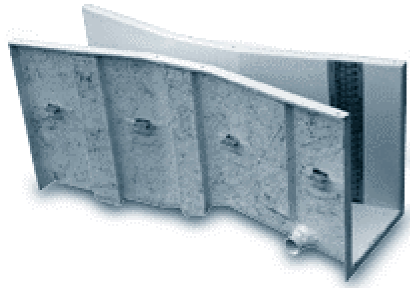


Figure 3.6: Parshall flume (Plati-Fab Inc.)

The area or slope (or both) of the flume is different from that of the channel, causing an increase in water velocity and a change in the level of the water flowing through the flume (Grant 1989). Stage-flow relationships have been established for a variety of flume configurations (USGS 1980; Gupta 1989; Stevens 1991).

Figure 3.7: H-flume (Tracom Inc.)

Considerations for Selection of Primary Flow Measurement Device

Consideration should be given to the following items when selecting a primary flow measurement device.

Range of Flows

Triangular thin-plate weirs have a large range in their ability to measure flows because of the 2.5-power relationship between flow depth and flow rate. That is, relative to other devices, flow increases quite rapidly as a function of head. The range of flow rates that can be measured accurately can vary by a factor (ratio of largest flow to smallest flow rate) of 200 for fully contracted weirs to around 600 for partially contracted 90^{o} notches that can utilize the allowable range of head (ASTM 1995).

For rectangular thin-plate weirs, the range is typically about a factor of 90 and increases to about 110 for full-width weirs. These ranges depend somewhat on the crest length to channel width ratio. These results are based on a minimum head of 0.1 ft (0.03 m) and a suggested (although not absolute) maximum head of 2 ft (0.6 m). However, the range-ability of smaller rectangular weirs can be significantly less (ASTM 1995).

The range in flow measurement for Parshall flumes varies widely with size. The range of Palmer-Bowlus and other long-throated flumes depends on the shape of the throat cross-section and increases as the shape varies from rectangular toward triangular. For typical Palmer-Bowlus flumes of trapezoidal section, the range of flow rates that can be measured accurately generally varies by a factor of 30. The USGS has developed and tested a modified Palmer-Bowlus flume (USGS 1985) for use in circular pipes that carry highway stormwater runoff. This flow can occur under either open or pressurized channel flow. This flume has been designed to measure the discharge under pressurized flow by using two bubbler sensors, which detect the hydraulic pressure change between upstream and downstream locations on the flume. This system was found to be one of the most accurate after calibration is performed. However the range between low and high flows that can be measured accurately using a Palmer-Bowlus flume is not as large as some other types of devices.

In cases in which there is a need for measurement of extreme flow ranges along with sediment transport capability, which is often the case for stormwater runoff, the H, HS, or HL flumes should be considered. The range of flows that can be measured accurately using H-type flumes can exceed three orders of magnitude; for example, a 3 ft H flume can measure flows between 0.0347 cfs at 0.10 ft of head to 29.40 cfs at 2.95 feet of head.

For some cases when low flows are expected to occur for an extended period but will ultimately be superseded by much larger flow rates, the interim use of removable small flumes inserted inside larger flumes can provide a method for accurate measurement of the range of flows.

Flow Rate

As mentioned in the beginning of the section, one of the most important factors influencing the selection of a primary device is the flow capacity necessary to accommodate runoff. Small and moderate flows are generally best measured with thin-plate weirs, with the triangular notches most appropriate for the smallest flows (ASTM 1995). Small Parshall and Palmer-Bowlus flumes are also available to measure low flows. The flumes do not have issues related to sediment passage and head loss as do thin-plate weirs, but this comes at some sacrifice in potential accuracy (ASTM 1995). Flumes and broad-crested weirs are generally the best choices for the measurement of large discharges.

Accuracy

Weirs are generally recognized as more accurate than flumes (Grant and Dawson 1997). A properly installed weir can typically achieve accuracies of 2 to 5% of the rate of flow, while flumes can typically achieve accuracies of 3 to 10% (Spitzer 1996). The ASTM cites lower errors for weirs ranging from about 1 to 3% and Parshall and Palmer-Bowlus flumes with typical accuracies around 5%. However, the overall accuracy of the flow measurement system is dependant on a number of factors, including proper installation, proper location for head measurement, regular maintenance, the accuracy of the method employed to measure the flow depth, approach velocities (weirs), and turbulence in the flow channel (flumes). It should be noted, however, that the largest source of error in flow measurement of stormwater results from inaccuracies related to low flow or unsteady flow. Improper construction, installation, or lack of maintenance can result in significant measurement errors. A silted weir or inaccurately constructed flume can have associated errors of ±5 to 10% or more (Grant and Dawson 1997). Circumstances present in many stormwater monitoring locations can result in errors well in excess of 100%.

Potential inaccuracies in the method used to measure the depth of flow will tend to increase the error in flow measurement as the flow depth approaches the minimum head. For primary devices operating near minimum head, even a modest error can have a significant effect on the measured flow rate. Therefore, it is important to select sizes or combinations of primary devices that avoid prolonged operation near minimum head (Spitzer 1997).

Cost

The important factor of cost consideration should include manufacturing, installation, and operational costs. Weirs are often considerably less expensive to fabricate than flumes due to simpler design and material requirements (Grant and Dawson 1997). Weirs are also usually easier and less expensive to install, although installation of flumes designed for insertion into a pipe (e.g. Palmer-Bowlus and Leopold-Lagco) are generally straightforward. Despite the higher initial costs of flumes, the relatively low maintenance requirements may outweigh this with time (Grant and Dawson 1997). Consideration should be given to the expected sediment loads in the flow to be measured for likely accumulation and maintenance requirements for weir installations.

Head Loss and Flow Characteristics

The head difference that is required for a weir or flume to operate properly may be an important selection criterion. Examples include, when the elevation difference is not adequate to maintain the required flow or when the upstream channel cannot contain the backwater.

For the same flow conditions, thin plate weirs typically require the largest head difference, Parshall flumes require an intermediate amount of head, and the long-throated flumes require the least (ASTM 1995).

Weirs are typically gravity fed and must be operated within the available head of the system. Flumes also require a certain head range in which the discharge liquid level is low enough that it does not exert back pressure on the liquid in the throat of the flume, otherwise the flume will be in a submerged condition, and two head measurements will be required to determine the flow rate.

Operation of a weir is sensitive to the approach velocity, often necessitating a stilling basin or pond upstream of the weir to reduce the fluid velocity. Operation of a flume is sensitive to turbulence or waves upstream from the entrance to the flume, which can require a section of straight channel upstream of the flume.

Sediment and Debris

Flumes tend to be self-cleaning because of the high flow velocity and the lack of any obstruction across the channel (Spitzer 1997). A flume is therefore generally more suited to flow channels carrying solids than is a weir.

Debris accumulation is likely to occur behind a weir especially due to the presence of a stilling basin to reduce flow velocities to an acceptable rate. Debris accumulation behind a weir can affect flow measurement. This requires periodic inspection and maintenance to remove debris. To allow periodic removal of deposits, it is recommended that the weir bulkhead be constructed with an opening beneath the notch to sluice accumulated sediments (Spitzer 1997).

Flumes, while typically not susceptible to problems due to sedimentation, can have debris accumulate in the throat portion of the flume and require periodic maintenance (although generally less frequently than weirs).

Construction Requirements

The Parshall flume is usually the most difficult device to construct due to the relatively complex shape and the possible need to excavate the channel floor to accommodate the sharp downward slope of the throat. Because this flume is an empirical device it is necessary to closely follow the design specifications (ASTM 1995). The discharge coefficients for long-throated flumes can be obtained theoretically which allows for some departure from the prescribed dimensions. Many types of flumes are available in prefabricated sizes up to several feet in width.

Weirs are generally easier to construct than flumes. The most difficult task is the fabrication of the notch edges, which require a sharp edge so the nappe is free flowing.

Selection of Secondary Flow Measurement Device

A variety of instruments may be used to measure water depth. Because some techniques are relatively cumbersome, they are more useful for calibrating equipment than for routine or continuous data collection during storm events. The equipment required for each technique and the associated advantages and disadvantages for sampling runoff at BMP sites are described below. Table 3.3 summarizes available equipment for measuring depth of flow, major requirements for use, and typical use within a BMP monitoring program.

Table 3.3: Equipment for measuring depth of flow

Method	Major Requirements For Use	Typical Use in a BMP Monitoring Program
Visual Observations	Small number of sites and events to be sampled. No significant health and safety concerns	Manual sampling
Float Gauge	Stilling well required	Manual or automatic sampling
Bubbler Tube	Open channel flow. No velocities greater than 5 ft/sec	Automatic sampling
Pressure Transducer	Better if remains submerged	Automatic sampling
Ultrasonic Depth Sensor	Open channel flow. No significant wind, loud noises, turbulence, foam, steam, or floating oil & grease	Automatic sampling
Ultrasonic Uplooking	No sediments or obstructions likely to cause errors in measurement.	Automatic sampling
Radar/Microwave	Similar to Ultrasonic Depth Sensor but can see through mist and foam	Automatic sampling
3-D Point Measurement	Highly controlled systems. Typically not useful in the field	Automatic sampling
Pressure Probe	Open channel flow. No organic solvents or inorganic acids & bases	Automatic sampling

Float Gauge

A float gauge consists of a float that is free to move up and down in response to the rising and falling water surface in a channel. Prior to an actual stormwater sampling event, the site is calibrated to establish an initial reference depth. During the storm, the float rises and falls with changes in water surface elevation, and a device attached to the float records the magnitude of these changes. The changes in water surface elevation are converted to depth of flow by the float gauge. A data logger can record the depth of flow, and if capable of performing mathematical equations, can also determine the flow rate. The data can also be used as input to appropriate software to compute the flow rate.

In some applications, use of a float gauge requires a stilling well. A stilling well is a reservoir of water connected to the side of the conveyance that isolates the float and counterweight from turbulence in the main body of the flow. The need to retrofit an existing channel or conduit with a stilling well, a potentially expensive and time-consuming process, is the principal drawback of this technique. However, this method may be useful if sampling is conducted at a site where a float gauge and stilling well have previously been installed.

Bubbler Tube

Bubbler tubes are used by some types of automated flow meters to measure the depth of flow. Compressed air (or gas) is forced through a submerged tube attached to the channel invert (i.e., bottom of the channel). A pressure transducer measures the pressure needed to force a bubble out of the tube. This pressure, in turn, is linearly related to the depth of the overlying water:

$$P = \rho h \qquad \text{Equation 3.13}$$

where:

- P: hydrostatic pressure, N/m^2 (lb/ft^2)
- ρ: specific weight of water, N/m^3 (lb/ft^3)
- h: depth of water, m (ft)

Bubbler tubes are commonly integrated with a flow meter, or a data logger that is capable of performing mathematical calculations. This approach allows the measurement of depth to be immediately converted to a flow. These real-time inputs along with a program that tracks accumulated flow volumes can be used to trigger the collection of samples for flow-weighted compositing by an automated sampler.

Figure 3.8: Bubbler flow meter (ISCO)

Bubbler tubes are simple to use and are not usually affected by wind, turbulence, foam, steam, or air-temperature gradients. Accuracy is not lost under dry conditions in a conveyance between runoff events (some other types of probes must remain submerged). Although they are generally reliable, bubblers are susceptible to error under high velocity flow. That is, as flow velocity increases to over 1.5-1.8 m/s (5-6 ft/s), a low pressure zone is induced around the mouth of the bubbler tube, interpreted by the flow meter as a drop in flow rate. These instruments therefore, should not be used in channels where the slope of the bottom exceeds 5-7 percent. Sediments and organic material can also plug bubbler tubes. Some units are periodically purged with compressed air or gas to prevent this problem, but visual inspection and periodic maintenance are recommended for any unit installed in the field. Bubblers are commonly available in integrated systems, such as those manufactured by ISCO and American Sigma, but are also sold as independent devices.

Ultrasonic Depth Sensor

An ultrasonic depth sensor consists of a sonar-like device mounted above the surface of the water at a known distance above the bottom of the channel. A transducer emits a sound wave and measures the period of time taken for the wave to travel to the surface of the water and back to a receiver. This time period is converted to a distance and then converted to a depth of flow, based on measurements of the site configuration. As with bubbler tubes, an ultrasonic sensor can be integrated into a flow meter or interfaced with a data logger. An ultrasonic depth sensor and data logger can provide the real-time flow data necessary to trigger an automated sampler to collect a stormwater sample for flow-weighted compositing.

Figure 3.9: Ultrasonic-depth sensor module (ISCO)

Some manufacturers have built redundancy into their ultrasonic depth-measuring instruments. Redundancy helps to ensure that useful data will be collected even if some of the sensors in the array become fouled with grease, surface-active materials, or organisms. Experience has shown that this type of fouling can occur during storm events. Because an ultrasonic sensor is mounted above the predicted surface of the water, it is not exposed to contaminants in the runoff (unless the depth is greater than anticipated or installed in a pipe that reaches fully pressurized flow). However, ultrasonic signals can be adversely affected by wind conditions, loud noises, turbulence, foam, and steam, and they will require periodic inspection and maintenance. Ultrasonic signals can also be affected by changes in density associated with air temperature gradients; however, some manufacturers build a compensation routine into their instruments.

Background noise can interfere with a sensor's ability to accurately measure water depth. For example, an ultrasonic sensor was used in Portland, Oregon to measure the depth of flow at an urban stormwater sampling site located in a manhole, in which runoff from an arterial pipe splashed down into the main conveyance. To dampen the effect of the interfering signal, the ultrasonic sensor was retrofitted with a flexible noise guard.

Pressure Probe

A pressure probe consists of a transducer, mounted at the bottom of the channel, that measures the hydrostatic pressure of the overlying water. This hydrostatic pressure is converted to a depth of flow. Some pressure probes have a built-in thermometer to measure the temperature of the water, allowing for temperature compensation in the depth of flow calculation. As with bubblers and ultrasonic probes, the pressure probe can be integrated into a flow meter or interfaced with a data logger to provide real-time inputs to an automated sampler. If the instrument is fitted with a thermometer, the temperature data used for compensation can possibly also be input to memory and retrieved as additional useful data.

Figure 3.10: Pressure transducers (In-Situ Inc.)

Submerged probes are not adversely affected by wind, turbulence, foam, steam, or air temperature gradients. However, because contaminants in the water may interfere with or damage the probe, periodic inspection and maintenance is recommended. Dry conditions between storms can affect the accuracy of the probe, as can sudden changes in temperature.

Ultrasonic "Uplooking"

This depth of flow sensor is mounted at or near the bottom of the channel or pipe. It uses ultrasonic signals to determine the depth of the flow. This sensor is very accurate unless interference occurs. However, according to a vendor, this equipment is not recommended for stormwater applications because the sensor is likely to become covered by sediments and debris. This then interferes with the signal and does not allow the sensor to work properly.

Radar/Microwave

A variation of the ultrasonic method is a non-water contacting instrument that emits and reprocesses electromagnetic waves in the radar/microwave spectrum. By altering the wavelength of the electromagnetic signal, problems associated with foam, mist, and rapid changes in air temperature and pressure are eliminated or significantly reduced.

A radar/microwave sensor is used in the same manner as an ultrasonic "downlooking" sensor for measuring fluid levels in tanks. Based on experience, this device does not present a significant advantage over other methods of level measurement, since foam and mist are not typically a large concern during stormwater monitoring.

Radar/microwave sensors have not been extensively tested by manufacturers for this type of application, and there is no existing literature that shows them being used for stormwater monitoring.

Equipment for Measuring Velocity

Use of the continuity equation for measuring flow requires the estimation of average velocity as well as depth. The velocity of flow may be measured using visual methods (i.e., the float-and-stopwatch and the deflection, or drag-body methods), tracer studies, the use of instruments such as rotating-element current meters and pressure, acoustic, ultrasonic (Doppler), and electromagnetic sensors. Electromagnetic sensors have been found to be the most accurate. Among these methods, many are more useful for the calibration of automated equipment than for continuous data collection. Only the ultrasonic and electromagnetic methods are recommended for measuring velocity during a storm. In the following text, velocity measurement methods potentially suitable for calibration are described (more details are available in USGS 1980). More extensive discussions, including advantages and disadvantages related to sampling activities, are provided for the ultrasonic and electromagnetic sensors.

Methods Suitable for Calibration

The most important aspect of any calibration method is its ability to obtain accurate results with a high degree of certainty and repeatability. A variety of methods have been employed in the past. The most common methods are described in this section. Table 3.4 summarizes the available methods.

Table 3.4: Velocity measurement methods suitable for calibration

Method	**Comments**
Tracer Studies	**Recommended Method**. Where applicable, one of the best calibration methods. Requires complete mixing of tracer with flows.
Rotating-Element Current Meters	Useful for larger flows that do not rapidly vary with time. Typically useful for large systems with appreciable flows. Low flows are difficult to monitor.
Pressure Sensors	Not useful for velocities above 1.5-1.8 m/sec or in pipes with steep slopes (>5%).
Acoustical Sensors	Not applicable to most monitoring locations. Large flow rates are typically required. Base flow required to observe complete storm hydrograph. Typically applicable only to large channels.
Float-and-Stopwatch	Rarely accurate enough for calibration purposes. Not recommended for most situations.
Deflection (or Drag-Body) Method	Rarely accurate enough for calibration purposes. Not recommended for most situations.

Tracer Studies

Tracer methods have been developed to measure flow velocity under uniform flow (USGS 1980). As described in the flow measurement methods section, for Total Recovery Tracer Dilution studies, a discrete slug of tracer is injected into the flow. Concentration-time curves are constructed at two downstream locations. The time for the peak concentration of the dye plume to pass the known distance between the two locations is used as an estimate of the mean velocity of the flow. This method is not practical for continuous flow measurement, but is useful for site calibration.

Rotating-Element Current Meters

A current meter or current meter array can be used to measure the velocity at various points throughout a flow stream. The measured point velocities can be combined to estimate a mean velocity for the flow. As with the deflection or drag-body method, if employed for longer periods, a current meter inserted into the flow will accumulate debris causing it to malfunction and possibly break away. This method should therefore only be used for short-term measurements such as during equipment calibration or to develop a rating curve. Two types of readily available instruments that meet USGS standards are the type AA Price and Pigmy current meters.

Pressure Sensors

A pressure sensor or transducer measures the dynamic pressure head at a given point in the flow. The dynamic pressure is a measure of the point velocity and can be used to estimate the mean velocity of the flow. A common example of a pressure sensor is the pitot tube used on an airplane or on some boat speedometers.

The same caution described for bubbler tubes must be applied to pressure sensors. That is, as the velocity of the flow increases above 1.5-1.8 meter/second (5-6 feet/second), a low pressure zone is induced across the sensor, interpreted by the flow meter as a drop in flow rate. These instruments should not be used in channels where the slope of the bottom exceeds 5 to 7 %.

Acoustical Sensors

An acoustical sensor emits a sound wave under water across a channel and measures the time required for the signal's return. Transit time is correlated with channel width. The relative positions of the emitting and receiving sensors are used to estimate velocity. A minimum depth of flow is required. This type of sensor can only be used at sites with sufficient base flow to provide the medium in which the sound wave travels. If there is no base flow, the lower portions of the rising and falling limbs of the hydrograph will be lost.

Float-and-Stopwatch Method

In this method, the time it takes for a float to move a known distance downstream is determined. Velocity is calculated as the distance traversed divided by the travel time. The characteristics of a good float are: an object that floats such that it is partially submerged, allowing some averaging of velocity above and below the surface of the water; an object that is easily observed and tracked; an object that is not easily affected by wind; and an object that does not cause problems if not recovered. Citrus fruits such as oranges, limes, or lemons are commonly used as floats. Ping-pong and styrofoam balls float well but are too light and are easily blown by the wind (they may also pose environmental problems if not recovered).

In a variation of this method, a vertical float with a weighted end is used. The vertical float provides a better measure of mean velocity over the depth of the water column than a float moving primarily at the surface. In addition, it can be designed to minimize bias due to wind.

In most cases, this method is not accurate enough to be of significant utility in stormwater monitoring studies and is particularly inaccurate for very deep systems and where there is a significant difference in velocity across the water surface (e.g., in natural channels).

Deflection (or Drag-Body) Method

In this method, the deflection or drag induced by the current on a vane or sphere is used as a measure of flow velocity. This method is only practical for short-term, real-time measurements, such as equipment calibration, because an object of this size inserted into the flow will accumulate debris, causing it to change the hydraulic form, provide inconsistent data, and (possibly) break away.

Methods Most Suitable for Continuous Velocity Monitoring

Ultrasonic (Doppler) Sensors

An ultrasonic sensor applies the Doppler principle to estimate mean velocity. A sound wave, emitted into the water, reflects off particles and air bubbles in the flow. The shift in frequency of waves returning to the sensor is a measure of the velocity of the particles and bubbles in the flow stream. The instrument computes an average from the reflected frequencies, which is then converted to an estimate of the average velocity of the flow stream.

Figure 3.11: Area velocity sensors module (ISCO)

The sensor is mounted at the bottom of the channel. However, because the ultrasonic signal bounces off suspended particles, the signal may be dampened (i.e., not able to reach portions of the flow stream) when suspended solids concentrations are high. The sensor may also be mounted on the side of the channel, slightly above the invert. Combined with the appropriate hardware and software, the sensor can filter out background signals associated with turbulence in the flow.

Ultrasonic Doppler sensors can be used under conditions of either open channel or pressurized flow. When combined with the hardware and software required for real-time flow measurement, data logging, and automated sampling, and when properly calibrated, this system is capable of greater accuracy than one relying on a stage-flow (i.e., Manning's Equation) relationship. The ultrasonic sensor-based system may be more expensive but the additional expense may be justified by program objectives. Without routine maintenance, the accuracy of ultrasonic sensors may decrease due to fouling by surface-active materials and organisms.

Electromagnetic Sensors

Electromagnetic sensors work under the principle stated in Faraday's Law of electromagnetic induction; that is, a conductor (water) moving through an electromagnetic field generates a voltage proportional to its velocity. This instrument, mounted at or near the channel bottom, generates the electromagnetic field and measures the voltage inducted by the flow. Although velocity is measured at only a single point, that measurement is used to estimate the average velocity of the flow stream.

Electromagnetic sensors can be pre-calibrated for many types of site configurations. The sensor is usually mounted at the channel invert but can be mounted on the side of a channel, slightly above the invert, if high solids loadings are expected. A built-in conductivity probe senses when there is no flow in the conveyance.

These types of instruments are not sensitive to air bubbles in the water or changing particle concentrations, as is the ultrasonic sensor, but can be affected by extraneous electrical "noise." As with the ultrasonic system, when an electromagnetic sensor is combined with the hardware and software required for real-time flow measurement, data logging, and automated sampling, and when properly calibrated, it may be capable of greater accuracy in specific circumstances than a system relying on a stage-discharge relationship. On the other hand, the electromagnetic sensor-based system may also be more expensive, but the additional expense may be justified by program objectives.

Acoustic Path

These sensors are used to determine the mean velocity of streams and rivers, and where they are applicable, they have been found to be one of the most accurate flow measurement systems. The method consists of an array of sensor elements that are installed at an even elevation across the channel. The number of sensor elements used is dictated by the channel width (larger channels require more sensors). Due to the sensor array's height above the channel bottom, its use is generally limited to larger channels that have a base flow present. It is not practical for smaller diameter conveyances with no base flow, which may be found at a BMP site. Additionally, stormwater conduits for BMP runoff can be small enough that a single point measurement for velocity provides a reasonable estimate for the average velocity. For these reasons, acoustic path sensors are rarely applicable to BMP monitoring situations.

Water Quality Sample Collection Techniques

Grab Samples

The term "grab sample" refers to an individual sample collected within a short period of time at a particular location. Analysis of a grab sample provides a "snapshot" of stormwater quality at a single point in time. Grab samples are suitable for virtually all of the typical stormwater quality parameters. In fact, grab samples are the only option for monitoring parameters that transform rapidly (requiring special preservation) or adhere to containers, such as oil and grease, TPH, and bacteria.

The results from a single grab sample generally are not sufficient to develop reliable estimates of the event mean pollutant concentration or pollutant load because stormwater quality tends to vary dramatically during a storm event. Nevertheless, grab sampling has an important role in many stormwater monitoring programs for the following reasons:

- A single grab sample collected during the first part of a storm can be used to characterize pollutants associated with the "first flush." The first part of a storm often contains the highest pollutant concentrations in a storm runoff event, especially in small catchment areas with mostly impervious surfaces, and in storms with relatively constant rainfall. In such cases, the first flush may carry pollutants that accumulated in the collection system and paved surfaces during the dry period before the storm. Thus, the results from single grab samples collected during the initial part of storm runoff may be useful for screening-level programs designed to determine which pollutants, if any, are present at levels of concern. However, this strategy may be less effective in areas subject to numerous low-intensity, long duration storms with short inter-event times, because "first flush" effects are less obvious under such weather conditions.

- Some measurable parameters, such as temperature, pH, total residual chlorine, phenols, volatile organic compounds (VOCs), and bacteria transform or degrade so rapidly that compositing can introduce considerable bias. (Note: Grab sampling is the typical method for VOCs because VOCs can be lost through evaporation if samples are exposed to air during compositing. However, as discussed in Section 3.2.1 some automated samplers can be configured to collect samples for VOC analysis with minimal losses due to volatilization).

- Some pollutants, such as oil and grease and TPH, tend to adhere to sample container surfaces so that transfer between sampling containers must be minimized (if program objectives require characterization of the average oil and grease concentration over the duration of a storm, obtain this information from a series of grabs analyzed individually).

To estimate event mean concentrations or pollutant loads, you could collect a series of grab samples at short time intervals throughout the course of a storm event. There are several different approaches for obtaining information from a series of grab samples. One approach would be to analyze each grab sample individually. If the samples are analyzed individually, the results can be used to assess the rise and fall of pollutant concentrations during a storm and to estimate event mean concentrations of pollutants. This approach can be particularly useful if the monitoring objective is to discern peak pollutant concentrations or peak loading rates for assessing short-term water quality impacts. Analyzing each grab separately adds significantly to laboratory costs; consequently, this approach is rarely used except when program objectives require detailed information about changes in constituent concentrations over the course of a storm.

Composite Samples

Another approach is to combine appropriate portions of each grab to form a single composite sample for analysis, but this is generally impractical if there are more than a few stations to monitor. Moreover, manual monitoring can be more costly than automated monitoring if your program encompasses more than a few storm events. For these reasons, many monitoring programs have found that the use of automated monitoring equipment and methods are more appropriate for compiling composite samples than manual monitoring. If detecting peak concentrations or loading rates is not essential, composite sampling can be a more cost-effective approach for estimating event mean concentrations and pollutant loads. A composite sample is a mixture of a number of individual sample "aliquots." The aliquots are collected at specific intervals of time or flow during a storm event and combined to form a single sample for laboratory analysis. Thus, the composite sample integrates the effects of many variations in stormwater quality that occur during a storm event. Composite samples are suitable for most typical stormwater quality parameters, but are unsuitable for parameters that transform rapidly (e.g., fecal coliform, residual chlorine, pH, volatile organic compounds) or adhere to container surfaces (e.g., oil and grease).

The two basic approaches for obtaining composite samples are referred to as time-proportional and flow-proportional. A time-proportional composite sample is prepared by collecting individual sample "aliquots" of equal volume at equal increments of time (e.g., every 20 minutes) during a storm event, and mixing the aliquots to form a single sample for laboratory analysis. Time-proportional samples do not account for variations in flow; pollutant concentrations in sample aliquots collected during the portion of the storm with lower flows are given the same "weight" as sample aliquots collected during higher flows. Consequently, time-proportional composite samples generally do not provide reliable estimates of event mean concentrations or pollutant loads, unless the interval between sample aliquots is very brief and flow rates are relatively constant.

Flow-weighted composite samples are more suitable for estimating event mean concentrations and pollutant loads. The event mean concentration is discussed in detail in Section 2.5.3. A flow-weighted composite sample can be collected in several ways (EPA 1992):

1. Constant Time - Volume Proportional to Flow Rate - Sample aliquots are collected at equal increments of time during a storm event, and varying amounts of each aliquot are combined to form a single composite sample. The amount of water removed from each aliquot is proportional to the flow rate at the time the aliquot was collected. This type of composite sample can be collected using either manual or automated techniques.

2. Constant Time - Volume Proportional to Flow Volume Increment - Sample aliquots are collected at equal increments of time during a storm event, and varying amounts from each aliquot are combined to form a single composite sample. The amount of water removed from each aliquot is proportional to the volume of flow since the preceding aliquot was collected. This type of compositing is generally used in conjunction with an automated monitoring system that includes a continuous flow measurement device. It can be used with manual sampling in conjunction with a continuous flow measurement device, but this combination is uncommon.

3. Constant Volume - Time Proportional to Flow Volume Increment - Sample aliquots of equal volume are taken at equal increments of flow volume (regardless of time) and combined to form a single composite sample. This type of compositing is generally used in conjunction with an automated monitoring system that includes a continuous flow measurement device.

Select the flow-weighted compositing method most suitable for your program based on the monitoring technique (manual or automated) and equipment you plan to use. Compositing Methods 2 and 3 are more accurate than Method 1 because Methods 2 and 3 use the total volume of flow based on continuous flow measurement to scale the sample volume; in contrast, Method 1 uses a single instantaneous rate measurement to estimate the flow over the entire sampling interval. However, if you intend to use manual methods, compositing Method 1 is generally the most practical choice. If automated equipment is to be used, Method 3 is generally preferred because it minimizes the need for measuring and splitting samples, activities that can increase the chance for sample contamination. If you plan to use automated methods, review the equipment manufacturer's specifications and instructions to select the compositing method most appropriate for that particular make and model.

Storm events affect stream flows for variable lengths of time depending on the storm duration and antecedent conditions and catchment characteristics. Runoff may persist for a period of a few hours to one to two days. This suggests runoff rarely persists long enough to be considered comparable to chronic exposure duration. Discrete sampling over the course of the storm event will provide concentration information that can be used to determine how long water quality criteria were exceeded during the storm. Alternatively, discrete samples can be composited on a time-weighted basis over time scales comparable to the acute and chronic water quality criteria exposure periods (one hour and four days) respectively. However, the latter would likely include dry-weather flows since few storms last four days. For catchments which are relatively small (a few acres), it is recommended one or more one-hour composite samples be collected during the first few hours of flow by collecting and combining three or more grab samples.

Flow-weighted composite sampling can be used for comparison with water quality objectives (for example, if flow-weighted composites are collected to measure loads). However, it should be recognized that a flow-weighted sample would contain more water from peak flows than from the initial part of the storm. Results from Santa Clara Valley Nonpoint Source Monitoring Program indicated that for a large watershed with significant suspended sediment concentrations (200 - 400 mg/L), peak total metals concentrations are generally 1.5 times the flow-weighted composite concentrations (WCC 1993). Results from monitoring a smaller, highly impervious industrial catchment with the lower suspended sediment concentrations were more variable, and no conclusions could be drawn as to the relationship between flow-composite concentrations and grab samples due to difficulties in grab sampling runoff that only occurred during precipitation.

Automatic Sampling

Automated monitoring involves sample collection using electronic or mechanical devices that do not require an operator to be on-site during actual stormwater sample collection. It is the preferred method for collecting flow-weighted composite samples. Automated monitoring is generally a better choice than manual monitoring at locations where workers could be exposed to inadequate oxygen, toxic or explosive gases, storm waves, and/or hazardous traffic conditions. Also, automated methods are better than manual methods if you are unable to accurately predict storm event starting times. Automated samplers can be set so that sampling operations are triggered when a pre-determined flow rate of storm runoff is detected. Conversely, manual monitoring relies on weather forecasts (and considerable judgment and good luck) to decide when to send crews to their monitoring stations. It is very difficult to predict when stormwater runoff is likely to begin; consequently, manual monitoring crews may arrive too early and spend considerable time waiting for a storm that begins later than predicted, or they may arrive too late and miss the "first flush" from a storm that began earlier than predicted. If the automated equipment is set to collect flow-weighted composite samples using the constant volume-time proportional to flow method, it reduces the need to measure samples for compositing.

If you have determined that field-measured "indicator" parameters (e.g., turbidity, conductivity, dissolved oxygen, pH) are sufficient for your monitoring objectives, consider using electronic sensors and data loggers. Using electronic sensors and data loggers, you can obtain near-continuous measurements of indicator parameters at reasonable cost.

BMP monitoring can be an especially useful application for some automated systems (e.g., continuous flow recorders, auto samplers, continuous monitoring probes) for the following reasons:

- Automated systems can provide data covering virtually the entire volume of runoff that passes through the BMP (i.e., they are not likely to miss or leave out small events and the beginnings and ends of other events).

- Automated systems are well suited to providing data sets that are useful (recognizing that performance evaluations are generally based on the differences between inlet and outlet concentration data sets, both of which are inherently noisy).

- The information obtained from good performance monitoring programs can be very valuable by protecting against inappropriate BMP applications. Therefore, the cost of using automated systems is often justifiable.

Automatic Sampling Equipment

An automated sampler is a programmable mechanical and electrical instrument capable of drawing a single grab sample, a series of grab samples, or a composited sample, in-situ. The basic components of an automated sampler are a programming unit capable of controlling sampling functions, a sample intake port and intake line, a peristaltic or vacuum/compression pump, a rotating controllable arm capable of delivering samples into sample containers and a housing capable of withstanding moisture and some degree of shock. Commonly used brands include: ISCO, Lincoln, Nebraska; American Sigma, Medina, New York; Manning, Round Rock, Texas; and Epic/Stevens, Beaverton, Oregon.

An automated sampler can be programmed to collect a sample at a specific time, at a specific time interval, or on receipt of a signal from a flow meter or other signal (e.g., depth of flow, moisture, temperature). The sampler distributes individual samples into either a single bottle or into separate bottles which can be analyzed individually or composited. Some automated samplers offer multiple bottle configurations that can be tailored to program objectives.

Important features of automated samplers include:

- Portability.

- Refrigeration.

- Volatile organic compound (VOC) sample collection (if needed).

- Alternative power supplies.

Figure 3.12: Automatic sampler (American Sigma Inc.)

Portable samplers are smaller than those designed for fixed-site use, facilitating installation in confined spaces. If a suitable confined space is not available or undesirable (e.g., because of safety issues), the sampler can be housed in a secure shelter at the sampling site. Portable samplers can use a 12V DC battery power supply, solar battery, or AC power.

Although none of the portable samplers currently available are refrigerated, ice may be added to the housing of some units to preserve collected samples at a temperature as close to 4°C as possible. The objective of this cooling is to inhibit pollutant transformation before the sample can be analyzed. Refrigerated samplers hold samples at a constant temperature of 4°C. However, their large size and requirement for a 120V AC power prohibit most field installations.

Figure 3.13: VOC sampler (ISCO)

An automated sampler designed for VOCs is currently available from ISCO. The bladder pump used by this instrument minimizes physical disturbance of the sample (as opposed to the physical disturbances imparted by peristaltic vacuum pumps), reducing the loss of volatile compounds. The VOC sampler distributes the sample into sealed 40-ml sample bottles, as required by EPA protocol. However, at present, the caps for the sample bottles are not compatible with automated laboratory equipment, requiring more handling in the laboratory.

In typical installations for BMP sampling, for each of the types of samplers described above, an intake line is bracketed to the channel bottom. The intake tubing should be mounted as unobtrusively as possible, to minimize disturbance of the site hydraulics. Generally, the optimum position for the intake is to the channel bottom. However, if high solids loadings are expected and potential deposition could occur, the intake can be mounted slightly higher on one side of the channel wall. Typically, a strainer is attached to the intake to prevent large particles and debris from entering the tubing. The strainer is usually installed so that it faces upstream, into the flow. This configuration minimizes the development of local turbulence that could affect representative sampling of constituents in the particulate phase.

Two types of pumps are incorporated into automated samplers for typical water quality sampling (i.e., not VOC sampling): peristaltic and vacuum/compressor. A peristaltic pump creates a vacuum by compressing a flexible tube with a rotating roller, drawing a sample to the pump that is then pushed out of the pump. Field experience with peristaltic pumps has shown that their reliability in drawing a consistent sample volume is greatly reduced as the static suction head (i.e., distance between the flow stream surface and the sampler) increases. It may be possible to increase the efficiency of these samplers by placing the pump closer to the sample source, reducing the suction head. In general, the sampler itself should be installed no more than 6 meters (20 feet), and preferably less, above the channel bottom. If the sampler is to be installed at greater than 20 feet above the channel invert, it may be necessary to use a remote pump that is placed closer to the flow stream to ensure reliable sample collection.

The degree to which sampler lift affects the concentration of total suspended solids and other pollutant parameters (especially coarser materials) is not well known. That is, the mean transport velocity achieved by the peristaltic pump is sufficient to draw suspended solids; however, the pulsed nature of the flow may allow suspended solids to settle back down through the pump tubing during transport. In work performed by the USGS (FHWA 2001), it was found that suspended solids concentrations did not vary with pumping height (0 to 24 feet); however, sample volumes delivered to sample bottles did vary from sample to sample at high lift heights for some of the older sampler models.

Another concern with peristaltic pumps is their incompatibility with Teflon™-lined tubing in the pump assembly. Compression of the intake tubing by the rollers tends to create stress cracks and small recesses in the lining where particles can accumulate. Under these circumstances, some pollutant concentrations could be underestimated and the cross-contamination of samples can occur. Although Teflon™-lined tubing is preferable because it reduces the potential loss of pollutants through surface interactions, this advantage cannot be accommodated with a peristaltic pump.

A vacuum/compressor pump draws a sample by creating a vacuum. This type of pump can create a higher transport velocity in the intake tube and provide a more steady and uniform discharge than a peristaltic pump. However, the higher intake velocity can scour sediments in the channel near the sampler intake, resulting in disproportionately high concentrations of suspended solids.

After a sampler is installed, it must be programmed to collect the desired sample size. Calibration of peristaltic pumps is achieved by one of two methods: automatic or timed. In automatic calibration, the actual volume of sample drawn is measured using a fluid sensor located at the pump and the known pump speed. In timed calibration, the volume is determined from the number of revolutions of the peristaltic pump and the time taken for the sample to travel from its source to the sample container. Calibration by this latter method is site specific, incorporating the pump speed, the head (vertical distance above the sample source), and the length and diameter of the intake tubing. The Manning and Epic samplers, which employ vacuum pumps, permit adjustment for specific sample volumes via a fluid level device in a chamber. This chamber can cause sample cross-contamination, as it cannot be flushed as the tubing can.

Overland Flow Sampler

An overland flow sampler is a non-automated sampler that can be used to take discrete grab samples or a continuous sample over some duration. This type of sampler may be useful for collecting stormwater samples for certain types of BMPs (upstream of catch basins). One manufacturer's (Vortox, Claremont, California) unit within this class of samplers consists of an upper ball valve, a lower ball valve (through which runoff enters), and a sample container. The upper valve can be adjusted to control the rate of intake, allowing continuous sampling of storm events of different durations, provided depth of flow is not highly variable. The lower ball valve seals and closes the intake when the water level reaches the top of the container.

Overland flow samplers (manufactured by Vortex) are available in two sizes: 3 liters (0.8 gallon) and 21 liters (5.5 gallons). They can be set into existing sumps or in the ground, but they must be installed with the top of the sampler flush with the ground surface.

This instrument is inexpensive and simple to operate. Since the overland flow is not concentrated, there are no other methods for collecting this flow. However, this sampler is not capable of taking flow or time-weighted composites or of sampling the entire flow during a large storm event. In fact, there is no way of knowing what part of the storm was actually sampled, especially where flow depths are variable. Recently, the USGS developed and began testing an automated overland flow sampler that may be capable of time-weighted composite sampling.

In-situ Water Quality Devices, Existing Technology

The concentration of most pollutants in stormwater runoff is likely to vary significantly over the course of a given storm event. Some of this variability can be captured through the collection of multiple samples. The ideal data set would contain not just multiple samples, but also a continuous record of constituent concentrations throughout a storm, capturing both the timing and magnitude of the variations in concentration. Given the availability of other continuous data, this approach might allow better correlation with potential causative factors. Unfortunately, the laboratory costs for even a near-continuous data set would be prohibitive. USGS determined that between 12 and 16 individual samples resulted in a mean that was within 10 to 20 percent of the actual event mean concentration (FHWA 2001). In-situ monitoring devices offer a possible solution to obtaining a continuous record of water quality; however, at this time, they are only practical for a limited set of parameters.

In-situ water quality probes have been adapted from equipment developed for the manufacturing and water supply/wastewater industries. In-situ water quality monitors attempt to provide the desirable near-continuous data set described above at a relatively low cost, eliminating (or reducing) the need for analysis of samples in the laboratory.

In general, water quality monitors are electronic devices that measure the magnitude or concentration of certain specific target constituents through various types of sensors. Discrete measurements can be made at one minute or less intervals. Most monitors use probes that provide a controlled environment in which a physical and/or electrochemical reaction can take place. The rate of this reaction is typically driven by the concentration of the target constituent in the flow. The rate of reaction, in turn, controls the magnitude of the electrical signal sent to the display or a data-logging device.

Probes to detect and measure the following physical and chemical parameters are currently available for practical use in the field:

Physical parameters
Temperature
Turbidity

Chemical parameters
pH
Oxidation-reduction potential (redox)
Conductivity
Dissolved oxygen
Salinity
Nitrate
Ammonia
Resistivity
Specific conductance
Ammonium

There are some potential probes for heavy metals, but given the complexities associated with highly variable solids concentrations and other factors, studies have found that they are not practical for field application (FHWA 2001). Instruments can be configured to measure the concentrations of several of these parameters simultaneously (i.e., multi-parameter probes) and provide data logging and PC compatibility. Manufacturers of this type of instrument include YSI, Inc., Yellow Springs, Ohio; ELE International, England; Hydrolab, Austin, Texas; Solomat, Norwalk, Connecticut; and Stevens, Beaverton, Oregon.

In many cases, the electrochemical reaction that drives a probe's response is sensitive to changes in temperature, pH, or atmospheric pressure. Where appropriate, monitors are designed to simultaneously measure these associated properties. Data on the target constituent are then corrected through a mathematical routine built into the probe's microprocessor (e.g., dissolved oxygen probes are compensated for temperature and atmospheric pressure, pH probes for temperature and ammonia probes for pH), or are adjusted in a spreadsheet after downloading to a personal computer.

Despite the advantage of these instruments for measuring near-continuous data, they require frequent inspection and maintenance in the field to prevent loss of accuracy due to fouling by oil and grease, adhesive organics, and bacterial and algal films. Therefore, these instruments should always be cleaned and calibrated before use. Because water quality probes are designed to operate while submerged in water, exposure of the electrochemically active probe surface to air should be minimized.

In-situ Water Quality Devices, Future Technologies

There are several in-situ water quality devices that are used by industry but are not currently applicable to stormwater monitoring. However, as the technology advances they may become applicable and therefore are discussed in this section.

Ion-Selective Electrodes

An ion-selective electrode places a selectively permeable membrane between the flow and an internal solution of known ionic strength. The voltage differential across the membrane is proportional to the difference in ionic strength between the two solutions. Ion-selective probes are currently available for the ionic forms of a number of parameters, including ammonia, ammonium, copper, lead, nitrate, and nitrite.

An ion-selective electrode is specific to the targeted ion and will not measure other ions or other complexed forms. For example, depending on the target parameter, a nitrate-selective electrode will not measure the concentration of nitrite in the flow. However, these instruments are sensitive to interference from other ions, volatile amines, acetates, surfactants, and various weak acids. At present, the degree of interference can be judged only by comparing the performance of the probe to that of one in a reference solution, a procedure likely to prove unwieldy in the field. Consequently this type of probe is not typically used for stormwater monitoring.

On-Line Water Quality Analyzers

On-line water quality analyzers are spectrometers, similar to those used in analytical laboratories. A light source that generates a known intensity of light over a range of wavelengths (i.e., ultraviolet or infrared) is transmitted through a sample introduced into a flow cell. The instrument collects light absorbency information at multiple wavelengths and produces a light absorbency signature (manufacturer's specifications, Biotronics Technologies, Inc., Waukesha, Wisconsin, and Tytronics, Inc., Waltham, Massachusetts). The instrument is calibrated using 30 or more randomly varied mixtures of standards; the ultraviolet (UV) light-absorbency characteristics of a sample are then compared to a baseline calibration file of known "UV signatures."

On-line analyses are used in the water treatment and wastewater industries. Until recently, on-line spectrometric analyzers were impractical for stormwater field use. The state of technology of these systems was comparable to that in the field of computers 20 years ago: large machines requiring a controlled laboratory environment were operated by highly trained specialists. However, an increased demand for portability, the increased power and decreased cost of microprocessor technology, the development of new statistical and mathematical analysis software, and the availability of standardized control systems (i.e., communication interfaces, actuators, and programmable controllers) have fostered the emergence of a new generation of instruments.

Three types of spectrometers are currently available or under development for environmental applications:

- Ultraviolet-Array Spectroscopy (UVAS) employs a broad spectrum light generated by a Xenon lamp and delivered to the sample through fiber optic cables. Light is transmitted through the sample in specially designed optical probes. The light transmitted through the sample is collected and returned to the analyzer where it is dispersed into wavelengths and projected onto a photodiode detector array. Current applications are the detection of multiple contaminants (metals, nitrates, organics, and aromatic hydrocarbons) in groundwater, the detection of metals (chromium, zinc, and mercury) in industrial wastewater, and water treatment quality parameters (copper, iron, molybdate, triazole, phosphorate) in industrial processes and cooling waters.

- Liquid Atomic Emission Spectrometry (LAES) employs a photodiode detector array similar to that used in UVAS. A high-energy arc is discharged directly into the liquid as the source of excitation and the resulting atomic light emission is analyzed by special pattern recognition techniques. Qualitative analysis is derived from the detection of emission lines and quantitative analysis is a function of intensity. Use of LAES has been demonstrated for the analysis of metals, hydrogen, and sulfur.

- Like UVAS, Near Infrared (NIR) analysis employs the transmission of light through a liquid. This technology has been used extensively in the food processing industry and is under evaluation for application elsewhere.

To date, portable on-line analyzers have not been tested extensively for use in stormwater or BMP monitoring. The "ChemScan" analyzer, manufactured by Biotronics Technologies, Inc., is reported to adjust automatically for changes in the turbidity of the flow and fouling of the optical windows, features which suggest applicability to stormwater situations. According to the manufacturer, routine maintenance is limited to a periodic baseline correction and occasional chemical cleaning of the flow cell.

Particle Size Analyzers

There is a particle size analyzer available that can be installed in-situ. It employs laser diffraction to determine the particle size distribution. However, the unit costs approximately $30,000, is 3 feet long and 5 inches in diameter, and is required to be submerged. Currently it is not applicable for stormwater monitoring.

Research is currently being conducted on applying ultrasonics for particle size analysis. However, it is presently not available for stormwater application.

In-situ Filtration and Extraction System

Axys Environmental Systems, Ltd., British Columbia, Canada manufactures an in-situ filtration and extraction system for monitoring trace organics, metals, and radionuclides in stormwater. These systems retain the target pollutant on a resin filter as a portion of the flow passes through. After the storm event, the filter is taken to the laboratory and the pollutant is removed through solid phase extraction. The filtration system is comprised of a microprocessor, a pump, a flow meter, and a DC power supply. A prefilter for suspended solids can be attached if levels high enough to clog the resin filter are anticipated. Pollutants trapped in the prefilter can also be extracted and analyzed.

These systems can be programmed so that samples of the flow pass through the filter at equal time intervals, or so that signals from an external flow meter trigger flow- or time-weighted composite sampling. As with other types of automated samplers, the sampling history is stored in internal memory.

Filtration and extraction systems reduce the potential for contamination of a sample during handling in the field and eliminate the need to transport large volumes of water to an analytical laboratory. The detection limit of the samples depends on the amount of water flowing through. Because large volumes of water can be passed through the system, even very small concentrations of pollutants can be detected. On the other hand, where suspended sediment concentrations are high, the prefilter may become clogged as a large volume of water passes through it. Metals can be lost from the filter if the pH drops to 6.0 or lower, and resin filters are available for only a limited number of pollutants. Due to the potential for clogging, this methodology may not be useful for BMP monitoring sites.

Remote Communications with Automatic Equipment

The ability to remotely access the memory and programming functions of automated samplers is a highly desirable feature for large stormwater sampling networks. Although this feature increases the capital cost for a system, it can greatly reduce the expertise and training necessary for field crews because many of the technical aspects of equipment set-up and shut-down can be conducted by a system supervisor remotely.

Currently, modem communication is an available option to most commercially produced automated samplers. However, there are several common drawbacks that may be encountered with the communication systems currently offered by manufacturers:

- Full access to all sampler programming features is limited. This means that trained field crews may still be necessary to ensure sampler programming is correct.

- For multiple instrument systems (i.e., separate flow meter and automated sampler) communication and complete operation of both components through one modem system is generally not available.

Remote communication for both samplers and flow meters is a rapidly advancing technology, and companies like American Sigma and ISCO are developing systems that address the problems described above.

Manual Sampling

Manual monitoring involves sample collection and flow measurement by personnel using hand-operated equipment (e.g., bailer, bottle). For a monitoring program that is modest in scope (i.e., relatively few sampling sites and storm events), manual methods for obtaining grab and composite samples may be preferable to those employing automated equipment. Also, if your program requires monitoring large streams, you may need to use manual methods in order to collect cross-section composites. The principal advantages to manual sampling are its relatively low capital cost and high degree of flexibility. In addition to the capital outlay required for the purchase of automated samplers, other costs, such as installation, training personnel to use the samplers correctly, and field maintenance and operations (replacing batteries, interrogating data loggers, retrieving and cleaning sample jars) can be substantial.

Manual sampling is usually preferred under the following circumstances:

- When available resources for equipment purchase/installation (e.g., funds, personnel, time) are very constrained and/or there is not the political will to invest in a program, despite the inherent value of the resultant information.

- When the target pollutants are ones that do not lend themselves to automated sampling or analysis (e.g., oil and grease, volatile organic compounds, bacteria).

- When the physical setting of the BMP does not allow the use of automated systems.

However, manual monitoring may not be feasible if:

- Monitoring personnel are not available after normal working hours.

- Monitoring personnel have strict job descriptions that do not include sampling.

- The organization's insurance policy doesn't cover stormwater monitoring activities.

- Managers and monitoring personnel are not able to deal with sick days, vacations, and competing priorities.

Manual sampling is generally less practical than automated monitoring for large-scale programs (e.g., monitoring programs involving large numbers of sites or sampling events over multiple years). It is difficult to collect true flow-weighted composites using manual methods. Under these circumstances, labor costs and logistical problems can far outstrip those associated with automated equipment. For the same reason, manual sampling is seldom practiced if specific program objectives require that samples be composited over the entire duration of a storm, which is recommended for BMP monitoring.

Manual equipment can be used in collecting grab samples, composite samples, or both, as described below.

Manual Grab Sampling Equipment

Manual sampling techniques and equipment have been reviewed in more detail by Stenstrom and Strecker (1993). If site conditions allow, a grab sample can be collected by holding the laboratory sample bottle directly under the lip of an outfall or by submerging the bottle in the flow. A pole or rope may be used as an extension device if field personnel cannot safely or conveniently approach the sampling point. Alternatively, a clean, high-density polyethylene bucket may be used as a bailer and sample bottles may be filled from the bucket. Care should be taken not to stir sediments at the bottom of the channel.

As described earlier, the concentrations of suspended constituents tend to stratify within the flow stream depending on their specific gravity and the degree to which flow is mixed by turbulence. Use of a discrete-depth sampler for multiple samples should be considered when constituents lighter or heavier than water are targeted, or if the flow is too deep and/or not well mixed enough to be sampled in its entirety (Martin et al. 1992). However, stormwater BMPs often drain relatively small catchments and contain fairly shallow flows. Collection of depth-integrated samples at these sites is not usually performed.

Given the extremely low detection limits that laboratory analytical instruments can achieve, leaching of water quality constituents from the surface of a bailing device or sample bottle can affect water quality results. Sample bottles of the appropriate composition for each parameter are usually available from the analytical laboratory. Depending upon the pollutant to be analyzed, bailers and discrete-depth samplers should be made of stainless steel, Teflon™ coated plastic, or high-density polyethylene. When in doubt, a laboratory analyst should recommend an appropriate material type for the collection device.

Manual Composite Sampling Equipment

If grab samples will be composited based on flow rate (i.e., grab samples collected during high flow contribute more to the composited sample than those collected during low flow), some receptacle for storing the individual grab samples prior to compositing will be required. The use of polyethylene jugs, or the polyethylene cubes with screw-on caps manufactured for shipping chemicals, is recommended. These can be shaken to remix the sample prior to pouring out the required volume. The volume required from each receptacle can be measured in a graduated cylinder and poured into a bucket for compositing. Both the cylinder and the bucket should be made from a Teflon™-coated plastic or high-density polyethylene and should be cleaned prior to use.

3.2.4.3 Error Analysis and Measurement Accuracy

Every measurement has an unavoidable uncertainty due to the precision of the measuring tool, the accuracy of the calibration, and the care with which the measurement is made. If all other sources of error are minimized or removed, then the uncertainty in the measurement is generally on the same order of the smallest numerical value that can be estimated with the measuring instrument. The true value is typically contained in the range of values reflecting the experimental uncertainty of the measurement. Calculating the mean of multiple measurements if the measurement errors are random in nature and not systematic can provide a better estimate of the true value.

Indeterminate (random) errors result from instrument precision, calibration, and inaccuracies in the measuring process. The size and magnitude of indeterminate errors cannot be determined (hence the name) and result in different values from a measuring process when the process is repeated. There are several ways indeterminate errors can be introduced, including operator error, variation in the conditions in which the measuring process is conducted, and the variability of the measuring instrument.

Determinate (systematic) errors have an algebraic sign and magnitude and result from a specific cause introducing the same error into every measurement. Determinate errors are more serious than indeterminate errors because taking the average of multiple measurements cannot reduce their effects. This is because determinate errors have the same sign and magnitude, which prevents positive and negative errors from off setting each other. Causes of this type of error can include operator bias, (consistent) operator error such as incorrect reading of the instrument, or improper calibration of the measuring instrument.

Expressing Errors

Absolute and relative methods are the standard forms for expressing errors. Absolute error is expressed as a range of values reflecting the uncertainty in the measurement and is reported in the same units as the measurement. Measured values followed by the ± sign express the absolute error.

Relative (or fractional) error is expressed as the ratio of the uncertainty in the measurement to the measurement itself. This is difficult to estimate, because it is a function of the true value of the quantity being measured, which is unknown, otherwise the error estimate would be zero. Typically this error estimate utilizes the measured value as the “true” value.

The type of measurement and instrumentation can provide an indication of the appropriate form of expressing the error. For example, a pressure probe used to measure depth of flow is likely to have the accuracy of the instrument expressed as a relative percent, while readings on a staff gauge would have an absolute error related to the markings on the gauge. In these instances the reported depth measurements would be expressed in the same manner as the precision of the measuring instrument.

Propagation of Errors

Quite often, measurements taken of one or more variables are used in equations to calculate the value of other variables. For example, to calculate the area of a rectangle, the length and width are usually measured. For a cube, the length, width, and height are measured to calculate the volume. Each measurement has a potential error associated with it and, as a result, the variable calculated from the individual measurements will also contain some error. The magnitude of the error in the calculated variable can be of a different order than the error associated with any one of the measurements depending on the algorithm that describes their relationship.

A detailed discussion of the propagation of errors and methods for calculating estimates of errors as a result of propagation are provided in Appendix A.

3.2.5 Recommendation and Discussion of Storm Criteria

The establishment and application of appropriate storm selection criteria can be a challenging aspect of planning BMP monitoring programs. Ideally, one would want to obtain data from all phases of all storms for as long a study period as possible, for the following reasons:

- To know what the BMP does during periods of very low flow, normal flow, and very high flows. Some BMPs' performance varies dramatically with throughput rate (some may even release pollutants that had been previously trapped).

- To estimate performance on the basis of differences of relatively noisy data sets (i.e., inlet versus outlet data). This intensifies the value of large volumes of credible data (not just a few samples from portions of a few storms).

- To characterize the water quality of dry weather flows for some BMPs with significant wet storage and/or base flows. This is particularly important when the wet volume of the BMP is large relative to the storm event. The comparison of inflow to outflow during a storm event is not valid because the outflow may have little or no relationship to the incoming storm. This mistake has been made often in past studies.

Despite the desire for extensive and high quality data, there is still a need to tailor your methods to be consistent with available resources. The types of storms to be monitored and optimal temporal distribution of monitoring events also should be considered during project planning (Caltrans 1997).

3.2.5.1 Storm Characteristics

The application requirements for NPDES permits that require monitoring specify that "representative" storms must be monitored. As defined in the regulations, a "representative" storm must yield at least 0.1 inch of precipitation; must be preceded by at least 72 hours with less than 0.1 inch of precipitation; and, if possible, the total precipitation and duration should be within 50 percent of the average or median storm event for the area. Programs that are not part of the NPDES permit application process or in fulfillment of an NPDES permit may have other requirements.

In general, it is desirable to monitor a broad range of storm conditions rather than just “representative” storms as they are really not representative in many cases. For example, in the Pacific Northwest, it is often difficult (and rare) to identify storms where there has been a 72-hour dry period prior to the storm.

Because the initial objective of the monitoring is to consider a "worst-case" picture, it is desirable to select storms with the highest pollutant concentrations rather than a representative mix of storms. Worst-case conditions are likely to occur after long antecedent dry periods (72 hours to 14 days). Therefore, if feasible, storms should be selected with antecedent periods greater than 72 hours. Few relationships between storm volume and water quality have been observed. Lacking any basis for storm volume selection for worst-case conditions, and acknowledging that storm characteristics are highly dependent on climatic region, the following may be used as a starting point:

Rainfall Volume:	0.10 inch minimum No fixed maximum
Rainfall Duration:	No fixed maximum or minimum
Typical Range:	6 to 24 hours

Antecedent Dry Period: 24 hours minimum

Inter-event Dry Period: 6 hours

If these criteria prove inappropriate for your situation, you can develop site-specific storm event criteria by analyzing long-term rainfall records using EPA’s SYNOP or another appropriate analytical program such as EPA’s SWMM model (which incorporates the features of SYNOP).

It should be noted that biasing the storm selection to the "worst case" would not provide a representative sample of the population of all types of storm events. The resulting data should be used in screening mode and not to estimate statistically derived exceedance frequencies. The level of effort required to sample all representative types and combinations of storm conditions in order to generate reliable population statistics is beyond the resources of most agencies. For this reason, it is recommended a "worst case" approach be taken. Often permits require that you monitor "representative" storms that have been predefined. Operationally and practically, storm event criteria may need to be further defined beyond the regulatory definition. The use of a probability of rainfall above a certain magnitude, during a specific period, based on a quantitative precipitation forecast (QPF) serves as a good indication of when and how to mobilize for monitoring efforts. QPFs for a geographic area can be obtained from the National Weather Service and site specific information can be obtained from private weather consultants.

3.2.6 Recommendation and Discussion of QA/QC

Prior to sample collection, you should prepare a Quality Assurance/Quality Control (QA/QC) plan that describes the sample collection and laboratory analysis procedures. The first step in preparing a QA/QC plan is to determine the data quality objectives (DQOs) appropriate to your program. Ideally, the QA/QC plan should be prepared by someone with a good understanding of chemical analytical methods, field sampling procedures, and data validation procedures. Select an analytical laboratory that has been accredited to perform the analyses required for your program. The analytical laboratory should provide its input to ensure the plan is realistic and consistent with the laboratory's operating procedures.

It is recommended that the QA/QC plan should summarize the project organization, data quality objectives, required parameters, field methods, and laboratory performance standards for the measurements. A typical QA/QC plan for stormwater monitoring may include the following sections:

1. Project Description

2. Project Organization and Responsibility

3. Data Quality Objectives

4. Field Methods
   - sample collection methods
   - field QA procedures such as equipment cleaning and blanks
   - collection of field duplicate samples
   - sample preservation methods
   - type of bottles for subsampling

5. Laboratory Procedures
   - constituents for analysis
   - laboratory performance standards (e.g., detection limits, practical quantitation limits, objectives for precision, accuracy, completeness)
   - analysis method references
   - frequency and type of laboratory QA samples (e.g., laboratory duplicates, matrix spikes and spike duplicates, laboratory control samples, standard reference materials)
   - data reporting requirements
   - data validation procedures
   - corrective actions

It is important that you develop your QA/QC plan in concert with your field personnel and your analytical laboratory. If you have not already done so, you should visit the monitoring locations to verify that the selected monitoring methods are feasible. Inform your managers of any modifications to either the DQOs or laboratory performance standards due to field or laboratory constraints.

Potential Sources of Error

This section describes some potential sources of error that can occur in the process of sampling or transferring monitoring results to a database. These common errors can be specifically addressed in the QA/QC plan to increase awareness and potentially reduce their occurrence.

In many cases error is introduced in the process of transferring or interpreting information from the original data records. These errors most likely result from typographical errors or format and organizational problems. In most cases, water quality data are returned from the lab in some tabular format. Data are then entered into a database, typically with separate records for each monitoring station and each storm event. The inconsistency of data formats between monitoring events can considerably increase the potential for errors in entering data into the database and subsequently interpreting and using the processed (digital) data.

Where errors in data are present in the processed information, format is often a causative factor. In some circumstances interpretation of the data presented is not possible due to missing explanations of the data format; in these cases, data should be excluded. It has been found that missing records typically have to do with inadvertent skipping of a column or row of data. Errors in data or parameter type, that were not typographical, typically resulted from misalignment of rows or columns. Supporting information and useful summaries of parameters, such as characteristics of the watershed, are often included as text in a general information column, or in a report or record external to the water quality database. In addition to making the extraction of this supporting information laborious, checking for errors in information not formatted succinctly can also be quite cumbersome.

In addition to these "paper" errors, many other opportunities abound for introduction of other errors, including errors in interpretation and reporting of supporting information (e.g., misreading of maps, poor estimates of design, watershed, and environmental parameters, etc.) and reporting of information from previous studies that may have been originally incorrect.

In addition to potential reporting errors, all field collected and/or laboratory analyzed data on flow and water quality are subject to random variations that cannot be completely eliminated. These variations are defined as either "chance variations" or "assignable variations." Chance variations are due to the random nature of the parameters measured; increased testing efforts and accuracies cannot eliminate these variations. Although assignable variations cannot be eliminated altogether, these variations can be reduced and the reliability of the data increased. Assignable variations are those errors that result from measurement error, faulty machine settings, dirty containers, etc. Increasing both the length of a study and/or the number of storms sampled can reduce the assignable variations and increase the reliability of the data (Strecker 1992). Many monitoring studies take place over relatively short periods and have a small number of monitored storms during those periods. Thus the resultant data sets are often susceptible to both of these types of variations in addition to any reporting errors.

Prepare Health and Safety Plan

As part of the QA/QC plan, the health and safety of personnel involved in the monitoring program should be considered. Aside from ensuring quality results and efficient implementation of monitoring procedures, human health and safety are a priority.

The health and safety of field personnel should be considered throughout development of your monitoring program. You should select monitoring locations and methods that have the lowest potential for health and safety problems. You should then prepare a health and safety plan. The first step is an assessment of the physical and chemical hazards likely to be associated with each monitoring activity. Some of the potential considerations include:

- Wet (and possibly cold) weather conditions.
- Physical obstructions that complicate access to the site and sample collection point (e.g., steep slopes, dense blackberry bushes).
- Traffic hazards.
- Manholes (i.e., confined space entry, including toxic, explosive, or otherwise unsafe conditions).
- Flooding and fast moving water.
- Dim lighting.
- Slippery conditions.
- Contact with water that could be harmful (e.g., caustic, pathogenic).
- Lifting and carrying heavy and bulky pieces of equipment, including carboys and sample bottles filled with water.

Based on the hazard assessment, identify the appropriate equipment and procedures to protect field personnel from the potential hazards you have identified. Also, consider adjusting your monitoring locations and/or methods if necessary to minimize the risk of health and safety problems.

3.2.6.1 Sampling Methods

Proper sampling methods are essential in conducting a BMP monitoring program in order to ensure resulting data are meaningful and representative of the water and other media being processed by the BMP. Sampling methodologies and techniques that maintain and confirm the integrity of the sample are discussed below.

Grab Sample Collection Techniques

During moderate flow events, grab samples can be collected at some stations simply by approaching the water to be sampled and directly filling up the bottles, being careful not to loose any preservative already contained in the bottle. It is important also to be aware of surface conditions of the sampled water body, avoiding layers of algae and debris and areas of dense vegetation if possible. The bottle cap should be handled carefully, making sure not to introduce any extraneous dirt, water, debris or vegetation while filling the bottle; bottle caps should not be placed on the ground facing downward.

Low flow events may not provide sufficient flows to allow filling of bottles directly. In this case, sample collectors may be used to collect the low flow runoff and transfer the water into the sample bottles. These sample collectors are typically cup to bucket sized containers with a wide mouth and no neck, allowing the collector to be placed close to the bottom surface of the flow path and then filled with the small depth of flow. Sample collectors must be compatible in material with the sample bottles and the constituents to be analyzed. Sample collectors made of stainless steel, teflon or glass could be considered after investigating the compatibility of these materials with each constituent to be analyzed. After each sample bottle has been filled, and before the next monitoring site is to be sampled, the sample collector should be rinsed thoroughly with deionized water to prevent cross-contamination between sites. At least four rinses with deionized water are necessary, followed by filling the sample collector several times with new monitoring site runoff before finally using the collector to fill the sample bottles.

During high flow events, runoff may be unsafe to approach directly to collect the sample. Modified sample collectors can be designed to allow remote sampling. Many stainless steel buckets or cookware (asparagus cookers) have handles to which ropes may be tied at a length that allows the sample collector to be lowered into the runoff and raised back up after filling with water. These sample collectors with rope are ideal to use if sampling a creek from a bridge or sampling an outfall from a creek bank. In addition, modified sample collectors will work well to sample runoff in a manhole, eliminating the need to enter the confined space during higher flows. The advantage of the rope and bucket device is that a significant length of rope can be attached to the sample bucket to allow for sampling from great heights, yet the rope can be coiled and stored compactly. If a sturdier sampling device is needed, sample collectors may be attached to a pole using tape or rope and lowered into the runoff. Again, cross-contamination between sample sites should be prevented by rinsing the sampling collector with deionized water and new sample water several times.

Contamination/Blanks

Control over sample contamination is critical when attempting to measure concentrations of compounds at the parts-per-billion level. Contamination can be introduced either during the bottle/equipment preparation steps or during the sample collection, transport, or analysis steps. Control over all of these steps can be achieved through the use of standardized equipment cleaning procedures, clean sampling procedures, and clean laboratory reagents. The level of contamination introduced during each of these steps is determined by analysis of different types of blank samples. Each of these different types of blanks is described below:

- Method Blanks are prepared by the laboratory by analysis of clean Type II reagent water. They are used to determine the level of contamination introduced by the reagents and laboratory processing.

- Source Solution Blanks are determined by analysis of the deionized or Type II reagent water used to prepare the other blanks. The source solution blank is used to account for contamination introduced by the deionized water when evaluating the other blanks.

- Bottle Blanks are prepared by filling a clean bottle with source solution water and measuring the solution concentration. Bottle blanks include contamination introduced by the source solution water and sample containers. By subtracting the source solution blank result, the amount of contamination introduced by the sample containers can be determined.

- Travel Blanks are prepared by filling a sample container in the laboratory with Type II reagent water and shipping the filled water along with the empty sample containers to the site. The travel blank is shipped back with the samples and analyzed like a sample. The bottle blank result can be subtracted from the travel blank to account for contamination introduced during transport from the laboratory to the field and back to the laboratory.

- Equipment Blanks are usually prepared in the laboratory after cleaning the sampling equipment. These blanks can be used to account for sample contamination introduced by the sampling equipment, if the bottle blank results are first subtracted.

- Field Blanks account for all of the above sources of contamination. Field blanks are prepared in the field after cleaning the equipment by sampling Type II reagent water with the equipment. They include sources of contamination introduced by reagent water, sampling equipment, containers, handling, preservation, and analysis. In general, field blanks should be performed prior to or during the sample collection. Because the field blank is an overall measure of all sources of contamination, it is used to determine if there are any blank problems. If problems are encountered with the field blank, then the other components of the sampling process should be evaluated by preparation of other blanks in order to identify and eliminate the specific problem.

EPA's recent guidance on the use of clean and ultra-clean sampling procedures for the collection of low-level metals samples (EPA 1993a,b) should be considered to ensure bottles and equipment are cleaned properly and samples are collected with as little contamination as possible. While ultra-clean techniques throughout are likely not necessary for stormwater runoff samples, some of the laboratory procedures should be employed. For example, metals levels in highway runoff are typically much greater than introduced errors associated with in-field clean sampling techniques. These techniques are typically employed in receiving waters where their applicability is more relevant.

Reconnaissance and Preparations

Reconnaissance and preparation is an important component of any field sampling program. Proper reconnaissance will help field operations to go smoothly and ensure field personnel are familiar with the sampling locations.

Site Visits

During the planning stage, a site visit should be performed by the field personnel, prior to conducting sampling. The purpose of the site visit is to locate access points where a sample can be taken and confirm that the sampling strategy is appropriate. Because of the transient nature of meteorological events, it is possible sites may need to be sampled in the dark. For this reason, the actual persons involved in the field sampling should visit the site during reconnaissance as a complement to a training program for the monitoring effort.

The training program should include:

- A discussion of what the programs goals are and why their efforts are important.
- Familiarization with the site.
- Training on the use and operation of the equipment.
- Familiarization with field mobilization, sampling, and demobilization procedures.
- Health and safety requirements.
- QA/QC procedures.

Laboratory Coordination

Coordination with the laboratory is a critical step in the planning and sampling process. The laboratory should be made aware of specific project requirements such as number of samples, required laboratory performance objectives, approximate date and time of sampling (if known), required QA/QC samples, reporting requirements, and if and when containers or ice chests will be required. Laboratory personnel should be involved early in the process so they can provide feedback on methods and performance standards during the planning phase. Notifying the laboratory that stormwater sampling is planned is also important to allow the laboratory to plan for off-hours sample delivery and to set-up any analysis with short holding times.

Sample Containers/Preservation/ Holding Times

EPA recommends that samples be collected and stored in specific types of sample container materials (e.g., plastic, glass, Teflon). For analysis of certain parameters, addition of specific chemical preservatives is recommended to prolong the stability of the constituents during storage. Federal Register 40 CFR 136.3 lists recommended sample containers, preservatives, and maximum recommended holding times for constituents. Sample holding times should be compared to recommended maximum holding times listed in the Federal Register. Laboratory quality control sample data should be compared to target detection limits as well as precision and accuracy goals and qualified according to EPA functional guidelines for data validation (EPA 1988).

If composite sampling procedures are to be used to collect one large sample that will be subsampled into smaller containers, the composite sample bottle should be compatible with all of the constituents to be subsampled. In general, the use of glass containers will allow subsampling for most parameters (with the exception of fluoride).

Sample volumes necessary for the requested analysis should be confirmed with the laboratory prior to sample collection. Extra sample volume should be collected for field and laboratory QA/QC samples. As a general guide, if one station is to be used for both field and laboratory QA/QC measurements, four times the normal volume of water should be collected.

Recommended Field QA/QC Procedures

Listed below are the recommended quality control samples and field procedures.

Field Blanks

Field blanks should be prepared at least once by each field sampling team to prevent or reduce contamination introduced by the sampling process. It is recommended that field blanks be routinely prepared and analyzed with each sampling event. In addition, it is desirable to prepare field blanks prior to the actual sampling event as a check on procedures. This will ensure field-contaminated samples are not analyzed. Additional field blanks should be prepared if sampling personnel, equipment, or procedures change.

Field Duplicate Samples

Field duplicate samples should be collected at a frequency of 5% or a minimum of one per event, whichever is greater. Field duplicate samples are used to provide a measure of the representativeness of the sampling and analysis procedures. These types of duplicates are recommended, but often not done due to expense.

Field Sample Volumes

Sufficient sample volumes need to be collected to enable the required laboratory QA/QC analysis to be conducted. In general, one station should be targeted for extra sample volume collection and identified on the chain-of-custody as the laboratory QA/QC station. If possible, this station should be the one where the data quality is most critical.

Chain of Custody

All sample custody and transfer procedures should be based on EPA-recommended procedures. These procedures emphasize careful documentation of sample collection, labeling, and transfer procedures. Pre-formatted chain-of-custody forms should be used to document the transfer of samples to the laboratory and the analysis to be conducted on each bottle.

Recommended Laboratory QA/QC Procedures

Method Blanks

For each batch of samples, method blanks should be run by the laboratory to determine the level of contamination associated with laboratory reagents and glassware. Results of the method blank analysis should be reported with the sample results.

Laboratory Duplicates

For each batch of samples, one site should be used as a laboratory duplicate. For the laboratory duplicate analysis, one sample will be split into two portions and analyzed twice. The purpose of the laboratory duplicate analysis is to assess the reproducibility of the analysis methods. Results of the laboratory duplicate analysis should be reported with the sample results.

Matrix Spike and Spike Duplicates

Matrix spike and spike duplicates should be used to determine the accuracy and precision of the analysis methods in the sample matrix. Matrix spike and spike duplicate samples are prepared by adding a known amount of target compound to the sample. The spiked sample is analyzed to determine the percent recovery of the target compound in the sample matrix. Results of the spike and spike duplicate percent recovery are compared to determine the precision of the analysis. Results of the matrix spike and spike duplicate samples should be reported with the sample results.

External Reference Standards

External reference standards are artificial standards prepared by an external agency. The concentrations of analytes in the standards are certified within a given range of concentrations. These are used as an external check on laboratory accuracy. One external reference standard appropriate to the sample matrix should be analyzed and reported at least quarterly by the laboratory. If possible, one reference standard should be analyzed with each batch of samples.

3.2.7 Recommendations for Data Management

A monitoring program may generate a considerable amount of information in a wide variety of forms. Before you begin monitoring, you should establish procedures for managing the data you expect to generate and for presenting the results.

Data management is an important component of your overall stormwater quality program. You need to be able to store, retrieve, and transfer the diverse hard copy and electronic information generated by your monitoring program. Before you begin monitoring, you should establish:

- A central file to accommodate the hard copy information your program is expected to generate and practical dating and filing procedures to help ensure that superseded information is not confused with current information.

- A database to accommodate digital information such as results of laboratory analyses, information recorded by data loggers (e.g., flow, precipitation, in-situ water quality measurements), maps in CAD or GIS, spreadsheets, etc. It is recommended that data be stored and reported according to the protocols described in Section 4 of this Manual.

In many cases, the laboratory can provide the analytical results in an electronic format (i.e., an "Electronic Data Deliverable" or EDD) that you can input directly to your database. This can save time and reduce the potential for data entry errors. You should work with the analytical laboratory to determine if electronic data transfer makes sense for your program.

If you do not have one, you may want to consider instituting an electronic filing system to help ensure that draft reports (including text, tables, and graphics) and unvalidated analytical data can be easily distinguished from final reports and validated data.

After data from the field and/or laboratory have been received and the originals have been stored in the project file, they may be routed to designated staff members who will perform one or more of the activities. These activities include data validation, calculations and analysis, and data presentation.

Data reports should be reviewed for completeness as soon as they are received from the laboratory. Reports should be checked to ensure all requested analyses were performed and all required QA data are reported for each sample batch. If problems with reporting or laboratory performance are encountered, corrective actions (re-submittal of data sheets or sample re-analysis) should be performed prior to final data reporting or data analysis.

3.2.7.1 Database Requirements

This section provides general guidance on storing data and is based on QA/QC procedures developed for the ASCE/EPA National Stormwater Best Management Practices Database.

Databases provide a significant level of control over the types of data that are valid for a particular field. These “rules” limit the format and structure of individual fields. For example any field where a date is present should be entered in the mm/dd/yyyy format. In addition, drop down boxes with lookup tables of relevant values can be used extensively in a database in order to maintain consistency between records.

Additional fields can be included on forms in order to allow comments to be provided in each data table. Water quality information can be entered in a tabular format where one row is used for each sample and one column for each constituent. Macros can then be written to parse the tabular format into a one-record-per-constituent format similar to that used in the National Stormwater Best Management Practices Database (Database).

Analysis of Database Links

In creating a complex database, records are often linked between tables. Once all data have been entered into a database, a check of the established links should be done between the tables storing event data for flow, precipitation, and water quality. The start and stop date and time of each water quality record can be checked against the date and time of the linked flow and precipitation event. This can be conducted using a combination of database queries by identifying dates that do not pair up. All dates that do not match should be flagged and the links should be checked by hand. This process ensures internal consistency between the separate tables in the database. Where any errors are encountered, the original document should be consulted.

Analysis of Outlying Records

An analysis of the data contained in database tables can be done to identify outlying values that resulted from typographical errors during data entry (e.g., wrong decimal place), unit errors (e.g., mg instead of µg), and incorrectly assigned STORET Codes. Two types of outlying records can appear in the database: data entry errors (i.e., manifestations of the data extraction process) and real outlying values (i.e., values present in a study’s original documents). The efforts conducted during outlier analysis seeks to identify and correct data entry errors. The assumption in looking for outlying errors is that recorded water quality parameter values lie within an expected reasonable range. Values that are outside of this range may be incorrectly entered into the database and deserve close attention. This method is particularly useful for identifying errors in units.

The usefulness of identification of outliers varies from constituent to constituent. For example any mistyped entries are easily identified in pH or temperature data. If one digit is off in pH or temperature data it is quite obvious, and, thus, there is a greater degree of confidence in the quality of the data based on an outlier analysis of pH or temperature than for other water quality parameters. Unfortunately, on the other end of the scale are other parameters such as Fecal Coliform. Even an error in excess of two orders of magnitude is not readily identified in a series of Fecal Coliform records, and thus an outlier analysis provides little or no additional information about the quality of Fecal Coliform records.

Sample Comparisons Between Original Documents and Final Data Set

Finally, to better quantify the quality of the data stored in a data set, sample comparisons can be made of the data set with the original source documents. A percentage of all records can be checked in order to assess data quality. All errors identified in these documents should be flagged and corrected. The sample comparisons conducted provide insight into overall quality of the data entry process.

Digital Conversion of Data

In the event that data is provided in a digital format that is different from the designated ASCE/EPA BMP Database format (see Section 3.4 of this Guidance), conversion of the data is necessary. Data can be easily imported between database, spreadsheet, and word processing software in more recent versions of most software. However, this data should be carefully evaluated and checked for transition errors. Often, different programs will automatically round numbers to a certain decimal and then truncate the remaining digits. Evaluation and comparison between the original document or database and the converted data is recommended for all records to ensure that the quality of the data is maintained.

Double Data Entry and Optical Character Recognition

Before data entry begins, both digital and hard copy data extraction/entry forms should be created along with instructions for the data entry process. These forms should be based directly on the database table structure. This methodology will allow the data collection and entry process to take place in a consistent, uniform environment.

To improve the quality of data entry during any process that requires hand entry of large data sets, it is typically necessary to implement a double entry procedure with automated flagging and formal correction of all inconsistencies. This method should be considered as a potential part of any data entry protocols. This is one of the few systematic methods for ensuring very small error rates. In circumstances where significant understanding of the source of the data is required on the part of the data entry personnel, the cost of this approach could be prohibitive.

In some cases, optical character recognition (OCR) can be used effectively to increase the speed of data entry. In cases where OCR is used, all results should be hand checked to ensure data quality. The data resulting from OCR typically contains a smaller number of errors compared to hand entered data, depending on format of data.

3.3 Phase III - Implementation of Monitoring Plan

3.3.1 Training of Personnel

Each member of the monitoring team must receive whatever training is necessary to properly perform his or her assigned roles. Generally, the first step is for each team member (including back-up personnel) to review the monitoring plan and health and safety plan. Next, the team members attend an initial orientation session that includes a "dry run" during which team members travel to their assigned stations and simulate monitoring, sample documentation, packaging, etc., under the supervision of the instructor (usually the principal author of the monitoring plan). Health and safety precautions should be reinforced during the dry run. Periodic "refresher" orientation sessions should be conducted after long dry periods, or when the monitoring team composition changes.

3.3.2 Installation of Equipment

If you plan to use manual monitoring techniques, equipment installation may be unnecessary. If you plan to use automated monitoring methods, you must install the sampling and flow measurement equipment at the monitoring locations. Equipment installation procedures vary depending on the specific equipment and the configuration of the monitoring location. Follow the equipment manufacturer's instructions for installation. Some general recommendations for equipment installation are listed below:

- Personnel must follow the health and safety plan when installing equipment. Some monitoring locations may require use of protective clothing, traffic control, combustible gas meters, and special training in confined space entry procedures.

- Bubbler tubes, pressure transducers, and velocity sensors typically are mounted on the bottom of the channel in the middle of the channel cross-section, facing upstream. Ultrasonic depth sensors typically are mounted above the water surface.

- In most cases, the automated sampler intake tube is mounted facing upstream and parallel to the flow in order to reduce any flow distortion that could bias the sampling of suspended solids. The intake often is covered with a strainer to prevent clogging.

- Probes, sensors, and intake lines usually are anchored to the pipe or channel. The intake tubing should be anchored throughout its length so that it will not bend, twist or crimp under high flows.

- Weirs and flumes must be secured to the bottom of the pipe or channel. If the monitoring location is in a swale, the weir or flume cutoff walls must be buried in each bank so that the structure extends all the way across the channel and all flow is directed through the weir or flume.

- If not installed inside a manhole vault, the flow meter and automated sampler should be placed in a sturdy shelter to protect the equipment from vandalism and other damage.

- If batteries are used as the power supply, install fresh batteries at the frequency recommended by the manufacturer or before each anticipated storm monitoring event.

3.3.3 Testing and Calibrating Equipment

Water quality probes (e.g., pH, conductivity), automated samplers, and flow meters must be periodically calibrated in order to ensure reliable operation and credible results. Typical calibration procedures are summarized in this section; however, you should always follow the manufacturer's instructions when calibrating a specific monitoring device.

Calibration of pH meters, conductivity meters, dissolved oxygen meters, and other water quality instruments generally involves two steps:

1. Use the instrument to measure a known standard and determine how much the instrument's measurement differs from the standard.

2. Adjust the instrument according to the manufacturer's instructions until it provides an accurate measurement of the standard.

Automated sampling equipment should be calibrated after installation to ensure it pumps the correct volume of sample. The condition of the sampler pump and intake tubing, the vertical distance over which the sample must be lifted, and other factors can affect the volume drawn. Therefore, you should test the sampler after installation and adjust the sampler programming if necessary to be sure the system consistently draws the correct sample volume.

Flow meters can be affected by the hydraulic environment in which they are placed; consequently, they should be calibrated after installation to ensure accuracy. Because sediments, debris, and other materials carried by stormwater can damage or clog bubbler tubes and pressure transducers used for depth measurements, they must be frequently inspected and calibrated by checking the flow depth with a yard stick or staff gauge. Ultrasonic velocity sensors and other instruments that measure flow rate must also be inspected and checked against velocity measurements made using a current meter.

3.3.4 Conducting Monitoring

After you have completed the advance preparations described above, you are ready to begin monitoring.

The general steps for automated monitoring are:

1. Perform routine inspection and maintenance to help ensure that the equipment will function properly when a storm event occurs.

2. Keep track of precipitation. After each storm, check the local rainfall records (or preferably a rain gauge at or near the center of the basin) to see if the amount of precipitation and the antecedent dry period met your pre-determined criteria.

- If the storm did not meet your criteria, remove the sample bottles from the sampler and replace them with clean bottles. Empty the sample bottles and arrange for them to be cleaned.

- If the storm criteria were met, remove the sample bottles. Check them to be sure they received the proper amount of sample. Check the sampling times against the storm duration to see how much of the storm was sampled. If this meets your criterion, complete the sample labels, chain-of-custody form and other field documentation, then deliver the samples to the laboratory for analysis.

3. If the sampler overfilled or underfilled the sample bottles, refine the sampler programming.

4. Reset the sampler and inspect all of its systems for possible damage or clogging so that it will be ready to sample the next storm.

The general steps for manual monitoring are:

1. The monitoring team leader or another designated person tracks the weather forecasts.

2. When the weather forecasts indicate that a potentially acceptable storm is approaching, the monitoring team leader contacts the monitoring team and the analytical laboratory. If any of the primary team members are unavailable, the monitoring team leader arranges for back-ups. The team members check their instructions, communications protocols, monitoring equipment, and supplies to ensure they are ready.

3. The monitoring team leader contacts NOAA (or some other meteorological service, if better information is available) to get updated forecasts as the storm approaches. When the forecasts indicate that the storm is likely to start within the next few hours, and it still appears likely to meet the storm selection criteria, the team leader directs the team members to proceed to their assigned monitoring stations so that they arrive before the predicted start time. The team leader also alerts the lab that samples are likely to be delivered soon.

4. The team members travel to their assigned locations and start collecting samples and taking flow measurements as soon as possible after stormwater runoff begins. They fill out the sample labels, chain-of-custody forms, and other field documentation.

5. During monitoring, the team members may contact the team leader (usually by cellular phone) to ask questions, notify him or her of changing conditions, receive direction, etc.

6. After samples have been collected, they are shipped or delivered to the analytical laboratory.

7. If the lab is to prepare flow-weighted composite samples, the monitoring team members must use the flow data they collected to determine the amount of each sample to be used

to form the composite. Usually, the team will calculate the amounts using a spreadsheet and fax the completed spreadsheet to the lab.

If you are using manual methods, you will need to maintain a vigilant "weather watch." This is essential if you wish to monitor the initial runoff from a storm event. You need some advance notice of an impending sampling event in order to have enough time to contact the monitoring team, arrange for back-ups if the primary members are unavailable, notify the analytical laboratory, work out communications protocols, pick up ice, and travel to the monitoring locations. Also, if your are able to obtain reasonably accurate estimates of storm start times, you can reduce the amount of stand-by time for your monitoring team. Finally, a close weather watch can help reduce the risk of a "false start" which can occur when a predicted storm fails to materialize or turns out to be a brief shower.

3.3.5 Coordinate Laboratory Analysis

Most stormwater monitoring programs involve laboratory analysis. Exceptions include (1) field screening programs that rely solely on visual observations and field test kits, and (2) programs that rely on "in-situ" monitoring of indicator parameters (e.g., pH, dissolved oxygen, turbidity) using probes and data loggers.

It is a good idea to involve laboratory personnel in identifying the analytical methods establishing communications protocols and QA/QC protocols. Typically, the laboratory will provide the pre-cleaned sample bottles and distilled/deionized water used for monitoring.

Your mobilization protocols should include notifying the laboratory when a storm monitoring event appears imminent. They should also include contacting the laboratory shortly after the monitoring event to ensure that the samples were received in good condition and to answer any questions the lab may have regarding the analyses to be conducted. Also, it is a good idea to periodically contact the laboratory while the analyses are being conducted. Frequent communication with the laboratory helps reduce the risk of incorrect analysis and other potential unpleasant "surprises."

3.4 Phase IV - Evaluation and Reporting of Results

3.4.1 Validate Data

You should evaluate the quality or adequacy of the laboratory analytical results before you interpret the results. This evaluation is known as "data validation" or data quality review. The basic steps are listed below.

1. Check that all requested analyses were performed and reported. Check that all requested QA/QC samples were analyzed and reported.

2. Check sample holding times to ensure that all samples were extracted and analyzed within the allowed sample holding times.

3. Check that the laboratory's performance objectives for accuracy and precision were achieved. This includes a check of method blanks, detection limits, laboratory duplicates, matrix spikes and matrix spike duplicates, laboratory control samples, and standard reference materials.

4. Check that field QA/QC was acceptable. This includes a check of equipment blanks, field duplicates, and chain-of-custody procedures.

5. Check that surrogate recoveries were within laboratory control limits.

6. Assign data qualifiers as needed to alert potential users of any uncertainties that should be considered during data interpretation.

If the laboratory and field performance objectives were achieved, further data validation is not generally needed. Specifics of the instrument calibration, mass spectral information, and run logs are not usually recommended for review unless there is a suspected problem or the data are deemed critical. If performance objectives were not achieved (e.g., due to contaminated blanks, matrix interference, or other specific problems in laboratory performance), the resulting data should be qualified. EPA functional guidelines for data validation (EPA 1994a,b) should be used as a guide for qualifying data.

3.4.2 Evaluate Results

After the chemical data have been validated, you should perform a preliminary data evaluation. The main purpose of the preliminary evaluation is to determine whether you have obtained enough information of sufficient quality to meet BMP assessment goals. If the answer is no, you should continue monitoring until you have collected sufficient information. If the answer is yes, you should proceed with the definitive evaluations that are best suited to your specific objectives.

3.4.2.1 Preliminary Data Evaluation

After the analytical results have been validated, consider graphing the flow and rainfall data vs. time for each storm event in order to produce a storm hydrograph (flow rate versus storm duration). It is often helpful to plot rainfall volume versus storm duration on the same graph. In addition, you should denote the times when the grab or composite samples were collected. This information can be very helpful in interpreting the chemical results.

Generally, stormwater quality variability is so high that statistical evaluation is not worthwhile until you have monitored several events (at least four). You should conduct an initial statistical analysis using the validated chemical data. This analysis will provide summary statistics that indicate how well your sample results represent stormwater quality at a given site. Summary statistics include sample mean, variance, standard deviation, coefficient of variation, coefficient of skewness, median, and kurtosis. Stormwater quality typically exhibits a lognormal distribution (EPA 1983; WCC 1989). Therefore, you should calculate these descriptive statistics based on an assumed lognormal distribution. Non-detects should be included in calculating the initial statistics using a maximum likelihood estimator approach.

The initial statistical analysis can help you determine whether it will be useful to statistically test various hypotheses regarding the existing data set. For example, if the standard deviations are several times larger than the means (i.e., the coefficient of variation is 3 or more), hypothesis testing may not be worthwhile. You may need to conduct additional monitoring to compensate for the observed variability and allow statistically significant differences to be discerned.

3.4.2.2 Definitive Evaluations

If your initial statistical analysis indicates that your samples are representative of water quality at the site(s) in question, you should conduct additional statistical analyses (or perhaps modeling) as needed to answer the key questions about your stormwater catchment area.

Consider the initial statistics when selecting the statistical procedure(s) you will use to answer the key questions about your stormwater catchment area. For example, if the data set does not appear to follow a normal or lognormal distribution, or if the data set contains a high proportion (i.e., >15%) of non-detects, non-parametric tests may be more appropriate than parametric tests.

The results of your monitoring program may also serve as input to a water quality model. Loadings can be calculated using SUNOM (previously the simple model, Schueler 1987), or one of several dynamic models. The simple model estimates the mean pollutant loading from a particular outfall or subbasin to a receiving water. A dynamic model takes into account the variability inherent in stormwater discharge data including variations in concentration, flow rate, and runoff volume. A dynamic model can therefore be used to calculate the entire frequency distribution for the concentration of a pollutant and the theoretical frequency distribution (i.e., the probability distribution) for loadings from the outfall or subbasin. Thus, the modeler can describe the effects of observed discharges on receiving water quality in terms of the frequency by which water quality standards are likely to be exceeded. Dynamic models include EPA's

Stormwater Management Model (SWMM) and Hydrologic Simulation Program Fortran (HSPF), the U.S. Army Corps of Engineers' Storage, Treatment, Overflow, Runoff Model (STORM), and Illinois State Water Survey's Model QILLUDAS (or Auto-QI) (EPA 1992).

3.4.3 Report Results

The results of your monitoring program should be presented in one or more reports. The appropriate report frequency and content depends on your monitoring program objectives and your audience. If you are monitoring to comply with a permit, the permit will generally specify the minimum frequency and content of the reports.

Most monitoring programs involve two types of reports: status (or progress) reports and final reports. To determine the appropriate frequency of status reports, consider your monitoring frequency and objectives, particularly any permit requirements. Many programs produce status reports on a quarterly or semi-annual basis. A typical status report may contain the following information:

- Summary of work accomplished during the reporting period
- Summary of findings
- Summaries of contacts with representatives of the local community, public interest groups, or state federal agencies
- Changes in key project personnel
- Projected work for the next reporting period

You should prepare more comprehensive reports at the end of the monitoring program (for short-term programs) or at the end of each year (for multi-year programs). Consider including the above-listed information and the following information in your annual or final report:

- Executive summary
- Monitoring program background and objectives
- Monitoring station descriptions, analytical parameters, analytical methods, and method reporting limits
- Summary descriptions of the conditions and stations, equipment inspections and calibrations, etc.
- Sample collection, precipitation, and flow measurement methods

- Flow, precipitation, and water quality results and data validation information

- Qualitative and statistical data evaluations/hypothesis testing as required for your specific program objectives (see Section 3.4.2 and Appendix I)

- Summary and conclusions, including any caveats or qualifying statements that will help the reader understand and use the reported information in the appropriate context

- Recommendations regarding management actions (e.g., changes in monitoring program, implementation of BMPs)

3.4.3.1 National Stormwater BMP Database Requirements

This section is designed to provide guidance for consistent reporting of results collected from BMP monitoring studies. The protocols described are based on those specified in the National Stormwater Best Management Practices Database, which has been developed by the Urban Water Resources Research Council of ASCE under grant funding from EPA to serve as a tool for data organization and reliable comparison of BMPs. Minimum requirements for acceptance in the National Database are outlined in this section, and standard format examples that can be used as templates for reporting results of stormwater monitoring studies are provided.

The National Stormwater BMP Database was developed to provide a scientifically sound tool for the determination of the effectiveness of BMPs under various conditions for a range of design parameters. The data fields included in this database have undergone intensive review by many experts and encompass a broad range of parameters including test site location, watershed characteristics, climatic data, BMP design and layout, monitoring instrumentation, and monitoring data for precipitation, flow and water quality. In order to effectively compare the performance of different BMPs under a variety of conditions, a set of "required" database fields were identified. These "required" fields are considered the minimum requisites for acceptance into the National Stormwater BMP Database. The database requirements vary with the different types of BMPs, and special requirements exist for unique hydraulic conditions. Database requirement categories and fields are as follows:

1) Information required for all BMPs (Table 3.5)

- General Test Site Information
- Watershed Information
- Monitoring Station Information
- Precipitation Data
- Flow Data
- Water Quality Data

Table 3.5: National Stormwater BMP Database requirements for all BMPs

Data Element	Description
General Test Site Information	
BMP Test Site Name	Name that site is known by locally.
City	City closest to test site.
State	State where test was performed.
Zip Code	Zip code of the test site.
Country	Country where the test site is located.
Altitude	Altitude to nearest 100 ft or 30 m.
Sponsoring and Monitoring Agencies for Test Site	
Address	Includes monitoring and sponsoring agency name and contact information.
Watershed Information	
Subject Watershed Name	Name that watershed is referred to locally.
Total Watershed Area	Topographically defined area drained by system.
Percent (%) Impervious Area	Total percent of impervious surface in watershed.
Regional Climate Station (US)	Regional climate station in US that is most relevant to test site.
Land Use Information	Description of land uses (only required for non-structural BMPs).
Monitoring Stations	
Station	User-defined name for subject monitoring station.
Identify Upstream BMP	BMP upstream of the monitoring point (if any).
Identify Relationship to Upstream BMP	Identify the relationship of the monitoring station to the upstream BMP (i.e. inflow, outflow or not applicable).
Identify Downstream BMP	BMP downstream of the monitoring point (if any).
Identify Relationship to Downstream BMP	Identify the relationship of the monitoring station to the downstream BMP (i.e. inflow, outflow or not applicable).
Monitoring Instrumentation	
Monitoring Station Name	Select monitoring station where the instrument is located.
Precipitation Data	
Monitoring Station Name	Identify monitoring station where precipitation event was monitored.
Storm Runoff and Base Flow Data	
Monitoring Station Name	Select monitoring station where flow event was monitored.
Type of Flow	Base flow or stormwater runoff.
Flow Start Date	Month, day and 4-digit year (e.g. 01/01/1998).
Total Bypass Volume (if any)	Total runoff volume minus runoff volume influent to BMP.
Total Storm Flow Volume into or from BMP	Total runoff volume minus the bypass volume.
Dry Weather Base Flow Rate	Flow rate during dry-weather conditions.

(Table continued on the following page)

Water Quality Sampling Event	
Monitoring Station Name	Select monitoring station where samples were collected.
Related Flow-Event	Select flow data corresponding to water quality data.
Date Water Quality Sample Collected	Month, day and 4-digit year the water quality sample was collected.
What Medium Does the Instrument Monitor	e.g. Groundwater, surface runoff.
Water Quality Parameters	STORET water quality parameters analyzed.
Value	Value of measured constituent.
Unit	Units of measured constituent.
Qualifier	Select STORET qualifier code.

2) Data required for structural BMPs (Table 3.6)

Table 3.6: National Stormwater BMP Database requirements for structural BMPs

Data Element	Description
Structural BMP Information	
Structural BMP Name	Common name by which BMP is referred to locally.
Structural BMP Type	Select the type of BMP being monitored at the site (drop-down list).
Date Facility Was Put Into Service	Month, day and 4-digit year facility became operational.
Number of Separate Inflows	Number of inflows into the facility.
Describe the Type and Design of Each BMP Outlet	Description of the outlet configuration (i.e. Perforated riser).
Is the BMP Designed to Bypass When Full?	Select “Overflow” or “bypass” characteristics of BMP.
BMP Drawing	Plan view and profile of BMP (in bitmap format for database).

3) Information required for non-structural BMPs (Table 3.7)

Table 3.7: National Stormwater BMP Database requirements for non-structural BMPs

Data Element	Description
Non-structural BMP Information	
Non-structural BMP Type	Type of non-structural BMP (e.g. educational, maintenance practices, etc.).
Non-structural BMP Name	The name by which the non-structural BMP is referred to locally.
Date Test Began	Month, day and 4-digit year.
Describe the Quantity or Measure of the BMP Being Practiced	Measure of the educational, maintenance, recycling or source control BMP.

4) Individual structural BMP requirements (Table 3.8) for:

- Detention Basins.
- Grass Filter Strips.
- Infiltration Basins.
- Media Filters.
- Porous Pavement.
- Retention Ponds.
- Percolation Trenches and Dry Wells.
- Wetland Channels and Swales.
- Wetland Basins.
- Hydrodynamic Devices.

Table 3.8: National Stormwater BMP Database requirements for individual structural BMPs

Data Element	Description
Detention Basin Design Data	
Water Quality Detention Volume	The volume of runoff that is captured and released over time.
Water Quality Detention Area (when full)	The area of water surface in basin at full water quality detention volume.
Water Quality Detention Basin Length	Distance between inflow and outflow (average for multiple inflows).
Detention Basin Bottom Area	Area of the bottom of the detention basin, including bottom stage area.
Brim-full Volume Emptying Time	Emptying time of water quality detention volume.
Half Brim-full Volume Emptying Time	Emptying time of lower half of water quality detention volume.
Bottom Stage Volume (if any)	The volume of the lower “bottom stage” of the detention basin.
Bottom Stage Surface Area	The surface area of the lower “bottom stage” of the detention basin.
Is there a Micro Pool?	“Yes” or “No” indication of micropool.
Forebay Volume	Volume of the forebay portion of the detention basin.
Forebay Surface Area	Surface area of the forebay portion of the detention basin.
Describe Vegetation Cover Within Basin	List and description of types of vegetation on the basin sides and bottom.
Flood Control Volume (if any)	Volume in excess of water quality detention volume.
Design Flood Return Periods	Design return period if basin is designed for flood control.
Grass Filter Strip Design Data	
Grass Strip Length	Length of strip in the direction of flow.
Grass Strip Slope	Slope of the strip along the flow path.
Flow Depth During 2-Year Storm	Design depth of flow during the 2-year peak flow.
2-Year Peak Flow Velocity	Design flow velocity during the 2-year peak flow.
Describe Grass Species and Densities	List of grass species and their densities.
Is Strip Irrigated?	“Yes” or “no” indication of irrigation.

(Table continued on the following page)

Infiltration Basin Design Data	
Capture Volume of Basin	The design runoff capture volume of the basin.
Surface Area of Capture Volume (When Full)	The area of the water surface in the infiltration basin, when full.
Infiltrating Surface Area	The plan area of the surface used to infiltrate the water quality volume.
Depth to Seasonal High Groundwater Table	Depth from basin bottom to seasonal high groundwater table.
Depth to Impermeable Layer (if any)	Depth from basin bottom to impermeable layer, if is present.
List of Plant Species	List of plant species and densities on infiltrating surface.
Describe Granular Material on Infiltrating Surface (if any)	Description of granular material depth and porosity.
Media Filter Design Data	
Permanent Pool Volume, Upstream of Filter Media (if any)	Volume of the permanent pool, if pool is part of filter basin.
Permanent Pool Surface Area	Area of water surface of permanent pool.
Permanent Pool Length	Distance between inflow and outflow (average for multiple inflows).
Surcharge Detention Volume	The design water quality detention volume, including the volume above the filter.
Surcharge Detention Volume Surface Area	The surface area of the design water quality capture volume.
Surcharge Detention Volume's Design Drain Time	The drain time (in hours) of the water quality capture volume.
Surcharge Detention Volume Design Depth	Depth of water quality capture volume.
Media Filter Surface Area	Surface area of the media filter.
Angle of Sloping or Vertical Filter	Inclination of filter in degrees above the horizontal plane.
Number of Media Filter Layers	Number of layers of different filter material in BMP.
Describe Depth and Type of Each Filter Media Layer	Description of the type and depth of media used in the filter.

(Table continued on the following page)

Porous Pavement Design Data	
Porous Pavement Surface Area	Surface area of porous pavement.
Depth to Seasonal High Groundwater Table	Depth from pavement surface to seasonal high groundwater table.
Depth to Impermeable Layer (if any)	Depth from pavement surface to impermeable layer, if present.
Infiltration Rate	Rate of infiltration for site soils under saturated conditions.
Type of Granular or Other Material Used Below Pavement	Description of the type and depth of each granular material layer under the porous pavement.
Porosity of Granular Material (%)	The volumetric portion of the filter material that is not occupied by solid matter, expressed as a percent of the total filter volume.
Total Storage Volume Above Pavement (if any)	The volume of water stored in depressions or as a result of attenuation (if any) above the porous pavement surface.
Estimated Drain Time of the Storage Volume Above the Pavement (if any)	Drain time of holding areas above pavement, if any.
Total Storage Volume Under Pavement (if any)	Net available volume of pore spaces in the granular materials beneath the porous pavement.
Estimated Drain Time of Storage Volume Under Pavement	Total emptying time for water stored in granular materials.
Does Porous Pavement Have Underdrains?	"Yes" or "no" indication of presence of underdrains.
Retention Pond Design Data	
Volume of Permanent Pool	Volume of permanent pool in structure.
Permanent Pool Surface Area	Area of water surface of permanent pool.
Permanent Pool Length	Length of the permanent pool measured along the axis between the inflow and outflow. For more than one inflow, take an average.
Littoral Zone Surface Area	The surface area of the bank above the permanent pool that is periodically covered with water during a storm event.
Water Quality Surcharge Detention Volume (when full)	Water quality detention volume above permanent pool.
Water Quality Surcharge Area (when full)	The surface area (plan view) of the water quality surcharge detention volume.
Water Quality Surcharge Basin Length	Length of the water quality surcharge pool measured along the axis between the inflow and outflow. For more than one inflow, take an average.
Brim-full Emptying Time for Surcharge	Emptying time of water quality detention volume down to the permanent pool.
Half Brim-full Emptying Time for Surcharge	Emptying time of lower half of surcharge detention volume down to the permanent pool.
Forebay Volume	Volume of the forebay portion of the detention basin.
Forebay Surface Area	Surface area of the forebay portion of the detention basin.
Describe Vegetation Cover Within Basin	List and description of vegetation on basin sides and floor.
Flood Control Volume (if any)	Volume in excess of the retention basin water quality surcharge detention volume.
List Design Flood Return Period (in years)	Design return periods if pond was designed for flood control.

(Table continued on the following page)

Percolation Trench and Dry Well Design	
Percolation Trench/Well Surface Area	The surface area of the top of the percolation trench/well.
Percolation Trench/Well Length	Length of percolation trench or diameter of the well.
Percolation Trench/Well Depth	The depth of trench or well that is exposed to permeable soils.
Depth to Seasonal High Groundwater Table	Depth below the bottom of the trench or well to the seasonal high groundwater table.
Depth to Impermeable Layer (if any)	Depth below the bottom of the trench or well to impermeable layer, if impermeable layer is present.
Depth and Type of Each Soil Layer Adjacent to and Below Trench/Well	Description of the stratification and the depth of each layer of soils at the BMP site.
Type of Gradation of Granular Materials Used in Trench/Well	Description of the type and depth of granular material used in the trench or well.
Was Geotextile Used Above Granular Trench Fill?	“Yes” or “no” indication of geotextile use above granular fill.
Was Geotextile Used on the Side of Granular Fill?	“Yes” or “no” indication of geotextile use on sides of granular fill.
Was Geotextile Used on the Bottom of Granular Fill?	“Yes” or “no” indication of geotextile use below granular fill.
Give Porosity (%) of the Granular Fill	The volumetric portion of the granular material that is not occupied by solid matter, expressed as a percent of the total volume.
Total Storage Pore Volume in Trench	Volume of available pore space in the trench or well.
Describe Type of Geotextile Used	Description of types and locations of geotextile fabrics.
Hydraulic Conductivity of Adjacent Soil	Hydraulic conductivity of the soils adjacent to the trench or well.
Groundwater Flow Gradient	Slope of the local groundwater table without influence from the BMP.
Wetland Channel and Swale Design Data	
Length of Channel/Swale	Length of channel or swale from stormwater inflow to outflow point.
Longitudinal Slope of Channel/Swale	Measured slope between grade control structures in swale.
Bottom Width of Channel /Swale	Average width between side slopes.
Side Slope of Channel Swale	Average slope of swale sides.
2-Year Flow Design Depth in Channel/Swale	Average depth of water in channel/swale during 2-yr flow.
2-Year Peak Design Flow Velocity	Design velocity for 2-yr flow.
Type of Plant Species in Wetland Zone or Swale	List and description of plant species, percent of cover and densities.

(Table continued on the following page)

Wetland Basin Design Data	
Volume of Permanent Pool	Volume of permanent pool in structure.
Permanent Pool Surface Area	Surface area of permanent pool.
Permanent Pool Length	Length of the permanent pool of water, measured at the water surface along the axis of the inflow and outflow (average for multiple inflows).
Water Quality Surcharge Detention Volume (when full)	Water quality detention volume above permanent pool.
Water Quality Surcharge Area (when full)	The surface area of the water quality surcharge detention volume.
Water Quality Surcharge Basin Length	Water quality surcharge basin length, measured at the water surface along the axis of the inflow and outflow (average for multiple inflows).
Brim-full Emptying Time for Surcharge	Emptying time of water quality detention volume down to the permanent pool.
Half Brim-full Emptying Time for Surcharge	Emptying time of lower half of surcharge detention volume down to the permanent pool.
Forebay Volume	Volume of the forebay portion of the detention basin, when full.
Forebay Surface Area	Water surface area of the forebay portion of the detention basin.
Describe Vegetation Cover Within Basin	Description of types of vegetative cover within the basin.
Flood Control Volume (if any)	Volume in excess of the water quality detention volume.
List Design Flood Return Period (in years)	Design return period if basin is designed for flood control.
Wetland Surface Area	The surface (plan view) area of the total wetland.
Percent of Wetland Pond with 12 inches Depth	Percent of wetland surface area with less than 12 inches of standing water.
Percent of Wetland Pond with12-24" Depth	Percent of wetland surface area with 12-24 inches of standing water.
Percent of Wetland Pond with 24-48" Depth	Percent of wetland surface area with 24-48 inches of standing water.
Percent of Wetland Pond with >48" Depth	Percent of wetland surface area with greater than 48 inches of standing water.
Percent of Wetland Basin's Area That is Meadow Wetland	Percent of wetland surface area with meadow wetlands (no standing water).
List All Known Plant Species in the Wetland	List of plant species, percent of cover and densities.
Hydrodynamic Devices	
Volume of Permanent Pool	Volume of permanent pool in structure.
Permanent Pool Surface Area	Surface area of the permanent pool.
Permanent Pool Length	Distance between inflow and outflow (average for multiple inflows).
Water Quality Surcharge Detention Volume (when Full)	Water quality detention volume above permanent pool.
Inlet Chamber Volume (if any)	Volume of the inlet chamber portion of the hydrodynamic device.
Brim Full Emptying Time for Surcharge	Emptying time of water quality detention volume down to the permanent pool.
Half Brim Full Emptying Time for Surcharge	Emptying time of lower half of surcharge detention volume down to the permanent pool.

5) Requirements for non-structural and structural BMPs that are based on minimizing directly connected impervious areas (Table 3.9).

Table 3.9: National Stormwater BMP Database requirements for non-structural BMPs and structural BMPs that are based on minimizing directly connected impervious areas

Data Element	Description
Watershed Information	
Total Length of Grass-Lined Channel	Total length of natural and grass-lined channels in watershed.
Total Watershed Area Disturbed	Total watershed area that is actively disturbed or under construction.
Percent Irrigated Lawn and/or Agriculture in Watershed	Percent of lawn or agricultural areas that are irrigated.
Percent of Watershed Served by Storm Sewers	The percent of watershed served by storm sewers.
Average Runoff Coefficient	Based on area-weighted average.
Soil Type	NRCS soil type.
Type of Vegetation	Type of vegetation predominant in pervious area.
Roads and Parking Lots	
Total Paved Roadway Area	Total area of paved roads, streets and alleys in watershed..
Total Length of Curb/Gutter on Paved Roads	Total length of curb/gutter on paved roads.
Total Unpaved Roadway Area	Total unpaved roadway area.
Total Length of Curb/Gutter on Unpaved Roads	Total length of curb/gutter on unpaved roads.
Percent of Paved Roads Draining to Grass Swales/Ditches	Percent of paved roads draining to swales/ditches.
Percent of Unpaved Roads Draining to Grass Swales/Ditches	Percent of unpaved roads draining to swales/ditches.
Type of Pavement on Roads, Streets and Alleys	Description of type of pavement (i.e. concrete, asphalt, etc.).
Total Paved Parking Lot Area	Total area of paved parking lots in the watershed.
Total Length Curb/Gutter on Paved Lots	Total length curb/gutter on paved lots.
Total Unpaved Parking Lot Area	Total unpaved parking lot area.
Total Length Curb/Gutter on Unpaved Lots	Total length of curb/gutter on unpaved lots.
Percent Paved Lot Area Draining to Grass Swales	Percent of paved lot area draining to swales.
Percent Unpaved Lot Area Draining to Grass Swales	Percent of unpaved lot area draining to swales.
Type of Pavement in Parking Lots	Type of pavement in parking lots.

6) Requirements for structural BMPs that are based on minimizing directly connected impervious areas (Table 3.10)

Table 3.10: National Stormwater BMP Database requirements for structural BMPs that are based on minimizing directly connected impervious areas

Data Element	Description
Watershed Information	
Storm Sewer Design Return Period	Most common design return period for the storm sewers in the watershed.
Average Watershed Slope	Average unit less slope of the watershed (i.e. ft/ft, in/in).
NRCS Hydrologic Soil Group	Dominant NRCS hydrologic soil group.

3.4.3.2 Standard Format Examples

The purpose of this section is to provide standard format examples that can serve as a guidance tool for developing monitoring plans and promoting consistent reporting and documentation of stormwater monitoring studies. These forms include, but are not limited to, the required data entry fields for the National Stormwater BMP Database. The database requirements were used as a guideline for development and organization of forms because of its ability to aid in consistently evaluating BMP effectiveness under different conditions. The following sections provide standardized document formats that can be used as a template when performing a BMP monitoring study. Each form is categorized based on the sub-sections presented in the National Stormwater BMP Database.

General Test Site Information

The general test site information form provides data to aid in the identification of the testing location. Location information is important because it enables identification of the general climatic conditions under which a BMP was evaluated. Data reported on this form also provides a cross-link with other national EPA databases. The general test site information form includes data about the sponsoring and monitoring agencies conducting the study and georeferencing information for exact identification of the site location. A detailed description of the data element fields for the general test site information form is available in Table 3.11. The General Test Site Information form, Form A, follows:

Table 3.11: General test site form data element descriptions

Data Element	Description
BMP Test Site Name[1]	Name that the site is known by locally (e.g., Shop Creek, First Bank).The site may contain more than one BMP, but ONLY if the watersheds tributary to these BMPs are virtually identical.
City[1]	City closest to the test site. The site does not have to be within the city limits.
County	County in which test site is located.
State[1]	State where test was performed (2 characters).
Zip Code[1]	Zip code of the test site.
Country[1]	Country where the test site is located (2 characters).
Time Zone	Time zone in which the BMP test site is located off-set in hours from Greenwich Mean Time. For example, in the United States, Eastern Time is -5, Central Time is -6, Mountain Time is -7 and Pacific Time is -8.
Georeferencing Information	
USGS Quadrangle Map Name	U.S. Geological Survey (USGS) 7.5-minute map on which the site can be located. This information should be provided for U.S. sites only.
Principal Meridian	Local or international meridian from which the degrees of longitude locating the BMP test site are measured.
Range	Range identifies the site distance and direction (east or west) from the selected principal meridian. For example, Range 60 West (R60W). This information can be found on a U.S. Geological Survey quadrangle map (U.S. sites only).
Township	Townships are located by their distance and direction (north or south) from a selected baseline. For example, Township 2 North (T2N) (U.S. sites only).
Section	Section is a land area usually containing one square mile (640 acres) that can be identified on a U.S. Geological Survey quadrangle map. There are 36 sections in a given township and range numbered from 1 to 36 (U.S. sites only) .
Quarter-Quarter-Quarter section	Quarter-Quarter-Quarter section should be provided to locate the BMP test site on a U.S. Geological Survey quadrangle map. U.S. sites only.
Latitude	Latitude is the North-South coordinate that locates the project to the nearest second on the globe relative to the equator. The degree, minute and second measures of the latitude can be obtained from a U.S. Geological Survey Quadrangle Map.
Longitude	The East-West coordinate that locates the project to the nearest second on the globe relative to the selected principal meridian. The degree, minute and second measures of the latitude can be obtained from a U.S. Geological Survey (USGS) Quadrangle.
Altitude[1]	Elevation above mean sea level provided to the nearest 100 feet from a U.S. Geological Survey quadrangle map or to the nearest 30 meters for studies outside of the United States.
Sponsoring and Monitoring Agency Information	
Agency Type[1]	Agency type, such as city, county, state, industry, federal, special district, council of governments, authority, consultant, or other.
Address[1]	Address information including agency name, department (if any), street or post office address, city, state, zip code, country, phone, fax and e-mail.

[1] – National Stormwater BMP Database requirement for all BMPs

Form A

GENERAL TEST SITE INFORMATION

Test Site Name ______________________

City ____________ County ____________ State ____________

Zip Code ____________ Country ____________ Time Zone ____________

Georeferencing

Township ____________ Range ________ Principal Meridian ______

USGS Quadrangle Map ____________________ Altitude ______ Section _____

Quarter Sections: Quarter ______ Quarter-Quarter _____ Quarter-Quarter-Quarter _____

Latitude: Degrees _____ Minute _____ Seconds ______

Longitude: Degrees _____ Minute _____ Seconds ______

Sponsoring Agency

Sponsor's Name ______________________________

Sponsoring Agency's Description ______________________________

Address ______________________ City ____________

______________________ State ____________

____

Zip Code __________ Country ____________

Phone ____________ Fax ____________ E-Mail ____________

Monitoring Agency

Monitoring Agency Name ______________________________

Monitoring Agency Description ______________________________

Address ______________________ City ____________

______________________ State ____________

____

Zip Code __________ Country ____________

Phone ____________ Fax ____________ E-Mail ____________

Comments

Watershed Information

The watershed form contains important information about the physical and relational characteristics of the watershed where the BMP was monitored. Watershed characteristics play a significant role in the quantity and type of pollutants in stormwater runoff. The form includes information on the physical characteristics of the watershed, parking lots and roads, streams and land uses. This information plays a significant role in comparing BMP performance under various watershed conditions. If multiple watersheds were examined at a single test site then additional watershed information forms can be completed for each watershed. Table 3.12 provides descriptions of the watershed form data elements, and the watershed form is presented as Form B.

Table 3.12: Watershed form data elements description

Data Elements	Description
Subject Watershed Name[1]	Name by which the watershed is referred to locally.
Hydrologic Unit Code	The U.S. Geological Survey (USGS) 8-digit hydrologic unit code (HUC) which represents a geographic area containing part or all of a surface drainage basin or distinct hydrologic feature.
EPA Reach Code	EPA-designated RF1 or RF3 river reach with which the station is associated. Sites will either have an RF1 code or an RF3 code, but not both.
Unit System (S.I. or U.S. Standard)	The unit system used for measurement for the study. The unit system should be consistent for all reported data.
Physical Characteristics	
Total Watershed Area[1]	Topographically defined area drained by an urban system, channel, gulch, stream, etc., such that all outflow is directed to a single point.
Total Length of Watershed	Length of the watershed along the main drainage path to the furthest point on the watershed divide.
Total Length of Grass-Lined Channel [5]	Total length of grass-lined and natural channels in the watershed. This is the portion of the storm drainage network in the watershed that is not conveyed in concrete channels, storm sewers or pipes.
Total Watershed Area Disturbed [5]	Total watershed area that is actively disturbed or under construction. This parameter may be useful in indicating the types and levels of pollutant loads in stormwater.
Percent (%) Irrigated Lawn and/or Agriculture in Watershed [5]	Percent of watershed area that is irrigated.
Percent (%) Total Impervious Area in Watershed[1]	The percent of the total watershed that is impervious can be determined as the total impervious area divided by the total area of the watershed. Common impervious surfaces include, but are not limited to, rooftops, walkways, patios, driveways, parking lots, storage areas, concrete or asphalt paving, gravel roads, packed earthen materials, and macadam or other surfaces that similarly impede the natural infiltration of urban runoff. Rainfall on impervious areas can cause rapid overland flow to drainage inlets.
Percent (%) of Total Impervious Area (above) that is Hydraulically Connected	Parameter calculated by dividing the hydraulically connected impervious area by the total impervious area. An example of hydraulically connected impervious area includes building rooftops that drain onto paved areas.
Percent (%) of Watershed Served by Storm Sewers[5]	The percentage of watershed area served by storm sewers (typically higher in urbanized areas than in rural areas).

(Table continued on the following page)

Data Elements	Description
Storm Sewer Design Return Period (yrs)[6]	Most common design storm return period for the storm sewers in the watershed provided in years. For example, most storm sewers in the watershed may be designed to handle flows generated by the 25-year storm.
Average Watershed Slope[6]	Average unitless slope of the watershed (i.e., ft fall/ft run or m fall/m run--unitless). Slope for each linear reach can be determined as the elevation difference for the reach divided by the length of the reach, and the average slope for the watershed can be calculated as a weighted sum of the slopes of individual reaches.
Average Runoff Coefficient[5]	Rational Method runoff coefficient. If data permits, calculate the average of individual storm runoff coefficients using each storm's runoff volume divided by its rainfall volume. Otherwise determine as area-weighted average for watershed land uses.
NRCS Hydrologic Soil Group[6]	Dominant Natural Resource Conservation Service (NRCS--formerly Soil Conservation Service) hydrologic soil group--A, B, C, or D.
Soil Type[5]	NRCS soil type--(c)lay (s)ilt, s(a)nd. Clay particles are smaller than 0.002 millimeters (mm) in diameter. Silt particles are between 0.002 and 0.05 mm in diameter. Sand particles range from 0.05 mm to 2.0 mm.
Type of Vegetation[5]	Type of vegetation predominant in pervious areas (i.e. grass turf, dry land grasses, etc.).
Roads	
Total Paved Roadway Area[5]	Total area of paved roads, streets and alleys in the watershed. Associated paved shoulders should be included in this area.
Total Length Curb/Gutter on Paved Roads[5]	Total length of curb & gutter along paved roads, streets, and alleys.
Total Unpaved Roadway Area[5]	Total area of unpaved roads, streets, and alleys in the watershed. Unpaved shoulders should be included in this area.
Total Length Curb/Gutter on Unpaved Roads[5]	Total length of curb & gutter along unpaved roads, streets, and alleys.
% Paved Roads Draining to Grass Swales/Ditches[5]	Parameter calculated by dividing the length of paved roads, etc., draining to grass swales and ditches by the total length of paved roads, streets and alleyways in the watershed.
% Unpaved Roads Draining to Grass Swales/Ditches[5]	Percentage of unpaved roads, street and alley areas draining to grass swales/ditches that can be calculated by dividing the length of unpaved roads, etc., draining to grass swales and ditches by the length of unpaved roads, streets and alleyways in the watershed.
Type of Pavement on Roads, Streets and Alleys[5]	Pavement Type. Can be (C)oncrete,(A)sphalt, or a Mix of (B)oth.
Parking Lots	
Total Paved Parking Lot[5] Area	Total area of all paved parking lots within the watershed.
Total Length Curb/Gutter on Paved Lots[5]	Total length of curb & gutter along paved parking lots.
Total Unpaved Parking Lot Area[5]	Total area of all unpaved parking lots within the watershed.
Total Length Curb/Gutter on Unpaved Lots[5]	Total length of curb & gutter along unpaved parking lots.
% Paved Lot Area Draining to Grass Swales[5]	Percentage of parking lot areas draining to grass swales or ditches. This can be calculated by dividing the total parking lot area draining to swales by the total parking lot area.

(Table continued on the following page)

Data Elements	Description
% Unpaved Lot Area Draining to Grass Swales[5]	Percentage of unpaved parking lot areas draining to grass swales or ditches. This can be calculated by dividing the total unpaved parking lot area draining to swales by the total unpaved parking lot area.
Type of Pavement in Parking Lots	Can be (C)oncrete,(A)sphalt, or a Mix of (B)oth. Additionally, provide the percentages of porous concrete, porous asphalt and porous modular pavement present relative to the total paved parking lot area.
Land Uses	
Land Use Information[3]	Should be provided for each land use present in the watershed. The percent of each land use in the watershed, categorized according to % Light Industrial, % Heavy Industrial, % Multi-family Residential, % Office Commercial, % Retail, % Restaurants, % Automotive Services, % Rangeland, % Orchard, % Vegetable Farming, etc.

[1] – National Stormwater BMP Database requirement for all BMPs
[3] – National Stormwater BMP Database requirement for all Non-Structural BMPs
[5] – National Stormwater BMP Database requirement for Non-Structural and Structural BMPs that are based on minimizing directly connected impervious areas
[6] – National Stormwater BMP Database requirement for Structural BMPs that are based on minimizing directly connected impervious areas

Form B

WATERSHED INFORMATION

Watershed Name ______________________________

Hydrologic Unit Code (8-digit) ________________ EPA Reach Code (RF1 or RF3) __________

Unit System (S.I. or U.S. Standard) ____________

Physical Characterstics

Total Watershed Area ______________ Total Length of Watershed ______________

Total Length of Grass-Lined Channels ____________

Total Disturbed Area ____________

% Irrigated Lawn and/or Agriculture __________ % Total Impervious Area in Watershed _______

% of Total Impervious Area that is Hydraulically Connected ______________

% of Watershed Served by Storm Sewers _______ Storm Sewer Design Return Period _________

Average Watershed Slope ____________ Average Runoff Coefficient ______

Hydrologic Soil Group ____________ Soil Type ____________

Type of Vegetation

Roads

Total Paved Roadway Area ____________ Total Unpaved Roadway Area ____________

Total Length of Curb and Gutter on Paved Roads ________________

Total Length of Curb/Gutter on Unpaved Roads ________________

% Paved Roads Draining to Grass Swales/Ditches ________________

% Unpaved Roads Draining to Grass Swales/Ditches ______________

Type of Pavement on Roadways _____________

Sheet 1 of 2

WATERSHED INFORMATION

Parking Lots

Total Paved Parking Lot Area ____________ Total Unpaved Parking Lot Area ____________

Total Length of Curb and Gutter on Paved Roads ____________

Total Length of Curb/Gutter on Unpaved Parking Lots ____________

% Paved Parking Lot Draining to Grass Swales/Ditches ____________

% Unpaved Parking Lot Draining to Grass Swales/Ditches ____________

Type of Pavement in Parking Lots ____________

% Porous Concrete ______ % Porous Asphalt ____________

Land Uses

Land Use Type ____________

% of Land Use in Watershed ____________

Sheet 2 of 2

Structural BMP Information

The purpose of the structural BMP form is to provide general BMP information inherent to all structural BMP types. Structural BMPs include constructed facilities or measures to help protect receiving water quality and control stormwater quantity. Representative practices include structures for storage, infiltration and filtration. Structural BMP information requested includes items such as date of installation, various design parameters, design drawings, and rehabilitation and maintenance frequencies. Structural BMP form data elements and the form are presented in Table
3.13: and Form C, respectively.

Table 3.13: Structural BMP form data elements description

Data Element	Description
BMP Name[2]	The name by which the BMP is referred to locally.
Type of BMP Being Tested[2]	The type of structural BMP being tested at the site. Major categories of structural BMPs include detention basins, retention ponds, wetland channels and swales, wetland basins, hydrodynamic devices, percolation trenchs and dry wells**,** media filters, grass filter strips, porous pavement and infiltration basins.
What date was the BMP facility put into service?[2]	Month, day and 4-digit year (e.g., 04/05/1998) when BMP became operational. If the exact day is unknown, use the first day of the month.
How many separate inflow points does the facility have? [2]	Number of separate inflow points. For example, a wet pond may receive flow from two (2) storm sewers and one (1) natural drainage, for a total of three (3) separate inflow points.
Is the BMP designed to bypass or overflow when full?[2]	Identifies 'Bypass" or "Overflow" when full..
Describe the type and frequency of maintenance, if any	Type of frequency and maintenance. Practices include: Tree/Shrub/Invasive Vegetation Control, Mowing, Algae Reduction, Sediment Removal/Dredging, Litter/Debris Control, Erosion Control/Bank Stability, Inlet Cleaning, Outlet Cleaning, Media Replacement/Regeneration, Pump Cleaning/Repair, Valve Cleaning/Repair, Pipe Cleaning/Repair, General Maintenance, Odor Control, Mosquito Control, Vector Control.
What was the last date that the facility was rehabilitated, if any?	Month, day and 4-digit year (e.g., 04/05/1998) of most recent rehabilitation. If the exact day is unknown, use the first day of the month.
Describe the type of rehabilitation, if any	Description of rehabilitation activities such as structural modification or major repair.
Describe the type and design of each BMP outlet[2]	Outlet configuration and design information.
BMP Drawing [2]	Drawings of the BMP in plan, profile and layout view.

[2] – National Stormwater BMP Database requirement for all Structural BMPs

Form C

STRUCTURAL BMP INFORMATION

BMP Name ____________________ Type of BMP Being Tested ____________________

Date Facility Placed in Service __________ Number of Inflow Points __________

BMP Designed to Bypass or Overflow __________

Maintenance Type and Frequency

Last Rehabilitation Date __________

Type of Rehabilitation

Description, Types, and Designs of Outlets

BMP Layout Drawing

Non-Structural BMP Information

The purpose of the non-structural BMP form is to provide general BMP information inherent to all non-structural BMP types. A non-structural BMP can generally be described as a preventative action to protect receiving water quality that does not require construction. Nonstructural BMPs rely predominantly on behavioral changes in order to be effective. Major categories of non-structural BMPs include education, recycling, maintenance practices and source controls, as described below.

- Educational BMPs: Include efforts to inform city employees, the public, and businesses about the importance of using practices that protect stormwater from improper use, storage, and disposal of pollutants, toxics, household products, etc. The ultimate goal of educational BMPs is to cause behavioral changes.

- Recycling BMPs: Include measures such as collecting and recycling automotive products, household toxics, leaves, landscaping wastes, etc.

- Maintenance practices: Include measures such as catch basin cleaning, parking lot sweeping, road and street pavement repair, road salting and sanding, roadside ditch cleaning and restoration, street sweeping, etc.

- Source controls: Include preventing rainfall from contacting pollutant-laden surfaces and preventing pollutant-laden runoff from leaving locations such as automobile maintenance, salvage and service stations; commercial, restaurant and retail sites; construction sites; farming and agricultural sites; industrial sites, etc.

The Non-structural BMP form data reports narrative/descriptive information on the type and extent of the BMP being practiced, as well as cost data. The non-structural BMP form and the form fields are described in Table 3.14: and Form D, respectively.

Table 3.14: Non-structural BMP form data elements description

Data Element	Description
Non-structural BMP Type[3]	Categories of non-structural BMPs, such as education, recycling, maintenance practices and source controls.
BMP Name for the subject non-structural BMP[3]	BMP Name for the subject non-structural BMP (e.g., Erosion and Sediment Control Pamphlets).
Date Test Began[3]	Date (month, day and 4-digit year) that the BMP test was begun (e.g., 01/01/1998).
Educational BMP[3] "measurements"	Measure of eductational BMP effectiveness/progress. Examples include: the number of brochures distributed per resident and employee in watershed per year, number of radio ads, percent of stormwater inlets in watershed stenciled, etc.

(Table continued on the following page)

Data Element	Description
Recycling BMP "measurements" [3]	Measure of recycling BMP effectiveness/progress. Could include gallons of used oil collected per resident in the watershed; pounds of household toxics collected per resident in the watershed; tons of landscaping waste per resident collected, etc.
Maintenance BMP "measurements" [3]	Measure of maintenance BMP effectiveness/progress. Could include percent of stormwater catch basins cleaned once each year, twice each year, etc.; tons of materials removed per average inlet each year; lane miles of street swept each year and tons of material removed per lane mile each year; etc.
Source Control "measurements" [3]	Measure of source control BMP effectiveness/progress. Could include percent of industrial storage area in watershed that is covered; etc.
Cost Information	
Initial Costs	Initial costs, including the time and measures necessary to design and implement a program.
Annual Costs	Year-to-year costs once the initial program has been developed.

[3] – National Stormwater BMP Database requirement for all Non-Structural BMPs

Form D

NON-STRUCTURAL BMP INFORMATION

BMP Name ______________________________

Type of BMP Being Tested ______________________

Date Test Began __________

Description of Quantity or Measure of BMP

Cost Information

Initial Costs ______________

Annuel Costs ______________

Detention Basin Design Data

The primary purpose of the detention basin design data form is to provide structural BMP information specific to detention basins. Detention basins are designed to collect stormwater runoff and completely empty sometime after the end of the runoff event. Detention basins used for water quality purposes differ from flood control basins only by their outlet structures. Detention basin design characteristics are extremely important for comparing their performance under various hydrological and environmental conditions. The detention basin form and the form data elements are presented respectively in Form E and Table 3.15.

Table 3.15: Detention basin design form data elements list

Data Element	Description
Water Quality Detention Volume[4]	The volume of storm runoff that is captured and slowly drained over a period of time (e.g., 12 to 48 hours).
Water Quality Detention Surface Area When Full[4]	The area of the water surface in the detention basin at full water quality detention volume.
Water Quality Detention Basin Length[4]	Length of the water quality detention basin, measured as the distance between inflow and outflow. If there is more that one inflow point, use the average distance between the inflow points and the outflow weighted by the tributary impervious area.
Detention Basin Bottom Area[4]	Area of the bottom of the entire detention basin, not including the side slopes but including the bottom stage area.
Brim-full Volume Emptying Time[4]	Emptying time (in hours) of the water quality detention volume.
Half Brim-full Volume Emptying Time[4]	Emptying time (in hours) of the lower half of the water quality detention volume.
Bottom Stage Volume, If Any[4]	The volume of the lower “bottom stage” portion (if applicable) of the detention basin.
Bottom Stage Surface Area, If Any[4]	The surface area of the lower “bottom stage” portion (if applicable) of the detention basin.
Is There a Micro Pool?[4]	“Yes” or “No” indication of micropool.
Forebay Volume[4]	Volume of the forebay portion of the detention basin when filled to the point of overflow into the rest of the basin.
Forebay Surface Area[4]	Surface area of water in the forebay at the level of overflow to the bottom stage.
Describe Vegetation Cover Within Basin[4]	Describe the types of vegetation on the basin sides and floor.
Flood Control Volume, If Any[4]	The flood control detention volume in excess of the water quality detention basin volume (if any).
List Design Flood Return Periods[4]	List the flood return period (in years) for which the flood control volume is designed (e.g., 25-year).
Depth to Seasonal High Water Table, If Known	The minimum depth from the basin bottom to the water table during the monitoring season.
Detention Basin Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which cost estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.

(Table continued on the following page)

Data Element	Description
Structural Control Devices	The estimated cost of establishing all structural control devices, such as inlet and outlet structures, trash racks and energy dissipaters, including cost of materials and construction.
Vegetation and Landscaping Costs	The estimated cost of establishing vegetation for the BMP, including acquiring landscape materials, establishing vegetation, and establishing the irrigation infrastructure, if any.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land or the cost of acquiring the land.
Rehabilitative Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove sediment accumulated in the detention basin.
Average Annual Revegetation Costs	Estimated average annual cost to revegetate the sides and floor of the detention basin.

[4] – National Stormwater BMP Database requirement for all Non-Structural BMPs

Form E

DETENTION BASIN DESIGN DATA

Test Site Name ______________________________

Watershed Name ____________________ BMP Name ____________________

Design Information

Water Quality Detention Volume ______________

Water Quality Detention Surface Area When Full ______________

Water Quality Detention Basin Length ______________

Detention Basin Bottom Area ______________

Brim-full Volume Emptying Time ________ Half Brim-full Volume Emptying Time ________

Bottom Stage Volume, If Any ______________ Is there a micro pool? ☐

Bottom Stage Surface Area, If Any ______________

Forebay Volume ______________ Forebay Surface Area ______________

Vegetation Cover Within Basin

Flood Control Volume, If Any ______________ Design Flood Return Periods

Depth to Water Table ______________

Detention Basin Construction Cost Estimates

Year of Cost Estimate __________

Construction Costs:

Excavation __________ Structural Control Devices __________

Vegetation and Landscaping __________ Engineering and Overhead __________

Land Costs and Value __________

Rehabilitative Costs:

Average Annual Sediment Removal __________

Average Annual Revegetation __________

Retention Pond Design Data

The retention pond design data form reports BMP specific information for retention ponds. Retention ponds are also commonly known as “wet ponds” because they have a permanent pool of water, unlike detention basins, which dry out between storms. The permanent pool of water is replaced in part, or in total, by stormwater during a storm event. The design is such that any available surcharge capture volume is released over time. Retention of stormwater in the permanent pool over time can provide biochemical treatment. A dry weather base flow, pond liner and/or high groundwater table are required to maintain the permanent pool. The retention pond form and the form data elements descriptions are shown in Form F and Table 3.16:

Table 3.16: Retention pond design form data elements list

Data Element	Description
Volume of permanent pool[4]	Volume of the permanent pool of water.
Permanent Pool Surface Area[4]	Area of the water surface in the permanent pool.
Permanent Pool Length[4]	Length of the permanent pool of water, measured along the axis of the inflow and outflow. If more that one inflow point, use the average distance between the inflow points and the outflow weighted by the tributary impervious area.
Littoral Zone Surface Area[4]	Surface area of the littoral zone. The littoral zone refers to the area above the level of the permanent pool that is periodically and temporarily covered by captured storm runoff.
Littoral Zone Plant Species List	List plant species (by Latin name, if known), percent of cover and densities in the littoral zone.
Water Quality Surcharge Detention Volume When Full[4]	Water quality detention volume above permanent pool, when full.
Water Quality Surcharge Surface Area When Full[4]	The surface area of water quality detention volume above the permanent pool, if applicable.
Water Quality Surcharge Basin Length[4]	Length of the water quality detention volume, measured along the axis between the inflow and outflow. If more that one inflow point, use the average distance between the inflow points and the outflow weighted by the tributary impervious area.
Brim-full Emptying Time For Surcharge[4]	Time (in hours) required for the retention pond water quality surcharge detention volume to be released to the permanent pool level.
Half Brim-full Emptying Time For Surcharge[4]	Time (in hours) required for the lower half of the retention pond water quality surcharge detention volume to be released to the permanent pool.
Forebay Volume[4]	Volume of the forebay portion of the retention basin when it is filled to the point of overflow into the lower part of the basin.
Forebay Surface Area[4]	Surface area of water in the forebay when it is filled to the point of overflow into the lower part of the basin.
Describe Vegetation Cover Within Basin[4]	Describe the types of vegetation (provide Latin names, if known) on the basin sides and floor.
Flood Control Volume, If Any[4]	The flood control detention volume in excess of the retention basin volume (if any).
List Design Flood Return Periods (in years)[4]	List the flood return period (in years) for which the flood control volume is designed (e.g., 25-year).

(Table continued on the following page)

Data Element	Description
Retention Pond Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which cost estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.
Structural Materials Costs	The estimated cost of materials used in constructing the retention pond, excluding vegetation costs.
Basin Construction Costs	The estimated cost for construction of the retention pond, including site survey and construction activities.
Structural Control Devices Costs	The estimated cost of establishing all retention pond control devices, such as inlet and outlet structures, spillways, and culverts. Includes the cost of materials and construction.
Vegetation and Landscaping Costs	The estimated cost of establishing vegetation for the BMP, including acquiring landscape materials, etc.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove sediment accumulated in the retention pond.
Average Annual Revegetation Costs	Estimated average annual cost to revegetate and/or reseed the retention pond.

[4] – National Stormwater BMP Database requirement for all Retention Ponds

Form F

RETENTION POND DESIGN DATA

Test Site Name ______________________________

Watershed Name ____________________ BMP Name ____________________

Design Information

Volume of Permanent Pool ______________

Permanent Pool Surface Area ______________

Littoral Zone Surface Area ______________

Littoral Zone Plant Species

Permanent Pool Length ______________

Water Quality Surcharge Detention Volume ______________

Water Quality Surcharge Surface Area, When Full ______________

Water Quality Surcharge Basin Length, When Full ______________

Brim-full Emptying Time __________ Half Brim-full Emptying Time __________

Forebay Volume ______________ Forebay Surface Area ______________

Flood Control Volume ______________ Design Flood Return Periods

Retention Pond Construction Cost Estimate

Year of Cost Estimate __________

Construction Costs:

Excavation __________ Structural Materials Cost __________

Basin Construction __________ Structural Control Devices __________

Vegetation and Landscaping __________ Engineering and Overhead __________

Land Costs and Value __________

Rehabilitative Costs:

Average Annual Sediment Removal __________

Average Annual Revegetation __________

Percolation Trench and Dry Well Design Data

The percolation trench and dry well form contains essential design information for percolation trenches and dry wells. Percolation or infiltration trenches can be generally described as trenches or excavations filled with porous media designed to encourage rapid percolation of runoff to the groundwater. A dry well is a drilled well, often drilled through impervious layers to reach lower pervious layers. The percolation trench and dry well form and data elements are presented in Table 3.17: and Form G.

Table 3.17: Percolation trench and dry well design form data elements list

Data Element	Description
Percolation Trench/Well Surface Area[4]	The top surface area of the percolation trench or well.
Percolation Trench/Well Length[4]	The length of the percolation trench, or the diameter of the well.
Percolation Trench/Well Depth[4]	The depth of the trench or the well that is exposed to permeable soils.
Depth to Seasonal High Groundwater Below Bottom of Trench/Well[4]	The minimum depth to the seasonal high groundwater table below the trench or well.
Depth to Impermeable Layer Below Bottom of Trench/Well[4]	The depth to the first impermeable layer below the trench or well.
Depth and Type of Each Soil Layer Adjacent To and Below Trench/Well[4]	The order of stratification (from the surface downward) and the depth of each layer of soils at the BMP site.
Type and Gradation of Granular Materials Used in Trench/Well[4]	Describe the type and depth of granular material used in the trench or well.
Was Geotextile Used Above Granular Trench Fill? [4]	"Yes" or "no" indication of geotextile use above granular fill.
Was Geotextile Used On the Sides of Granular Fill? [4]	"Yes" or "no" indication of geotextile use on sides of granular fill.
Was Geotextile Used On the Bottom of Granular Fill? [4]	"Yes" or "no" indication of geotextile use below granular fill.
Give porosity (in percent) of the granular fill material[4]	The volumetric portion of the granular material that is not occupied by solid matter (expressed as a percent).
Total Storage Pore Volume in Trench[4]	The volume of the available pore space in the granular materials.
Describe Type of Geotextile Used[4]	Describe the types and locations of the geotextile fabrics used in the trench or well, if any. Include the effective pore opening of the fabrics.
Hydraulic Conductivity of Adjacent Soils[4]	The hydraulic conductivity of the soils adjacent to the trench or well infiltration surfaces.
Groundwater Flow Gradient[4]	The flow gradient of groundwater below the infiltration basin (expressed as unit length per unit length, e.g., feet/feet).
Purpose of Trench or Well	Describe the purpose of the percolation trench or well (e.g., water quality treatment, reduction of surface runoff, groundwater recharge, etc.).
Percolation Trench and Dry Well Construction Costs Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which cost estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.
Well Drilling	The estimated cost of establishing the well, if this is a dry well.

(Table continued on the following page)

Data Element	Description
Trench Construction Costs	The estimated cost of establishing the trenches, if this is a percolation trench.
Structural Control Devices Costs	The estimated cost of establishing all percolation trench or dry well control devices, such as inlet and outlet structures and culverts. Include the cost of materials and construction.
Structural Materials Costs	The estimated cost of materials used in the percolation trench, such as granular fill and geotextiles.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove sediment accumulated in the retention pond.

[4] – National Stormwater BMP Database requirement for all Percolation Trenches and Dry Wells

Form G

PERCOLATION TRENCH AND DRY WELL DESIGN DATA

Test Site Name ______________________

Watershed Name ______________ BMP Name ______________

Design Information

Percolation Trench/Well Surface Area __________

Percolation Trench/Well Length __________ Percolation Trench/Well Depth __________

Depth to Groundwater __________ Depth to Impermeable Layer __________

Depth and Type of Each Soil Layer

Type and Gradation of Granular Materials Used

Was geotextile fabric used above granular trench fill? ☐

Was Geotextile Used On the sides of granular fill? ☐

Was Geotextile Used On the Bottom of Granular Fill? ☐

Type of Geotextile Used, If Any

Porosity of Granular Material

Total Storage Volume __________

Hydraulic Conductivity of Soils __________

Groundwater Flow Gradient __________

Purpose of Trench or Well

Percolation Trench and Dry Well Construction Cost Estimates

Construction Costs: Year of Cost Estimate __________

Excavation __________ Well Drilling __________

Trench Construction __________ Structural Control Devices __________

Structural Materials __________ Engineering and Overhead __________

Land Costs or Value __________

Rehabilitative Costs:

Average Annual Sediment Removal __________

Media Filter Design Data

The media filter design data form contains design information related to the performance of media filters. A Media Filter is a facility that uses some form of granular or membrane filter, with or without a pre-settling basin, to remove a fraction of the constituents found in stormwater. The most typical filter is sand, but other materials, including peat mixed with sand, compost with sand, geotextiles, and absorption pads and beds are commonly used. The media filter form and data elements are presented in Table 3.18 and Form H.

Table 3.18: Media filter design form data elements list

Data Element	Description
Permanent Pool Volume Upstream of Filter Media, If Any[4]	Volume of the permanent pool (if any) if the pool is part of the filter basin installation and not a separate pretreatment retention pond or a detention basin.
Permanent Pool Surface Area of Sedimentation Basin Preceding Filter, If Any[4]	Area of the water surface in the permanent pool (if any).
Permanent Pool Length of Sedimentation Basin Preceding Filter, If Any[4]	Length of the permanent pool (if any) measured as the distance from pool inflow to outflow. If more than one inflow point, use the average length.
Surcharge Detention Volume, Including Volume Above Filter Bed[4]	The design water quality capture volume, including the volume above the filter.
Surcharge Detention Volume Surface Area[4]	The surface area of the design water quality captured runoff including the area above the filter.
Surcharge Detention Volume Length	The length of the design captured runoff volume, including the portion above the filter, measured as the distance along the flow path. If more than one inflow point, use the average length.
Surcharge Detention Volume's Design Drain Time, If Controlled and Known [4]	The design time for complete drawdown (in hours) of the water quality capture volume if the drain time is controlled by a flow regulating device such as an orifice. Leave blank if the drain rate is only a fraction of the filter's flow-through rate.
Surcharge Detention Volume Design Depth[4]	The design depth of water quality capture volume that can be stored above the filter before overflow or runoff bypass occurs.
Media Filter Surface Area[4]	Surface area of the media filter (e.g., the sand bed or geotextile filter) as a whole orthogonal to the flow.
Angle of Sloping or Vertical Filter[4]	Inclination of filter in degrees above the horizontal plane.
Number of Media Layers in Filter[4]	The number of layers of different filter materials in this BMP.
Describe Depth and Type of Each Filter Media Layer[4]	Describe the type of media used in the filter (Example: ASTM C-33 Sand with d_{50}=0.7 mm, 50% ASTM C-33 Sand with d_{50}=0.6 mm and 50% Peat).
Media Filter Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which the above estimates were made.

(Table continued on the following page)

Data Element	Description
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.
Basin Construction Costs	The estimated cost for construction of the media filter, including site survey and construction activities.
Filter Construction Costs	The estimated cost of establishing the filter system itself, including filter material and the underdrain system. Include costs of materials and construction.
Structural Control Devices Costs	The estimated cost of establishing all BMP control devices, such as inlet devices, trash racks, energy dissipaters, and outlet structures. Include costs of materials and construction.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative/ Maintenance Costs:	
Average Annual Sediment Removal and Media Replacement Costs	Estimated average annual cost to remove sediment accumulated in the media filter and replace the filter material.

[4] – National Stormwater BMP Database requirement for all Media Filters

Form H

MEDIA FILTER DESIGN DATA

Test Site Name ____________________

Watershed Name ____________________ BMP Name ____________________

Design Information

Permanent Pool Volume Upstream of Media Filter, If Any ____________

Permanent Pool's Surface Area ____________ Permanent Pool's Length ____________

Surcharge Detention Volume, Including Volume Above Filter Bed ____________

Surcharge Detention Volume Surface Area, Including Volume Above Filter Bed ____________

Surcharge Detention Volume's Length ____________

Surcharge Detention Volume's Design Depth ____________

Surcharge Detention Volume's Drain Time in Hours ______

Media Filter's Surface Area ____________

Angle of sloping or vertical filter media in degrees (0 to 90) ______

Number of Filter Layers ______

Type and Depth (or Thickness) of Each Filter Media Layer

Media Filter Construction Cost Estimates

Year of Cost Estimate ________

Construction Costs:

Excavation ____________ Basin Construction ____________

Filter Construction ____________ Structural Control Devices ____________

Engineering and Overhead ____________ Land Costs and Value ____________

Rehabilitative Costs:

Average Annual Sediment Removal and Media Filter Replacement Costs ____________

Grass Filter Strip Design Data

The grass filter strip form provides design information specific to grass filter strips. Grass filter strips, sometimes called buffer strips, are vegetated areas designed to accept sheet flow provided by flow spreaders which accept flow from an upstream drainage area. Vegetation may take the form of grasses, meadows, forests, etc. The primary mechanisms for pollutant removal are filtration, infiltration, and settling. The grass filter strip form and data elements are shown in Table 3.19 and Form I.

Table 3.19: Grass filter strip form data elements list

Data Element	Description
Grass Strip Length[4]	Length of the grass strip in the direction of the flow path.
Grass Strip Slope[4]	The slope of the strip along the flow path expressed as unit length per unit length (e.g., feet/feet).
Flow Depth during 2-Year Storm[4]	The design depth of flow over the strip during the 2-year storm peak flow.
2-Year Peak Flow Velocity[4]	The design flow velocity over the strip during the 2-year peak flow.
Describe Grass Species and Densities[4]	List of grass species and their densities.
Is Strip Irrigated?[4]	"Yes" or "no" indication of irrigation.
Estimated Manning's n During 2-Year Flow	The estimated Manning's roughness factor, n, during the 2-year flow event.
Depth to Groundwater or Impermeable Layer	Depth to the seasonal high groundwater table and/or the impermeable layer, whichever is shallower.
Measured Saturated Infiltration Rate, if Known	Rate of infiltration into the filter strip under saturated soil conditions.
NRCS Hydrologic Soil Group	The Natural Resource Conservation Service Hydrologic Soil Group (e.g., A, B, C, or D) comprising the infiltrating surface.
Grass Filter Strip Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which the above estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.
Structural Control Devices Costs	The estimated cost of establishing all BMP control devices, such as slotted curbing or other flow spreading devices, and outflow collection and conveyance systems. Include costs of materials and construction.
Vegetation and Landscaping Costs	The estimated cost of establishing vegetation for the BMP, including acquiring landscape materials, establishing vegetation, and establishing the irrigation infrastructure, if any.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove sediment accumulated on the grass filter strip.
Average Annual Revegetation Costs	Estimated average annual cost to revegetate and/or reseed the grass filter strip.

[4] – National Stormwater BMP Database requirement for all Grass Filter Strips

Form I

GRASS FILTER STRIP DESIGN DATA

Test Site Name ____

Watershed Name ____________________ BMP Name ____________________

Design Information

Grass Strip's Length __________ Longitudinal Slope _______

Flow Depth during 2-Year Storm __________ 2-Year Peak Flow Velocity __________

Grass Species and Densities

Is Strip Irrigated? ☐

Manning's n During 2-year Flow _______

Depth to Groundwater __________

Saturated Infiltration Rate __________

Soil Group _____

Percolation Trench and Dry Well Construction Cost Estimates

Year of Cost Estimate ______

Construction Costs:

Excavation __________ Structural Control Devices __________

Vegetation and Landscaping __________ Engineering and Overhead __________

Land Costs or Value __________

Rehabilitative Costs:

Average Annual Sediment Removal Costs __________

Average Annual Revegetation Costs __________

Wetland Channel and Swale Design Data

The purpose of the wetland channel and swale design form is to consistently collect and report wetland channel and swale information. A wetland channel is a channel designed to flow very slowly, probably less than two feet per second at the two-year flood peak flow rate. It has, or is designed to develop, dense wetland vegetation on its bottom. A swale is a shallow grass-lined channel designed for shallow flow near the source of storm runoff. The wetland channel and swale form and data elements are provided in Table 3.20 and Form J.

Table 3.20: Wetland channel and swale form data elements list

Data Element	Description
Average Longitudinal Inflow Spacing	The average longitudinal spacing between all separate stormwater inflow points.
Length of Channel/Swale[4]	The length of the wetland channel or swale, from the stormwater inflow to outflow point.
Longitudinal Slope of Channel/Swale[4]	The average longitudinal slope (in unit length per unit drop, e.g., feet per feet or meter per meter) of the wetland channel or swale, as measured between grade control structures.
Bottom Width of Channel/Swale[4]	The average width of the nearly flat bottom of the channel or swale between its side slopes.
Side Slope of Channel/Swale[4]	The average (in vertical unit length per horizontal unit length) of the channel or swale's side slopes.
2-Yr Flow Design Depth in Channel/Swale[4]	The average depth of water in the channel or swale during the two-year flood peak flow.
2-Yr Peak Design Flow Velocity[4]	The flow velocity in the channel or swale during the two-year flood peak flow.
2-Yr Manning's n	The Manning's roughness factor, n, for the 2-year peak flow.
Type of Plant Species in Wetland Zone or Swale[4]	List the plant species, percent of cover and densities.
Maximum Design Flow Capacity Return Period of Swale	The flood return period that the channel has been designed to convey within its banks in addition to the water quality design event. (Example: 2-year and 10-year flood).
Depth to High Groundwater or Impermeable Layer	The minimum depth to the water table during the high water table season, or to the first impermeable layer.
Groundwater Hydraulic Conductivity	The hydraulic conductivity of the groundwater below the channel or swale.
Wetland Channel and Swale Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which cost estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.
Structural Control Devices Costs	The estimated cost of establishing all wetland channel or swale control devices, such as inlet and outlet devices, trash racks, etc. Include the cost of materials and construction.

(Table continued on the following page)

Data Element	Description
Vegetation and Landscaping Costs	The estimated cost of establishing vegetation for the BMP, including acquiring landscape materials, establishing vegetation, and establishing the irrigation infrastructure, if any.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove sediment accumulated in the swale/wetland channel.
Average Annual Revegetation Costs	Estimated average annual cost to revegetate the sides and floor of the swale/wetland channel.

[4] – National Stormwater BMP Database requirement for all Wetland Channels/Swales

Form J

WETLAND CHANNEL AND SWALE DESIGN DATA

Test Site Name ____________________

Watershed Name ____________________ BMP Name ____________________

Design Information

Length of Channel/Swale ____________ Bottom Width of Channel/Swale ____________

Side Slope of Channel/Swale ____________ Longitudinal Slope of Channel/Swale ____________

Average Longitudinal Inflow Spacing ____________

2-Year Flow Design Depth in Channel/Swale ____________

2-Year Peak Design Flow Velocity ____________ 2-Year Manning's n ____________

Depth to High Groundwater ____________ Groundwater Hydraulic Conductivity ____________

Plant Species in Wetland Zone/Swale

Design Flow Return Periods

Wetland Channel and Swale Construction Cost Estimates

Year of Cost Estimate ________

Construction Costs:

Excavation Costs ____________ Control Devices ____________

Vegetation ____________ Engineering and Overhead ____________

Land ____________

Rehabilitative Costs:

Sediment Removal ____________

Revegetation ____________

Porous Pavement Design Data

The porous pavement form provides design information particular to porous pavement BMPs. There are two forms of porous pavement: modular block, which is made porous through its structure, and poured-in-place concrete or asphalt which is porous due to the mix of the materials. Modular block porous pavement consists of perforated concrete slab units underlain with gravel. The surface perforations are filled with coarse sand or sandy turf. It is used in low traffic areas to accommodate vehicles while facilitating stormwater runoff at the source. It should be placed in a concrete grid that restricts horizontal movement of infiltrated water through the underlying gravels. Poured-in-place porous concrete or asphalt is generally placed over a substantial layer of granular base. The pavement is similar to conventional materials, except for the elimination of sand and fines from the mix. If infiltration to groundwater is not desired, a liner may be used below the porous media along with a perforated pipe and a flow regulator to slowly drain the water stored in the media over a 6 to 12 hour period. The porous pavement design form and data elements are given in Table 3.21 and Form K.

Table 3.21: Porous pavement form data elements

Data Element	Description
Porous Pavement Surface Area[4]	Surface area of the porous pavement.
Depth to Seasonal High Groundwater[4]	The minimum depth to the seasonal water table below the porous pavement.
Depth to Impermeable Layer[4]	The depth to the first impermeable layer below the BMP, if known.
NRCS Hydrologic Soil Group	The Natural Resource Conservation Service Hydrologic Soil Group (e.g., A, B, C, or D) comprising the infiltrating surface.
Infiltration Rate[4]	Rate of infiltration for site soils under saturated conditions.
Type of Granular or Other Materials Used in or Below Pavement[4]	Describe the type and depth of each granular material layer under the porous pavement, if any. Include each layer of geotextile fabric used as though it was a granular layer.
Porosity of Granular Materials, as a Percent[4]	Porosity measures the volumetric portion of the filter material that is not occupied by solids. If the layer is geotextile fabric, give the effective pore size.
Is Grass Growing in Modular Pores?	“Yes” or “No” indication of grass growing in modular pores.
If Yes, is Grass Healthy?	“Yes” or “No” indication of grass health, if applicable.
Describe Depth of Each Soil Layer Below Pavement, If Known	The order of stratification (from the surface downward) and the depth of each layer of soils below the porous pavement, to a depth of at least ten feet (3.05 meters).
Total Storage Volume Above Pavement, If Any[4]	The volume of water stored in depressions or as a result of attenuation (if any) above the porous pavement surface.
Estimated Drain Time (hrs) of Storage Volume Above Pavement, If Any[4]	The emptying time of the storage volume above the pavement.
Total Storage Volume Under Pavement, If Any[4]	The net available volume of the pore spaces in the granular materials under the porous pavement, if any.
Estimated Drain Time of Storage Volume Under Pavement, If Any[4]	The total emptying time (in hours) for the storage detention volume under the pavement.

(Table continued on the following page)

Data Element	Description
Groundwater Hydraulic Conductivity	The hydraulic conductivity of the groundwater underlying the BMP.
Groundwater Flow Gradient	The flow gradient (in unit length per unit length, e.g. feet/feet) of groundwater below the infiltration basin.
Does Porous Pavement Have Underdrains?[4]	"Yes" or "No" indication of underdrains for the porous pavement.
Describe Purpose of Porous Pavement	Describe the purpose(s) of the porous pavement (examples: water quality treatment, reduction in peak surface runoff rate and volume, groundwater recharge, etc.)
Porous Pavement Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which cost estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.
Structural and Piping Costs	The estimated cost of establishing the structural and piping features of the BMP, including modular blocks, retaining concrete, sub-base material, and inlay material. Include costs of materials and construction.
Granular Fill Costs	The estimated cost of establishing the granular fill for the BMP, including sand or gravel inlay materials, filter fabric, and perforated underdrain (if any). Include costs of materials and construction.
Paving Costs	If poured-in-place porous concrete or asphalt paving was used, this is the estimated cost of establishing the paving. Include costs of materials and construction.
Curb and Gutter Costs	The estimated cost of establishing curbs and gutters for the BMP. Include costs of materials and construction.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative/ Maintenance Costs:	
Average Annual Vegetation Replacement and Granular Media Replacement and Maintenance Costs	Estimated average annual cost to revegetate void spaces in modular block pavement. If poured-in-place porous pavement, report estimated average annual cost to wash, vacuum, pressure wash, patch, gutter clean, etc. at a frequency that ensures the continued function of the BMP.

[4] – **National Stormwater BMP Database requirement for all Porous Pavement**

Form K

POROUS PAVEMENT DESIGN DATA

Test Site Name ______________________________

Watershed Name ____________________ BMP Name ____________________

Design Information

Porous Pavement Surface Area ______________ Depth to Groundwater ______________

Depth to Impermeable Layer ______________ NRCS Hydrologic Soil Group ________

Infiltration Rate ______________

Type of Granular or Soil Materials Used in or Below Pavement

Porosity of Granular or Soil Materials

Is grass growing in modular pores? ______ If yes, is grass healthy? ______

Total Storage Volume Above Pavement, If Any ______________

Estimated Drain Time of Storage Volume Above Pavement, If Any ____________

Total Storage Volume in the Granular Media Below Pavement ______________

Estimated Drain Time of Porous Media Volume ____________

Groundwater Hydraulic Conductivity ______________

Groundwater Flow Gradient __________

Does porous pavement have underdrains? ______

Depth of Each Soil Layer Below Pavement

Purpose of Basin Above Pavement

Porous Pavement Construction Cost Estimates

Construction Costs: Year of Cost Estimate ____________

Excavation ____________ Granular Fill ____________ Paving ____________

Structural and Piping ____________ Curb and Gutter ____________

Land Costs and Value ____________ Engineering and Overhead ____________

Rehabilitative Costs:

Average Annual Vegetation Replacement and Granular Media Replacement Costs __________

Infiltration Basin Design Data

The infiltration basin form reports important design information for infiltration basins. An infiltration basin is a basin that can capture a given stormwater runoff volume and infiltrate it into the ground, transferring this volume from surface flow to groundwater flow. The infiltration basin form and data elements are listed in Table 3.22 and Form L.

Table 3.22: Infiltration basin form data elements list

Data Element	Description
Capture Volume of Basin[4]	The design runoff capture volume of the basin.
Surface Area of Capture Volume, When Full[4]	The area of the water surface in the infiltration basin, when full.
Infiltrating Surface Area[4]	The plan area of the surface used to infiltrate the water quality volume.
Basin Length	Length of the infiltration basin, measured as the distance between inflow and outflow.
Depth to Seasonal High Groundwater Below Infiltrating Surface[4]	Depth to the seasonal high groundwater table.
Depth to Impermeable Layer Below Infiltrating Surface[4]	Depth to the impermeable layer, if any.
NRCS Hydrologic Soil Group	The Natural Resource Conservation Service Hydrologic Soil Group (e.g., A, B, C, or D) comprising the infiltrating surface.
Depth and Type of Each Layer of Soil	The order of stratification (from the surface downward) and the depth of each layer of soils at the infiltration basin site, to a depth of at least ten feet (3.05 meters).
Field Measured Infiltration Rate	The saturated soil infiltration rate, based on soil surveys, infiltrometer measurements or observed draw down of a new basin.
List Plant Species on Infiltrating Surface[4]	List the plant species (by Latin names, if known) and densities of cover on the bottom of the infiltration basin.
Describe Granular Material on Infiltrating Surface, If Any[4]	Describe the granular material and its depth and porosity (if any).
Hydraulic Conductivity of Underlying Soils	The hydraulic conductivity of the soils underlying the infiltration surface.
Groundwater Flow Gradient	The flow gradient (in unit length per unit length, e.g. feet/feet) of groundwater below the infiltration basin.
Flood Control Volume Above Water Quality Detention Volume	The volume of the flood control detention volume above the infiltration basin volume.
List All Design Flood Control Return Periods	List the flood return period (in years) for which the flood control volume is designed (e.g., 25-year).
Describe Purpose of Basin	Describe the purpose of the infiltration basin (e.g., surface water quality only, groundwater recharge, etc.).
Infiltration Basin Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which cost estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.

(Table continued on the following page)

Data Element	Description
Structural Materials Costs	The estimated cost of materials used in constructing the infiltration basin, excluding vegetative cover.
Basin Construction Costs	The estimated cost for construction of the infiltration basin, including site survey and construction activities.
Structural Control Devices Costs	The estimated cost of establishing all BMP control devices, such as inlet devices, trash racks, energy dissipators, and outlet structures. Include costs of materials and construction.
Vegetation and Landscaping Costs	The estimated cost of establishing vegetation for the infiltration basin, including acquiring landscape materials, establishing vegetation, and establishing the irrigation infrastructure, if any.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative/ Maintenance Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove sediment accumulated in the infiltration basin.
Average Annual Revegetation Costs	Estimated average annual cost to revegetate the infiltration basin.

[4] – National Stormwater BMP Database requirement for all Infiltration Basins

Form L

INFILTRATION BASIN DESIGN DATA

Test Site Name ______________________

Watershed Name ______________ BMP Name ______________

Design Information

Capture Volume of Basin ____________ Basin Length ____________

Surface Area of Capture Volume When Full ____________

Infiltrating Surface Area ____________

Depth to Groundwater ____________ Depth to Impermeable Layer ____________

Soil Group ________

Depth and Type of Each Soil Layer Below Basin

Infiltration Rate ____________

Flow Gradient ____________

Hydraulic Conductivity of Underlying Soils ____________

Plant Species on Infiltrating Surface

Granular Material on Infiltrating Surface

Design Flood Control Return Periods

Purpose of Basin

Flood Control Volume above Water Quality Detention Volume: ____________

Infiltration Basin Construction Cost Estimates

Construction Costs:

Year of Cost Estimate ____________

Excavation ____________

Basin Construction ____________

Structural Materials Cost ____________

Vegetation and Landscaping ____________

Structural Control Devices ____________

Land Costs and Value ____________

Engineering and Overhead ____________

Rehabilitative Costs:

Average Annual Sediment Removal ____________

Average Annual Revegetation ____________

Hydrodynamic Device Design Data

The hydrodynamic device form provides important design criteria specific to hydrodynamic devices. The hydrodynamic device BMP category includes BMPs such as oil-water separators, sand interceptors, swirl-type concentrators, sedimentation vaults, and other prefabricated and package-type treatment devices. The hydrodynamic device form and data elements are provided in Table 3.23 and Form M.

Table 3.23: Hydrodynamic device form data elements

Data Element	Description
Volume of Permanent Pool[4]	Volume of the permanent pool (dead pool) of water.
Permanent Pool Surface Area[4]	Area of the water surface in the permanent pool (dead pool).
Permanent Pool Length[4]	Length of the permanent pool of water, measured as the distance between inlet and outlet. If more than one inlet location, use the average distance between the inlet location and the outlet location.
Water Quality Surcharge Detention Volume When Full[4]	The surcharge detention volume above the permanent pool volume (device active storage volume).
Inlet Chamber Volume, If Any[4]	Volume of the inlet chamber portion of the hydrodynamic device when it is filled to the point of overflow into the lower (next) part of the device.
Brim-full Emptying Time For Surcharge[4]	Time (in hours) required for the hydrodynamic device water quality surcharge detention volume to be released from the outlet discharge.
Half Brim-full Emptying Time For Surcharge[4]	Time (in hours) required for the lower half of the hydrodynamic device water quality surcharge detention volume to be discharged from the outlet.
Comments.	This field can be used for comments and other miscellaneous information such as model type and related manufacturer's specifications for design.
Hydrodynamic Device Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which cost estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring, and backfilling.
Structural Materials Costs	The estimated cost of materials such as gravel, pavement and vegetation necessary for the installation of the hydrodynamic device. These costs should include installation costs but exclude the cost of the device itself.
Device Construction Costs	The estimated cost for supply, construction, and installation of the hydrodynamic device, including site survey and construction activities.
Structural Control Devices Costs	The estimated cost of establishing all hydrodynamic device control devices, such as inlet and outlet structures (manholes), spillways, pipelines and culverts. Include the cost of materials and construction.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove oils, sediments, and trash accumulated in the hydrodynamic device.

[4] – National Stormwater BMP Database requirement for all Hydrodynamic Devices

Form M

HYDRODYNAMIC DEVICE DESIGN DATA

Test Site Name ______________________________

Watershed Name ______________ BMP Name ______________

Design Information

Volume of Permanent Pool ______________

Permanent Pool Surface Area ______________ Permanent Pool Length ______________

Water Quality Surcharge Detention Volume When Full ______________

Brim-full Emptying Time for Surcharge Detention Volume ______________

Half Brim-full Emptying Time for Surcharge Detention Volume ______________

Forebay Volume ______________

Comments

Hydrodynamic Device Construction Cost Estimates

Year of Cost Estimate ______________

Construction Costs:

Excavation ______________ Structural Materials Cost ______________

Basin Construction ______________ Structural Control Devices ______________

Engineering and Overhead ______________ Land Costs and Value ______________

Rehabilitative Costs:

Average Annual Sediment Removal ______________

Wetland Basin Design Data

The wetlands basin form provides important design information specific to wetland basins. A wetland basin is a BMP similar to a retention pond (with a permanent pool of water) with more than 50% of its surface covered by emergent wetland vegetation, or similar to a detention basin (no significant permanent pool of water) with most of its bottom covered with wetland vegetation. The wetland basin data form and data elements list are shown in Table 3.24 and Form N.

Table 3.24: Wetland basin form data elements list

Data Element	Description
Volume of permanent pool[4]	Volume of the permanent pool of water, if any.
Permanent Pool Surface Area[4]	Area of the water surface in the permanent pool, if any.
Permanent Pool Length[4]	Length of the permanent pool of water, measured at the water surface along the axis of the inflow and outflow. If more that one inflow point, use the average distance between the inflow points and the outflow weighted by the tributary impervious area.
Water Quality Surcharge Detention Volume When Full[4]	The water quality surcharge detention volume above the permanent volume (when full).
Water Quality Surcharge Surface Area When Full[4]	The surface area of any supplementary water quality detention volume above the permanent pool, if applicable.
Water Quality Surcharge Basin Length [4]	Length of the water quality detention volume, measured at the water surface along the axis of the inflow and outflow. If more that one inflow point, use the average distance between the inflow points and the outflow weighted by the tributary impervious area.
Brim-full Emptying Time For Surcharge [4]	Time (in hours) required for the wetland basins water quality surcharge detention volume to be released to the permanent pool.
Half Brim-full Emptying Time For Surcharge [4]	Time (in hours) required for the lower half of the water quality surcharge detention volume to be released to the permanent pool.
Forebay Volume [4]	Volume of the forebay portion of the wetland basin when it is filled to the point of overflow into the rest of the basin.
Forebay Surface Area [4]	Surface area of water in the forebay when it is filled to the point of overflow into the rest of the basin.
Describe Vegetation Cover Within Basin [4]	Describe the types of vegetation on the basin sides and floor.
Flood Control Volume, If Any [4]	The volume of the flood control detention volume above the wetland basin volume.
Design Flood Return Periods [4]	List the flood return period (in years) for which the flood control volume is designed (e.g., 25-year).
Wetland Surface Area [4]	Surface area of the wetland basin, including all pond areas and meadow wetland areas. Use permanent pool surface area if no other wetland area exists adjacent to the pool.

(Table continued on the following page)

Data Element	Description
Percent of Wetland Pond with 12 inches (0.3 m) Depth [4]	Percent of the wetland basin's surface area typically having 12 inches (0.3 m) or less water depth.
Percent of Wetland Pond with 12 - 24" (0.3 – 0.6 m) Depth [4]	Percent of the wetland basin's surface area typically having 12 to 24 inches (0.3 - 0.6 m) water depth.
Percent of Wetland Pond with 24 - 48" (0.6 – 1.3 m) Depth [4]	Percent of the wetland basin's surface area typically having 24 to 48 inches (0.6 - 1.3 m) water depth.
Percent of Wetland Pond with > 48" (> 1.3 m) Depth	Percent of the wetland basin's surface area typically having greater than 48 inches (> 1.3 m) water depth.
Percent of wetland basin's area that is meadow wetland [4]	Percent of the wetland basin that is meadow area, that is, area without standing water.
List All Known Plant Species in the Wetland [4]	Type and percent cover of the wetland basin by each wetland species, and densities.
Wetland Basin Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which the above estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.
Structural Materials Costs	The estimated cost of materials used in the wetland basin, such as imported topsoil or fill.
Basin Construction Costs	The estimated cost of establishing the wetland basin itself, not including vegetation costs.
Structural Control Devices Costs	The estimated cost of establishing all wetland basin control devices, such as inlet and outlet devices, trash racks, etc. Include the cost of materials and construction.
Vegetation and Landscaping Costs	The estimated cost of establishing vegetation for the BMP, including acquiring landscape materials, establishing vegetation, and establishing the irrigation infrastructure, if any.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove sediment accumulated in the wetland basin.
Average Annual Revegetation Costs	Estimated average annual cost to revegetate the sides and floor of the wetland basin.

[4] – National Stormwater BMP Database requirement for all Wetland Basins

Form N

WETLAND BASIN DESIGN DATA

Test Site Name ______________________________

Watershed Name ____________________ BMP Name ____________________

<u>Design Information</u>

Volume of Permanent Pool ______________

Permanent Pool Surface Area ______________

Permanent Pool Length ______________

Water Quality Surcharge Detention Volume ______________

Water Quality Surcharge Surface Area, ______________

Water Quality Surcharge Basin Length, When Full ______________

Brim-full Emptying Time ________ Half Brim-full Emptying Time ________

Forebay Volume ______________ Forebay Surface Area ______________

Flood Control Volume ______________ Design Flood Return Periods

Wetland Surface Area ______________

% of Pond 12" (0.3m) Deep Depth ______ % of Pond with 12" - 24" (0.3-0.6m) Depth ______

% of Pond with 24" to 48" (0.6-1.3 m) Depth ______ % of Pond with >48" (1.3m) Depth ______

% of Wetland Basin Area Without Standing Water ______

Plant Species in the Wetland

<u>Wetland Basin Construction Cost Estimates</u>

Year of Cost Estimate __________

Construction Costs:

Excavation __________ Structural Materials __________

Basin Construction __________ Structural Control Devices __________

Vegetation and Landscaping __________ Engineering and Overhead __________

Sheet 1 of 2

WETLAND BASIN DESIGN DATA

Land Costs and Value ______________

Rehabilitative Costs:

Average Annual Sediment Removal ______________

Average Annual Revegetation ______________

Sheet 2 of 2

Monitoring Station Information

Monitoring station information is requested for both structural and non-structural BMPs in a test site. The monitoring station information form contains information on monitoring station locations, instrumentation, and monitoring costs. More than one instrument may be present in a monitoring station. For example, a monitoring station may contain a flow gauge and a water quality sampler. A single form should be filled out for each individual monitoring station at the site. The monitoring station form and data elements list are provided in Table 3.25 and Form O.

Table 3.25: Monitoring station form data elements

Data Element	Description
Monitoring Station Information	
Monitoring Station Name[1]	User-defined name for subject monitoring station.
Identify Upstream BMP[1]	BMP upstream of the monitoring point (if any).
Identify Relationship to Upstream BMP[1]	Identify Relationship to Upstream BMP. These may include inflow, outflow, bypass, intermediate or not applicable.
Identify Downstream BMP[1]	BMP downstream of the monitoring point (if any).
Identify Relationship to Downstream BMP[1]	Identify Relationship to Downstream BMP. These may include inflow, outflow, bypass, intermediate or not applicable.
Site Monitoring Instrumentation	
Select monitoring station where instrument is located[1]	A monitoring station that contains the instrument must be selected or defined before entering data on specific instruments.
What date was the instrument installed?	Provide the date (month, day and 4-digit year) the instrument was installed (e.g., 6/1/1998).
What type of instrument is in place?	The instrument type at the monitoring station. These may include a Bubble Gauge, Digital Recorder, Graphic Recorder, Land Line Telemetered, Radio Telemetered, Satellite Relayed, ADHAS, Crest Stage Indicator, Tide Gauge, Deflection Meter, Stilling Well, CR Type Recorder, Weighing Rain Gauge, Tipping Bucket Rain Gauge, Acoustic Velocity Meter, or Electromagnetic Flow Meter, Pressure Transducer, Unknown or Other.
What type of monitoring is conducted?	The type of data collected by the instrument based on U.S. Geological Survey (USGS) code. Data types may include: Tide, Water Flow/Stage Continuous, Water Flow/Stage Intermittent, Water Quality Continuous, Water Quality Grab, Precipitation Continuous, Precipitation Intermittent, Evaporation Continuous, Evaporation Intermittent, Wind Velocity Continuous, Wind Velocity Intermittent, Tide Stage Continuous, Tide Stage Intermittent, Water Quality Probe Continuous, Water Quality Probe Intermittent, Unknown, or Other.
What type of control structure is in place, if any?	Type of control structure in place at the monitoring station (i.e. 90-degree V-notched weir, etc.).
Additional Comments	May be necessary to explain special features associated with the instrument or other information deemed important to the user.
Site Monitoring Costs	
Number of years in which monitoring was conducted	The number of years over which the monitoring station was in operation

(Table continued on the following page)

Data Element	Description
Comments	May be needed to clarify unusual monitoring costs or other details as deemed appropriate by the user.
Fixed Monitoring Station Costs	Those costs associated with fixed monitoring instrumentation installed for long-term use. For example, a shed may be constructed to house the instrumentation. Year of cost basis, equipment, maintenance, sampling and laboratory costs are requested for fixed monitoring stations.
Temporary Monitoring Station Costs	Costs associated with temporary monitoring instruments not intended for long-term use. Year of cost basis, equipment, sampling and laboratory costs are requested for temporary monitoring stations.
Year of Cost Basis	Year that the monitoring activities were conducted or equipment purchased.
Equipment Costs	Costs of sampling and flow gauging equipment (rental or purchase) and installation in U.S. currency.
Maintenance Costs	Annual maintenance costs for equipment in U.S. currency.
Sampling Costs	Annual costs of sampling in U.S. currency.
Laboratory Costs	Annual costs of sample analysis by a laboratory.

[1] – National Stormwater BMP Database requirement for all BMPs

Form O

MONITORING STATION INFORMATION

Site Name

BMP Name __________

Monitoring Station Information

Monitoring Station Name __________

Upstream BMP Name __________ Relationship to Upstream BMP __________

Downstream BMP __________ Relationship to Downstream BMP __________

Site Monitoring Instrumentation

Date of Installation __________

Instrument Type __________ Data Type __________

Type of Control Structure __________

Additional Comments

Site Monitoring Costs

Number of Years Monitoring Conducted __________

Year of Cost Basis (Fixed Station) __________

Equipment Costs __________ Sampling Costs __________

Maintenance Costs __________ Laboratory Cost __________

Year of Cost Basis (Temporary Station) __________

Equipment Costs __________ Sampling Costs __________

Laboratory Cost __________

Comments

Precipitation Data

The precipitation form contains important precipitation data, which can be used for evaluating the performance of BMPs under various conditions. Precipitation information requested includes data such as time and date that the event began and ended, total depth and one-hour peak precipitation rate. The precipitation data form and data elements list are provided in Table 3.26 and Form P.

Table 3.26: Precipitation Form Data Elements

Data Element	Description
Event ID	User provided name or identifier for the precipitation event.
Select Monitoring Station for Event[1]	Monitoring station name where the precipitation event was monitored.
Start Date	Calendar date (month, day and 4-digit year) that storm started (e.g., 01/01/1998).
Start Time	Time that the storm started, e.g., 21:00. If only storm duration is available, record 00:00 for start time and enter the storm duration for end time.
End Date	Calendar date (month, day and 4-digit year) that storm ended (e.g., 01/01/1998). Use six hours as the separation criteria to define a new storm.
End Time	Time that the storm ended, e.g., 13:21. If only storm duration is available, record 00:00 for start time and enter the storm duration for end time.
Total Storm Precipitation	Amount of precipitation that occurred during the storm. For example, a total of 4 inches of rain fell during a 12-hour storm.
Peak One Hour Precipitation Rate	The most intense one-hour of rainfall for the storm. For storms with less than one-hour duration, divide the storm rainfall depth by one hour.

[1] – National Stormwater BMP Database requirement for all BMPs

Form P

WATER QUALITY INFORMATION

BMP Test Site

Watershed

Monitoring Station ____________________

Station Type ________________________________

Sample Type ________________________________ Number of Samples, If Composite ____

QA/QC Description ____

Comments

Sample ID	Sample Date	Sample Time	Related Flow Event	STORET Parameter	Value	Qualifier	Analysis Method

Flow Data

The flow data form provides on-site stormwater runoff information. Accurate flow data coupled with water quality information can be used to estimate removal efficiencies for BMPs, providing a relative measure of a BMP's ability to remove certain pollutants. The flow data form contains information on the date and time of the beginning and end of the flow event and total flow volumes and peak flow rates for runoff and baseflow. Each flow event should have a related precipitation event recorded on the precipitation form. The flow form and data elements list are provided in Table 3.27 and Form Q.

Table 3.27: Flow form data elements

Data Element	Description
Monitoring Station[1]	Provide monitoring station where flow event was monitored.
Select the type of flow[1]	The type of flow: base flow or storm runoff.
If storm runoff, select the related precipitation event, if available[1]	The start-date of the precipitation event associated with the current flow event.
Flow Start Date[1]	Date (month, day and 4-digit year) that the measurement began being taken (e.g., 01/01/1998).
Flow Start Time	Time at beginning of measurement event, e.g., 23:30. If only flow duration is provided, enter 00:00 for start time and enter the flow duration for end time.
Flow End Date	Date (month, day and 4-digit year) that the measurement event ended (e.g., 01/01/1998). The end of runoff event can be defined as that point in time when the recession limb of the hydrograph is <2% of the peak or is within 10% of the pre-storm base flow, whichever is greater.
Flow End Time	Time at the end of the measurement event, e.g., 01:30. The end of runoff event can be defined as that point in time when the recession limb of the hydrograph is <2% of the peak or is within 10% of the pre-storm base flow, whichever is greater.
Total Storm Flow Volume into or from BMP[1]	Total Runoff Volume minus the Bypass Volume.
Peak Storm Flow Rate into or from BMP	Greatest rate of storm flow into or from the BMP.
Total Bypass Volume, if any[1]	Total Runoff Volume minus the Runoff Volume Influent to the BMP.
Peak Bypass Flow Rate, if any	Peak rate of flow measured for flows bypassing the BMP.
Dry Weather Base Flow Rate[1]	Flow rate during dry-weather conditions. Base flow is collected during non-wet weather conditions.

[1] – National Stormwater BMP Database requirement for all BMPs

Form Q

FLOW INFORMATION

BMP Name

Watershed Name ______________________

Monitoring Station Name ______________________

Flow Start Date	Flow Start Time	Type of Flow: Runoff or Base Flow	Related Precipitation Event	Flow End Date	Flow End Time	Total Flow Volume	Peak Flow Rate	Total Bypass	Peak Bypass Flow Rate	Dry Weather Base Flow Rate

Water Quality Data

The water quality sampling event form provides the general information for a water quality sampling event such as date, time, location, and QA/QC measures used for a study. Provided water quality information must have associated flow and precipitation information recorded on the precipitation and flow forms. The water quality data form and data elements list are provided in Table 3.28 and Form R.

Table 3.28: Water quality form data elements

Data Element	Description
Sample ID	User provided name or identifier for the water quality sample.
Select Monitoring Station Where Data Collected[1]	Monitoring station name where the data was collected.
Related Flow Event[1]	Flow event associated with the water quality sampling event.
Date Water Quality Sample Collected[1]	Date that the water quality sample began being collected.
Time Water Quality Sample Collected	Time that the water quality sample began being collected.
What medium does the instrument monitor? [1]	Groundwater, Surface Runoff/Flow, Soil, Dry Atmospheric Fallout, Wet Atmospheric Fallout, Pond/Lake Water, Accumulated Bottom Sediment, Biological, or Other.
What type of samples are collected?[1]	The type of samples that the instrument collects, including: Flow Weighted Composite EMCs (Event Mean Concentrations), Time Weighted Composite EMCs, Unweighted (mixed) Composite EMCs, or Grab Sample.
Provide the Number of Samples, If Composite	The number of samples collected or mixed (if composite).
Describe Quality Assurance/Quality Control Measures in Place for the Sampling Event	Describe the types of Quality Assurance/Quality Control (QA/QC) measures in place for both laboratories and field activities.
Provide Additional Comments, If Needed	Discuss special circumstances associated with the sampling event.
Water Quality Parameter (STORET)[1]	The STORET name for the U.S. Environmental Protection Agency's STORET water quality database for streams and other waterbodies throughout the United States.
Value[1]	Value of the measured constituent should be provided. If the value is below detection limits, provide the reported detection limit with a "U" qualifier in the qualifier field and place a minus sign in front of the value.
Unit[1]	Unit of the measured constituent should be provided.
Qualifier[1]	Numerical STORET qualifier associated with a data point.
Analysis Method	Analysis Method should be provided for the constituent. For example EPA 8270 or Standard Method 513.

[1] – National Stormwater BMP Database requirement for all BMPs

Form R

WATER QUALITY INFORMATION

BMP Test Site

Watershed

Monitoring Station ______________

Station Type ______________

Sample Type ______________ **Number of Samples, if Composite** ___

QA/QC Description ______________

Comments

Sample Date	Sample Time	Related Flow Event	STORET Parameter	Value	Qualifier	Analysis Method

3.4.3.3 On-line Information

Forms and field descriptions can be printed from the world-wide-web at www.bmpdatabase.org. Each set of forms is subcategorized into its subsequent BMP type. Each folder contains all of the necessary forms and information needed for monitoring and reporting for a particular BMP type. BMP categories include:

• Non-Structural BMPs. • Detention Basins. • Retention Ponds. • Percolation Trenches and Dry Wells. • Media Filters. • Grass Filter Strips.	• Wetland Channels and Swales. • Porous Pavement. • Infiltration Basins. • Hydrodynamic Devices. • Wetland Basins.

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INDEX

APPENDIX A
ERROR ANALYSIS

Estimating flow in a pipe or open channel is generally accomplished by measuring two or more variables and relating them with an equation to calculate the flow. The continuity equation relates flow to area and velocity:

$$Q = A \times v \tag{A.1}$$

where,

A: Area
v: Velocity

For a rectangular channel, the cross-sectional area can be calculated as the water depth multiplied by the width of the channel.

$$A = H \times w \tag{A.2}$$

where,

H: Depth
W: Width

Velocity can be directly measured with a mechanical current meter or Doppler technology. Estimating flow in the rectangular channel requires three measured variables; each will have an error associated with it:

$$Q = H \times w \times v \tag{A.3}$$

For depth and width measurements, the accuracy will usually be expressed as absolute error governed by the tolerance of the measuring device (i.e. measured depth $\pm$ X cm). For velocity, the error in measurement will most likely be a relative error expressed as a percent of the measured value (i.e. measured velocity $\pm$ X %). The total error in the calculated flow measurement will include all of the errors associated with the individual measurements as illustrated in the following example:

Equipment tolerances provided by manufacturers generally are based on laboratory data under ideal conditions (e.g. steady state, laminar flow), which may not be representative of installed conditions. A recent USGS study compared several flow monitoring devices designed specifically for stormwater application, and found the error in the observed measurements ranged from 12 to 28 percent.

The actual error is most likely somewhat less than the maximum error and mathematical formulas have been described by Taylor (1997), which describe how error propagates when variables (with associated errors) are combined.

If variables x_i (for I=1 to n) are measurements with small but known uncertainties δx_i and are used to calculate some quantity q, then δx_i cause uncertainty in q as follows.

If q is a function of one variable, $q(x_1)$, then

$$dq = \left|\frac{dq}{dx_1}\right| dx_1 \tag{A.4}$$

If q is the sum and/or difference of x_is then

$$dq = \left[\sum_{i=1}^{n} (dx_i)^2\right]^{1/2} \quad \text{(for independent random errors)} \tag{A.5}$$

Estimates of δq from Equation A.2 are always less than or equal to:

$$dq = \sum dx_i$$

where x_i are measured with small uncertainties δx_i.

If q is the product and quotient of x_is then

$$dq = \left[\sum_{i=1}^{n} \left(\frac{dx_i}{x_i}\right)^2\right]^{1/2} \quad \text{(for independent random errors)} \tag{A.6}$$

Estimates of δq from Equation A.6 are always less than or equal to:

$$dq = \sum \frac{dx_i}{|x_i|} \tag{A.7}$$

This approach can be directly applied to the analysis of error propagation. Examples for applying this method to flow measurement follow.

Relative Error in Flow Versus Relative Error in Head

Errors in flow measurements are most often caused by field conditions that are inconsistent with the conditions under which rating curves for flow devices were calibrated. However, even under ideal conditions, errors in flow measurement can be significant. This section discusses calculations for estimating the theoretical error associated with flow measurement equipment under ideal circumstances. It can be seen that errors, particularly in low flow measurements, can be quite large.

Equations relating the head (H) measured in a primary device to discharge (Q) (i.e., Rating Equations) fall into four general forms:

1) $Q = aH^{d}$
2) $Q = a(H + c)^{d}$
3) $Q = a(bH + c)^{d}$
4) $Q = a + b_1 H + b_2 H^2 + b_3 H^3 + \cdots + b_n H^n$

The first rating equation is a straight forward application of error propagation for a power function. This equation is

$$dQ = Q\left(d\,\frac{dH}{H} \right) \tag{A.8}$$

Flow and head can only be positive values and the power for Rating Equation 1 is always positive (i.e., flow increases proportionally to head, not decreases), thus the absolute value sign is omitted in the above equation. The relative error in flow equals the relative error in head multiplied by the exponent d.

Rating Equations 2, 3, and 4 require an equation relating the error in flow to the derivative of the flow equation and the error in the measured head, which is:

$$dQ = \left| \frac{dQ}{dH} \right| dH \tag{A.9}$$

Before applying this equation, the derivatives of Rating Equations 2, 3, and 4 are taken with respect to H.

For Rating Equation 2:

$$\frac{dQ}{dH} = ad(H + c)^{d-1} \tag{A.10}$$

For Rating Equation 3:

$$\frac{dQ}{dH} = abd(bH + c)^{d-1} \tag{A.11}$$

For Rating Equation 4:

$$\frac{dQ}{dH} = b_1 + 2b_2 H^1 + 3b_3 H^2 + \cdots + nb_n H^{n-1} \tag{A.12}$$

Prior to applying the equation to the derivatives of Rating Equations 2, 3, and 4 the equation is modified by dividing each side of the Equation by the flow (Q). This yields an equation for the relative error in the flow on the left hand side.

$$\frac{dQ}{Q} = \left|\frac{dQ}{dH}\right|\frac{dH}{Q} \tag{A.13}$$

Substituting flow Rating Equation 2 for Q and the derivative of Rating Equation 2 for dQ/dH into the right hand side of the above equation, yields:

$$\frac{dQ}{Q} = ad\,(H+c)^{d-1}\,\frac{dH}{a(H+c)^{d}} \tag{A.14}$$

which reduces to:

$$\frac{dQ}{Q} = \frac{d}{\left(1+\dfrac{c}{H}\right)}\frac{dH}{H} \tag{A.15}$$

Equation A.11 relates the relative error in the flow to the relative error in the head.

A similar analysis for Rating Equation 3 yields:

$$\frac{dQ}{Q} = \frac{d}{\left(1+\dfrac{c}{bH}\right)}\frac{dH}{H} \tag{A.16}$$

Determining an equation for the relative error for Rating Equation 4 is more cumbersome, but is calculated the same way:

$$\frac{dQ}{Q} = b_1 + 2b_2H^1 + 3b_3H^2 + \cdots + nb_nH^{n-1}\,\frac{dH}{a + b_1H + b_2H^2 + b_3H^3 + \cdots + b_nH^n} \tag{A.17}$$

Rearranging yields:

$$\frac{dQ}{Q} = \frac{b_1 + 2b_2H^2 + 3b_3H^3 + \cdots + nb_nH^n}{a + b_1H + b_2H^2 + b_3H^3 + \cdots + b_nH^n}\frac{dH}{H} \tag{A.18}$$

Equation A.4, A.11, A.12, and A.14 relate the relative error in flow to the relative error in head for four common equations describing flow through a primary device. While the equations can be unwieldy, it is a relatively simple exercise to enter them into a spreadsheet program to estimate the error in flow based on estimated error in head and other variables. Most primary devices have a relatively simple flow equation that is sufficiently accurate throughout most of the flow range for the device, which allows for the use of an error equation related to one of the Rating Equations.

The equations relating the relative error in the estimate of flow to the relative error in the measurement of head can also be expressed in terms of absolute errors by multiplying each side of the equations by Q. For example the flow Equation 3 becomes:

$$Q\times\frac{dQ}{Q}=\frac{d}{\left(1+\frac{c}{bH}\right)}\frac{dH}{H}\times a(bH+c)^{d} = abd(bH+c)^{d-1}dH \qquad \text{(A.19)}$$

An Example of Error Analysis for a BMP

The following example illustrates how estimates of error propagation can be applied to flow measurements. This example assumes a stormwater BMP has two separate sources of inflow and one outflow. The flow measurement devices and errors are listed in Table 1.

Table A.1: Example of inputs for estimation of errors in flow measurement devices

Station	**Variable**	**Equipment**	**Measured Value or formula**	**Accuracy**
Inlet 1	Width	Tape Measure	3 meters	$\pm$ 0.025 meters
	Depth	Pressure Transducer	1.2 meters	$\pm$ 0.007 meters
	Velocity	Doppler	0.071 meters/sec	$\pm$ 4 %
Inlet 2	Depth	Bubbler	0.12 meters	$\pm$ 0.001 meters
		0.457 m (1.5') Palmer-Bowlus Flume	Q (L/s) = $1076.4(H + 0.005715)^{1.8977}$	$\pm$ 3 %
Outlet	Depth	Pressure Transducer	0.70 meters	$\pm$ 0.007 meters
		45^{o} V notch weir	Q (L/s) = $571.4H^{2.5}$	$\pm$ 6 %

For Inlet 1, the flow calculation is:

$$Q_{inlet-1} = (3)\,m\times(1.2)\,m\times(0.071)\ m/s$$
$$Q_{inlet-1} = 0.2556\ m^{3}/s$$

The error associated with this measurement can be calculated using the equation for error of products and quotients (i.e., Equation A.6):

Assuming that the errors are independent and randomly distributed, the relative error in q equals:

$$\frac{dq}{q} = \sqrt{\left(\frac{dw}{w}\right)^2 + \left(\frac{dH}{H}\right)^2 + \left(\frac{dv}{v}\right)^2} = 0.0413$$

$$\frac{dq}{q} = \sqrt{\left(\frac{.025}{3}\right)^2 + \left(\frac{0.007}{1.2}\right)^2 + (0.04)^2}$$

$$dq = 0.2556\ m^3 / s \times 0.0413 = 0.011\ m^3/s$$

So that:

$$Q_{inlet-1} = 0.2556 \pm 0.011\ m^3/s$$

For the Palmer-Bowlus Flume installed in **Inlet 2**, the equation that describes flow (L/s) as function of water depth is:

$$Q_{inlet-2} = 1076.4 \times (H + 0.005715)^{1.8977}$$

Therefore:

$$Q_{inlet-2} = 1076.4 \times (0.12 + 0.005715)^{1.8977}$$
$$Q_{inlet-2} = 21.032 L / s = 0.0210\ m^3/s$$

The error associated with flow measurement above is proportional to the precision of the transducer used to measure the water depth (i.e., $\pm$ 0.007 meters) and the error intrinsic to the primary device (a relative error of 3%). Rating Equation 1 is used for this case; Equation A.8 can be used to determine the magnitude of relative error in the flow measurement as:

$$\frac{dQ}{Q} = \frac{d}{\left(1 + \frac{c}{H}\right)} \frac{dH}{H}$$

$$\frac{dQ}{Q} = \frac{1.8977}{\left(1 + \frac{0.005715}{0.12\ m}\right)} \frac{0.007\ m}{0.12\ m} = 0.11$$

$$dQ = 0.021 m^3 / s \times 0.11 = 0.00231\ m^3/s$$

Relative error for the flume itself also has to be included. Since the error is a function of one variable, it can be calculated using Equation A.4:

$$dq = \left|\frac{dq}{dx}\right| dx = 0.03 \times 0.021\ m^3/s = 0.00063\ m^3/s$$

The total error is therefore the sum of errors associated with the measuring device (Equation A.5).

$$dq_{inlet-2(total)} = \sqrt{0.0023^2 + 0.00063^2} = 0.0024 \ m^3/s$$

$$Q_{inlet-2} = 0.0210 \pm 0.0024\, m^3/s$$

For the **Outlet weir**, the flow can be calculated using the following equation:

$$Q = 571.4 \times H^{2.5}$$

$$Q = 571.4 \times 0.70^{2.5} = 234.25 L/s = 0.234 \ m^3/s$$

This is also a power function (Rating Equation 1) and the error can be calculated similarly to the equation for the flume:

$$dQ = |2.5| \frac{0.007}{0.70} 0.234\, m^3/s = 0.059\, m^3/s$$

The error associated with the weir itself is a single variable as was the flume:

$$dq = 0.06 \times 0.234 m^3/s = 0.014\, m^3/s$$

The total error is the sum of the errors associated with the measuring device and is calculated as follows:

$$dq_{Outlet(total)} = \sqrt{0.059^2 + 0.014^2} = 0.061\, m^3/s$$

$$Q_{outlet} = 0.234 \pm 0.061\, m^3/s$$

Results of this error analysis are provided below in Table A.2.

Table A.2: Summary of examples demonstrating the propagation of errors in flow measurement

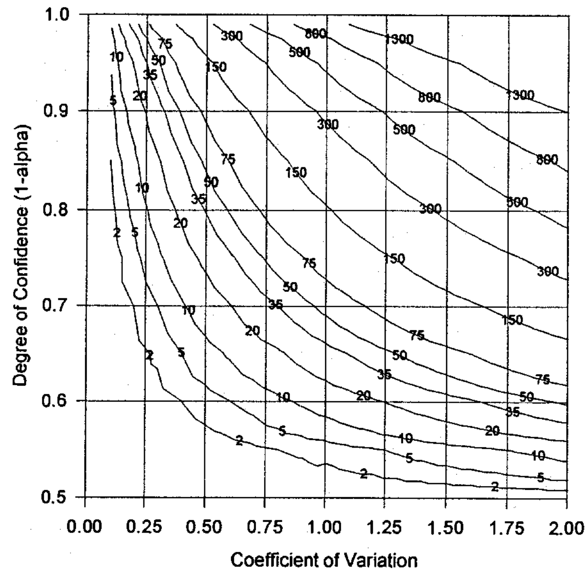
	Flow (m^3/sec)	Total Error (m^3/sec)	Total Relative Error (m^3/sec)
Inlet-1	0.255	$\pm$ 0.011	4%
Inlet-2	0.021	$\pm$ 0.0024	11%
Outlet	0.234	$\pm$ 0.061	26%

APPENDIX B

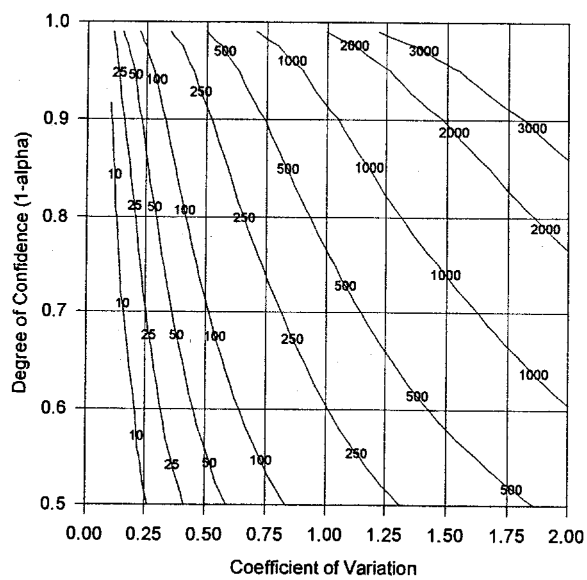
NUMBER OF SAMPLES REQUIRED FOR VARIOUS POWERS, CONFIDENCE INTERVALS, AND PERCENT DIFFERENCES

The figures in this Appendix are from: R. Pitt and K. Parmer. *Quality Assurance Project Plan (QAPP) for EPA Sponsored Study on Control of Stormwater Toxicants*. Department of Civil and Environmental Engineering, University of Alabama at Birmingham. 1995.

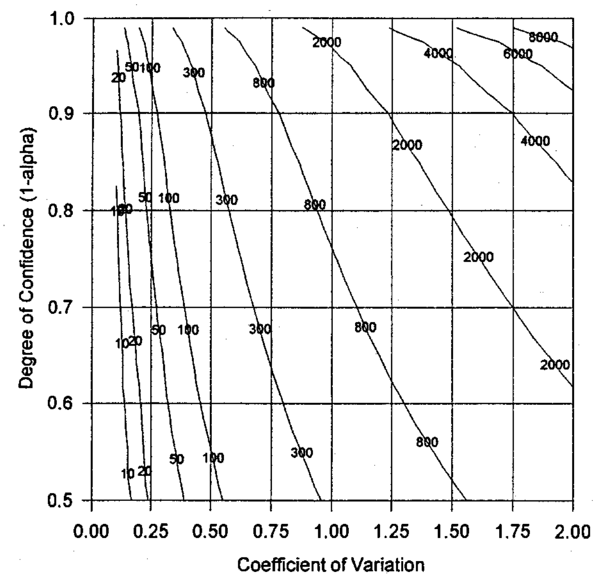
Number of Sample Pairs Needed
(Power = 0.5 Difference = 10%)



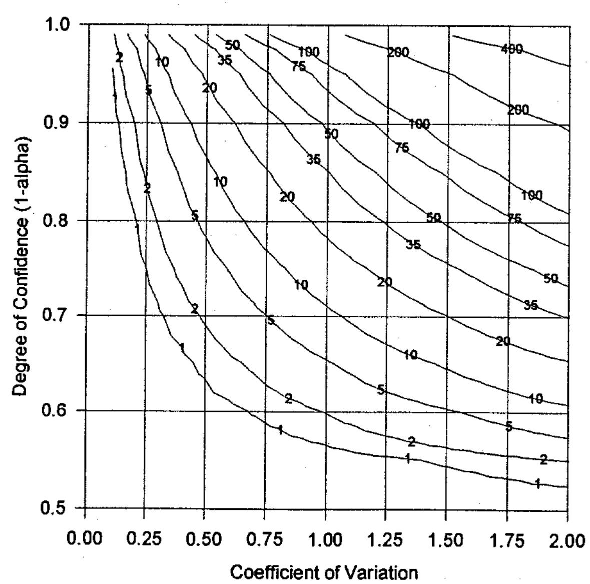
Number of Sample Pairs Needed
(Power = 0.8 Difference = 10%)



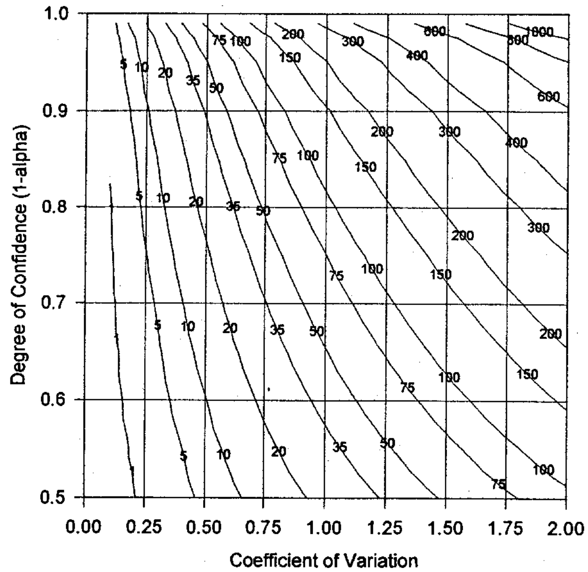
Number of Sample Pairs Needed
(Power = 0.9 Difference = 10%)



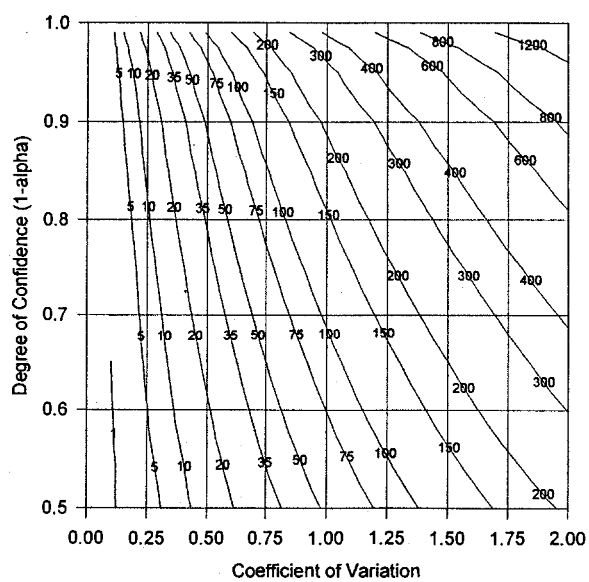
Number of Sample Pairs Needed
(Power = 0.5 Difference = 25%)



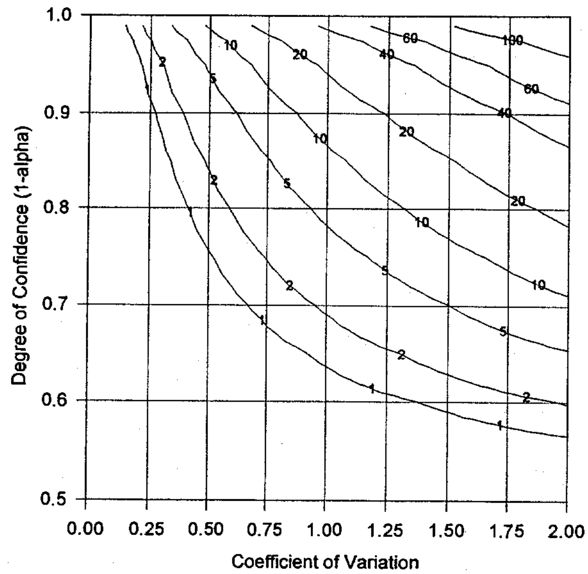
Number of Sample Pairs Needed
(Power = 0.8 Difference = 25%)



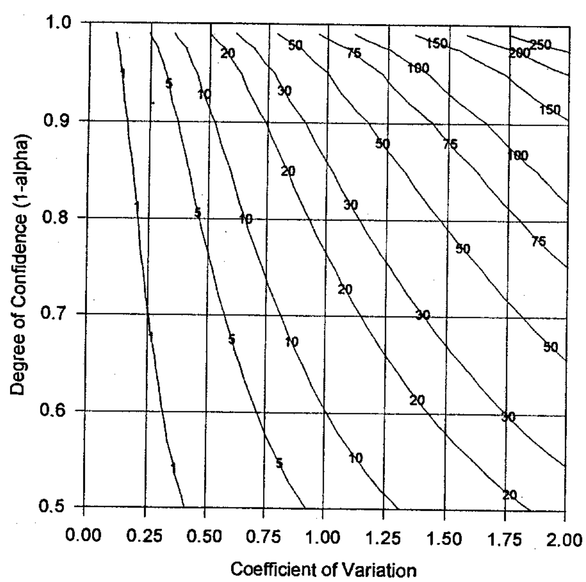
Number of Sample Pairs Needed
(Power = 0.9 Difference = 25%)



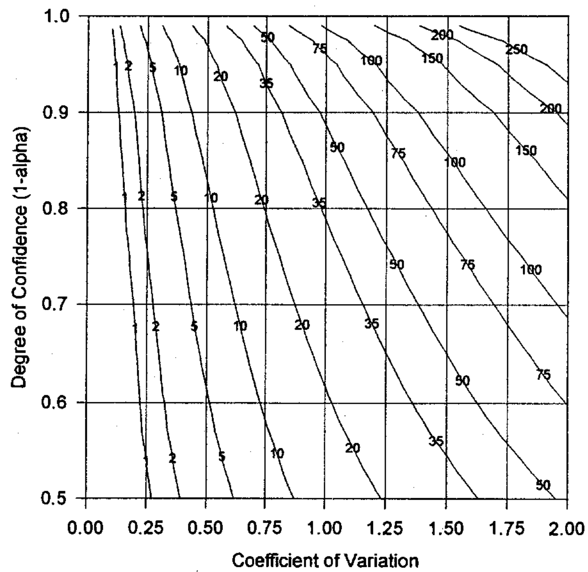
Number of Sample Pairs Needed
(Power = 0.5   Difference = 50%)



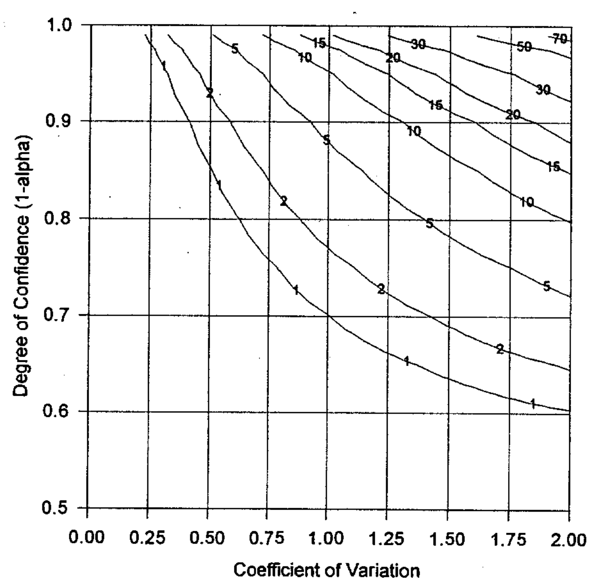
Number of Sample Pairs Needed
(Power = 0.8 Difference = 50%)



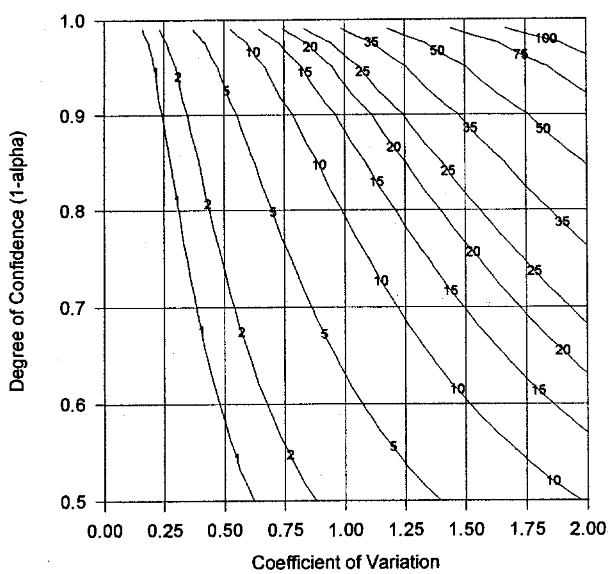
Number of Sample Pairs Needed
(Power = 0.9 Difference = 50%)



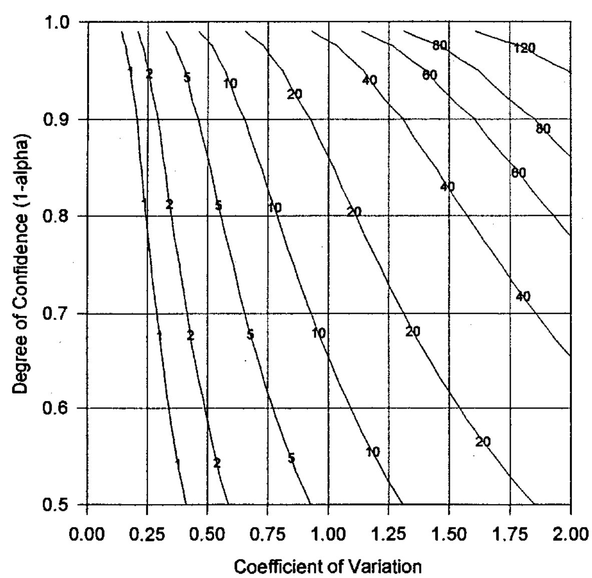
Number of Sample Pairs Needed
(Power = 0.5 Difference = 75%)

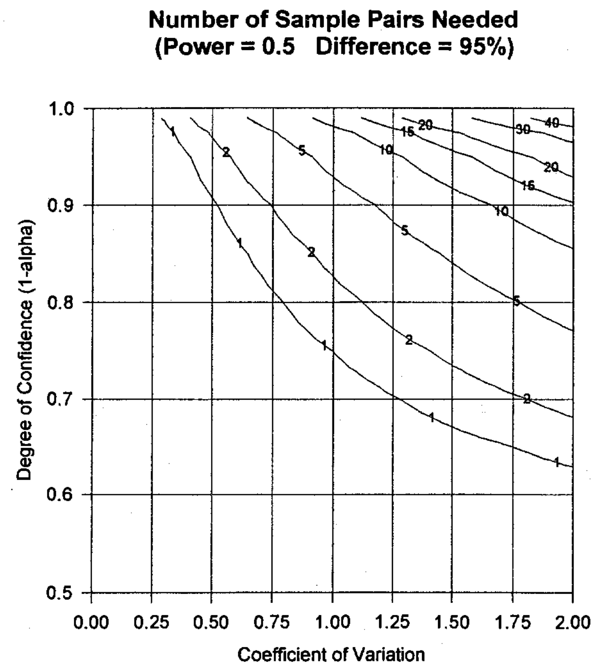


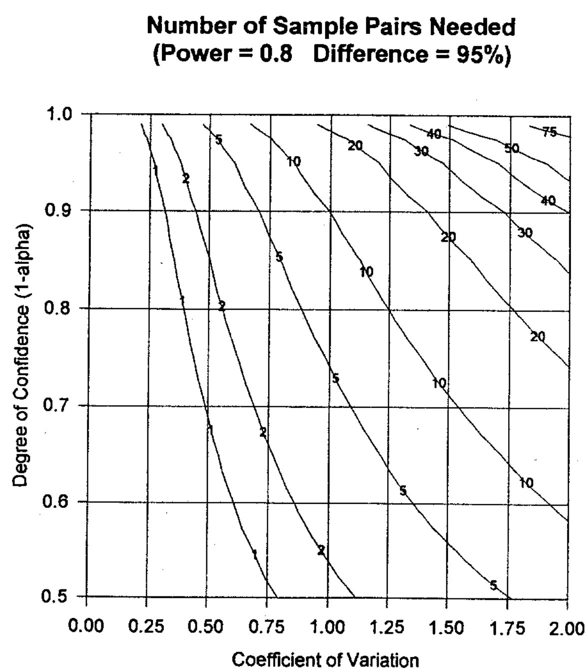
Number of Sample Pairs Needed
(Power = 0.8   Difference = 75%)



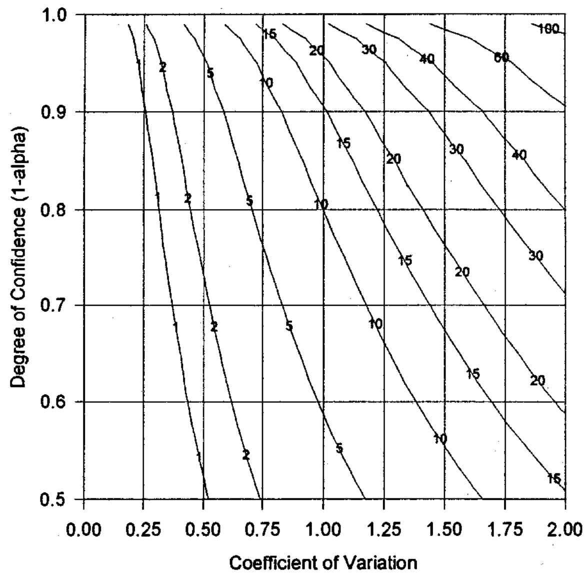
Number of Sample Pairs Needed
(Power = 0.9   Difference = 75%)



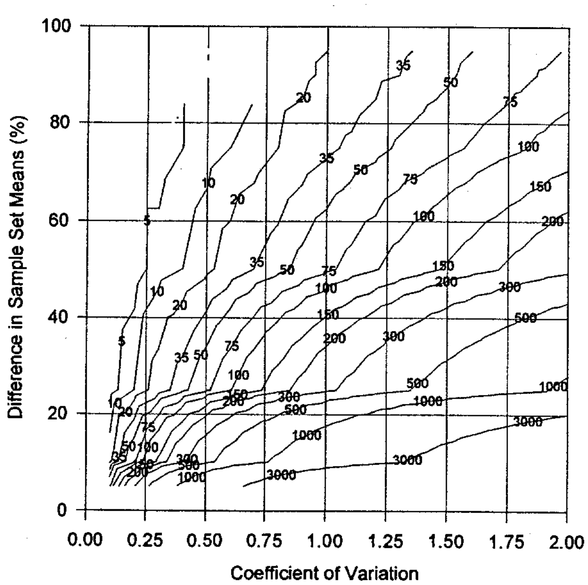

Number of Sample Pairs Needed
(Power = 0.5 Difference = 95%)
Degree of Confidence (1-alpha)
Coefficient of Variation
1.0
0.9
0.8
0.7
0.6
0.5
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00

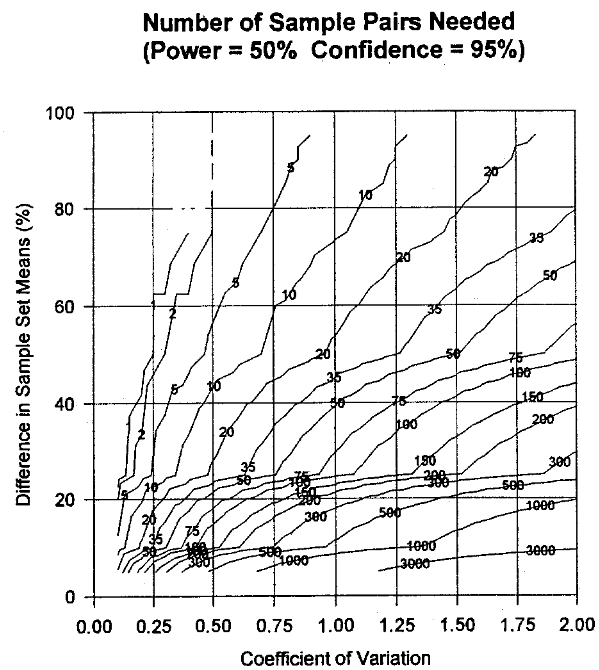

Number of Sample Pairs Needed
(Power = 0.8 Difference = 95%)
Degree of Confidence (1-alpha)
Coefficient of Variation
1.0
0.9
0.8
0.7
0.6
0.5
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00

Number of Sample Pairs Needed
(Power = 0.9   Difference = 95%)



Number of Sample Pairs Needed
(Power = 90% Confidence = 95%)




Number of Sample Pairs Needed
(Power = 50% Confidence = 95%)
Difference in Sample Set Means (%)
Coefficient of Variation
0
20
40
60
80
100
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00

APPENDIX C
DERIVATION OF THE NUMBER OF SAMPLES REQUIRED TO MEASURE A STATISTICAL DIFFERENCE IN POPULATION MEANS

Define: COV = σ / $\bar{C}$

$$\%\ \text{removal} = \left(\bar{C}_{in} - \bar{C}_{out}\right) \big/ \bar{C}_{in}$$

Setting the lower boundary of the influent confidence interval to the upper boundary of the effluent confidence interval gives:

$$\bar{C}_{in} - Z_{a/2}\frac{s_{in}}{\sqrt{n}} = \bar{C}_{out} + Z_{a/2}\frac{s_{out}}{\sqrt{n}}$$

The COV is substituted for the σ in the above equation. While the σ of a BMP effluent is almost certainly less than the σ of the BMP influent, the assumption that $COV_{in} = COV_{out}$ is a more reasonable one. In most instances the COV of the BMP effluent would be less than the influent. Ample data are available for estimating the COV for influent flows to stormwater BMPs, such as the ASCE database; this is not the case for effluent flows. It is also assumed that n is the same for the influent and effluent ($n_{in} = n_{out}$). These assumptions simplify the equation.

Substituting σ_{in} = COV $\times$ $\bar{C}_{in}$ and σ_{out} = COV $\times$ $\bar{C}_{out}$, where $COV_{in} = COV_{out}$ yield:

$$\bar{C}_{in} - Z_{a/2}\frac{COV \times \bar{C}_{in}}{\sqrt{n}} = \bar{C}_{out} + Z_{a/2}\frac{COV \times \bar{C}_{out}}{\sqrt{n}}$$

rearranging:

$$\bar{C}_{in} - \bar{C}_{out} = COV \times Z_{a/2}\left(\frac{\bar{C}_{in} + \bar{C}_{out}}{\sqrt{n}}\right)$$

Substituting for $\bar{C}_{out} = \bar{C}_{in} - \bar{C}_{in}(\%removal)$ gives:

$$\bar{C}_{in} \times \%removal = COV \times Z_{a/2}\left(\frac{2 \times \bar{C}_{in} - \%removal \times \bar{C}_{in}}{\sqrt{n}}\right)$$

Dividing both sides by $\bar{C}_{in}$ and solving for n yields:

$$n = \left[\frac{Z_{a/2} \times COV \times (2 - \%removal)}{\%removal}\right]^2$$

The above approach considers the number of samples required for a power of 50%. For an arbitrary power the equation becomes:

$$n = \left[\frac{\left(Z_{a/2} + Z_{b/2} \right) \times COV \times \left(2 - \%removal \right)}{\%removal} \right]^2$$

where,

$Z_{\beta/2}$: false negative rate (1-β is the power. If used, a value of β of 0.2 is common, but it is frequently ignored, corresponding to a β of 0.5.)

APPENDIX D
RELATIONSHIPS OF LOG-NORMAL DISTRIBUTIONS

Table D.1

T = EXP (U)	S = M * CV
M = EXP (U + 0.5 * W^2)	W = SQRT (LN (1 + CV^2)
M = T * SQRT (1 + CV^2)	U = LN (M/EXP (O.5 * W^2))
CV = SQRT (EXP (W^2) - 1)	U = LN (M/SQRT (1 + CV^2)

Parameter designations are defined as:

	Arithmetic	**Logarithmic**
MEAN	M	U
STD DEVIATION	S	W
COEF OF VARIATION	CV	
MEDIAN	T	

LN(x) designates the base e logarithm of the value x
SQRT(x) designates the square root of the value x
EXP(x) designates e to the power x

Appendix E: Example Storm Water BMP Ordinances (assembled from other Utah communities)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PART A: STORM WATER POLLUTION PREVENTION PLAN AND EROSION CONTROL PLAN (SWPPP)

SECTION 1. GENERAL

The purpose of this ordinance is to prevent the discharge of sediment and other construction related pollution from construction sites by storm water runoff. Construction sites are a major source of pollution to waterways and storm drain systems located within Uintah County and the surrounding area. Storm Water runoff carries sediment from construction sites into nearby water ways, lakes, canals, irrigation systems and storm drain systems. The sediment clogs storm drain systems, pollutes the water in the streams and lakes and damages wildlife habitat and water quality. The same potential for polluting waterways, lakes, canals, irrigation systems, and storm drain systems can occur from commercial or industrial operations. Existing and future commercial and industrial operations which are allowing sediments to be discharged from the operation site or allowing sediments to be tracked onto public or private roads and streets must also comply with the provisions of this ordinance.

A second purpose of this ordinance is to minimize long-term changes in storm water runoff quantity and quality associated with development. Land development projects and associated increases in impervious cover alter the hydrologic response of local watersheds and can increase stormwater runoff rates and volumes, flooding, stream channel erosion, and sediment transport and deposition. Other potential hydrologic alterations include reduced infiltration rates and lower in-stream base flow levels. These hydrologic changes adversely affect local fishery resources and aquatic habitat, and are often accompanied by increased pollutant loadings. This ordinance is intended to minimize these adverse effects by requiring developments to incorporate permanent, post-construction Best Management Practices (BMPs) that treat storm water runoff quantity and quality and maximize on-site infiltration of runoff to promote groundwater recharge.

This Part shall establish guidelines for the preparation of the SWP3/ECP, which will include both temporary and permanent BMPs to control erosion and prevent polluted runoff both during and after construction.

SECTION 2. DEFINITIONS

For the purpose of this ordinance and part, the definitions listed hereunder shall be construed as specified in this section.

APPLICANT- Any person or entity which files or is required to file an application for a SWP3 and ECP.

APPLICATION- The form and supporting information filed with Uintah County/Vernal City/Naples City for review and approval of a SWP3 and ECP.

APPROVAL- The proposed plan conforms to this ordinance and part in the opinion of the County Engineer.

BEST MANAGEMENT PRACTICES (BMPs)- Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the state. BMPs also include treatment requirements, operating procedures, and practices to control site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

COMMENCEMENT OF CONSTRUCTION- The initial disturbance of soils associated with clearing, grading or excavating activities or other construction activities.

CONTROL MEASURE- Any Best Management Practice or other method used to prevent or reduce the discharge of pollutants.

CIVIL ENGINEER- A professional engineer registered in the State of Utah to practice in the field of civil works.

CWA- Clear Water Act or the Federal Water Pollution Control Act.

DEVELOPMENT OR DEVELOPMENT ACTIVITY- Any of the following activities requiring a permit pursuant to the Codes and Ordinances of Uintah County/Vernal City/Naples City.

A. Construction, clearing, filling, excavating, grading, paving, dredging, mining, drilling or otherwise significantly disturbing the soil of a site.

B. Building, installing, enlarging, replacing or substantially restoring a structure, impervious surface, and the long-term stockpiling of materials.

C. Construction, elimination or alteration of a driveway onto a public road.

DISCHARGE OF STORM WATER ASSOCIATED WITH CONSTRUCTION ACTIVITY- Storm Water “point source” discharges from areas where soil disturbing activities (e.g. clearing, grading, or excavating, etc.), construction material or equipment activities (e.g. fill piles, concrete truck washout, fueling, etc.), or other industrial storm water directly related to the construction process (e.g. concrete or asphalt batch plants, etc.) are located.

DISTURBANCE- To alter the physical location, natural appearance, existing vegetation of the land by clearing, grubbing, grading, excavating, filling, building or other construction activity.

EPA- The United States Environmental Protection Agency.

EROSION- is the wearing away of the ground surface as a result of the movement of wind, water or ice.

EXCAVATION- Is the mechanical removal of earth material.

EXISTING GRADE- Is the grade prior to grading.

FILL- Is a deposit of earth material placed by artificial means.

FINAL STABILIZATION- All soil disturbing activities at the site have been completed, and that a uniform (e.g. evenly distributed, without large bare areas) perennial vegetative cover with a density of 70% of the native background vegetative cover for the area has been established on all unpaved areas and areas not covered by permanent structures, or equivalent permanent stabilization measures (such as the use of rip rap, gabions, or geotextiles) have been employed. In some parts of the County, background native vegetation will cover less than 100% of the ground (e.g. arid areas). Establishing at least 70% of the natural cover of native vegetation meets the vegetative cover criteria for final stabilization. For example, if the native vegetation covers 50% of the ground, 70% of 50% would require 35% cover for final stabilization.

FINISHED GRADE- The final grade of size which conforms to the approved plan.

GAS STATION- A permanent commercial or private facility that involves transferring fuel into mobile vehicles or equipment.

GEOTECHNICAL ENGINEER- See “soils engineer.”

GRADE- The vertical location of the ground surface.

GRADING- Any excavating or filling or combination thereof.

IMPERVIOUS SURFACE - Any surface which prevents or retards the penetration of water into the ground, including, but not limited to, paved streets, graveled or paved areas such as driveways, parking areas, packed earth material, oiled macadam or other treated surfaces, sidewalks, walkways, roof surfaces, patios and formal planters.

MAXIMUM EXTENT PRACTICABLE- A level of effort to be undertaken where technical feasibility and financial cost to be incurred are appropriate for the probable negative impacts to water quality to be minimized. Implementation of a storm water management practice is considered practicable unless one or both of the following apply:

A. The practice is not technically feasible for the proposed use and physical characteristics of the site; or

B. The cost of implementing the practice would outweigh the benefits of maintaining water quality. Costs are considered to outweigh benefits only if they exceed $0.50 per square foot of the lot or land on which the development takes place.

NATURAL LANDSCAPE- The cover and topography of land before any man-made change, or, in areas where there have been man-made modifications, that state of the area and topography of land as of the date of adoption of this Article.

PERMIT- A Uintah County/Vernal City/Naples City Storm Water Pollution Prevention Permit and Erosion Control Permit.

PERMITTEE- The recipient of a Uintah County/Vernal City/Naples City Storm Water Pollution Prevention Permit and Erosion Control Permit.

PERSON- Any individual, corporation, partnership, association, company or body politic, including any agency of the State of Utah and the United States Government.

PLAN- A Storm Water Pollution Prevention Plan and Erosion Control Plan.

POINT SOURCE- Any discernable, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, collection system, from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture or agricultural storm water runoff.

PROFESSIONAL INSPECTION- The inspection required by this ordinance to be performed by the civil engineer, soils engineer, hydrologist, or engineering geologist. Such inspections include that performed by persons supervised by such engineers, hydrologists or geologists and shall be sufficient to form an opinion relating to the conduct of the work.

ROUGH GRADE- The stage at which the grade approximately conforms to the approved plan.

RUNOFF COEFFICIENT- The fraction of total rainfall that will appear at a conveyance as runoff.

SITE- Any lot or parcel of land or contiguous combination thereof, under the same ownership, where grading is performed or permitted.

SLOPE- An inclined ground surface the inclination of which is expressed as a ration of horizontal distance to vertical distance.

SOIL- Naturally occurring superficial deposits overlying bedrock.

SOILS ENGINEER (GEOTECHNICAL ENGINEER)- An engineer experienced and knowledgeable in the practice of soils engineering (geotechnical) engineering.

SOILS ENGINEERING (GEOTECHNICAL ENGINEERING)- The application of the principles of soils mechanics in the investigation, evaluation and design of civil works involving the use of earth materials and the inspection or testing of the construction thereof.

STORM WATER- Storm water runoff, snow melt runoff, and surface runoff and drainage.

STORM WATER DISCHARGE ASSOCIATED WITH INDUSTRIAL ACTIVITY- Existing Commercial or Industrial operations whose operation may allow sediment, mud or debris to flow from the site or is tracked onto adjacent public or private roads by vehicles leaving the site.

SWP3- Storm water pollution prevention plan, referring to the plan required in the permit.

UNSTABILIZED- Areas of land which are disrupted or whose natural landscape has been changed due to excavation, grading grubbing and clearing, or other construction activity and which has not been finally stabilized.

SECTION 3. STORM WATER POLLUTION PREVENTION PLAN AND EROSION CONTROL PLAN (SWPPP)

A. The Storm Water Pollution Prevention Plan and Erosion Control Plan shall contain the following:

(1) General Information including:
- a brief narrative description of the project
- legal description of site
- copies of relevant permits, easements, rights-of-way, and discharge permission agreements
- copies of maintenance easement(s) and covenant(s)
- total area of parcel/site
- area of expected disturbance by clearing, grading, excavation, filling, or other activities
- contact information for the applicant/permittee

(2) A Site Plan Map or maps that show:
- existing topography and proposed grades (2' contour interval or greater if needed for readability)
- existing drainage courses and impoundments (wet or dry)
- existing wetlands on or adjacent to the site
- existing soil and vegetation cover types
- environmentally sensitive features
- boundary of the 100-year flood plain (if applicable)
- receiving water body(ies) or , if far offsite, distance to and name(s) of receiving water body (ies)
- boundaries of individual drainage areas within the site and discharge point locations (per-and post-development, if different)
- location of construction activities
- extent/limits of clearing and grading
- existing and proposed utility locations
- location and finished elevations of proposed permanent structures including buildings, roads, and parking areas
- location of existing on-site or adjacent storm drain systems and canals
- landscaping plan, including any proposed irrigation system
- location of temporary and permanent stormwater runoff and erosion control BMPs

(3) Technical Information including:
- results of any soil or geologic tests/borings
- construction sequence and schedule for implementation of temporary erosion and sediment control measures

- area of new impervious surfaces and total post-development impervious area
- grades of all impervious surfaces
- hydrologic and hydraulic design calculations for the pre-development and post-development conditions for the design storms specified in this ordinance (see Part F for additional details)
- design drawings (plan and profile), construction details, grades, elevations, and supporting engineering calculations (as applicable) for individual permanent stormwater BMPs and proposed drainage systems (see Part E for details)
- a description of how the SWP3 and ECP use non-structural controls to the maximum extent practicable for long-term treatment of stormwater runoff, and justification for any use of large-scale structural surface runoff controls (use form provided in Part D).

B. The proposed measures and controls described in the SWP3 and ECP shall be designed to meet the following goals and criteria.

(1) The proposed measure and controls shall be designed to prevent or minimize, to the maximum extent practical, the discharge of sediment, debris and other construction- related pollutants from the construction site by storm water runoff.

(2) The proposed measures and controls shall be designed to prevent or minimize, to the maximum extent practicable, the deposit, discharge, tracking by construction vehicles or other vehicles leaving the construction site, or dropping of mud, sediment, debris or other potential pollutants onto public or private roads and streets. Any such discharge shall be cleaned up and removed prior to the end of the work shift in which the deposit occurred, or prior to sunset whichever comes first.

(3) The proposed measures and controls shall consist of the Best Management Practices (BMPs) available at the time that the plan is submitted. BMPs may include, but shall not be limited to, temporary silt or sediment fences, sediment traps and detension ponds, gravel construction (drain rock) entrances and wash down pads to reduce or eliminate off site tracking, straw bale sediment carriers, establishment of temporary and permanent vegetative cover, use straw mulch as a temporary ground cover, erosion control blankets, temporary interceptor dikes and swales, storm drain inlet protection, check dams, surface drains, pipe slope drains, level riprap pads for culvert outlet protection, reinforced soil retaining systems and gabions.

(4) Existing vegetation should be preserved wherever possible and disturbed portions of the site shall be stabilized. Stabilization practices may include, but not be limited to temporary seeding, permanent seeding, mulching, geotextiles, sod stabilization, vegetative buffer strips, protection of trees, preservation of nature vegetation, and other appropriate measures. Use of impervious surfaces for

stabilization shall be avoided. Except as provided below, stabilization measures shall be initiated as soon as possible in disturbed portions of the site where construction activities have temporarily or permanently ceased, but in no case more than 10 working days after the construction activity in that portion of the site has temporarily or permanently ceased.

(a) Where the initiation of stabilization measures by the 10th day after construction activity temporarily or permanently ceases is precluded by deep snow or frozen ground conditions, stabilization measures shall be initiated as soon as practicable.

(b) Where construction activity on a portion of the site is temporarily ceased, and earth disturbing will resume within 15 working days, temporary stabilization measures need not be initiated on that portion of the site.

(5) Measures shall be employed to minimize the risk of discharge of construction-related pollutants (such as paint, thinners, solvents, fuels and oils) from the construction site. Such measures may include implementation of storage practices to minimize exposure of the material to storm water as well as spill prevention and response.

(6) The SWP3 and ECP shall include long-term, post-construction runoff control measures that meet the following performance criteria:

(a) Peak Flow Rate Criteria. The flow rate of runoff from the proposed land development shall not exceed the pre-development runoff rate. Pre- and post- development rates shall be checked for the 10 and 100-year storm events. Structural controls such as detention or extended detention ponds shall include spillways that are adequate to transport the entire peak runoff of the 100-year storm event. The 10-year storm event shall be used for sizing underground storm water conveyance systems, i.e., pipe sections between catch basins and storm drainage manholes. Surface conveyance systems such as canals, drainage channels/ditches/swales, curb and gutters, and culverts shall be designed to safely pass the 100-year storm event. Design storms and runoff values shall be calculated using the methods described in Part F.

(b) Flood Control Criteria. Development activities that result in new releases of surface water from the development that inundate, erode, deposit sediment or otherwise damage downstream property, real or personal, shall not be allowed. Releases of runoff to downstream property that, prior to the proposed development, would not have received any runoff, will require that the downstream property owner provides an easement and consent that shall be written in the land record, and that Uintah County/Vernal City/Naples City grants approval. When releases of runoff are directed into an irrigation canal or ditch, written permission will be required from the canal company president for acceptance of storm water into a canal unless otherwise covered by a flood control agreement. The canal company may also stipulate how the storm drain will enter the canal and any erosion protection needed. Entrance into the smaller private ditches will require the approval of the relevant water right holder and owner of the property upon which the ditch is located. If there is a question as to whether or not the ditch can carry the additional storm water, a capacity evaluation shall be submitted for the ditch in question.

c) Water Quality Criteria. Surface and subsurface (i.e. infiltration) storm water BMPs shall be implemented and maintained such that they provide water quality treatment for (i.e., infiltrate or capture and treat) the runoff volume (WQ_v) associated with a storm event of **0.41 inch in 1 hour** under post-development site conditions. Storm water BMPs shall be designed to remove a proportion of the average annual load of Total Suspended Solids (TSS), according to the sliding scale shown in Part E. The required removal rate is based on the percentage of impervious cover under postdevelopment site conditions, and BMPs must be applied to all impervious areas in such a manner that the overall weighted average TSS removal rate (from one or more BMPs) equals or exceeds the required removal efficiency level. BMPs will also be implemented to remove floatibles from storm water runoff prior to discharge of the water from the development site.

(d) Groundwater Recharge Criteria. Annual groundwater recharge rates shall be maintained by promoting infiltration through the use of nonstructural and structural methods. At a minimum, annual recharge from the post development site shall mimic the annual recharge from predevelopment site conditions. Specifically, BMPs shall be implemented to ensure that the increase in surface runoff volume from the 1-hour, 0.41" storm event relative to pre-development conditions (i.e., the postdevelopment WQv minus the pre-development WQv) is recharged into the groundwater rather than discharged off-site as surface runoff. Infiltration facilities must be situated in areas with suitable soils and adequate depths to groundwater (see Part E for detailed suitability information). Adequate pretreatment must be provided for runoff from pollution “hot spots” prior to recharging such runoff into the ground. Pollution “hot spots” include:

- road salt storage facilities
- parking lots that receive road salt applications
- vehicle salvage yards and recycling facilities
- vehicle service and maintenance facilities
- vehicle and equipment cleaning facilities, including carwashes
- fleet storage areas

- industrial sites
- marinas (service and maintenance)
- outdoor liquid container storage
- outdoor loading/unloading facilities
- public works storage areas
- facilities that generate or store hazardous materials
- commercial container nurseries
- permanent, temporary, and mobile fueling operations

(e) Water Quality Criteria for Gas Stations. Because the paved portions of gas stations are sources of harmful pollutants such as oil, gas, grease, metals, and other organic compounds, new gas station developments shall be required to install oil/water separators approved by the County Engineer to treat runoff from all impervious surfaces. Examples of appropriate oil/water separator devices are provided in Part E. Oil/water separators shall be installed off-line, upstream of any additional water quality BMPs and detention basins, and as close to the source of oil-generating activity as possible. Separators shall be sized to the water quality design storm (WQv; 1-hour 0.41" storm) and shall be inspected monthly and maintained as needed. During larger storm events, excess flows should be safely directed away from the separator to another BMP. In addition to installing oil/water separators, gas stations must also install controls to meet all other treatment criteria listed above. Oil-water separators should not be used alone to treat storm water runoff, but rather as pretreatment to another storm water BMP or series of BMPs.

SECTION 4. TEMPORARY AND PERMANENT EROSION AND SEDIMENT CONTROL/STORMWATER TREATMENT METHODS

Refer to Parts B, C, D, and E for examples of temporary and permanent erosion and sediment control/stormwater treatment measures. The permittee may use those controls which may apply to his/her site, or may use other BMPs, and erosion and sediment control measures provided they are approved by the County Engineer. However, when selecting long-term (post-construction) stormwater treatment methods, the applicant must demonstrate that they have employed non-structural controls (e.g., reduction in paved area, disconnection of rooftop runoff, source control/pollution prevention, etc.) to the maximum extent practicable rather than relying solely on structural controls such as detention ponds. A more detailed list of non-structural control measures is provided in Part D. Non-structural controls are the preferred treatment method because they limit the increase in volume and rate of runoff associated with development, help preserve groundwater recharge, and limit pollutants at their source. Large scale structural surface runoff controls (e.g., large detention ponds) will only be permitted when the applicant demonstrates to the satisfaction of Uintah County/Vernal City/Naples City that it is not feasible to meet the storm water quantity and quality requirements through the use of non-structural and subsurface techniques alone. The worksheet included in Part D should be filled out by the applicant to demonstrate the use of non-structural techniques. If BMPs other than those shown in Part B, D or E are used, the permittee must demonstrate to the satisfaction of the County Engineer that the alternative controls will successfully meet the requirements listed in Section 3 above. Uintah County/Vernal City/Naples City may require more than the minimum control requirements specified if hydrologic, geologic, or topographic conditions warrant or if unique flooding, stream channel erosion, or water quality problems exist downstream from a proposed project.

SECTION 5. PROPER OPERATION AND MAINTENANCE

A. The permittee shall install the erosion and sediment control measures required by the approved SWP3 and ECP before commencing any construction activities on the site to which the plans apply, or at such time as indicated on the plan. The permittee shall contact County Engineer’s Office to schedule an inspection of the installed measures prior to commencing other construction activities.

B. The permittee shall maintain such measures on the site in good condition until the disturbed areas have been finally stabilized and the measures are no longer necessary to prevent or minimize, to the maximum extent practicable, the discharge of sediment, debris and other pollutants from the site by storm water runoff or vehicular tracking. The erosion control measures shall be properly installed and maintained in accordance with the manufacturers specifications and good engineering practices. Once the temporary erosion control measures have been deemed no longer necessary, or once the site is finally stabilized, the controls shall be removed from the site in a timely manner.

C. Maintenance Covenants

(1) Establishment of Covenant. Maintenance of all long-term stormwater management facilities, including non-structural practices such as natural area conservation and buffer establishment, shall be ensured through the creation of a formal maintenance covenant that must be approved by Uintah County/Vernal City/Naples City and recorded into the land record prior to final plan approval. As part of the covenant, the location of each permanent structure will be added to the county’s storm water map and a schedule shall be developed for when and how often maintenance will occur to ensure proper function of the stormwater management facility. The covenant shall also include plans for periodic inspections to ensure proper performance of the facility between scheduled cleanouts. The property owner listed on the land record is responsible for performing these periodic inspections and keeping written records of the inspections and any maintenance activities performed. Sample inspection forms are provided in Part G. These written records shall be retained for a minimum of three years from the date of the inspection or maintenance activity. A copy of these written records shall be sent to Uintah County/Vernal City/Naples City within one week of the inspection.

(2) Maintenance and Inspection Plan Requirements. All permanent stormwater management facilities must undergo, at the minimum, semi-annual inspections in the fall and in the spring to document maintenance and repair needs and ensure compliance with the requirements of this ordinance and accomplishment of its purposes. These needs may include; removal of silt, litter, and other debris from all catch basins, inlets and drainage pipes, grass cutting and vegetation removal, necessary replacement of landscape vegetation, and removal and replacement of contaminated filter media. Specific maintenance needs for individual long-term

BMPs are provided in Part E and sample inspection forms are provided in Part G. Following each inspection, a copy of the completed inspection form shall be sent to Uintah County/Vernal City/Naples City within one week of the inspection. Any maintenance needs found must be addressed in a timely manner.

(3) Failure to Maintain Practices. If a responsible party fails or refuses to meet the requirements of the maintenance covenant, Uintah County/Vernal City/Naples City, after reasonable notice, may correct a violation of the design standards or maintenance needs by performing all necessary work to place the facility in proper working condition. In the event that the stormwater management facility becomes a danger to public safety or public health, Uintah County/Vernal City/Naples City shall notify the party responsible for maintenance of the stormwater management facility in writing. Upon receipt of that notice, the responsible person shall have 30 days to implement maintenance and repair of the facility in an approved manner. After proper notice, Uintah County may assess the owner(s) of the facility for the cost of repair work; and the cost of the work shall be a lien on the property.

SECTION 6. INSPECTION AND ENTRY

A. The permittee shall allow authorized employees and representatives of Uintah County, State of Utah Division of Water Quality, and the Environmental Protection Agency (EPA), to enter the site to which the permit applies at any time during or after construction and to inspect the erosion and sediment control and permanent stormwater treatment measures installed and maintained by the permittee. The permittee shall allow inspection of any other construction activity pertaining to the conditions of the permit. This right of entry shall be formalized in a Maintenance and Inspection Easement that must be approved by Uintah County/Vernal City/Naples City and recorded into the land record such that the easement remains binding on all subsequent land owners.

B. Inspections During Construction

(1) For construction sites greater than 1 acre, qualified personnel (provided by the permittee) shall inspect disturbed areas of the construction site that have not been finally stabilized, areas used for storage of materials that are exposed to precipitation, areas with structural control measures, and locations where vehicles enter or exit the site at least once every seven (7) calendar days and within 24 hours of the end of a storm that is 0.5 inches or greater. Where sites have been temporarily stabilized, such inspection shall be conducted at least once every month.

(2) Disturbed areas and areas used for storage of materials that are exposed to precipitation shall be inspected for evidence of, or the potential for, pollutants entering the drainage system. Erosion and sediment control measures identified in the plan shall be observed to ensure that they are operating correctly. Where discharge locations or points are accessible, they shall be inspected to ascertain

whether erosion control measures are effective in preventing significant impacts to receiving waters. Locations where vehicles enter or exit the site shall be inspected for evidence of offsite sediment tracking.

(3) Based on the results of the inspection, the pollution prevention, erosion and sediment control, and stormwater runoff control measures identified in the SWP3 and ECP shall be revised as appropriate as soon as practical after such inspection. Such modifications shall provide for timely implementation of any changes to the plan within seven (7) calendar days following the inspection. Such modifications may include maintenance of existing controls, adjustments in the locations of controls, or addition of new controls to ensure that the ECP/SWP3 is meeting its goals and criteria.

(4) An inspection report summarizing the scope of the inspection, name(s) and qualifications of personnel making the inspection, the date(s) of the inspection, major observations relating to the implementation of the storm water pollution prevention plan, and actions taken in accordance with Section 6B(3) above, shall be made and retained as part of the SWP3/ECP Plan for at least three years from the date that the site is finally stabilized (see Part G for sample inspection forms). During construction, the reports shall be maintained onsite along with a copy of the SWP3/ECP Plan. The construction inspection reports shall identify any incidents of non-compliance. Where a report does not identify any incidents of non-compliance, the report shall contain a certification that the facility is in compliance with the storm water pollution prevention plan and this permit. The report shall be signed by the permittee or their duly authorized representative and the inspector.

SECTION 7. REVOCATION OR SUSPENSION OF SWP3 AND ECP

A. A SWP3 and ECP may be revoked or suspended by the County/City Engineer or designee upon the occurrence of any of the following:

(1) Failure of the permittee to comply with the plan or any portion thereof, or any condition of the permit; or

(2) Failure of the permittee to comply with any provision of this ordinance, or any other applicable law, ordinance, rule or regulation; or

(3) A determination by the County Engineer that the erosion and sediment control measures implemented by the permittee pursuant to the plan are inadequate to prevent or minimize, to the maximum extent practicable, the discharge of sediment, debris or other pollutants from the construction site by storm water runoff or vehicular tracking.

B. Uintah County/Vernal City/Naples City shall mail permittee written notice of non compliance or personally serve notice to the person responsible for maintaining the erosion control and sediment control measures, before revoking or suspending a permit.

The notice shall state the nature and location of the non compliance and shall specify what action is required for the permittee to avoid revocation or suspension of the permit, which in the absence of exceptional circumstances shall not be less than 5 working days or more than 10 working days. The notice shall be sent by certified mail to the address listed for the permittee on the application.

C. For the purposes of this ordinance, exceptional circumstances include, but are not limited to, situations which involve risk of injury to persons, damage to storm drain facilities, or damage to other property. Uintah County/Vernal City/Naples City may take any action deemed necessary to alleviate any such exceptional circumstances defined above and may bill the permittee, property owner, developer or contractor responsible for creating exceptional circumstances for the cost of alleviating said circumstance.

D. A stop work order on all construction activity on the site may be issued upon the revocation or suspension of a permit. No construction activity may be commenced or continued on any site for which a permit has been revoked or suspended and a stop work order issued until the permit has been reinstated or reissued.

E. A SWP3 and ECP may be reinstated or reissued upon review and approval of a written description of he permittee’s proposed actions to bring the erosion control and sediment control measures into compliance with all provisions of this ordinance, or submission, review and approval of a revised SWP3 and ECP.

SECTION 8. COMPLIANCE WITH FEDERAL AND STATE LAW

Nothing contained in this ordinance is intended to relieve any person or entity from any obligation to comply with applicable federal and/or state laws and any other regulations pertaining to clean water and/or storm water runoff and erosion control.

PART B: PERIMETER CONTROL EXEMPTIONS

DEFINITION: Certain construction sites may be exempt from installing silt fence or other temporary perimeter controls if the site meets certain criteria.

PURPOSE: Exemptions for silt fence or other perimeter controls are for construction sites where such controls may be ineffectual, excessive, and/or detrimental to nearby water resources and other natural resources.

APPLICATION: All exemptions must be approved by the Uintah County/Vernal City/Naples City Engineer and must meet the following criteria:

1. Total disturbance is less than 1 acre.
2. A 50 foot wide vegetated buffer exists down gradient from the disturbed portion(s) of the site.
3. A 100 foot wide vegetated buffer exists down gradient between the disturbed potions(s) of the site and any live stream or existing drainage way.
4. The site and vegetated buffer have less than 5% slope (slope must be documented).
5. The vegetated buffer has at least 70% ground cover.

PART C1: EROSION AND SEDIMENT CONTROLS

This list is not to be construed to be the limit of available BMPs, only as a partial list, and as examples which may be employed.

REVEGETATION

DEFINITION: Placement of seed material or sod over open area for temporary or permanent erosion control.

PURPOSE:

- Reduce velocity of storm water runoff.
- Reduce erosion by preventing rainfall directly hitting soil.

APPLICATION:

- All areas disturbed by construction activity, including cut and fill slopes.

LIMITATIONS:

- Revegetation on slopes steeper than 3:1 must utilize geotextiles to promote establishment of vegetative cover.

INSTALLATION:

Temporary Seeding

- Grade and shape the area to be seeded so that it will drain properly and accommodate seeding equipment.
- Loosen compacted soil by racking, or discing where hydraulic seeding will not be used, to provide for seed retention and germination.
- Apply seed and fertilization suitable for the area and season. The seed species and fertilization requirements must be developed by a professional or the local Soil Conservation Service Office.

Permanent Seeding

- Grade and shape the area to be seeded so that it will drain properly and accommodate seeding equipment. If slopes are steeper than 3:1, the use of hydraulic seeding equipment is encouraged.
- Loosen compacted soil by racking, or discing where hydraulic seeding will not be used, to provide for seed retention and germination.
- Spread at least 3 inches of topsoil, if required, before seeding. If topsoil is required, the subsoil should be serrated or disced to provide an interface.
- Apply seed and fertilization suitable for the area and season. The seed species and fertilization requirements must be developed by a professional or the local Soil Conservation Service Office.

MAINTENANCE:

- Inspect seeded areas after every rainfall event and at a minimum of monthly.

- Replace seed on any bare areas, or area showing signs of erosion as necessary.

MULCHING

DEFINITION: Placement of material such as straw, grass, wood-chips, wood-fibers or fabricated matting over open area.

PURPOSE:

- Reduce velocity of storm water runoff.
- Reduce erosion by preventing rainfall directly hitting soil.
- Facilitate plant growth by holding seeds and feI1ilizer in place, retaining moisture and providing insulation against extreme temperature.

APPLICATION:

- Any exposed area to remain untouched longer than 14 days and that will be exposed less than 60 days (seed areas to be exposed in excess of 60 days).
- Areas that have been seeded.
- Stockpiled soil material.

LIMITATIONS:

- Anchoring may be required to prevent migration of mulch material.
- Down-gradient control may be required to prevent mulch material being transported to storm water system.

INSTALLATION:

- Rough area to revive mulch to create depressions that mulch material can settle into.
- Apply mulch to required thickness and anchor as necessary.
- Recommended Application Rates:
    - Straw: 2-3 bales/l000 square feet (90-120 bales/acre)
    - Wood Fiber: 25-30 pounds/1000 square feet (1000-1500 pounds/acre)
- Ensure material used is weed free and does not contain any constituent that will inhibit plant growth.

MAINTENANCE:

- Inspect mulched areas after every rainfall event and at a minimum of monthly.
- Replace mulch and any bare areas and re-anchor as necessary.
- Clean and replace down-gradient controls as necessary.

Recommended Application Rates for Mulching.

Material	Application	Depth	Comments
Gravel: Washed 3/4" to 1½"	9 cu yd/1000 sq ft	3 inches	Good for traffic areas. Good for short slopes.
Straw: Air-Dried, free of seeds and coarse material.	2-3 bales/1000 sq ft	2 inches (Min.)	Subject to wind blowing. Tack down or keep moist.
Wood Fiber Cellulose: Free from growth inhibitors; dyed green	35 lb/1000 sq ft	1 inch (Min.)	For critical areas, double application rate; Limit to slopes <3% and < 150 feet

GEOTEXTILES

DEFINITION: Matting or netting made biodegradable materials (such as Excelsior blanket, jute, wood fiber, straw, coconut, paper , or cotton) to reduce rainfall impact and surface erosion on disturbed soils.

PURPOSE:

- Reduce velocity of storm water runoff.
- Reduce erosion by preventing rainfall directly hitting soil.
- Facilitate plant growth by holding seeds, fertilizer, and mulch in place, retaining moisture and providing insulation against extreme temperature.
- Provide flexible roadway ditch lining to promote establishment of vegetative cover.

APPLICATION:

- Areas that have been seeded, fertilized and mulched with slopes that are steeper than 3:1.
- Stabilize vegetated roadway ditches while permanent vegetative cover becomes established.

LIMITATIONS:

- Effectiveness may be reduced drastically if the fabric is not properly selected, designed, or installed.
- Should not be placed on 1:1 slopes if they are to be covered with overlying material.
- Many synthetic geotextiles are sensitive to light and must be protected prior to installation.

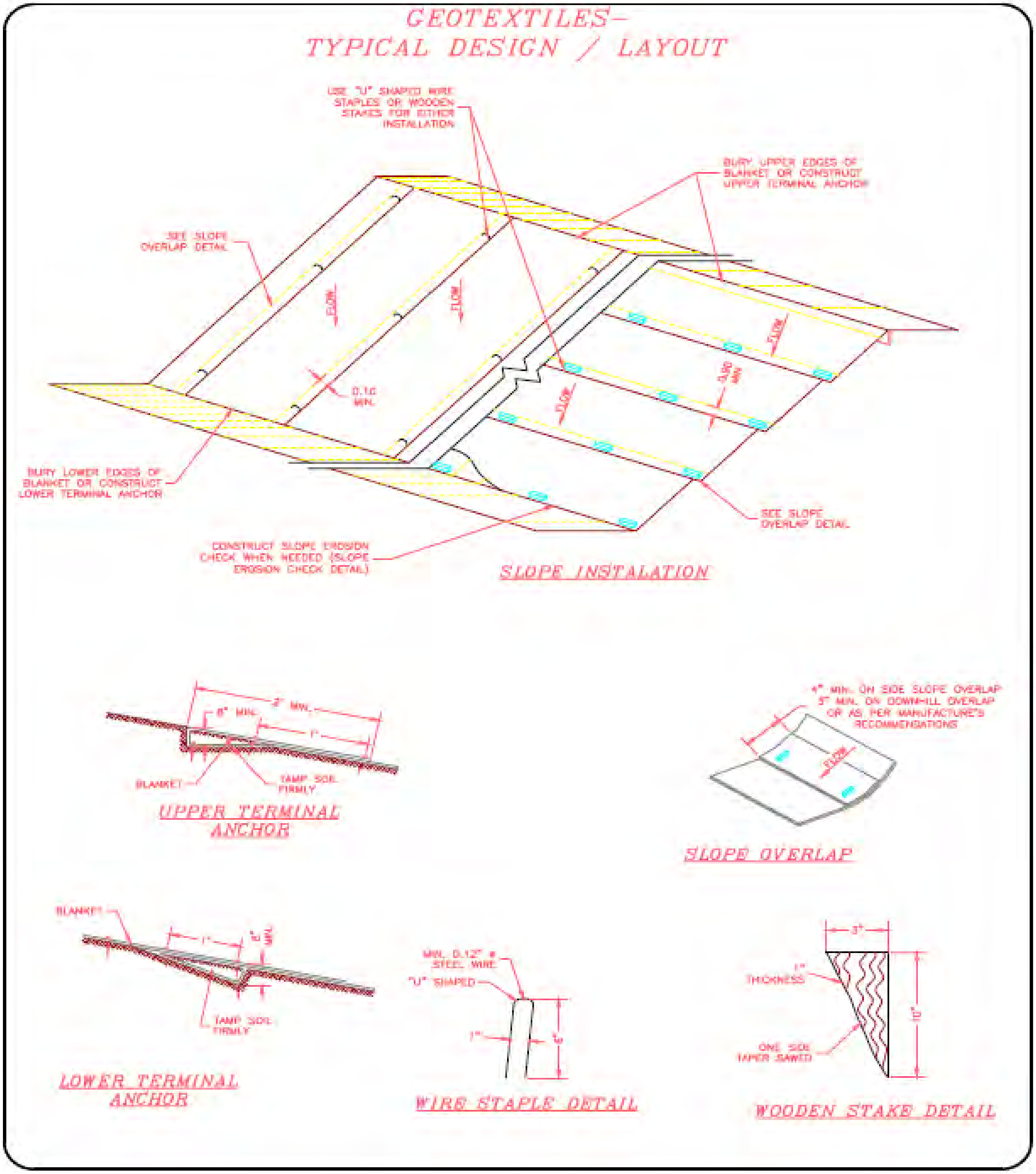
INSTALLATION:

- Allow for an overlap of 4 inches on both sides of each roll and 36 inches at the ends of the roll.
- The fabric must extend beyond the edge of the exposed area at least 12 inches at the sides and 36 inches at the top and bottom.
- At the top of the area, bury the end of each roll in a trench at least 8 inches deep. The trench should then be backfilled and tamped.

- Staples should be driven perpendicularly into the slope face. Staples must be of 3/16" diameter (or heavier) steel wire. Allow for spacing of approximately 5 feet apart along the sides and center of each roll and not more than 12 inches apart along upper end of a roll or at the overlap of two rolls.
- The soil must be reasonably smooth. Fill and compact any rills and gullies. Remove any protruding rocks and other obstructions.
- Apply the individual rolls up and down the slope, from top to bottom--never along the contour.
- Make sure that the fabric makes uniform contact with the slope face underneath. No bridging of rills or gullies should be allowed.

MAINTENANCE:

- At a minimum, inspect geotextiles on a monthly basis, and after rain events greater than 0.5 inch of precipitation.
- Clean and replace down gradient controls as necessary.


GEOTEXTILES–
TYPICAL DESIGN / LAYOUT
USE "U" SHAPED WIRE STAPLES OR WOODEN STAKES FOR EITHER INSTALLATION
BURY UPPER EDGES OF BLANKET OR CONSTRUCT UPPER TERMINAL ANCHOR
SEE SLOPE OVERLAP DETAIL
FLOW
FLOW
FLOW
FLOW
0.10 MIN.
BURY LOWER EDGES OF BLANKET OR CONSTRUCT LOWER TERMINAL ANCHOR
SEE SLOPE OVERLAP DETAIL
CONSTRUCT SLOPE EROSION CHECK WHEN NEEDED (SLOPE EROSION CHECK DETAIL)
SLOPE INSTALATION
2' MIN.
6" MIN.
1'
BLANKET
TAMP SOIL FIRMLY
UPPER TERMINAL ANCHOR
4" MIN. ON SIDE SLOPE OVERLAP
5" MIN. ON DOWNHILL OVERLAP
OR AS PER MANUFACTURE'S RECOMMENDATIONS
FLOW
SLOPE OVERLAP
BLANKET
1'
6" MIN.
TAMP SOIL FIRMLY
LOWER TERMINAL ANCHOR
MIN. 0.12" ø STEEL WIRE
"U" SHAPED
1"
6"
WIRE STAPLE DETAIL
3"
1" THICKNESS
ONE SIDE TAPER SAWED
10"
WOODEN STAKE DETAIL

SURFACE ROUGHENING

DEFINITION: Rough preparation of working areas leaving depressions and uneven surface.

PURPOSE: Depressions trap water and sediment reducing erosion and facilitating establishment of vegetative cover.

APPLICATION:

- Surface roughening is appropriate for all construction that will not be receiving impervious cover within 14 days and that will be exposed less than 60 days (seed areas to be open in excess of 60 days).

LIMITATIONS:

- Will not withstand heavy rainfall.
- Slopes steeper than 2:1 (50%) should be benched.

CONSTRUCTION:

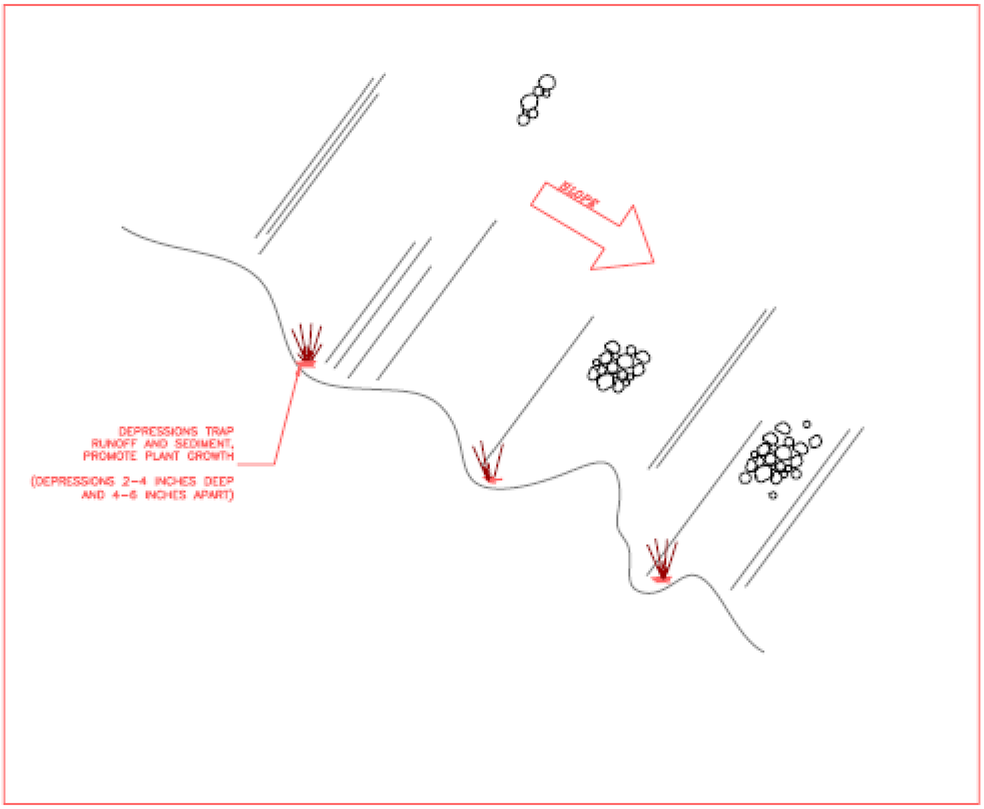
- Surface should be left in rough condition during initial earthwork activity.
- Surfaces that have become smoothed or compacted due to equipment traffic should be roughened by use of disks, spring harrows, teeth on front end loader, or similar, operating along the contour of the slope. Tracking (by crawler tractor driving up and down slope) may also be used to provide depressions parallel to contours.
- Avoid compaction of soils during roughening as this inhibits plant growth and promotes storm water runoff. Limit tracked machinery to sandy soil.
- Seed or mulch areas to be exposed in excess of 60 days.
- Employ dust controls.

MAINTENANCE:

- Inspect following any storm event and at a minimum of weekly.
- If erosion in the form of rills (small waterways formed by runoff) is evident, perform machine roughening of area.
- For vegetated slopes reseed areas that are bare or have been reworked.

SURFACE ROUGHENING

TYPICAL
DESIGN LAYOUT



SILT FENCE

DEFINITION: A temporary sediment barrier consisting of filter fabric stretched across and secured to supporting posts and entrenched.

PURPOSE: To filter storm water runoff from up-gradient disturbed area and trap sediment on site.

APPLICATION:

- Perimeter Control: Place fence at down-gradient limits of disturbance.
- Sediment Barrier: Place fence at an offset distance from the toe of slope or soil stockpile required to contain anticipated sediment and storm water.
- Protection of Existing Waterways: Place fence at top of stream bank.
- Inlet Protection: Place fence surrounding catch basins.
- Sediment Removal: Place fence to capture sediment moving through roadway ditches.

LIMITATIONS:

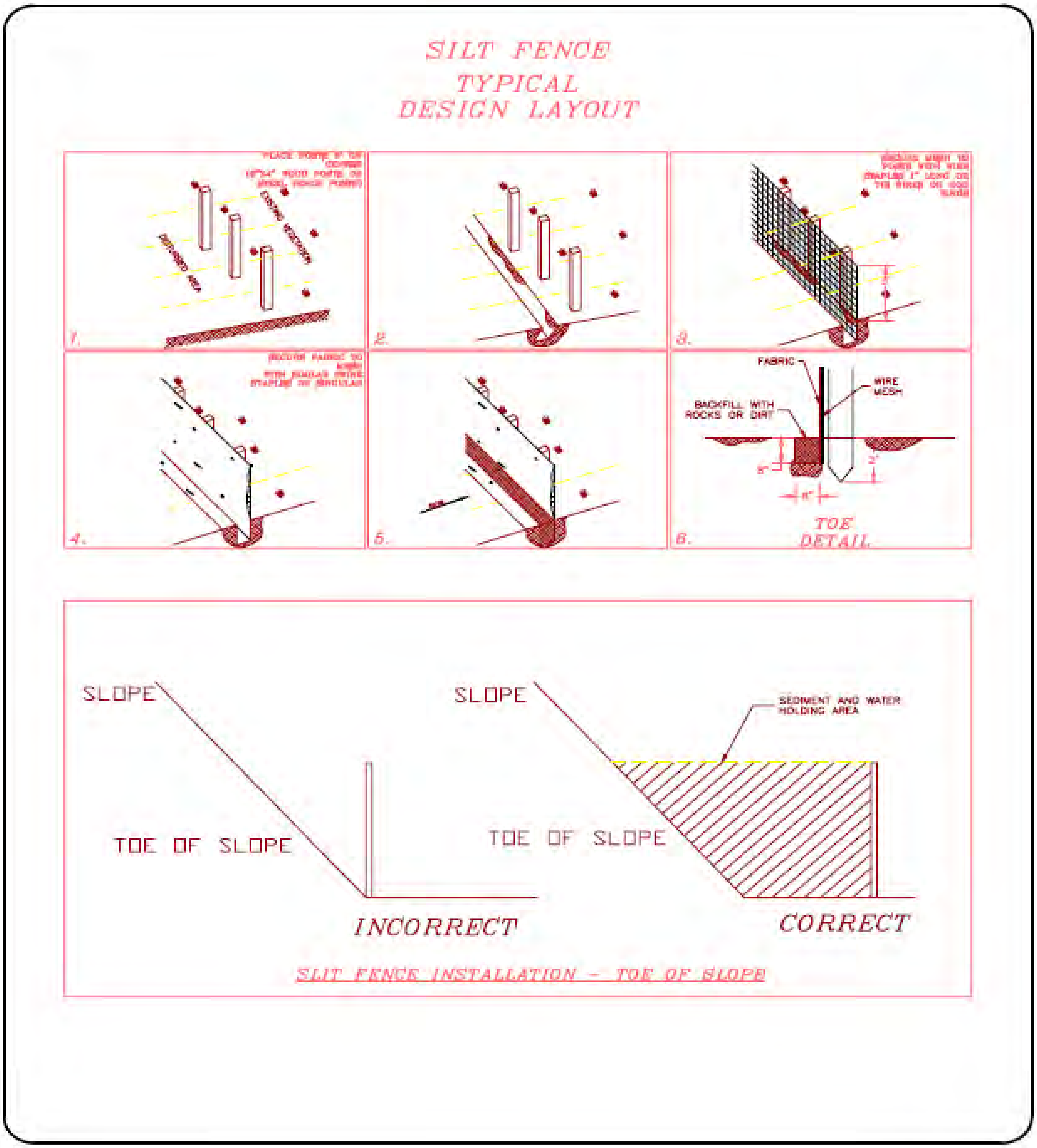
- Recommended maximum drainage area of 0.5 acre per 100 feet of fence.
- Recommended maximum up-gradient slope length of 150 feet.
- Recommended maximum uphill grade of 2:1 (50%).
- Long-term ponding should not be allowed behind fence.

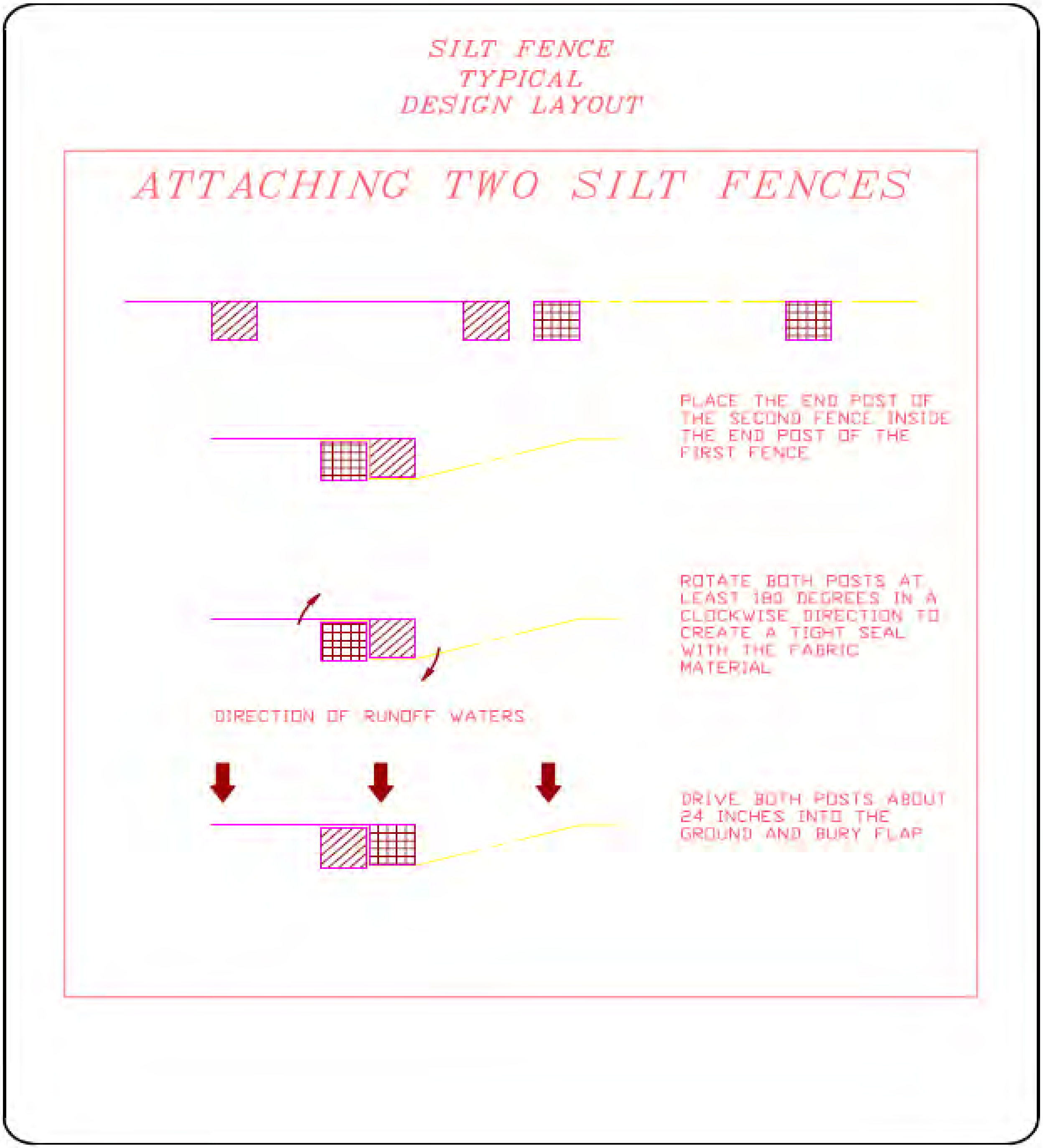
INSTALLATION:

- Place posts 6 foot on center along contour (or use preassembled unit) and drive 2 feet (min.) into ground. Excavate an anchor trench (8 inches wide and 8 inches deep) immediately up-gradient of posts.
- Secure wire mesh (14 gage min. with 6 inch openings) to up slope side of posts. Attach with heavy duty wire staples 1 inch long, tie wires or hog rings.
- Cut fabric to required width, unroll along length of barrier and drape over barrier. Secure fabric to, mesh with twine, staples, or similar, with trailing edge extending into anchor trench.
- Backfill trench over filter fabric to anchor.

MAINTENANCE:

- Inspect immediately after any rainfall and at least daily during prolonged rainfall.
- Look for runoff bypassing ends of barriers or undercutting fence (repair immediately).
- Repair or replace damaged areas of the fence and remove accumulated sediment.
- Re-anchor fence as necessary to prevent shortcutting.
- Remove accumulated sediment when it reaches ½ the height of the fence.


SILT FENCE
TYPICAL
DESIGN LAYOUT
1.
2.
3.
4.
5.
6.
FABRIC
WIRE MESH
BACKFILL WITH ROCKS OR DIRT
TOE DETAIL
SLOPE
TOE OF SLOPE
INCORRECT
SLOPE
SEDIMENT AND WATER HOLDING AREA
TOE OF SLOPE
CORRECT
SLIT FENCE INSTALLATION – TOE OF SLOPE


SILT FENCE
TYPICAL
DESIGN LAYOUT
ATTACHING TWO SILT FENCES
PLACE THE END POST OF THE SECOND FENCE INSIDE THE END POST OF THE FIRST FENCE
ROTATE BOTH POSTS AT LEAST 180 DEGREES IN A CLOCKWISE DIRECTION TO CREATE A TIGHT SEAL WITH THE FABRIC MATERIAL
DIRECTION OF RUNOFF WATERS
DRIVE BOTH POSTS ABOUT 24 INCHES INTO THE GROUND AND BURY FLAP

STRAW BALE BARRIER

DEFINITION: Temporary sediment barrier consisting of a row of entrenched and anchored straw bales.

PURPOSE: To filter storm water runoff from up gradient disturbed area and trap sediment on site.

APPLICATION:

- Perimeter Control: Place barrier at down gradient limits of disturbance.
- Sediment Barrier: Place barrier at an offset distance from the toe of slope or soil stockpile required to contain anticipated sediment and storm water.
- Protection of Existing waterways: Place barrier at top of stream bank.
- Velocity Dissipation: Reduce velocities in roadway ditches.

LIMITATIONS:

- Recommended maximum drainage area of 0.5 acre per 100 foot barrier.
- Recommended maximum up gradient slope length of 150 feet.
- Recommended maximum uphill grade of 2:1 (50%).

INSTALLATION:

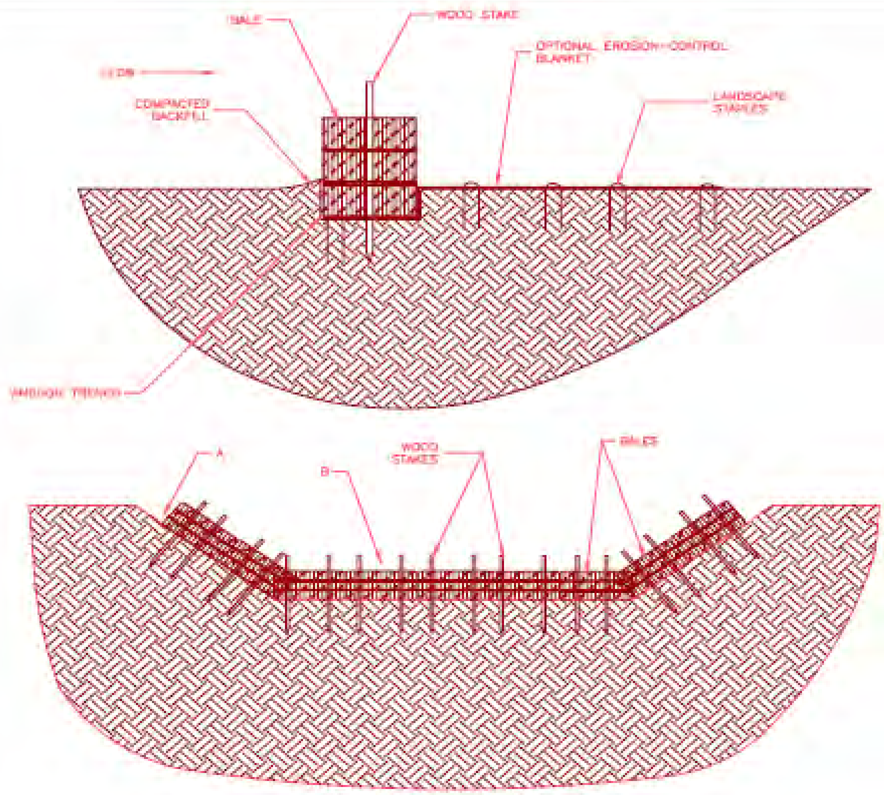
- Excavate a 4-inch minimum deep trench along contour line, i.e. parallel to slope, removing all grass and other material that may allow underflow.
- Place bales in trench with ends tightly abutting; fill any gaps by wedging loose straw into openings.
- Anchor each bale with 2 stakes driven flush with the top of the bale. Extend stakes 18 inches (min.) into the ground.
- Backfill around bale and compact to prevent piping, backfill on uphill side to be built up 4-inches above original ground at the barrier.
- In roadway ditches, straw bales should not be placed in such a way as to direct water around sides. Riprap should be placed around straw bale edges.

MAINTENANCE:

- Inspect immediately after any rainfall and at least daily during prolonged rainfall.
- Look for runoff bypassing ends of barriers or undercutting barriers.
- Repair or replace damaged areas of the barrier and remove accumulated sediment.
- Realign bales as necessary to provide continuous barrier and fill gaps.
- Re-compact soil around barrier as necessary to prevent piping.

STRAW BALE CHECK DAM

TYPICAL DESIGN LAYOUT



CHECK DAM SPACING

THE FOLLOWING TABLE PROVIDES CHECK SPACING FOR A GIVEN DITCH GRADE:

DITCH (%)	CHECK DAM SPACING (FEET)
1.0	200
2.0	100
3.0	66
4.0	50
5.0	40
6.0	33

STABILIZED CONSTRUCTION ENTRANCE

DEFINITION: A stabilized pad of crushed stone located where construction traffic enters or leaves the site from or to a paved surface.

PURPOSE: To reduce potential for vehicle tracking of sediment or flow of sediment onto a paved surface where it may runoff to a storm water collection system, waterway, or lake.

APPLICATION:

- At any point of ingress or egress at a construction site where adjacent traveled way is paved. Applies to all sites which require a Storm Water Pollution Prevention Permit and Erosion Control Permit.
- Any project having a duration of 3 months or more must install filter fabric beneath the crushed stone to minimize sediment pumping into the crushed stone.

LIMITATIONS: Not listed.

INSTALLATION:

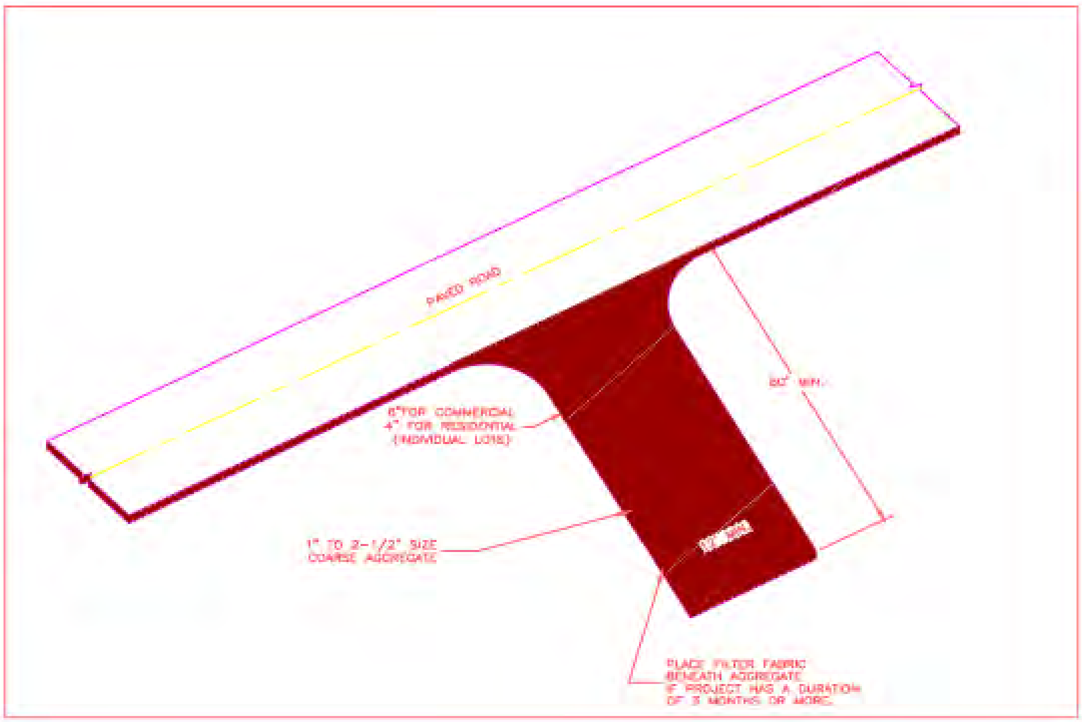
- Clear and grub area and grade to provide slope shown for driveway, or access/intersection. If adjacent to waterway, use a maximum slope of 2%.
- Compact sub-grade and place filter fabric if required.
- Place coarse aggregate, 1 to 2 ½ inches size, to a minimum depth of 6 inches for commercial projects, and 4 inches for residential projects.

MAINTENANCE:

- Inspect daily for loss of gravel or sediment buildup.
- Inspect adjacent roadway for sediment deposit and clean by sweeping or shoveling.
- Repair entrance and replace gravel as required to maintain control in good working condition.
- Expand stabilized area as required to accommodate traffic, and off site street parking and prevent erosion at driveway.

STABILIZED CONSTRUCTION ENTRANCE

TYPICAL DESIGN LAYOUT



DIVERSION DITCH/DIKE

DEFINITION: A temporary sediment barrier and storm water conveyance consisting of an excavated channel and compacted earth ridge.

PURPOSE: To protect down-gradient areas from sedimentation and erosion by diverting runoff to a controlled discharge point.

APPLICATION:

- Construct along the top of construction slope to intercept up-gradient runoff.
- Construct along the toe of construction slope to divert sediment laden runoff.
- Construct along midpoint of construction slope to intercept runoff and channel to a controlled discharge point.
- Construct around base of soil stockpiles to capture sediment.
- Construct around perimeter of disturbed areas to capture sediment.

LIMITATIONS:

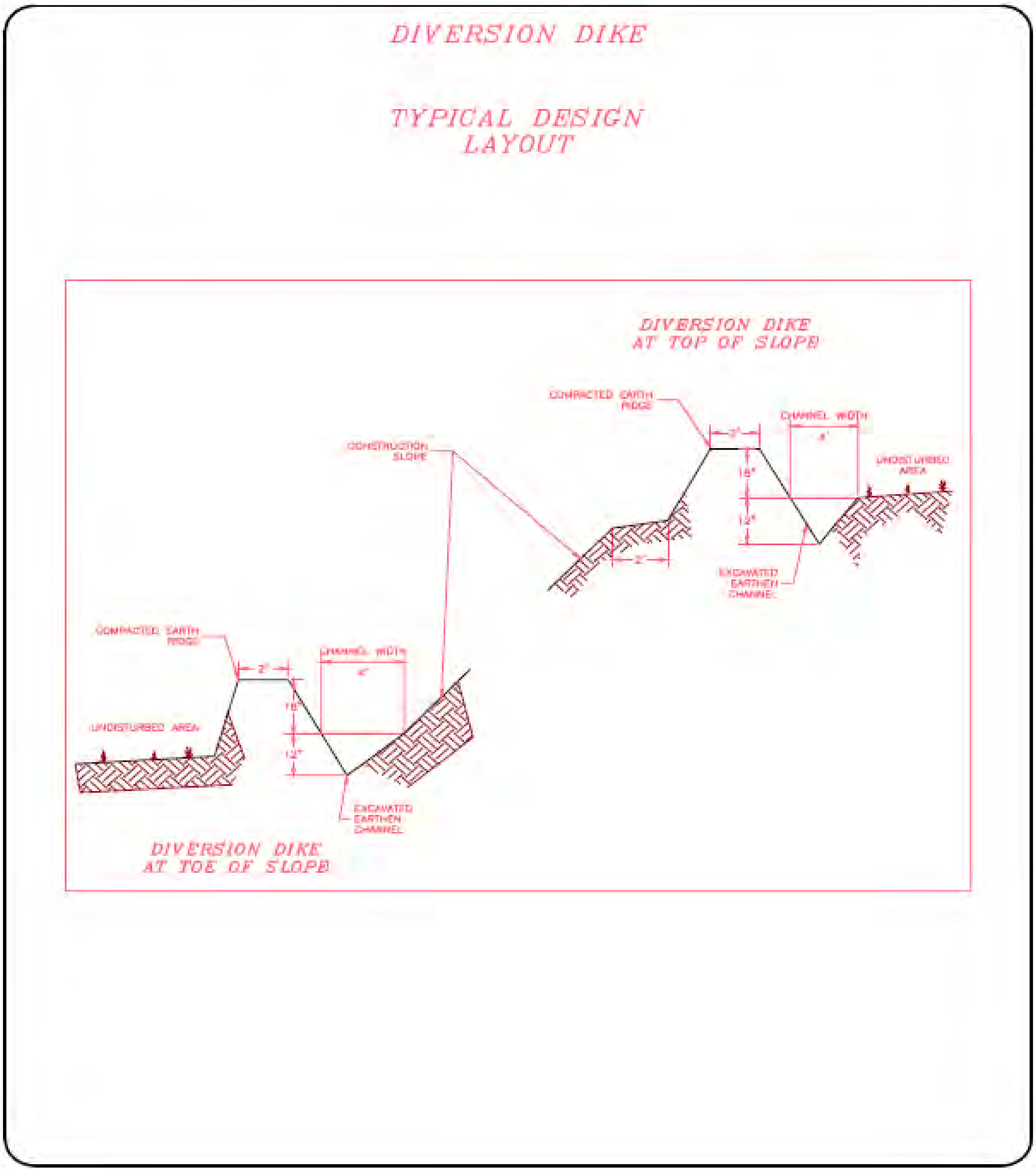
- Recommended maximum drainage of 5 acres.
- Recommended maximum side slopes of 2:1 (50%).
- Recommended maximum slope on channel of 1%.

INSTALLATION:

- Clear and grub area for ditch/dike construction.
- Excavate channel and place soil on down gradient side.
- Shape and machine compact excavated soil to form ditch/ridge.
- Place erosion protection (Riprap, mulch, appropriate geotextiles) at outlet.
- Stabilize channel and ridge as required with mulch, gravel or vegetative cover.

MAINTENANCE:

- Inspect immediately after any rainfall and at least daily during prolonged rainfall.
- Look for runoff breaching dike or eroding channel or side slopes.
- Check discharge point for erosion or bypassing of flows.
- Repair and stabilize as necessary.
- Inspect daily during vehicular or construction equipment activity on slope, check for and repair any traffic damage.


DIVERSION DIKE
TYPICAL DESIGN
LAYOUT
DIVERSION DIKE
AT TOP OF SLOPE
COMPACTED EARTH
RIDGE
CHANNEL WIDTH
CONSTRUCTION
SLOPE
UNDISTURBED
AREA
18"
12"
2'
EXCAVATED
EARTHEN
CHANNEL
UNDISTURBED AREA
DIVERSION DIKE
AT TOE OF SLOPE

WATER BAR

DEFINITION: A constructed drainage feature that diverts water off unpaved roads or trails to a controlled discharge point.

PURPOSE: To prevent water from ponding and/or flowing on/or along an unpaved road or trail by diverting runoff to a controlled discharge point.

APPLICATION:

- Construct along roads/trails to intercept up-gradient runoff and prevent rills from forming on fill slopes.
- Construct in low areas where water ponding is likely to occur to divert water off of the road/trail surface.
- Construct where erosion problems are occurring due to uncontrolled runoff.

LIMITATIONS:

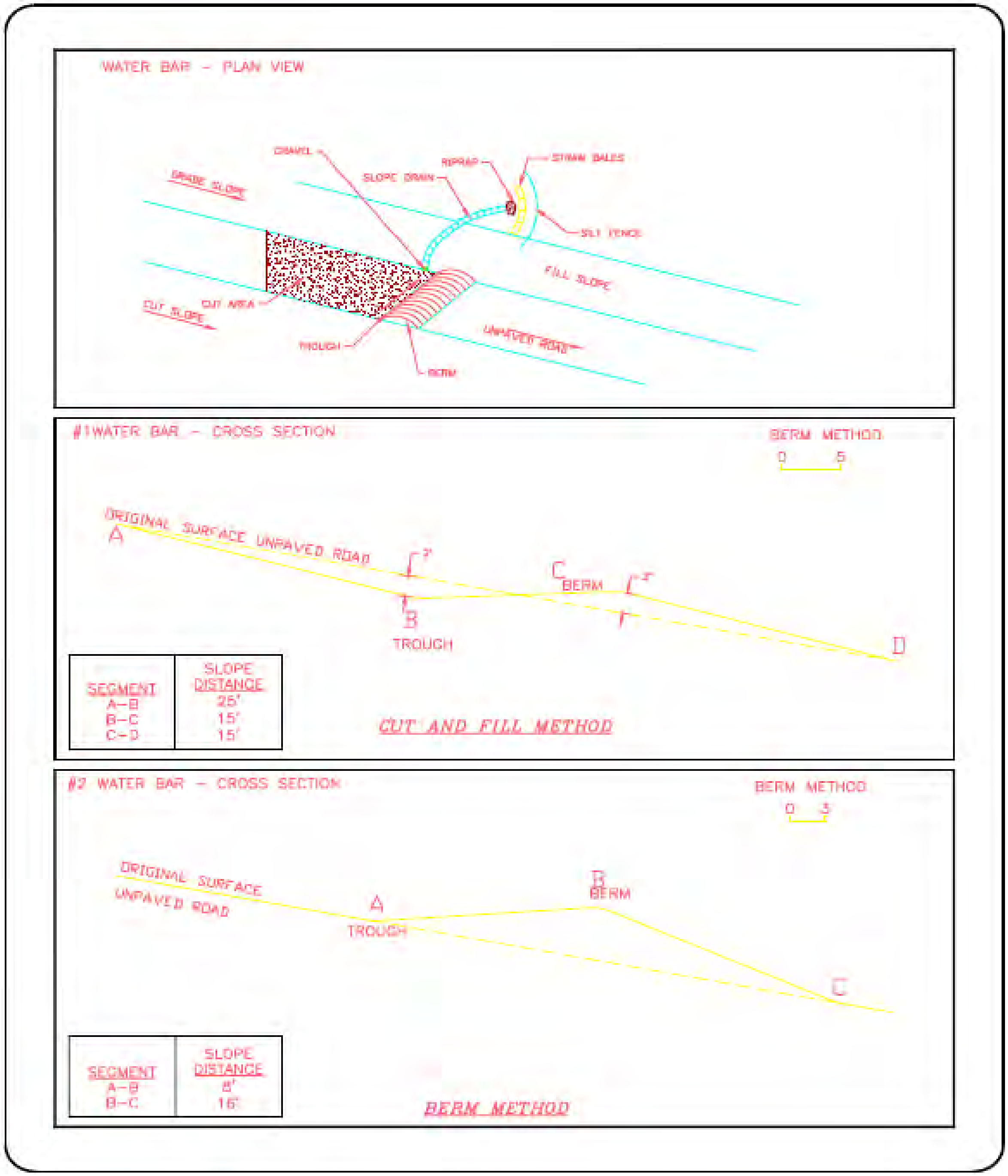
- Discharge point should be stable and not sensitive to increases in runoff.
- Unfiltered discharges should not be directed directly into natural waterways.
- Waterbars must be appropriately sized for specific traffic types and levels of use.

INSTALLATION:

- Location and frequency should be based on road slopes, runoff patterns, and topography.
- Determine discharge point and appropriate discharge method (slope drain, vegetated swale, rip rapped chute, or storm drain).
- Excavate trough and/or construct berm with fill.
- Compact the fill material.
- Construct discharge point.
- Use straw bales, silt fencing, gravel check dams, excavated sediment traps, or existing vegetation to filter the discharge as necessary.

MAINTENANCE:

- Inspect immediately after any rainfall and at least daily during prolonged rainfall.
- Remove sediment as necessary.
- Inspect for runoff breaching water bar or eroding at/or below the discharge point.
- Repair vehicle ruts on the top of the berm and stabilize as necessary.


WATER BAR – PLAN VIEW
GRAVEL
SLOPE DRAIN
RIPRAP
STRAW BALES
SILT FENCE
FILL SLOPE
CUT AREA
CUT SLOPE
UNPAVED ROAD
TROUGH
BERM
#1 WATER BAR – CROSS SECTION
BERM METHOD
0 5
ORIGINAL SURFACE UNPAVED ROAD
A
B
TROUGH
C
BERM
D
SEGMENT
A–B
B–C
C–D
SLOPE DISTANCE
25'
15'
15'
CUT AND FILL METHOD
#2 WATER BAR – CROSS SECTION
BERM METHOD
0 5
ORIGINAL SURFACE
UNPAVED ROAD
A
TROUGH
B
BERM
C
SEGMENT
A–B
B–C
SLOPE DISTANCE
8'
16'
BERM METHOD

STORM DRAIN INLET PROTECTION

DEFINITION: Concrete block, filter cloth, and gravel filter placed over inlet to storm drain system.

PURPOSE: Reduce sediment discharge to storm drain system by filtering storm Water flows and reducing flow velocities allowing deposition of sediment.

APPLICATION:

- Construct at storm drain inlets in paved or unpaved areas where up-gradient area is to be disturbed by construction activities.

LIMITATIONS:

- Recommended for maximum drainage of one acre.
- Excess flows may bypass the inlet requiring down gradient controls.
- Ponding will occur at inlet.

INSTALLATION:

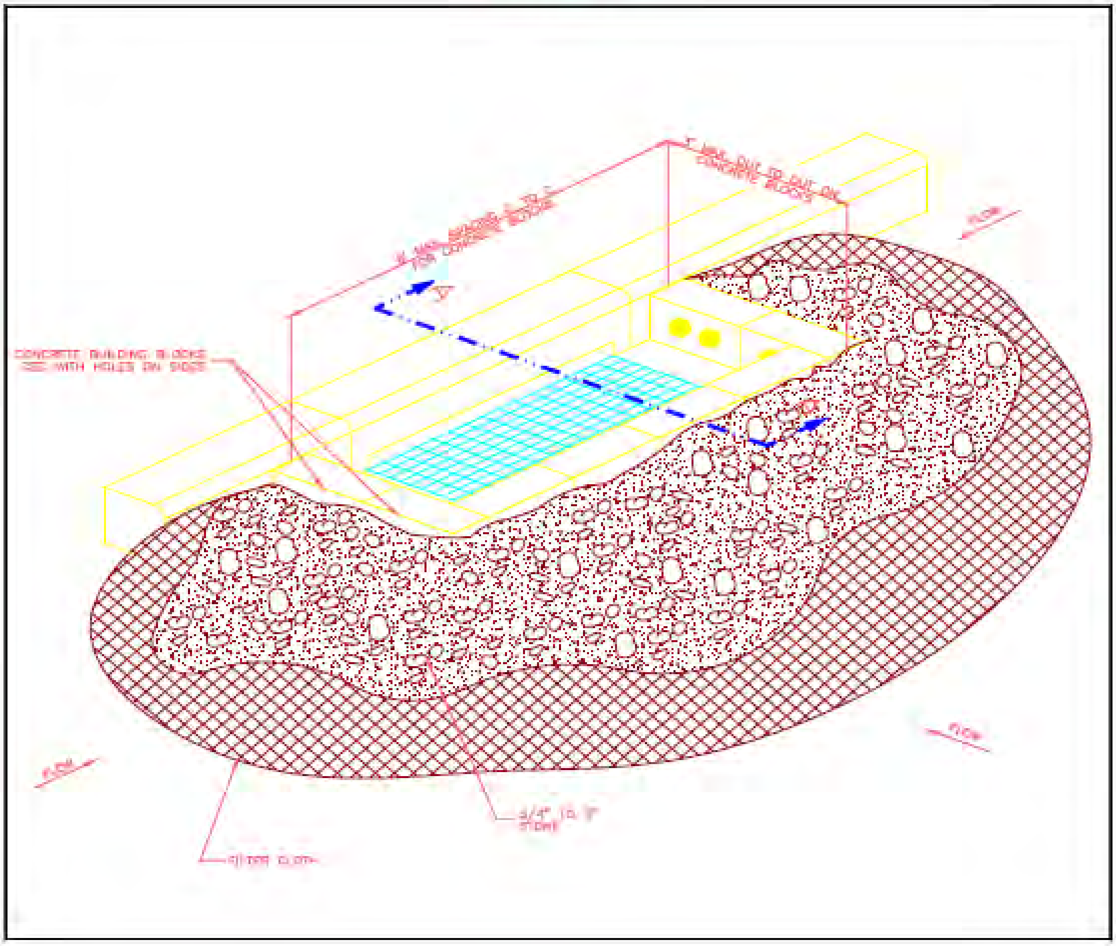
- Place wire (with ½ inch openings) over the inlet extending 12-inches past inlet opening. Place filter fabric over mesh.
- Place concrete blocks around the inlet with openings facing outward. Stack blocks to minimum height of 12-inches and a maximum height of 24-inches.
- Place wire mesh around outside of blocks.
- Place gravel (3/4 inch to 3 inches) around blocks.

MAINTENANCE:

- Inspect inlet protection after every large storm event and at a minimum of once monthly.
- Remove sediment accumulated when it reaches 4-inches in depth.
- Replace filter fabric and clean or replace gravel if clogging is apparent.

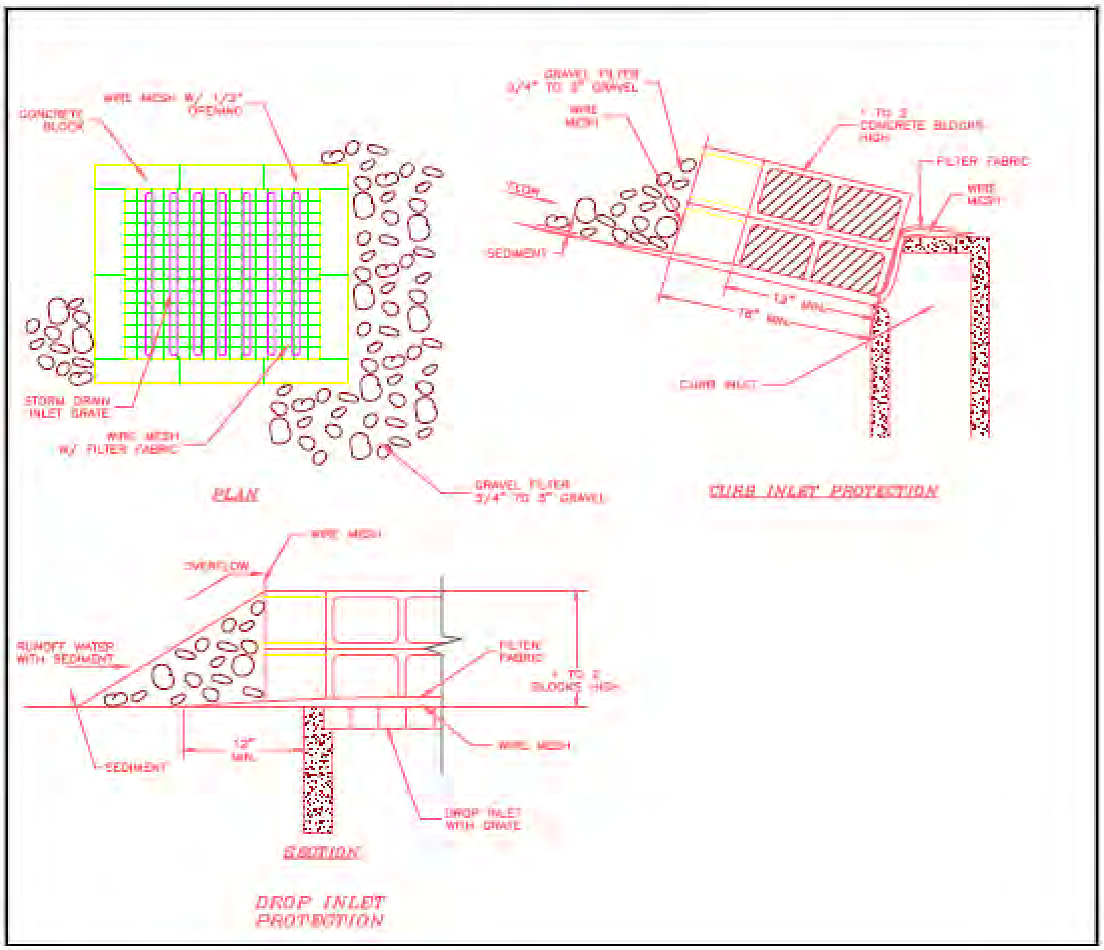
INLET PROTECTION

TYPICAL DESIGN LAYOUT



INLET PROTECTION

TYPICAL DESIGN LAYOUT



STRAW BALE DROP-INLET BARRIER

DEFINITION: Straw Bale placed around inlet to storm drain system. Bale drop-inlets operate by intercepting and ponding sediment-laden runoff. Ponding the water reduces the velocity of the incoming flow and allows most of the suspended sediment to settle out. When the pond height reaches the top of the barrier, water flows over the bales and into the drop inlet.

PURPOSE: Reduce sediment discharge to storm drain system by some filtering of storm water flows and reducing flow velocities allowing deposition of sediment.

APPLICATION:

- Construct at storm drain inlets in unpaved areas where up-gradient area is to be disturbed by construction activities.
- Use at median drop-inlet boxes.

LIMITATIONS:

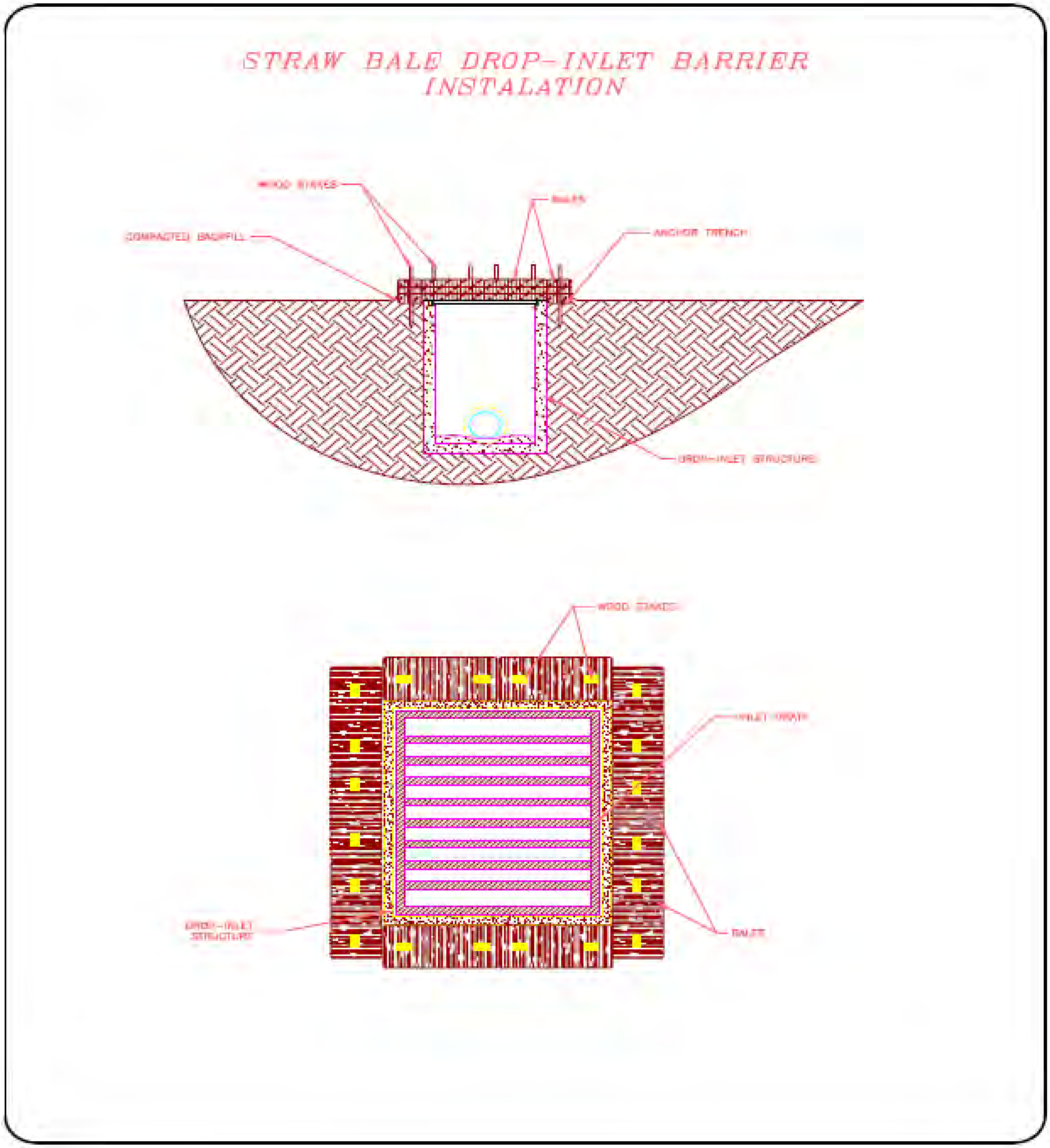
- Recommended for maximum drainage of one acre.
- Excess flows may bypass the inlet requiring down gradient controls.
- Ponding will occur at inlet.
- Do not use where ponding may stretch out onto adjacent roadway.

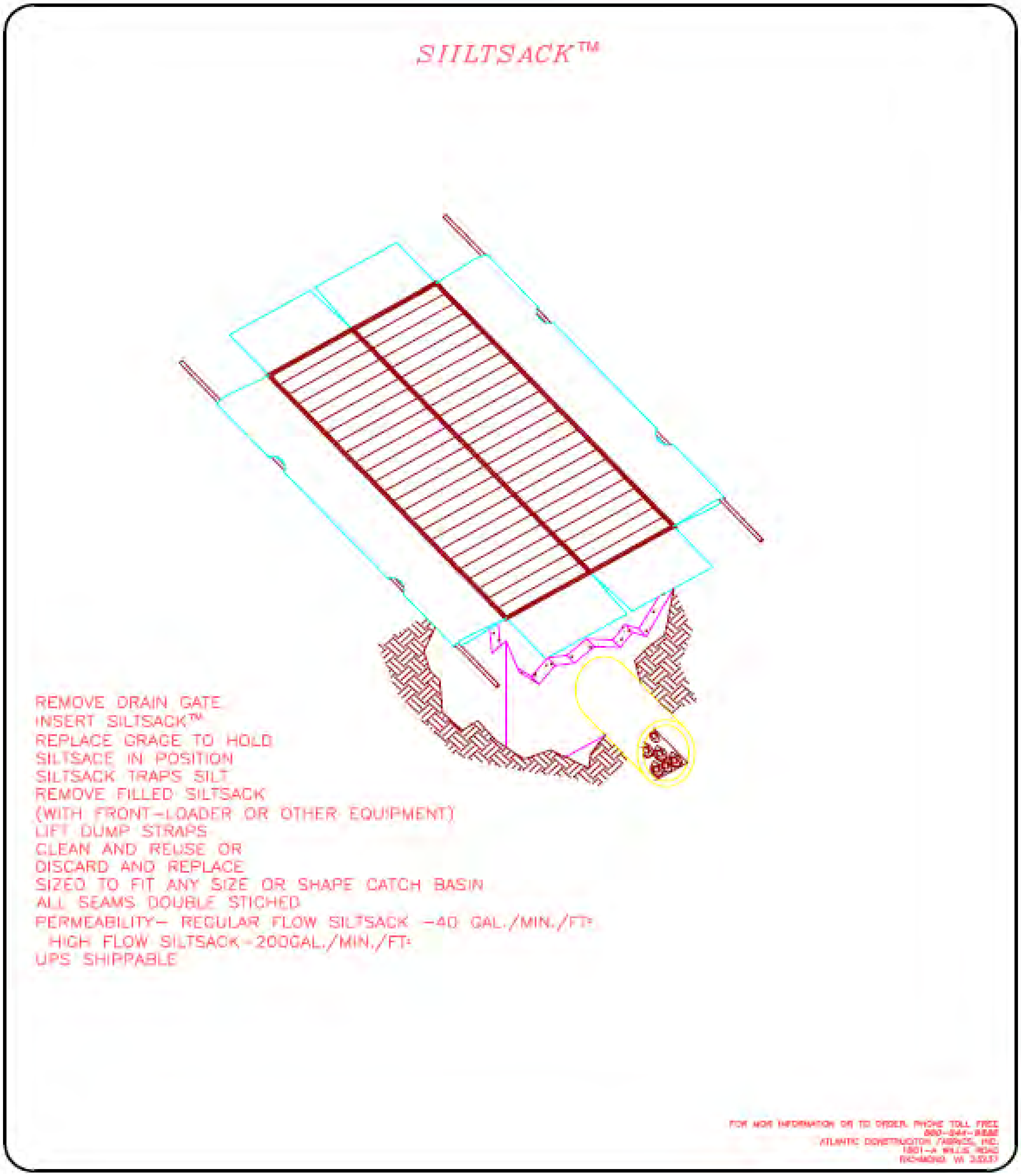
INSTALLATION:

- Excavate a trench around the perimeter of the drop inlet that is at least 6 inches deep by 1.5 times the width of the bale wide
- Place bales in the trench, making sure that they are butted tightly. Some bales mat need to be shortened to fit the trench around the drop inlet. Two stakes must be driven though each bale approximately 8 inches from each end. The stakes must be driven a minimum of 18 inches into the ground.
- The bales must also be placed directly against the outside of the drop-inlet. This allows overtopping water to flow directly into the inlet instead of onto nearby soil causing scour.
- Place the excavated against the outside of the bales and compacted. The compacted soil should be no deeper than 4 inches against the bale.
- This method may be enhanced with the use of a silt catching/filtering sack placed inside the drop-inlet.

MAINTENANCE:

- Inspect inlet protection after every large storm event and at a minimum of once weekly.
- Remove sediment accumulated when it reaches half the height of the bale.
- Replace bales which become damaged.
- Replace filter sack (if used) if clogging is apparent.


STRAW BALE DROP-INLET BARRIER
INSTALLATION
WOOD STAKES
BALES
COMPACTED BACKFILL
ANCHOR TRENCH
DROP-INLET STRUCTURE
WOOD STAKES
INLET GRATE
DROP-INLET
STRUCTURE
BALES


SIILTSACK™
REMOVE DRAIN GATE
INSERT SILTSACK™
REPLACE GRACE TO HOLD
SILTSACE IN POSITION
SILTSACK TRAPS SILT
REMOVE FILLED SILTSACK
(WITH FRONT-LOADER OR OTHER EQUIPMENT)
LIFT DUMP STRAPS
CLEAN AND REUSE OR
DISCARD AND REPLACE
SIZED TO FIT ANY SIZE OR SHAPE CATCH BASIN
ALL SEAMS DOUBLE STICHED
PERMEABILITY– REGULAR FLOW SILTSACK –40 GAL./MIN./FT²
HIGH FLOW SILTSACK–200GAL./MIN./FT²
UPS SHIPPABLE

BRUSH BARRIER

DEFINITION: A vertical barrier constructed of tree trimmings, limbs, and brush obtained from the clearing operation. A filter cloth should be used over the brush barrier to maximize effectiveness.

PURPOSE: To trap sediment and filter construction runoff.

APPLICATION:

- Sediment Barrier: Place barrier at toe of slope or soil stockpile.
- Velocity Dissipation: Reduce velocities and trap sediment at culvert outlets and in roadway ditches.

LIMITATIONS:

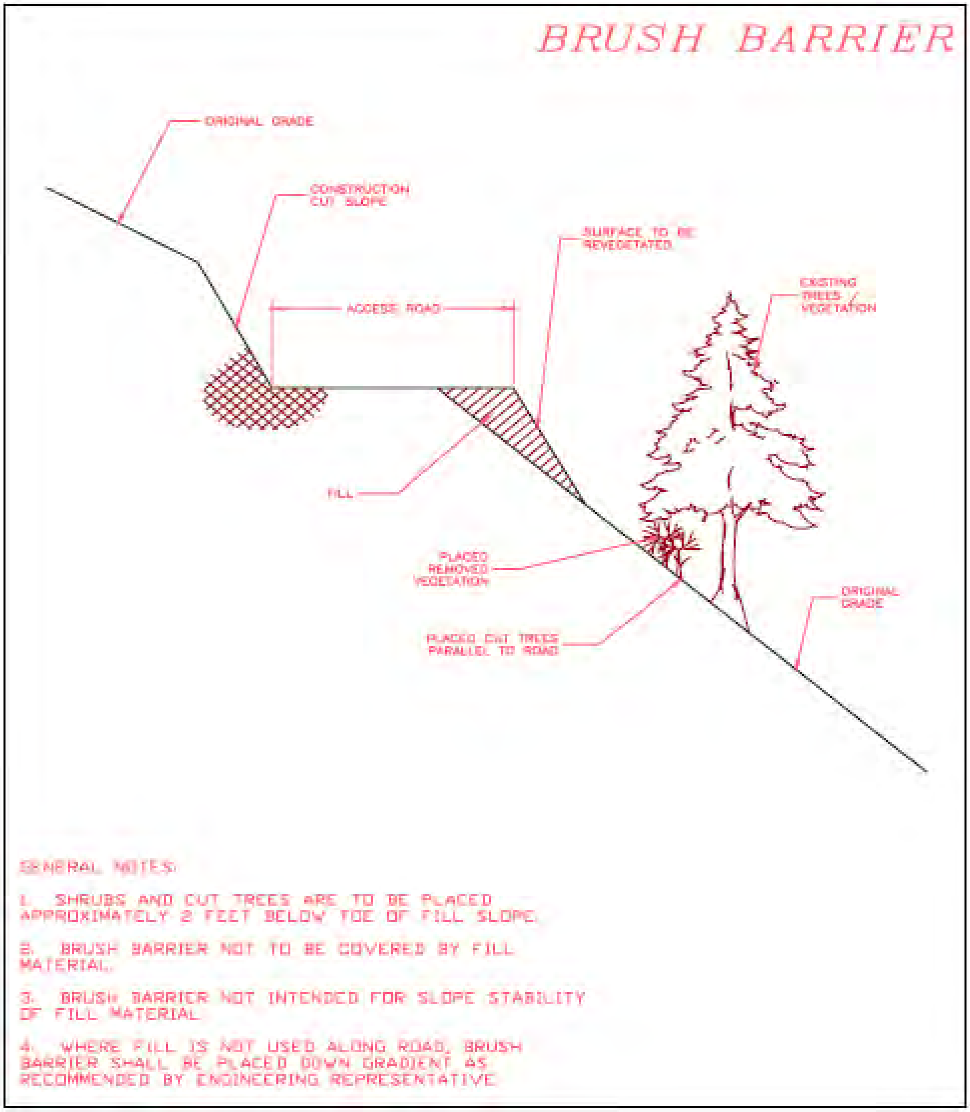
- Adequate material for the barrier is available from the clearing operation.

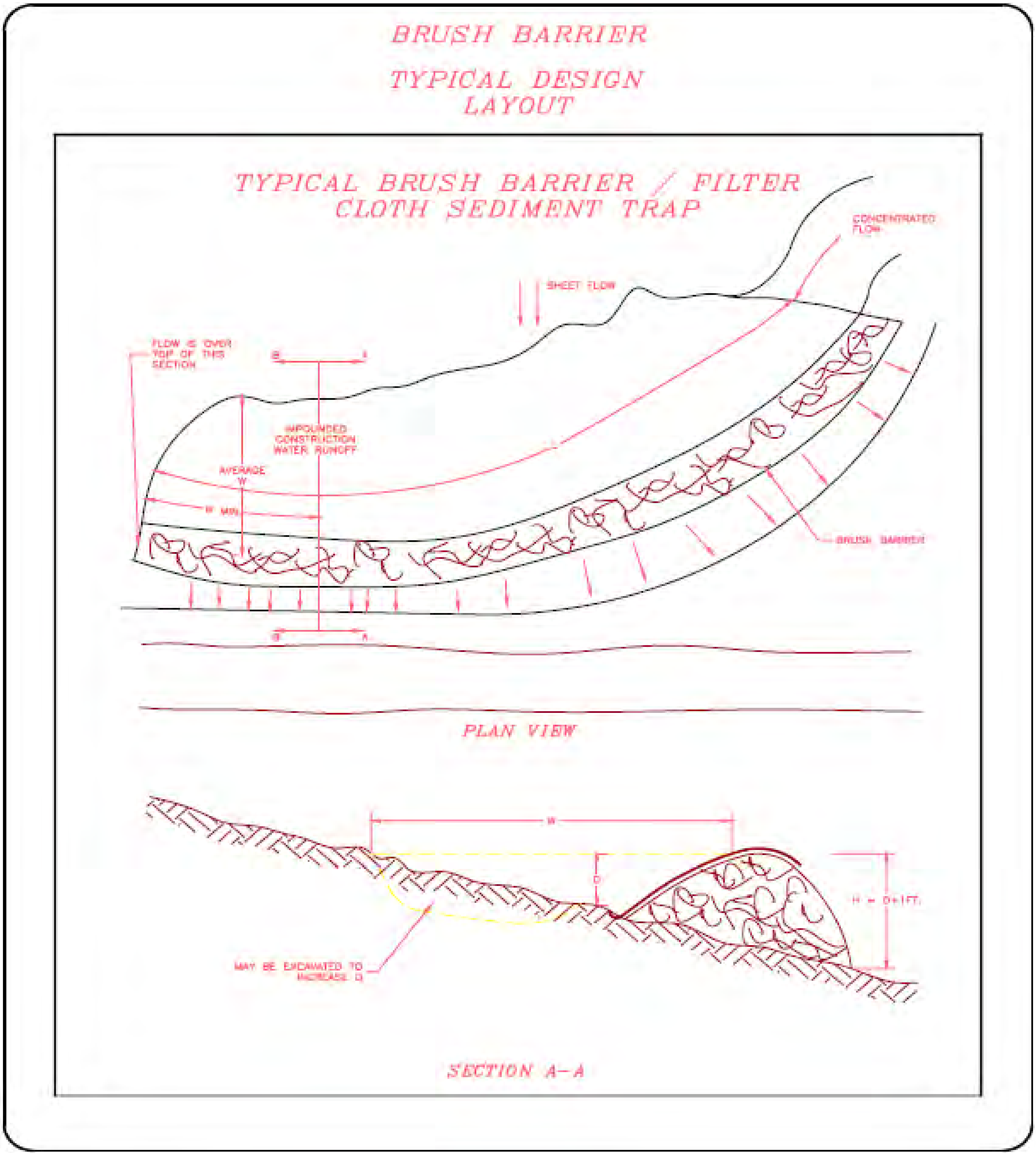
INSTALLATION:

- Construct barrier with trimmings, limbs, and brush and perform necessary trimming.
- Construct small trench (8 inches wide and 8 inches deep) on front side of barrier.
- Cut filter cloth to proper size and place over brush.
- Bury the filter cloth to prevent undermining.
- Attach filter cloth to brush by stapling or other means.
- Brush barriers located below pipe culverts should be constructed prior to culvert installation.

MAINTENANCE:

- Inspect immediately after any rainfall and at least daily during prolonged rainfall.
- Look for runoff bypassing ends of barriers or undercutting barriers.
- Repair or replace damaged areas of the barrier and remove accumulated sediment.
- Re-compact soil around barrier as necessary to prevent piping.


BRUSH BARRIER
ORIGINAL GRADE
CONSTRUCTION CUT SLOPE
SURFACE TO BE REVEGETATED
ACCESS ROAD
EXISTING TREES / VEGETATION
FILL
PLACED REMOVED VEGETATION
ORIGINAL GRADE
PLACED CUT TREES PARALLEL TO ROAD
GENERAL NOTES:
1. SHRUBS AND CUT TREES ARE TO BE PLACED APPROXIMATELY 2 FEET BELOW TOE OF FILL SLOPE.
2. BRUSH BARRIER NOT TO BE COVERED BY FILL MATERIAL.
3. BRUSH BARRIER NOT INTENDED FOR SLOPE STABILITY OF FILL MATERIAL.
4. WHERE FILL IS NOT USED ALONG ROAD, BRUSH BARRIER SHALL BE PLACED DOWN GRADIENT AS RECOMMENDED BY ENGINEERING REPRESENTATIVE.


BRUSH BARRIER
TYPICAL DESIGN LAYOUT
TYPICAL BRUSH BARRIER / FILTER CLOTH SEDIMENT TRAP
CONCENTRATED FLOW
SHEET FLOW
FLOW IS OVER TOP OF THIS SECTION
IMPOUNDED CONSTRUCTION WATER RUNOFF
AVERAGE W
W MIN.
BRUSH BARRIER
PLAN VIEW
W
D
H = D+1FT.
MAY BE EXCAVATED TO INCREASE D
SECTION A-A

GRAVEL CHECK DAMS

DEFINITION: Small temporary dam constructed across dry drainage path (i.e. not in live streams).

PURPOSE: To reduce erosion of drainage path by reducing velocity of flow and by trapping sediment and debris.

APPLICATION:

- Temporary drainage paths.
- Permanent drainage ways not yet stabilized.
- Existing drainage paths receiving increased flows due to construction.

LIMITATIONS:

- Maximum recommended drainage area is 10 acres.
- Maximum recommended height is 24".
- Do not use in running stream.

INSTALLATION:

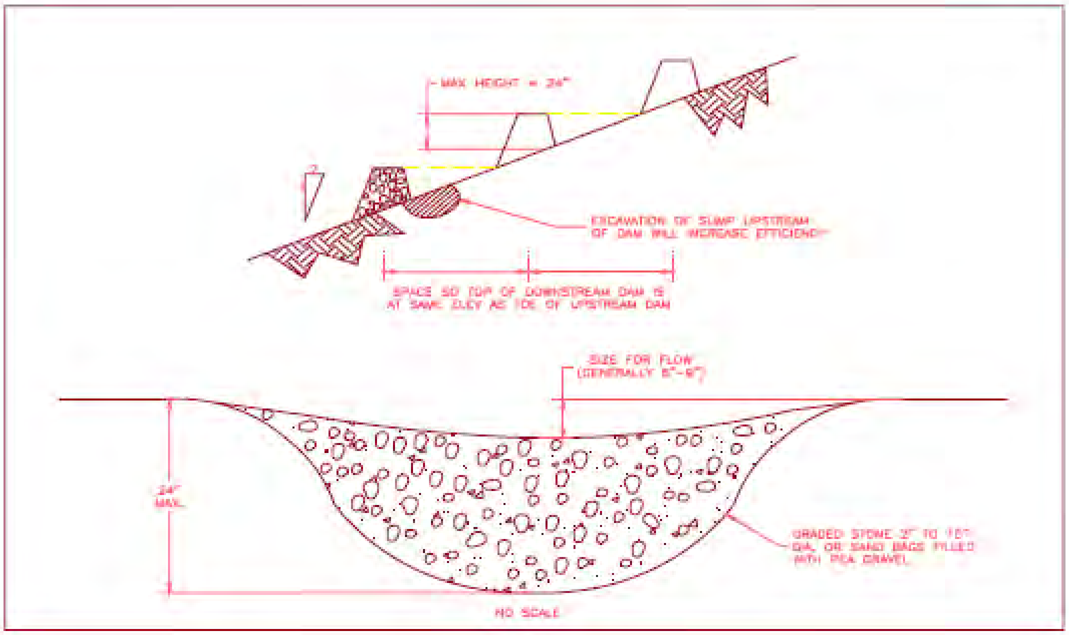
- Prepare location of dam by removing any debris and rough grading any irregularities in channel bottom.
- Place rocks by hand or with appropriate machinery, do not dump.
- Construct dam with center lower to pass design flow.
- Construct 50% side slopes on dam.

MAINTENANCE:

- Inspect dams daily during prolonged rainfall, after each major rain event and at a minimum of once monthly.
- Remove any large debris and repair any damage to dam, channel, or side slopes.
- Remove accumulated sediment when it reaches one half the height of the dam.

GRAVEL CHECK DAMS

TYPICAL DESIGN LAYOUT



DITCH GRADE (%)	CHECK DAM SPACING (FEET)
5.0	60
6.0	50
7.0	43
8.0	38
9.0	33
10.0	30

STRAW BALE CHECK DAMS

DEFINITION: Small temporary dam constructed across dry drainage path (i.e. not in live streams).

PURPOSE: To reduce erosion of drainage path by reducing velocity of flow and by trapping sediment and debris.

APPLICATION:

- Temporary drainage paths.
- Permanent drainage ways not yet stabilized.
- Existing drainage paths receiving increased flows due to construction.

LIMITATIONS:

- Maximum recommended drainage area is 10 acres.
- Sufficient number of bales is required to force runoff over the flow line.
- Do not use in ditches with slopes of 6% or more. For ditches with slopes over 6%, use rock check dams.
- Do not use where high flows are expected.
- Do not use directly in front of a culvert outlet.
- Do not use in running stream.

INSTALLATION:

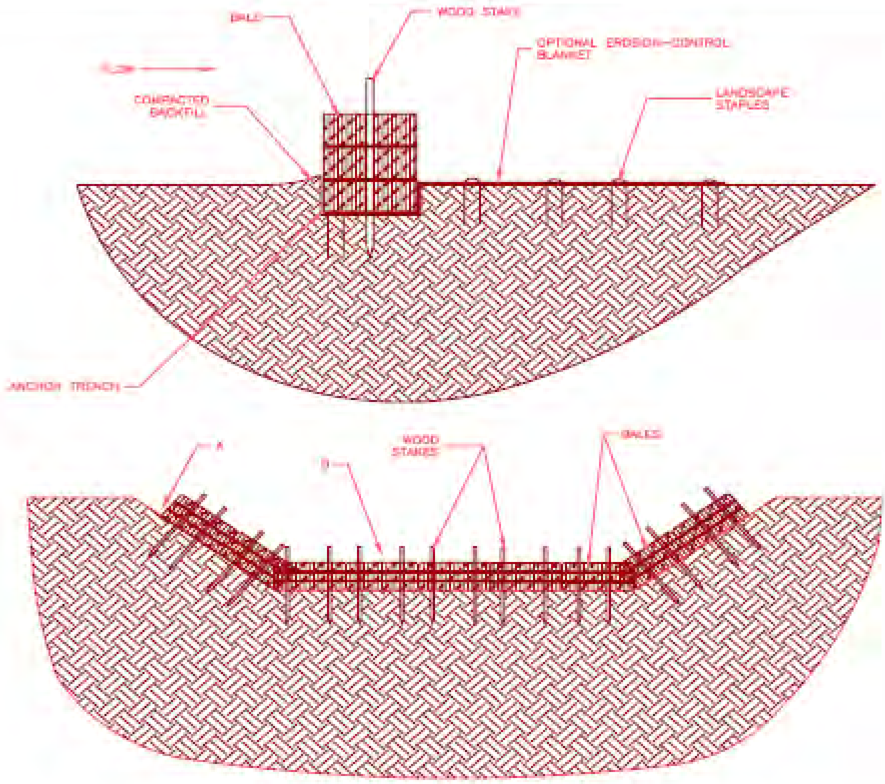
- Prepare location of dam by removing any debris and rough grading any irregularities in channel bottom.
- Bales must be free of weeds declared noxious by the State of Utah, Department of Agriculture.
- Excavate a vertical trench perpendicular to the ditch flow line the length of the straw bale dam that is 6 inches deep, and 1.5 time the width of the bale.
- Place bales in the trench, making sure that they are tightly butted against each other, and the excavated trench on the downstream side.
- Place two stakes through each bale, approximately 8 inches from each end and drive at least 18 inches into the ground.
- Construct dam with center lower to pass design flow.
- Place and compact the excavated material in the remaining trench area on the upstream side. The compacted soil should be no more than 4 inches deep and extend upstream no more than 24 inches.
- Use downstream scour apron where required.

MAINTENANCE:

- Inspect dams daily during prolonged rainfall, after each major rain event and at a minimum of once monthly.
- Remove any large debris and repair any damage to dam, channel, or side slopes.
- Remove accumulated sediment when it reaches one half the height of the dam.

STRAW BALE CHECK DAM

TYPICAL DESIGN LAYOUT



CHECK DAM SPACING

THE FOLLOWING TABLE PROVIDES CHECK SPACING FOR A GIVEN DITCH GRADE:

DITCH (%)	CHECK DAM SPACING (FEET)
1.0	200
2.0	100
3.0	66
4.0	50
5.0	40
6.0	33

SLOPE DRAIN

DEFINITION: A devise used to carry concentrated runoff from the top to the bottom of a slope.

PURPOSE:

- Convey runoff from offsite around a disturbed portion of the site.
- Drain saturated slopes that have the potential for soil slides.

APPLICATION:

- Use on cut or fill slopes before permanent storm water drainage structures have been installed.
- Use where diversion ditches or other diversion measures have been used to concentrate flows.
- Use on any slopes where concentrated runoff crossing the face of the slope may cause gullies, channel erosion, or saturation of slide-prone soils.
- Use as an outlet for a natural drainage way.

LIMITATIONS: Not suitable for drainage areas greater than 10 acres.

INSTALLATION:

- The slope drain design should handle the peak runoff for the 10-year 24-hour storm. Typical relationships between area and pipe diameter are shown below:

Maximum Drainage Area (Acres)	Pipe Diameter (inches)
0.50	12
0.75	15
1.00	18

- Place slope drain on undisturbed or well-compacted soils.
- Place filter cloth under the inlet, extend it to 3 to 6 feet in front of the inlet, and key it in 6 to 8 inches on all sides to prevent erosion. A 6 to 8 inches metal toe plate may also be used for this purpose.
- Securely stake the drain pipe to the slope at intervals of 10 feet or less, using grommets.
- Make sure that all slope drain sections are securely fastened together and have watertight fittings.
- Extend the pipe beyond the toe of the slope and discharge at a non-erosive velocity into a stabilized area or to a sediment trap. Use riprap outlet protection if necessary.

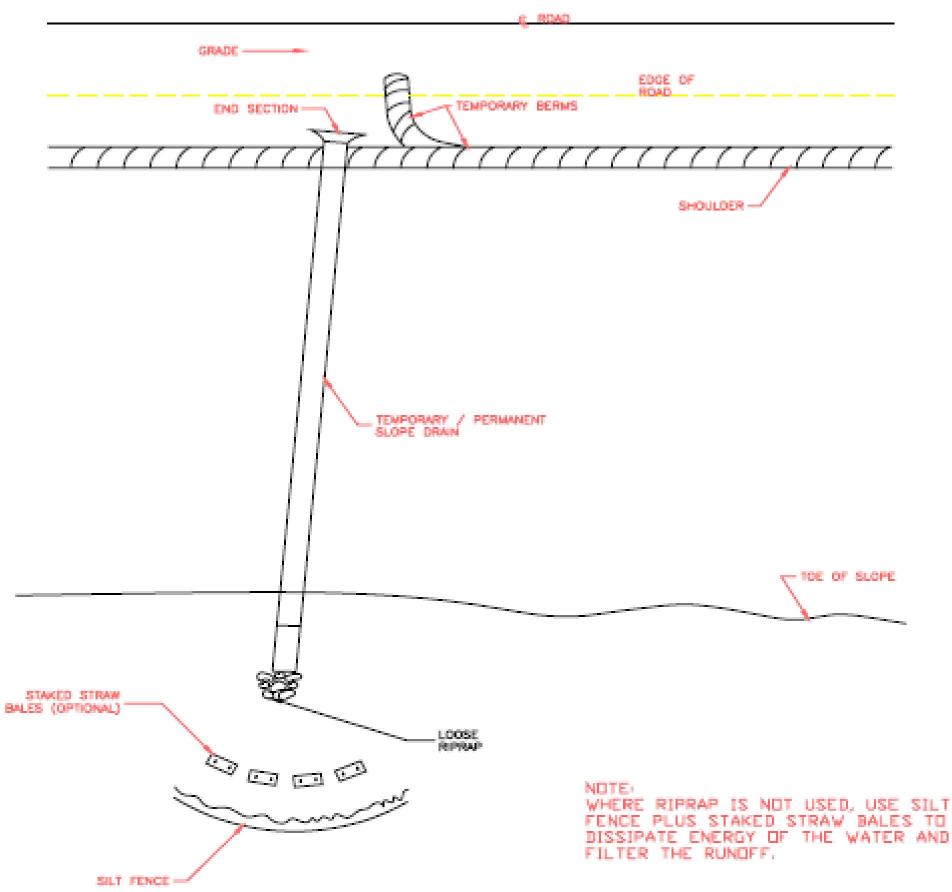
MAINTENANCE:

- Inspect the slope drain regularly and after every storm. Check to see if water is bypassing the inlet or undercutting the inlet or pipe. If necessary, install head walls or sandbags to prevent bypass flow.

- Check for erosion at the outlet point and check the pipe for breaks or clogs.

SLOPE DRAIN

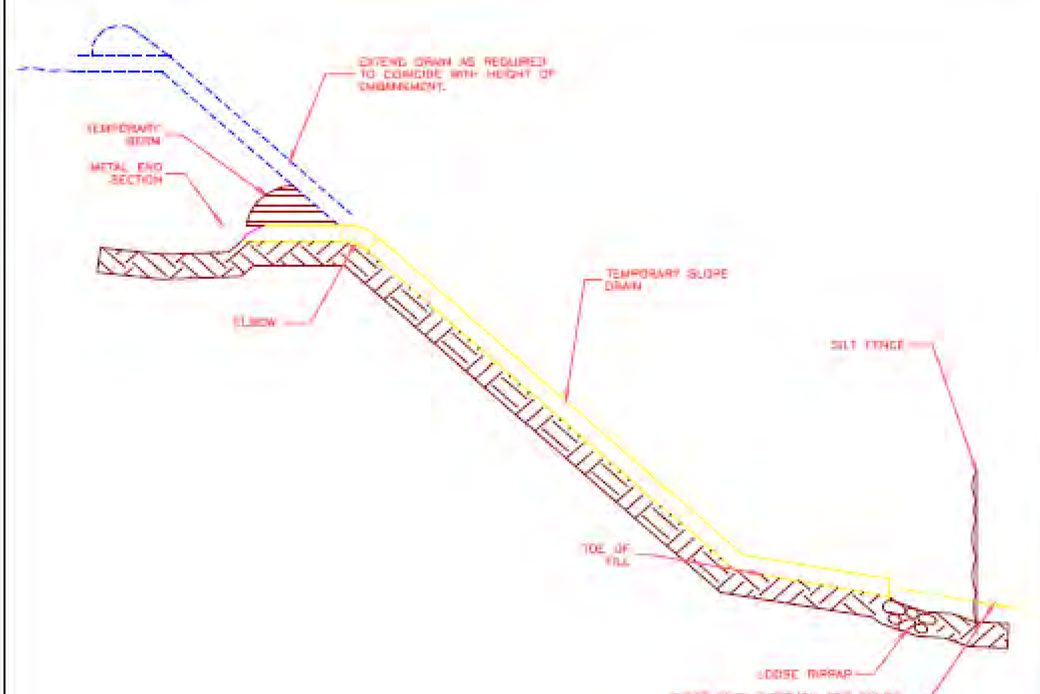
TYPICAL DESIGN LAYOUT



PLAN VIEW

SLOPE DRAIN

TYPICAL DESIGN LAYOUT



ELEVATION VIEW

OPEN CHUTE DRAIN

DEFINITION: An excavated channel placed across disturbed slopes used to protect exposed slopes by intercepting runoff and directing it to a stabilized outlet or sediment-trapping devise.

PURPOSE: Convey runoff over disturbed soil without causing further erosion of the slope.

APPLICATION:

- Used on cut and fill slopes as a permanent or temporary storm water drainage structure.
- Used where diversion ditches or other diversion measures have been used to concentrate flows.

LIMITATIONS:

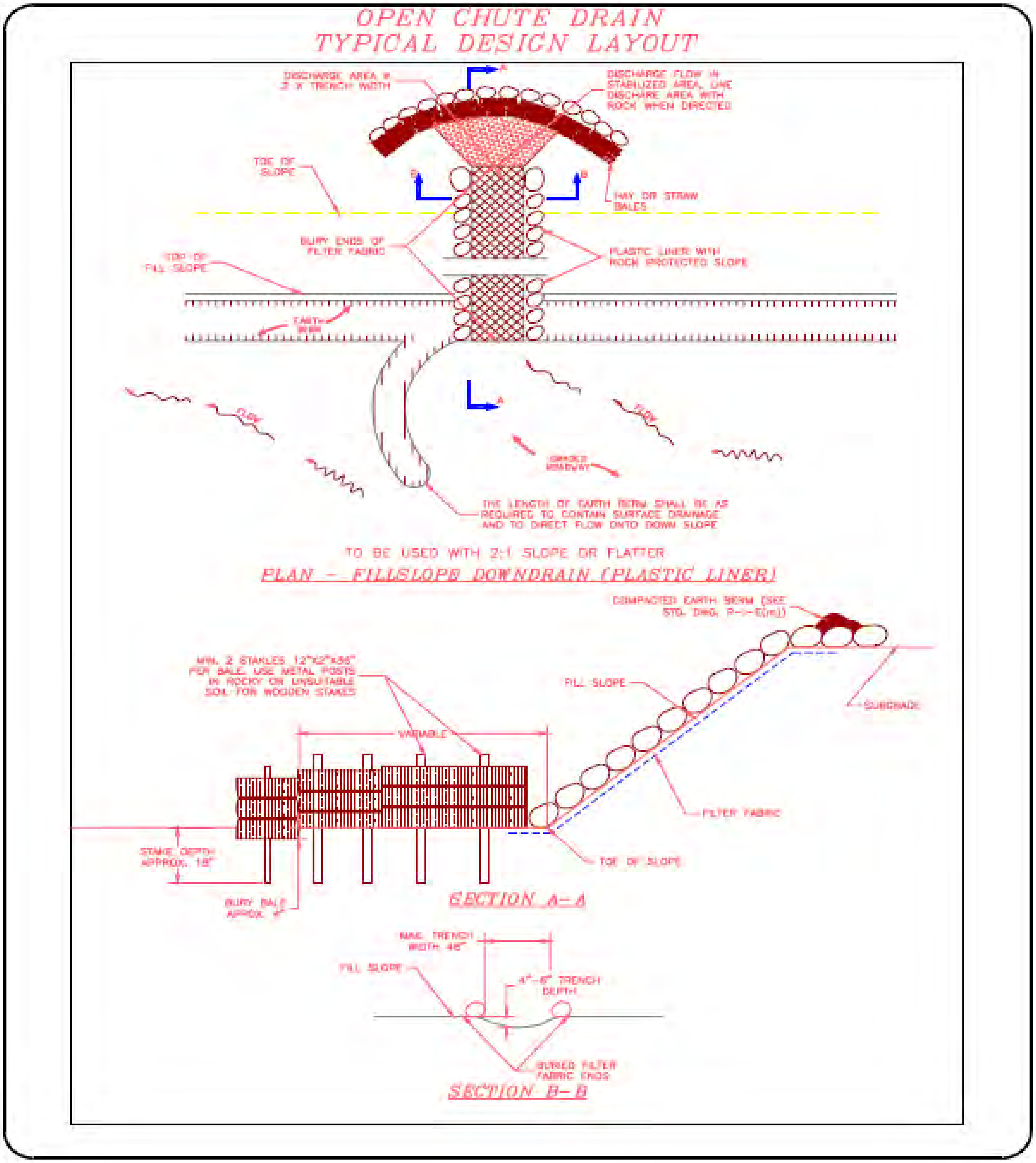
- Should be sized based on anticipated runoff, sediment loading and drainage area size.
- May require temporary slope drain until final grade is established and open chute drain is constructed.
- Recommended maximum slope of 2:1 (50%).
- Recommended minimum slope of 20:1 (5%).

INSTALLATION:

- Detail design is required.
- Implementation of energy dissipaters at the outlet end to protect against scour.
- The elevation of the top of the lining of the inlet structure must not be higher than the lowest diversion dike(s) or other devices that direct flow to the chute.
- Design with adequate capacity to convey the 50-year, 6-hour storm.
- Compact some soil around the inlet to ensure that a good bond is attained at the interface of the structure and diversion dikes and to prevent piping failure. Place Rip Rap if required.

MAINTENANCE:

- Inspect after major storms. Look for piping failure at the interface of the inlet and adjoining diversion dike(s) or berm(s).
- Repair any damage promptly.


OPEN CHUTE DRAIN
TYPICAL DESIGN LAYOUT
DISCHARGE AREA = 3 X TRENCH WIDTH
DISCHARGE FLOW IN STABILIZED AREA. LINE DISCHARE AREA WITH ROCK WHEN DIRECTED
TOE OF SLOPE
HAY OR STRAW BALES
BURY ENDS OF FILTER FABRIC
TOP OF FILL SLOPE
PLASTIC LINER WITH ROCK PROTECTED SLOPE
FLOW
FLOW
THE LENGTH OF EARTH BERM SHALL BE AS REQUIRED TO CONTAIN SURFACE DRAINAGE AND TO DIRECT FLOW ONTO DOWN SLOPE
TO BE USED WITH 2:1 SLOPE OR FLATTER
PLAN – FILLSLOPE DOWNDRAIN (PLASTIC LINER)
COMPACTED EARTH BERM (SEE STD. DWG. P-)-E(m))
MIN. 2 STAKLES 12"X2"X36" PER BALE. USE METAL POSTS IN ROCKY OR UNSUITABLE SOIL FOR WOODEN STAKES
FILL SLOPE
SUBGRADE
VARIABLE
FILTER FABRIC
STAKE DEPTH APPROX. 18"
TOE OF SLOPE
BURY BALE APPROX. 4"
SECTION A–A
MAX. TRENCH WIDTH 48"
FILL SLOPE
4"–6" TRENCH DEPTH
BURIED FILTER FABRIC ENDS
SECTION B–B

ROCK-LINED (RIP RAP) DITCHES

DEFINITION: A channel or ditch lined with rocks to prevent erosion. May be used as a temporary or permanent control.

PURPOSE: Convey runoff without causing erosion of the ditch or channel.

APPLICATION:

- Used in ditches or channels which may or may not have continuous flow.
- Used along roadways where the ditch or channel does not jeopardize the Clear Zone.

LIMITATIONS:

- Should be sized based on anticipated runoff, sediment loading and drainage area size.
- Recommended maximum slope of 2:1 (50%).
- Ditches or Channels having slopes greater than 8% must utilize geotextiles beneath the rock.
- Minimum Rock size shall be 6". The gradation shall be determined by the detailed design.

INSTALLATION:

- Detail design is required.
- Implementation of energy dissipaters at the outlet end to protect against scour.
- Design temporary ditches with adequate capacity to convey the 50-year, 6-hour storm. Design permanent ditches per Uintah County/Vernal City/Naples City Standards.
- Excavate ditch or channel to the designed cross section and grade. The ditch or channel side slope may be no steeper than 2:1.
- Place geotextiles (if required) along the full width of the excavated ditch or channel. Be sure to overlap the material as required in the manufacturer's guidelines.
- Place the rock by machine, or by hand as required.

MAINTENANCE:

- Inspect after major storms. Look for undermining failures.
- Repair any damage promptly.

GRASSED/MATTED SWALES

DEFINITION: A channel or ditch lined with vegetated mats to prevent erosion. May be used as a temporary or permanent control.

PURPOSE: Convey runoff without causing erosion of the ditch or channel.

APPLICATION:

- Used in ditches or channels which do not have continuous flow.
- Used along roadways where the ditch or channel is used to convey storm water.

LIMITATIONS:

- Should be sized based on anticipated runoff, sediment loading and drainage area size.
- Recommended maximum slope of 20:1 (5%).

INSTALLATION:

- Detail design is required.
- Implementation of energy dissipaters at the outlet end to protect against scour.
- Design temporary ditches with adequate capacity to convey the 50-year, 6-hour storm. Design permanent ditches per Uintah County/Vernal City/Naples City Standards.
- Excavate ditch or channel to the designed cross section and grade. The ditch or channel side slope may be no steeper than 3:1.
- Place matt along the full width of the excavated ditch or channel. Be sure to overlap the material if required in the manufacturer’s guidelines.

MAINTENANCE:

- Inspect after major storms. Look for undermining failures.
- Repair any damage promptly.

TEMPORARY EXCAVATED SEDIMENT TRAP

DEFINITION: A small temporary containment area with gravel (Rip Rap) outlet.

PURPOSE:

- Reduce velocities and peak discharge of storm water runoff.
- Create temporary ponding to allow settlement and deposition of suspended solids.
- Protect down-gradient discharge point from sediment laden runoff and eroding velocities.

APPLICATION:

- Temporary control for runoff from disturbed areas of less than 3 acres.
- Temporary control for discharge from diversion dike, surface benching, or other temporary drainage measures.

LIMITATIONS:

- Should be sized based on anticipated runoff, sediment loading and drainage area size.
- May require silt fence at outlet for entrapment of very fine silts and clays.

INSTALLATION:

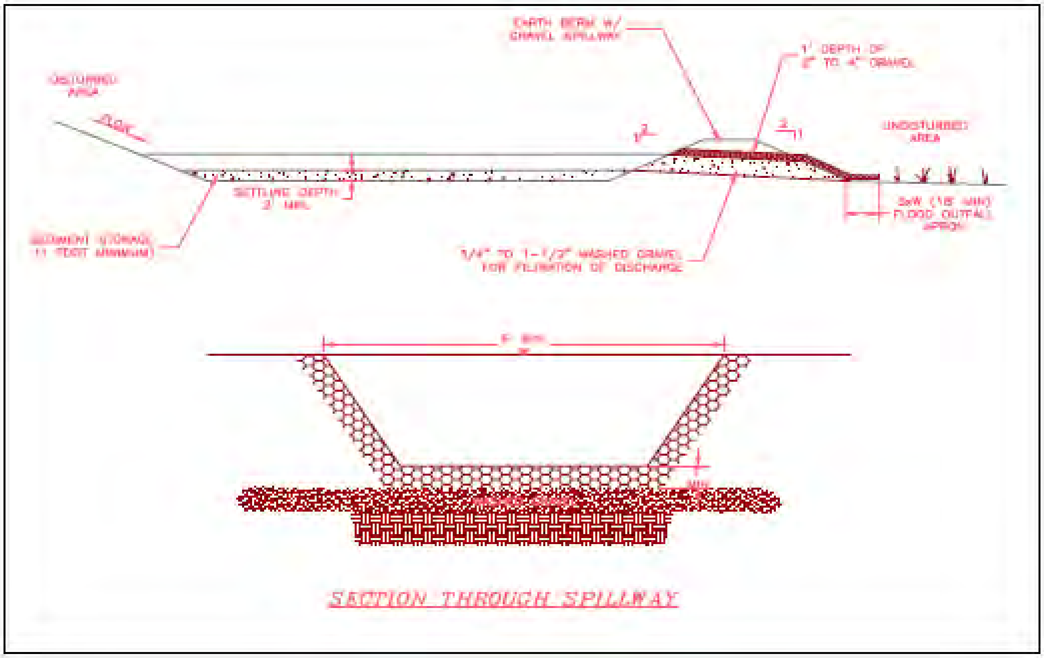
- Design basin for site specific location.
- Excavate basin or construct compacted berm containment.
- Construct outfall spillway with gravel (Rip Rap) apron.
- Provide downstream silt fence if necessary.
- Use straw bales in trap to reduce gullying.

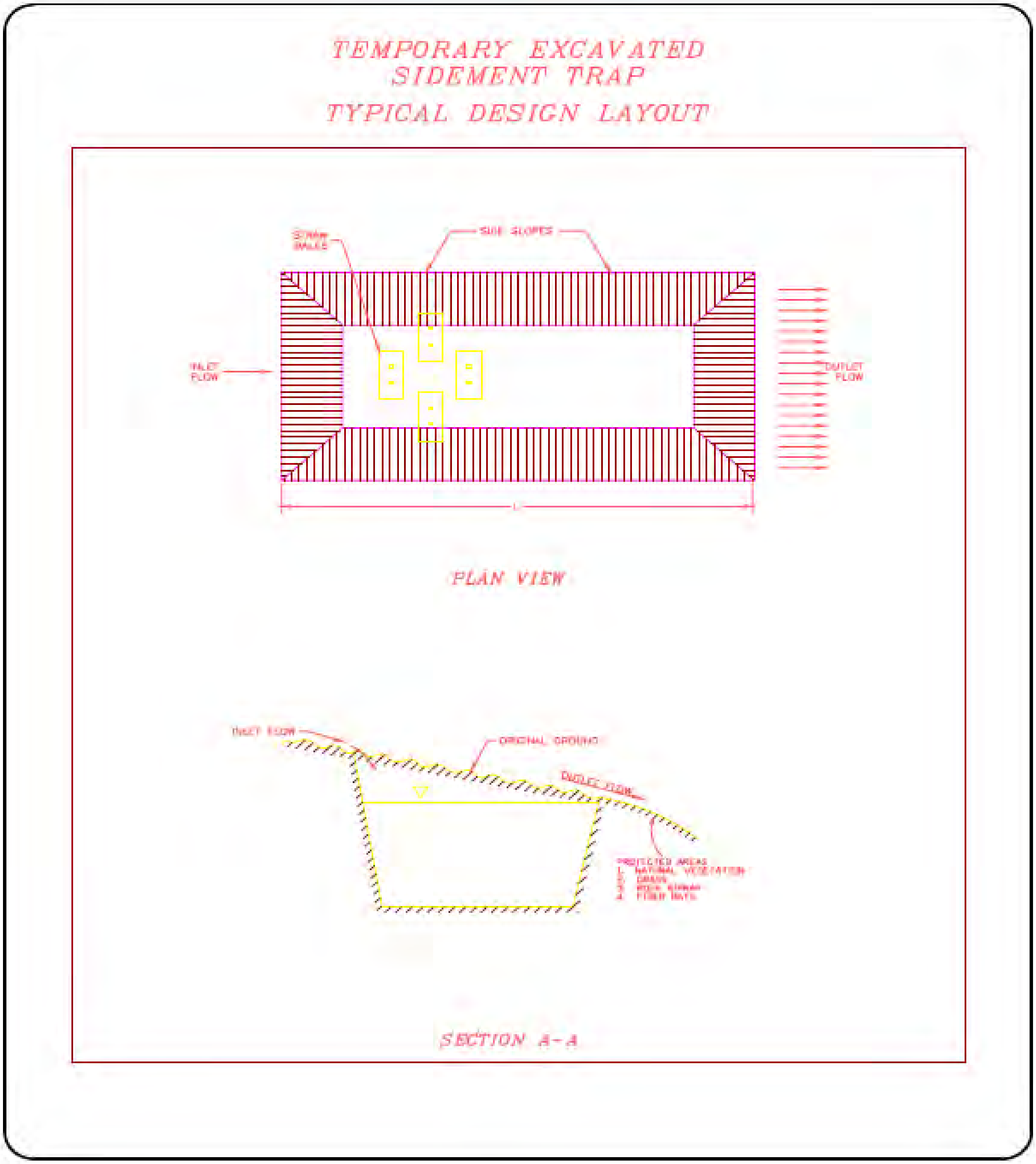
MAINTENANCE:

- Inspect after each rainfall event and at a minimum of monthly.
- Repair any damage to berm, spillway or sidewalls.
- Remove accumulated sediment as it reaches 50% height of available storage.
- Check outlet for sediment/erosion of down-gradient area and remediate as necessary. Install silt fence if sedimentation down stream is apparent.

TEMPORARY EXCAVATED SEIMENT TRAP

TYPICAL DESING LAYOUT





TEMPORARY EXCAVATED
SIDEMENT TRAP
TYPICAL DESIGN LAYOUT
STRAW BALES
SIDE SLOPES
INLET FLOW
OUTLET FLOW
PLAN VIEW
INLET FLOW
ORIGINAL GROUND
OUTLET FLOW
PROTECTED AREAS
1. NATURAL VEGETATION
2. GRASS
SECTION A-A

EQUIPMENT AND VEHICLE WASH DOWN AREA

DEFINITION: A stabilized pad of crushed stone for general washing of equipment and construction vehicles.

PURPOSE: To reduce potential of sediment being tracked onto roads and streets by vehicles leaving a construction site and entering a storm water collection systems, or waterways.

APPLICATION:

- At any site where regular washing of vehicles and equipment must occur to reduce the potential of sediment being tracked onto roads and streets by vehicles leaving a construction site.
- May also be used as a filling point for water trucks limiting erosion caused by overflow or spillage of water.

LIMITATIONS:

- Cannot be utilized for washing equipment or vehicles that may cause contamination of runoff such as fertilizer equipment or concrete equipment. Solely used to remove mud from vehicles leaving construction sites.
- A Sediment trap must be used in conjunction to control sediment runoff with wash water.

INSTALLATION:

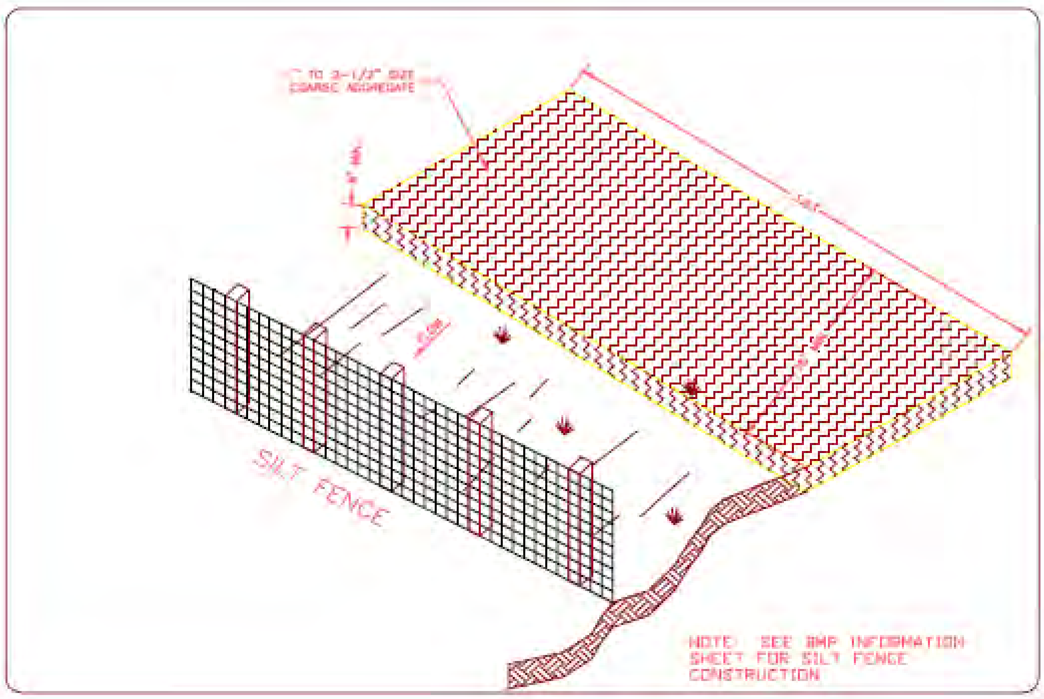
- Clear and grub area and grade to provide maximum slope of 1%.
- Compact subgrade and place filter fabric if desired (required for wash areas which will remain in use for 3 months or more).
- Place coarse aggregate, 1 to 2 ½ inches in size, to a minimum depth of 8 inches.
- For small projects, install silt fence down gradient (see silt fence BMP information sheet).
- For large projects, install sediment basin down gradient (see excavated sediment trap BMP information sheet).

MAINTENANCE:

- Inspect daily for loss of gravel or sediment buildup.
- Inspect adjacent area for sediment deposit and install additional controls if necessary.
- Repair area and replace gravel as required to maintain control in good working condition.
- Expand stabilized area as required to accommodate activities.
- Maintain silt fence as outline in specific silt fence BMP information sheet.
- Maintain sediment trap as outline in specific sediment trap BMP information sheet.

EQUIPMENT AND VEHICLE WASH DOWN AREA

TYPICAL DESIGN LAYOUT



MATERIAL STORAGE

DEFINITION: Controlled storage of on-site materials.

PURPOSE: To limit potential for materials contaminating storm water runoff.

APPLICATION:

- Storage of hazardous, toxic, and all chemical substances.
- Any construction site with outside storage of materials.

LIMITATIONS:

- Does not prevent contamination due to mishandling of products.
- Spill Prevention and Response Plan still required.
- Only effective if materials are actively stored in a controlled location.

INSTALLATION:

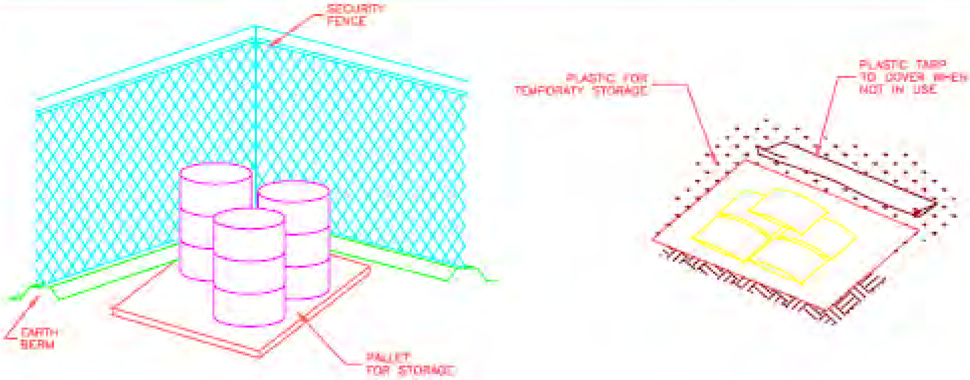
- Designate a secured area with limited access as the storage location. Ensure no waterways or drainage paths are nearby.
- Construct compacted earthen berm or similar perimeter containment around storage location for impoundment in the case of spills.
- Ensure all on-site personnel utilize designated storage area. Do not store excessive amounts of material that will not be utilize on-site.
- For active use of materials away from the storage area, ensure materials are not set directly on the ground and are covered when not in use. Protect storm drainage during use.

MAINTENANCE:

- Inspect daily and repair any damage to perimeter impoundment or security fencing.
- Check that materials are being correctly stored (i.e. standing upright, in labeled containers, tightly capped) and that no materials are being stored away from the designated location.

MATERIAL STORAGE

TYPICAL DESIGN LAYOUT



CONTROLED STORAGE LOCATION
BERMED PERIMETER IMPOUNDMENT
STORAGE OFF GROUND
COVER WHEN NOT IN USE

WASTE DISPOSAL

DEFINITION: Controlled storage and disposal of solid waste generated by construction activities.

PURPOSE: To prevent or reduce discharge of pollutants to storm water from improper disposal of solid waste.

APPLICATION: All construction sites.

LIMITATIONS: On-site personnel are responsible for correct disposal of waste.

INSTALLATION:

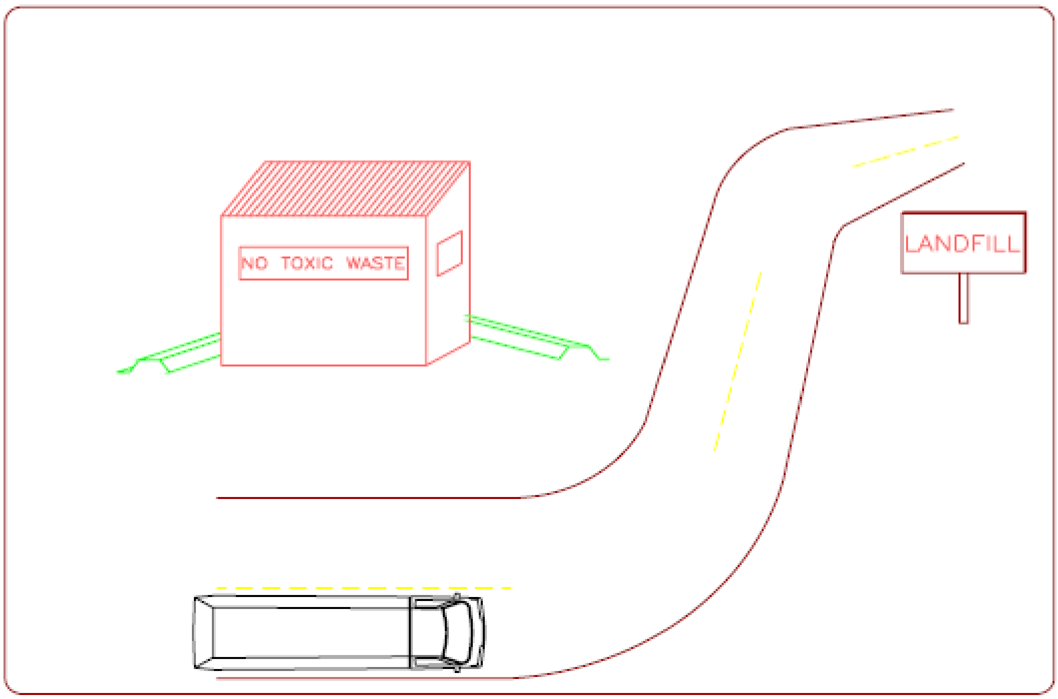
- Designate one or several waste collection areas with easy access for construction vehicles and personnel. Ensure no waterways or storm drainage inlets are located near the waste collection areas. Construct compacted earthen berm or similar perimeter containment around collection area for impoundment in the case of spills and to trap any windblown trash.
- Use water tight containers with covers which are to remain closed when not in use. Provide separate containers for different waste types where appropriate and label clearly.
- Ensure all on-site personnel are aware of and utilize designated waste collection area properly and for intended use only (e.g., all toxic, hazardous or recyclable materials shall be properly disposed of separately from general construction waste).
- Arrange for periodic pickup, transfer and disposal of collected waste at authorized disposal location. Include regular Porta-potty service in waste management activities.

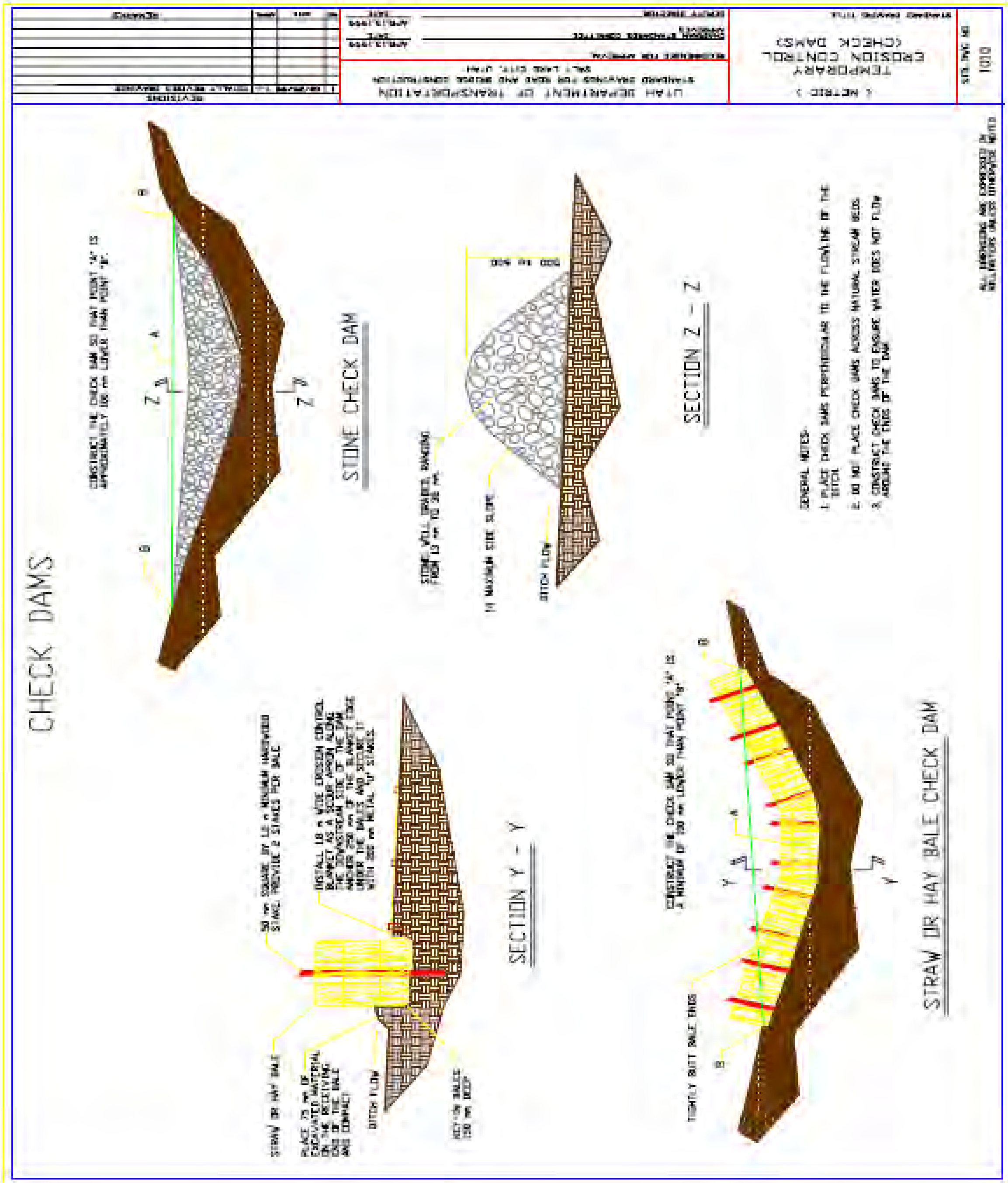
MAINTENANCE:

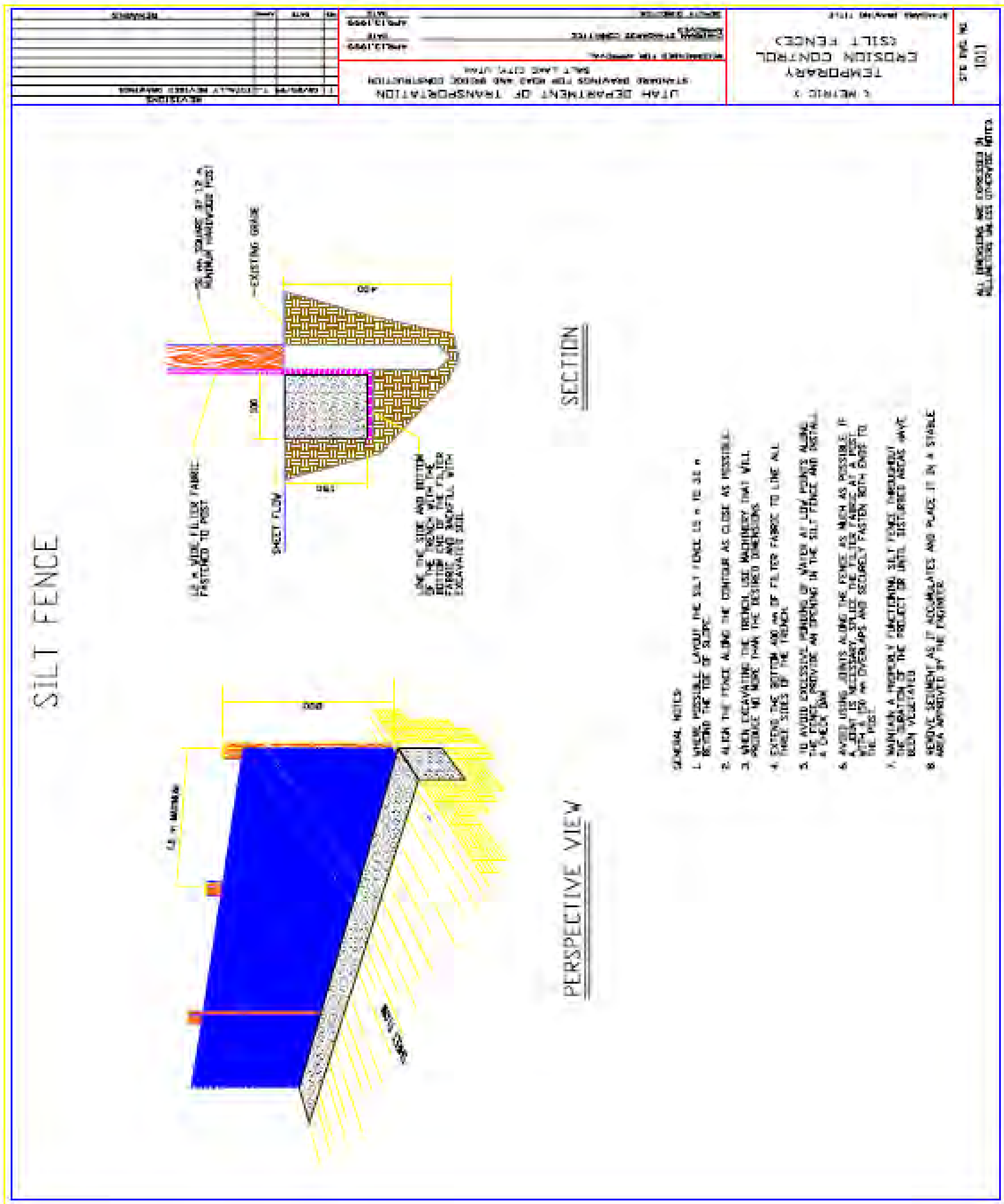
- Discuss waste management procedures at progress meetings.
- Collect site trash daily and deposit in covered containers at designated collection area.
- Check containers for leakage or inadequate covers and replace as needed.
- Randomly check disposed materials for any unauthorized waste (e.g., toxic materials).
- During daily site inspections check that waste is not being incorrectly disposed of on-site (e.g., burial, burning, surface discharge, discharge to storm drain).

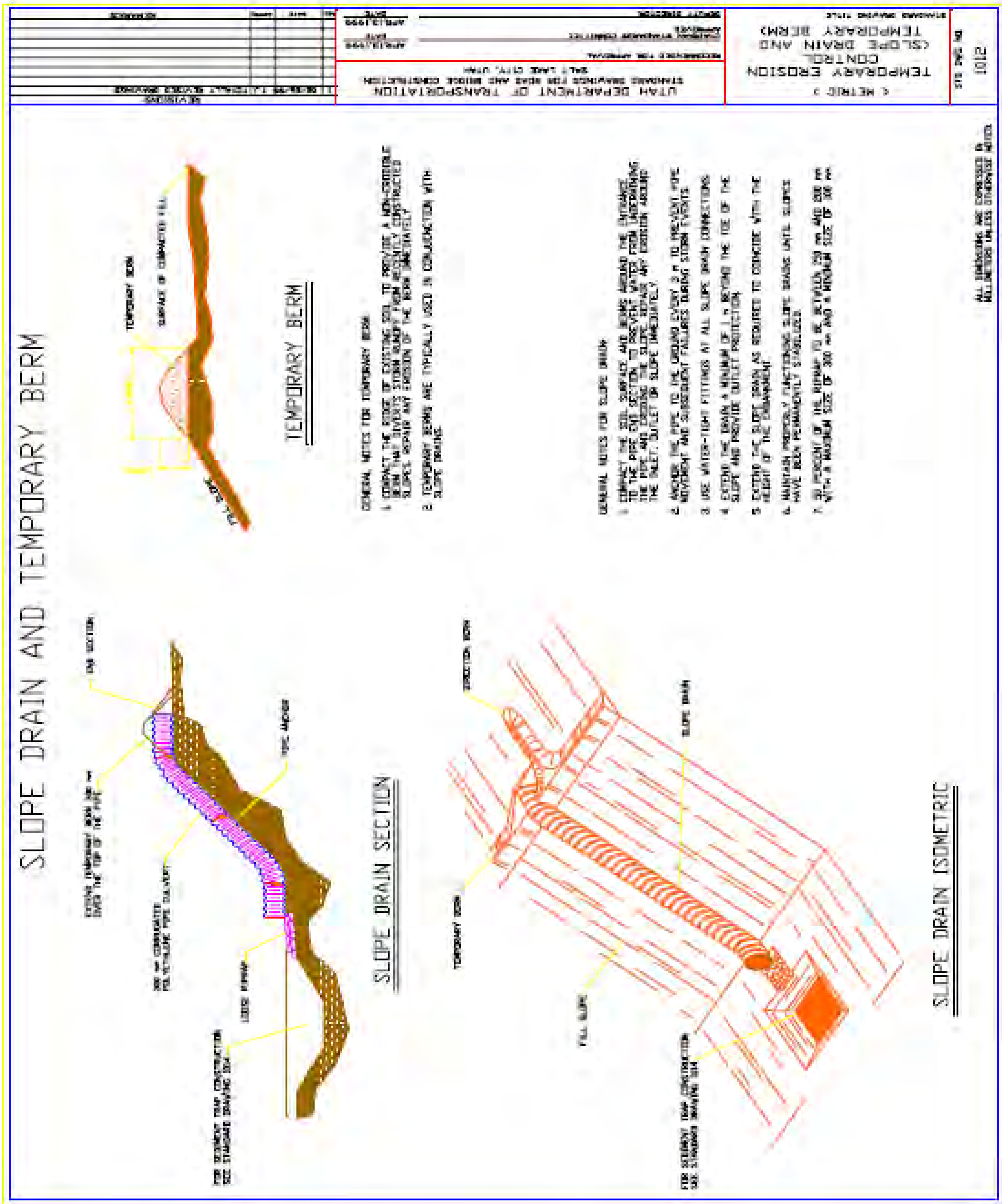
WASTE DISPOSAL

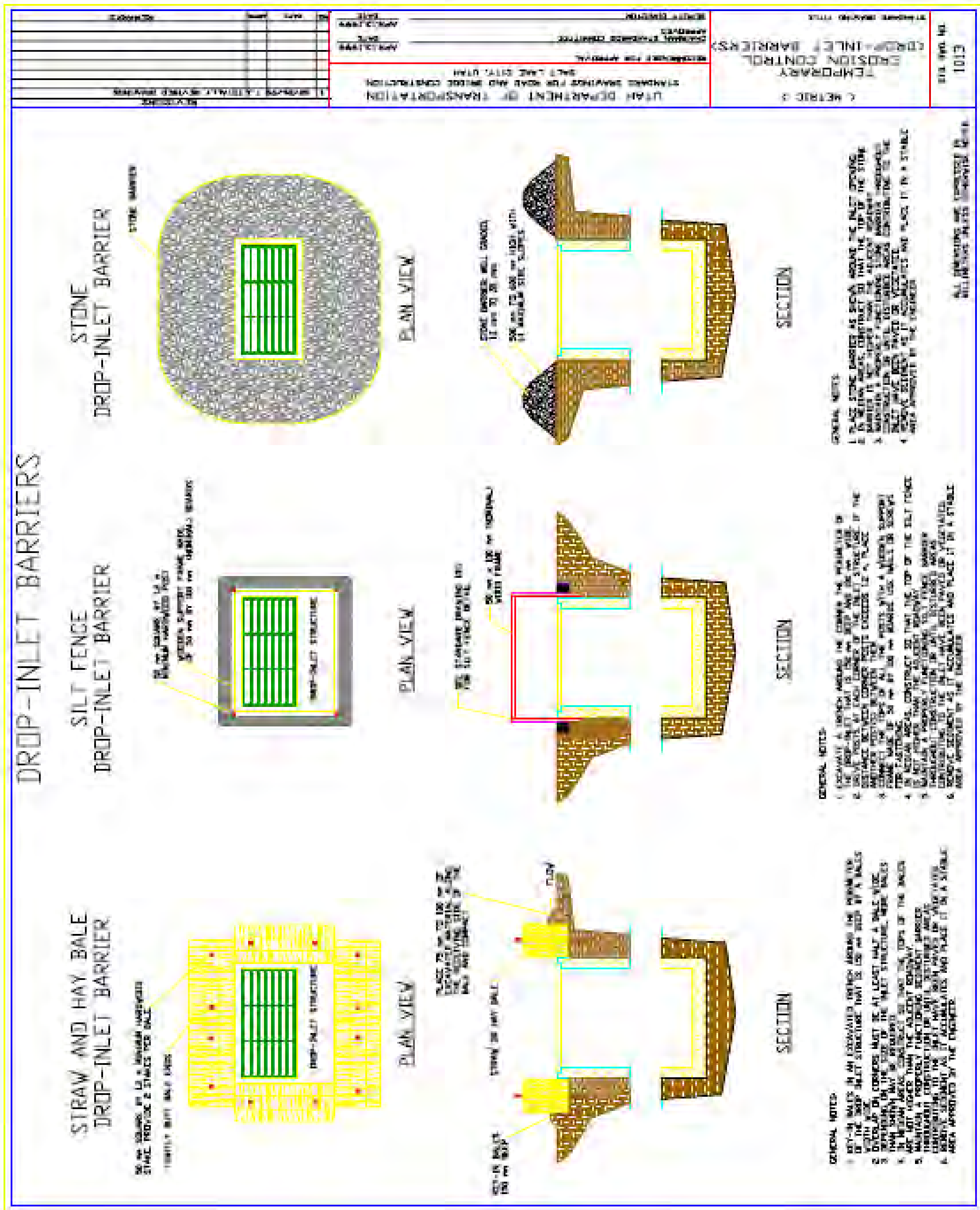
TYPICAL DESIGN LAYOUT

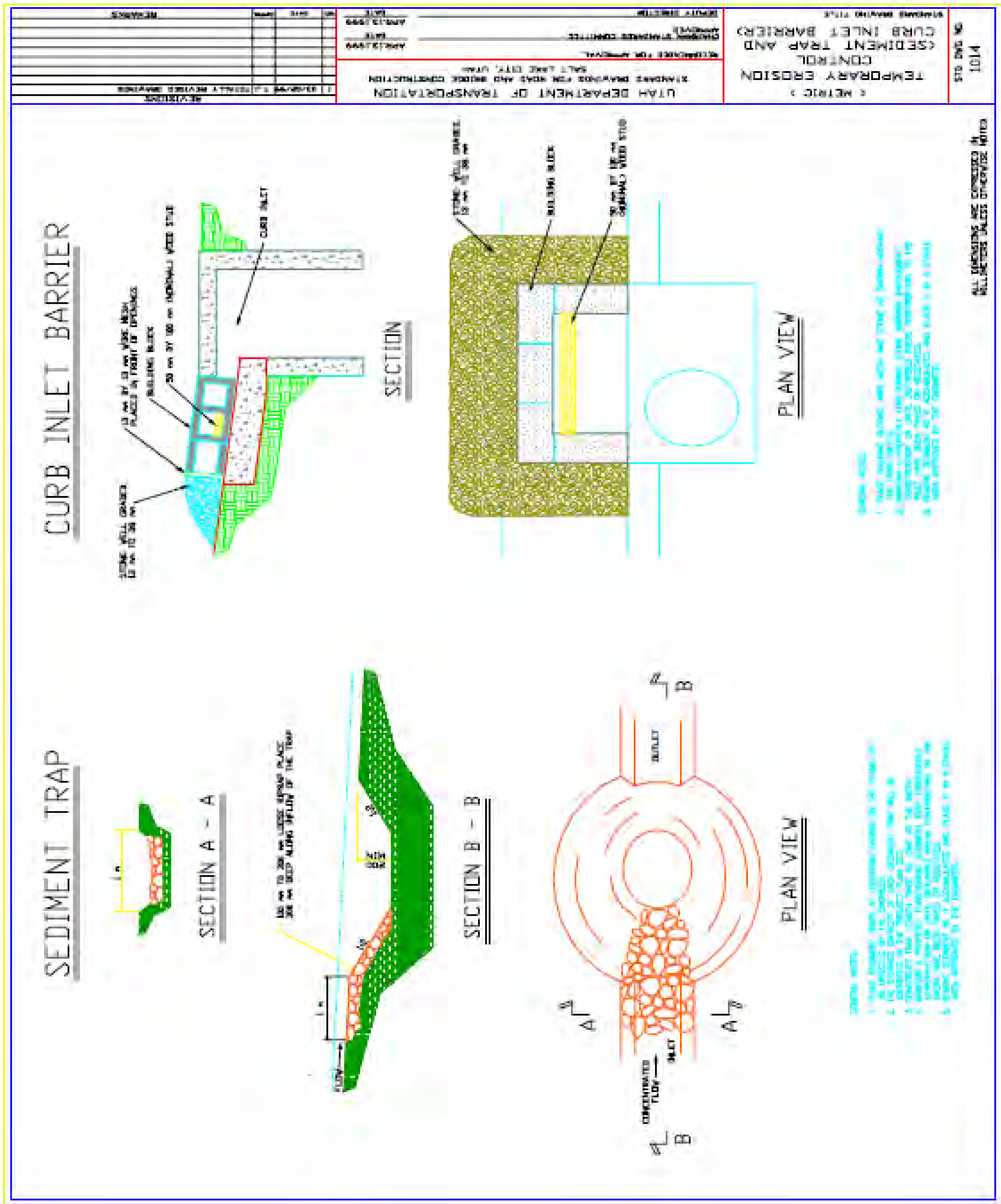



CHECK DAMS
STONE CHECK DAM
SECTION Z - Z
SECTION Y - Y
STRAW OR HAY BALE CHECK DAM
UTAH DEPARTMENT OF TRANSPORTATION
TEMPORARY EROSION CONTROL (CHECK DAMS)
(METRIC)

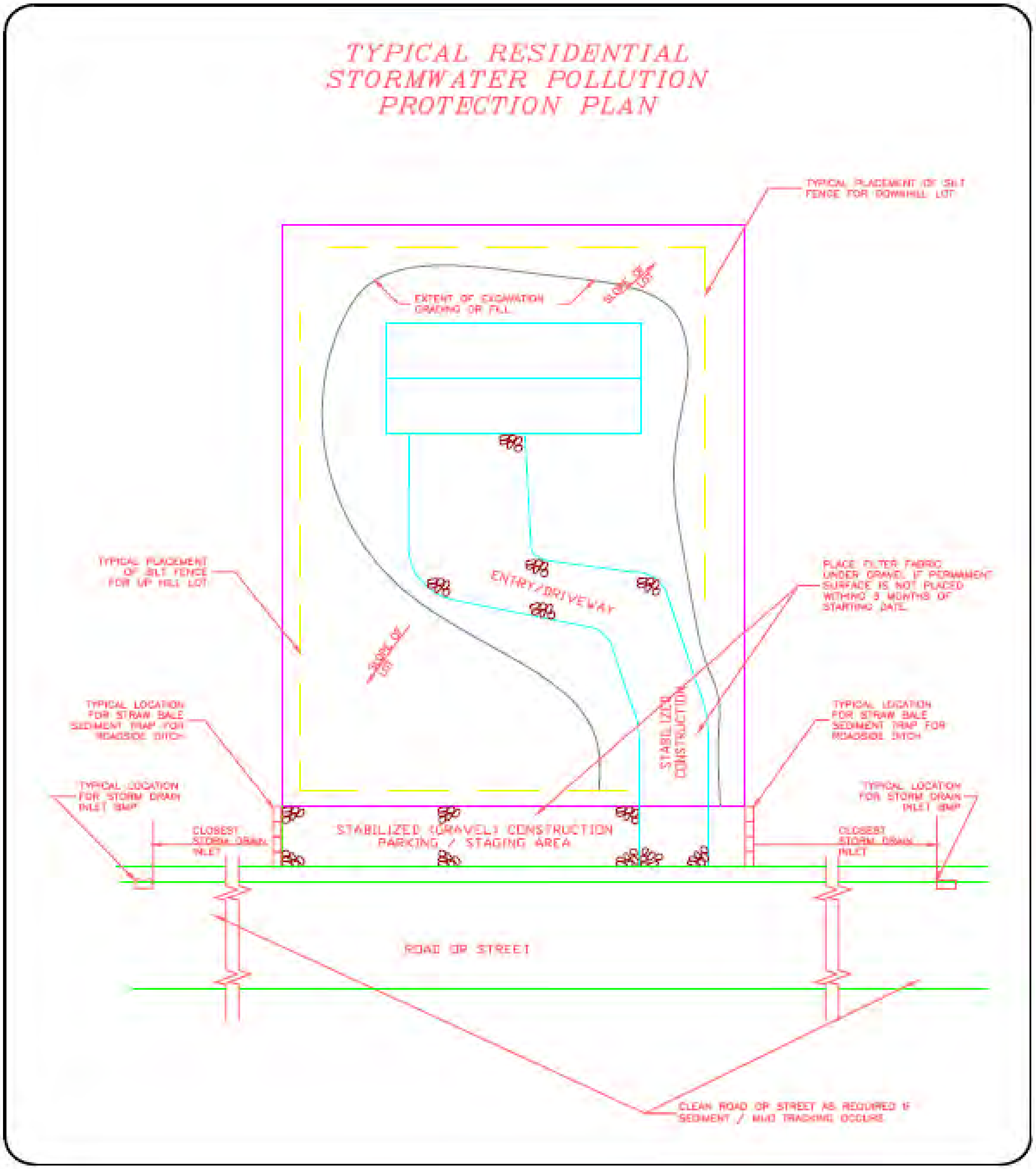

SILT FENCE
SECTION
PERSPECTIVE VIEW
TEMPORARY EROSION CONTROL (SILT FENCE)
UTAH DEPARTMENT OF TRANSPORTATION


SLOPE DRAIN AND TEMPORARY BERM
TEMPORARY BERM
SLOPE DRAIN SECTION
SLOPE DRAIN ISOMETRIC
UTAH DEPARTMENT OF TRANSPORTATION
TEMPORARY EROSION CONTROL
(SLOPE DRAIN AND TEMPORARY BERM)
< METRIC >
EC 1


DROP-INLET BARRIERS
STRAW AND HAY BALE DROP-INLET BARRIER
SILT FENCE DROP-INLET BARRIER
STONE DROP-INLET BARRIER
PLAN VIEW
PLAN VIEW
PLAN VIEW
SECTION
SECTION
SECTION
UTAH DEPARTMENT OF TRANSPORTATION
STANDARD DRAWINGS FOR ROAD AND BRIDGE CONSTRUCTION
SALT LAKE CITY, UTAH
TEMPORARY
EROSION CONTROL
(DROP-INLET BARRIERS)
(METRIC)


CURB INLET BARRIER
SECTION
PLAN VIEW
SEDIMENT TRAP
SECTION A - A
SECTION B - B
PLAN VIEW
UTAH DEPARTMENT OF TRANSPORTATION
TEMPORARY EROSION CONTROL
(SEDIMENT TRAP AND CURB INLET BARRIER)
< METRIC >
STD DWG NO.
1014

PART C2: TYPICAL RESIDENTIAL STORM WATER POLLUTION PREVENTION PLAN



TYPICAL RESIDENTIAL STORMWATER POLLUTION PROTECTION PLAN
TYPICAL PLACEMENT OF SILT FENCE FOR DOWNHILL LOT
EXTENT OF EXCAVATION GRADING OR FILL
SLOPE OF LOT
TYPICAL PLACEMENT OF SILT FENCE FOR UP HILL LOT
ENTRY/DRIVEWAY
PLACE FILTER FABRIC UNDER GRAVEL IF PERMANENT SURFACE IS NOT PLACED WITHING 3 MONTHS OF STARTING DATE.
STABILIZED CONSTRUCTION
TYPICAL LOCATION FOR STRAW BALE SEDIMENT TRAP FOR ROADSIDE DITCH
TYPICAL LOCATION FOR STRAW BALE SEDIMENT TRAP FOR ROADSIDE DITCH
TYPICAL LOCATION FOR STORM DRAIN INLET BMP
TYPICAL LOCATION FOR STORM DRAIN INLET BMP
CLOSEST STORM DRAIN INLET
CLOSEST STORM DRAIN INLET
STABILIZED (GRAVEL) CONSTRUCTION PARKING / STAGING AREA
ROAD OR STREET
CLEAN ROAD OR STREET AS REQUIRED IF SEDIMENT / MUD TRACKING OCCURS

PART D: SELECTED NONSTRUCTURAL POST-CONSTRUCTION BMPS

INTRODUCTION

As described in Part A, Section 4, Uintah County/Vernal City/Naples City requires that proposed developments utilize nonstructural stormwater control BMPs to the maximum extent practicable in order to meet the required criteria for long-term runoff control. This part provides a list and description of appropriate nonstructural BMPs that a permit applicant could choose to utilize in their design. This list is not intended to be comprehensive, and alternative nonstructural controls may be selected subject to approval by Uintah County/Vernal City/Naples City. A nonstructural BMP checklist is included in this Part. This checklist is intended for planners, designers and/or developers to utilize during the site planning, design, and construction phases of all developments. Additional information and detailed examples of nonstructural controls and environmentally-sensitive design principles can be obtained online at:

http://www.cwp.org/better_site_design.htm
http://www.georgiastormwater.com/vol2/1-4.pdf
http://www.stormwatercenter.net/
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/post.cfm

BMP 1: PRESERVATION OF UNDISTURBED NATURAL AREAS

This BMP involves formally designating appropriate undisturbed natural areas within the site as preservation areas. These areas must be specified in the maintenance covenant and recorded by the County in the land record to ensure they remain undeveloped in perpetuity. These areas must be clearly marked and remain undisturbed (i.e., no clearing, grubbing, or construction traffic) during construction. Areas that provide the greatest stormwater benefits through their preservation include:

- wetlands & meadows
- riparian buffers
- forested areas
- areas with high infiltration rates (e.g., hydrologic group A and B soils)
- groundwater recharge zones
- streams and natural drainageways

BMP 2: MINIMIZATION OF DISTURBANCE

This BMP involves using careful construction sequencing, well-designated limits of disturbance, and well-defined construction entrances/exits to minimize the total area of disturbance (e.g., excavation, grading, clearing, grubbing) and reduce soil compaction from construction traffic. Clearing and grading of forests and native vegetation at a site should be limited to the minimum amount needed to build lots, allow access, and provide fire protection. Site layouts and roadway patterns should be designed to conform with or “fit” the natural landforms and topography of a site. This helps to preserve the natural hydrology and drainageways on the site, as well as reduce the need for grading and disturbance of vegetation and soils.

BMP 3: REDUCTION OF IMPERVIOUS COVER

This BMP involves modifying the designs of permanent structures to reduce the overall area of impervious surfaces while still achieving development objectives. Specific modifications may include:

- reducing roadway lengths and widths to the minimum size needed to meet traffic and safety needs
- reducing building footprints (e.g., build up rather than out)
- reducing the parking footprint (build underground parking or multi-level parking decks; size a proportion of stalls for compact vehicles; use grass or alternative paving for overflow parking areas)
- reducing lot setbacks and frontages
- using fewer or alternative cul-de-sacs (e.g., install pervious vegetated islands in cul-desacs; reduce radius of cul-de-sacs; use alternatives such as T-shaped turnarounds)
- integrating porous areas such as landscaped islands, swales, filter strips, and bio-retention areas into parking lot designs
- using alternative paving techniques (e.g., use loose gravel, coarse sand, wood or bark chips, or disconnected pavers for all or parts of driveways and walkways)
- using vegetated swales instead of curb and gutter to convey road runoff

BMP 4: ROUTING OF RUNOFF TO PERVIOUS AREAS/DISCONNECTION OF RUNOFF

This BMP involves routing the runoff from impervious areas to pervious areas such as natural areas, buffers, lawns, landscaping, filter strips and vegetated channels. In this way, the runoff is "disconnected" from other impervious areas and paved collection/conveyance systems (e.g., curb and gutter) that do not allow for groundwater recharge or uptake of pollutants. Some of the methods for disconnecting impervious areas include:

- designing roof drains to flow to vegetated areas
- directing flow from paved areas such as driveways to stabilized vegetated areas
- breaking up flow directions from large paved surfaces and rooftops
- carefully locating and grading impervious areas and landscaped areas to achieve sheet flow runoff to the vegetated pervious areas

BMP 5: POLLUTION PREVENTION/SOURCE REDUCTION

This BMP involves implementing measures to reduce or contain potential sources of contamination at a site. Specific measures include:

- controlling litter (providing adequate numbers of trash receptacles, emptying receptacles regularly, keeping dumpster lids closed, etc.)
- sweeping streets and paved areas rather than hosing them down or using pressurized washers
- reducing rainfall contact with potential pollution sources by installing roofs/canopies over gas station fueling areas, salt/sand piles, hazardous material storage areas, etc.
- providing secondary spill containment (e.g., berms) for hazardous liquid storage containers
- clearly marking storm drains “No Dumping- Drains to Live Stream”

Checklist for Nonstructural BMPs

Project name:
Project location:
Contractor/builder information:
name:

address:

email:
phone/fax:

Site area (total acres):
Temporarily disturbed area (acres):
Permanently disturbed area (acres):
Undisturbed natural areas or preservation areas (acres):

Best Management Practices (BMPs)	Yes/ No	Comments (If applicable, describe actions taken or give explanation of no action)
Preservation of Undisturbed Natural Areas		
Specification of natural areas in maintenance covenant.		
Preservation is recorded in the land record.		
Clear demarcation of undisturbed areas during construction.		
Minimization of disturbance		
Construction sequence reduces the amount of land disturbed at one time.		
Well-defined construction access points.		
Limited site clearing.		
Site layout and roadway patterns conform to topography.		
Reduction of impervious cover		
Appropriate road sizing.		
Reduced building footprint.		
Reduction of impervious cover (Cont.)		
Reduced parking footprint.		

Best Management Practices (BMPs)	**Yes/ No**	**Comments (If applicable, describe actions taken or give explanation of no action)**
Reduced lot setbacks and frontages.		
Alternative cul-de-sac design.		
Integration of porous or infiltration areas (islands, swales etc.).		
Alternative paving.		
Use of vegetated swales in place of curb and gutter.		
Routing of runoff to pervious areas/Disconnection of runoff		
Drains and runoff are directed to vegetated areas.		
Runoff from large impervious surfaces (including pavement and rooftops) is broken into several flow paths.		
Design so that impervious areas direct runoff to vegetated areas.		
Pollution prevention/Source reduction		
Litter/trash control.		
Dry sweep rather than washing or hosing off areas.		
Provide secondary spill containment for hazardous liquid if stored on- site.		
Stencil storm drains.		

PART E: SELECTED STRUCTURAL POST-CONSTRUCTION BMPS

GENERAL

A. INTRODUCTION

This part provides a list and description of appropriate structural BMPs that a permit applicant could select from to meet the stormwater treatment requirements described in Part A. This list is not intended to be comprehensive, and alternative structural controls may be selected subject to approval by Uintah County/Vernal City/Naples City. Additional information and detailed examples of long-term post-construction stormwater BMPs can be found online at:

http://cfpub.epa.gov/npdes/stormwater/menuofbmps/post.cfm
http://www.deq.state.id.us/water/stormwater_catalog/index.asp

All structural post-construction BMPs shall be inspected regularly (at least every six months or as otherwise noted) to determine maintenance needs. For the purposes of meeting the water quality treatment requirements outlined in Part A, the sliding scale and TSS design removal rates shown in Tables 1 and 2 should be used. TSS removal rates for alternative structural controls will be determined by the applicant and approved by the County Engineer. Credible references justifying/documenting the removal rates used shall be submitted by the permit applicant.
For sites where newly-developed impervious areas lie within 50 feet of a live water body (perennial or intermittent stream, lake, pond, spring, or reservoir), the Table 1 sliding scale does not apply and the default 80% TSS removal standard must be met. The less-stringent removal efficiencies listed in Table 1 apply only to sites that refrain from creating new impervious cover near live water bodies.

B. LOCATION OF STRUCTURAL BMPS

Structural BMPs should never be constructed in natural streams (perennial or intermittent) or wetlands. BMPs should be designed to only intercept and capture storm water runoff, not natural stream channel runoff.

Table 1 Sliding Scale for Required TSS Removal Efficiency (adapted from City of Boise.)

% of parcel area that is impervious	% TSS removal efficiency required[a]
• •30	40
35	47
40	53
45	59
50	62
55	66
60	68
65	70
70	72
75	74
80	75
85	77
90	78
95	79
100	80

[a]for sites where newly-developed impervious cover lies within 50 feet of a live water body, the values in Table 1 do not apply and instead a removal efficiency of 80% must be met, even if the total site imperviousness % is less than 100%.

Table 2 TSS Removal Rates for Selected BMPs (adapted from Schueler 1997, Winer 2000, & EPA 1993).

BMP	Design Removal Rate (%)	Comments
Dry Detention Ponds	15	Quantity control pond
Wet Detention Ponds	60	Quantity control pond
Dry Extended Detention Pond	45	Sediment forebay included
Wet Extended Detention Pond	80	Sediment forebay included
Evaporation Pond	100	Designed to evaporate or retain
Bioinfiltration Swale	70	
Sand Filter	80	Pretreatment, includes Austin, underground, pocket, and Delaware designs
Organic Filter	80	Pretreatment, includes compost and peat/sand
Catch Basin Insert	25	Off-line only
Infiltration Facilities	95*	*removal rate only valid with adequate maintenance and pre-treatment
Sediment Trap	25	
Grass Buffer Strip	85	Minimum width of 10'
Oil/Water Separator	15	

BMP 1: OIL/WATER SEPARATORS

A. INTRODUCTION

This section includes standards for oil/water separators to be installed to treat runoff from gas stations and parking lots. These systems can be used to intercept and remove contaminants from storm water runoff. They can also be used during redevelopment to retrofit an existing system in order to provide water quality treatment. Oil/water separators and catch basin inserts should not be used alone to treat storm water runoff but rather in combination with other BMPs to improve water quality.

B. DESCRIPTION

These structures are used to capture floatables, oil and grease, and sediment found in runoff. Two types of oil/water separators are discussed in this section: coalescing plate interceptor (CP) (Figure 1.1) and the conventional gravity separator, or API (Figure 1.2). The CP and API separators can function as pre-treatment systems if regularly maintained. A third system, the spill control (SC) separator should be considered for sites where there is a risk of leaks and small spills, such as gas station sand chemical storage areas. It is not considered a pre-treatment system.

C. SIZING

The contributing area to any individual oil/water separator should be limited to one acre of impervious cover. The maximum allowable velocity through the throat of the separator (0.5 fps) will also limit the size of the area served. Separators, boxes, or vaults are sized based on the contributing runoff area, sedimentation rates of particles, and maximum velocities through the throat of the separator. Certain developments such as fuel farms or gas stations should consider properly sized facilities to capture floatables such as oil and grease. The American Petroleum Institute (API) standards related to oil rise rates and turbulence should be used to design these facilities.

D. ACCESS

Provide access for inspection, proper maintenance, and monitoring activities, including clearance from structures to allow for equipment to clean out devices. Provide access to each compartment. If the length or width of any compartment exceeds 15', an additional access point for each 15' is required.

E. DESIGN LIFE

The system shall be designed either to the manufacturer’s specifications or 50 years, whichever is greater. All metal parts should be corrosion-resistant. Acceptable materials include parts made of aluminum and stainless steel, fiberglass, or plastic. Metal parts that come in contact with storm water runoff should not be painted because the paint tends to wear off. Vault baffles should be made of concrete, stainless steel, fiberglass reinforced plastic, or other acceptable material and should be securely fastened to the vault. Apply the HS-20 traffic loading standard when locating the API and CP systems in parking lots.

F. MAINTENANCE

Clean accumulated oil, grease, sediments and floating debris every two years, unless inspections show that more frequent maintenance is necessary. Oil/water separators should be inspected monthly to insure proper maintenance.

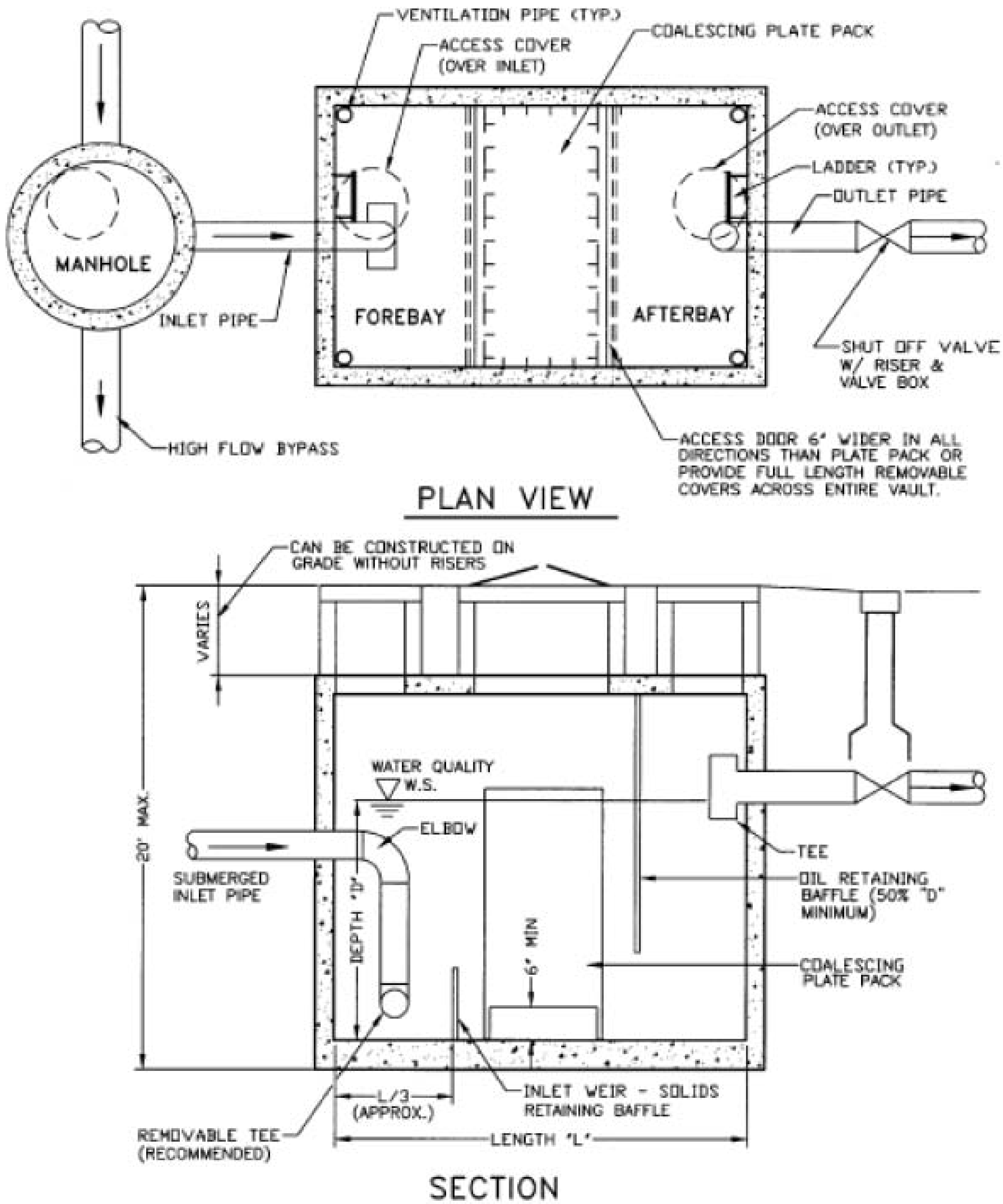


Figure 1.1 Coalescing Plate Oil/Water Separator.

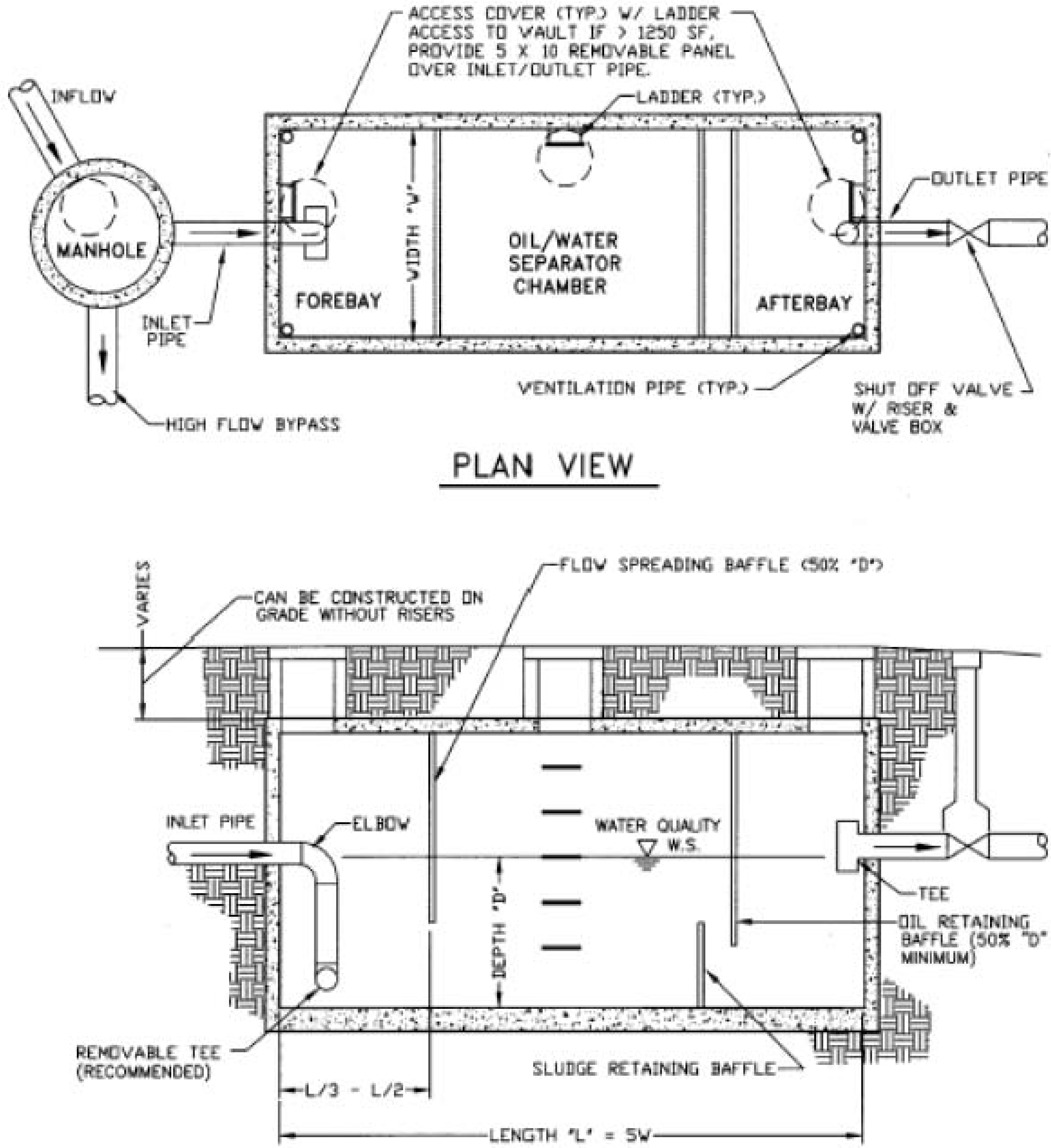


Figure 1.2 Conventional Gravity Oil/Water Separator.

BMP 2: CATCH BASIN INSERTS

A. INTRODUCTION

A catch basin insert is a device installed underneath a catch basin inlet that treats storm water through filtration, settling, absorption, adsorption, or a combination of these mechanisms. A variety of catch basin inserts are commercially available from various different manufacturers. Uintah County/Vernal City/Naples City does not endorse any single product or manufacturer over any other; however, each selected product will be subject to review by the County and must be approved prior to installation. Because they have limited capacity and limited sediment removal capabilities, catch basin inserts should NOT be used alone to treat storm water runoff but rather as pretreatment to another storm water management BMP or series of BMPs.

B. INSTALLATION

The insert must be fitted with oil-absorbent/adsorbent filter media. The filter must be changed monthly or when the filter media surface is covered with sediment. If the insert is installed in an existing catch basin, the insert shall be demonstrated to fit properly so that there is a positive seal around the grate to prevent low-flow bypass. If the insert is installed in a new or redevelopment project, it shall be installed according to the manufacturer's recommendations. The insert should be installed in the catch basin after the site has been paved or stabilized (for new development) or after completion of construction (for a redevelopment site that is already paved).

C. ACCESS

The catch basin insert shall be located in an easily-accessible area for maintenance activities. It should not be placed in an area with continuous vehicle parking. Consequently, redevelopment projects may have to modify a parking stall in order to provide access to a catch basin insert.

D. MAINTENANCE

Catch basin inserts shall be maintained at a frequency recommended by the manufacturer. Inspections should occur at least monthly during wet months and during periods of high runoff and once every 2 months during the remainder of the year. Full replacement or renewal of oil absorbent/adsorbent material shall be part of maintenance activities. In addition, the catch basin sump should be inspected for sediment accumulation. Filter media shall be disposed of in accordance with applicable regulations. In most cases, dewatered filter media may be disposed of as solid waste. To insure proper maintenance of the catch basin inserts inspections should occur monthly.

BMP 3: INFILTRATION FACILITIES (GENERAL)

A. INTRODUCTION

This section contains requirements for facilities that manage storm water by subsurface disposal through infiltration. Requirements are included for seepage beds (infiltration trenches), infiltration basins, and infiltration swales. A seepage bed (Figure 3.1) receives runoff in a shallow excavated trench that has been backfilled with stone to form a below-grade reservoir. Seepage beds are typically located beneath landscaped or parking areas. A seepage bed can also be open to the surface and covered with landscaping rock. This type of system is referred to as an open trench. An infiltration basin (Figure 3.2) impounds water in a surface pond until it infiltrates the soil. Infiltration basins do not maintain a permanent pool between storm events and should drain within 48-72 hours after a design storm event. Infiltration swales (Figure 3.3) are vegetated channels designed to retain/detain, treat and infiltrate stormwater runoff.

B. PLAN SUBMITTAL

For each infiltration facility, the applicant will be required to submit the general information listed in Section 3.A.1 of Part A as well as the following additional information:

- site characteristics that pertain to the proposed infiltration system (site evaluation information) soils report and geologic report with boring logs
- written opinion of site suitability by a hydrologist, geologist, soil scientist or engineer
- recommended design infiltration rate
- infiltration test data and results

C. CONSTRUCTION

Before the site is disturbed, the area selected for the infiltration system shall be secured to prevent heavy equipment from compacting the underlying soils. Runoff should be diverted away from the completed infiltration system during all phases of construction, until the site is completely stabilized. Excessive sediment loading during construction can severely impact the long-term performance of infiltration systems.

D. SETBACKS AND SEPARATION DISTANCES

- Infiltration facilities shall be located 100' from surface water supplies and tributaries used as drinking water and 50' from surface waters not used as drinking water, excluding drainage and irrigation water delivery systems.

- Infiltration facilities shall be located 100' from public and private drinking water wells.

- Infiltration facilities shall be located 5' from bedrock or basalt (vertical distance from bottom of facility to bedrock). Infiltration facilities must not be used on slopes >20%.

E. INFILTRATION RATE

The infiltration rate shall be measured at a depth equal to the proposed bottom grade of the facility. Appropriate soil types are those that have an infiltration rate of 0.5"/hour or greater, as initially determined from NRCS Soil Textural Classification and subsequently confirmed by field geotechnical tests. Maximum soil percolation rates shall generally not exceed 8" per hour.

F. MAINTENANCE

Systems should be inspected and cleaned during regular semi-annual inspections. This inspection schedule applies to all of the infiltration facilities unless otherwise noted. The maximum depth of sediment allowed should be stated in the O&M Plan with an estimate of impact on infiltration rate. Sediments shall be removed and disposed of properly.

BMP 3.1: SEEPAGE BEDS

A. LIMITATIONS

Seepage beds are prohibited in the following situations:

- where hazardous or toxic materials greater than SARA Title III “reportable quantities” are stored or handled, including loading and unloading areas
- where there is existing soil and/or ground water contamination
- on fill material, where there is the possibility of creating an unstable grade and potential for movement at the interface between the fill and in-situ soils

Vadose zone characteristics and depth to water will determine where seepage beds will be prohibited. A final determination regarding the use of seepage beds is based on evaluating the natural, unaltered characteristics of the proposed location for the system. Table 3 illustrates how restrictions may be applied.

Table 3 Restrictions for Seepage Beds.

	Vadose Zone			
Depth to groundwater (below ground surface)	Gravels, pebbly gravels, pebbles	Sands, sands interbedded with silt and or clays, silty clays	Rhyollite or Granitics	Basalts
< 15 feet[a]	seepage beds prohibited	seepage beds prohibited	seepage beds prohibited	seepage beds prohibited
15-30 feet	additional treatment required	no additional restrictions[1]	subject to further evaluation	subject to further evaluation
31-100 feet	additional treatment required	no additional restrictions[1]	subject to further evaluation	subject to further evaluation
>100 feet	additional treatment required	no additional restrictions[b]	subject to further evaluation	subject to further evaluation

[a] Assumes bottom of seepage bed is 5' below ground surface.
[b] Assumes the separation distance between the bottom of the seepage bed and ground water is 10'.

B. SETBACKS AND SEPARATION DISTANCES

- Seepage beds must be separated a minimum of 10'from ground water (vertical distance from bottom of facility to seasonal high ground water level). A test boring shall be drilled to a sufficient depth to verify that a 10' separation distance between the proposed bottom of the facility and seasonal high ground watertable is met. Each facility shall have one test boring, unless prior approval is obtained from Public Works.
- Seepage beds must be separated 10' from structures (foundations, septic systems, other seepage beds).

- Seepage beds must be separated 20' from basements.

- Seepage beds must be separated 10' from property boundaries.

C. Design

- Seepage beds should be designed to provide a direct method for removal of contaminants and sediments before direct discharge into the vadose zone. If the bed has a surface inlet, the system must be designed to capture sediment either through a grass buffer strip, biofiltration swale, or sediment trap. Depending on the expected site activities, a pretreatment system, such as an oil/water separator should also be considered.

- A vegetated buffer (20' minimum) is recommended for open trenches.

- A stone aggregate of clean, washed drain rock, 1.5- 2" in diameter should be used. This size of aggregate will give a void ratio of 30-40%. Aggregate between .5-2.0" may be used but the void ratio must be certified.

- The bottom of the seepage bed shall be covered with a 6-12" layer of clean, washed sand that meets either specification: ASTM C-33 or ITD Standard 703.02, “Fine Aggregate for Concrete”.

- The seepage bed aggregate must be lined on the sides by an appropriate geotextile fabric. If the trench is a open trench, it should also be lined at the top and the top fabric layer should be located 1' below the surface to prevent surface sediment from passing through into the stone aggregate. Filter fabric can be placed on the bottom of the trench. Filter fabric should have a minimum weight of at least 4 oz./yd 2, a filtration rate of 0.08"/second, and an equivalent opening size of30 for non-woven fabric.

- Seepage beds must have observation wells to determine how quickly the seepage bed drains after a storm. Wells shall be placed and every 2000 SF, with a minimum of 1 well/seepage bed. The observation well should be a perforated PVC pipe, 4-6" in diameter, extending to the bottom of the bed where it is connected to a foot plate. It should be capped and locked to prevent vandalism or tampering.

- If the seepage bed is located in a landscaped area, the bed should be constructed in one of the following ways: the bed should be covered with native soils and planted in grass, or if the seepage bed is an open trench, covered with stone aggregate and protected from sediment build-up with a vegetated buffer strip 20-25' wide on either side of the bed.

D. Operation and Maintenance

The system should be located so that it can be easily accessed by equipment necessary to maintain the pretreatment system and trench. The buffer and surface vegetation must be maintained by reseeding bare spots and mowing as frequently as needed to preserve aesthetics.

When ponding occurs at the surface or in the bed, corrective maintenance is required immediately. Ponding indicates the bed is clogged. Stripping off the top layer of soil, replacing the clogged filter fabric, and then replacing the top foot of aggregate or soil will correct the problem. Ponded water inside the trench (as visible from the observation well) after 24 hours or several days can indicate that the bottom of the trench is clogged. If this problem has occurred, then it is necessary to remove all of the layers and replace them.

E. Closure or Replacement

The owner is required to repair, replace, or reconstruct the infiltration system if it fails to operate as designed. A system fails to operate as designed when water is standing 24 hours or longer following the design storm. The maintenance and operation schedule for an infiltration system shall include such a provision. The owner is required to notify Uintah County/Vernal City/Naples City if the owner plans to close or replace the infiltration system. Additional studies may be required for all facilities depending on the land use of the site.

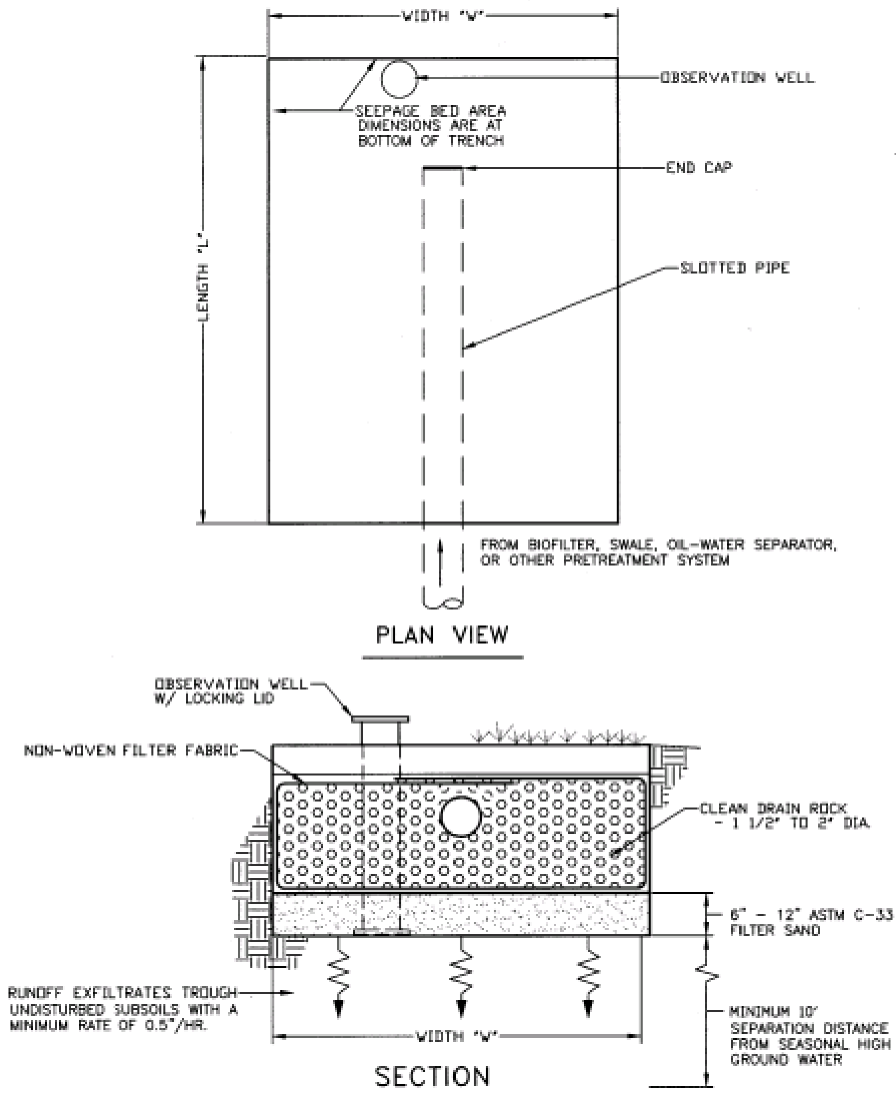


Figure 3.1 Seepage Bed.

BMP 3.2 INFILTRATION BASIN

A. APPLICABILITY

An infiltration basin is suitable in residential and commercial developments. Infiltration basins should not be placed in locations where the basin could cause flooding to downstream properties or in natural drainages such that the basin would restrict inflows to the point of causing upstream flooding.

B. SIZING

In determining the size of the basin, the critical parameters are the storage capacity and the maximum rate of runoff released from the basin. In addition the basin size should be based on expected sediment accumulation and frequency of maintenance.

C. FOREBAY/SEDIMENT TRAP

A rock or an earthen berm shall be constructed with a minimum top width of 4' and side slopes no steeper than 3:1. The forebay/sediment trap shall have a treatment volume equal to 0.75 times the runoff from the mean annual storm (0.23").

D. CONSTRUCTION REQUIREMENTS

Infiltration basins shall be constructed in appropriate soil types. Infiltration basins should be excavated in a manner that will minimize disturbance and compaction of the basin. The basin bottom should be sloped to maximize infiltration. In addition, infiltration basins should not be constructed in highly erodible contributing areas, on slopes > 15%, or within fill soils. Inlet and outlet channels must be stabilized.

E. SEPARATION DISTANCE

The bottom of the infiltration basin should be separated by at least 3' vertically from the bedrock layer or seasonal high water table, as indicated by on-site geotechnical test results. Within the 3' separation distance, there must be at least a 2' layer of soil that conforms to infiltration rate requirements.

F. PRETREATMENT

Each infiltration basin shall have additional pretreatment. One of the following techniques can be used:

- construct grass channel
- construct grass filter strip
- install bottom sand layer
- install upper filter fabric with 6" sand layer

- use washed cobble rock as aggregate
- vegetate basin with deep-rooted turf

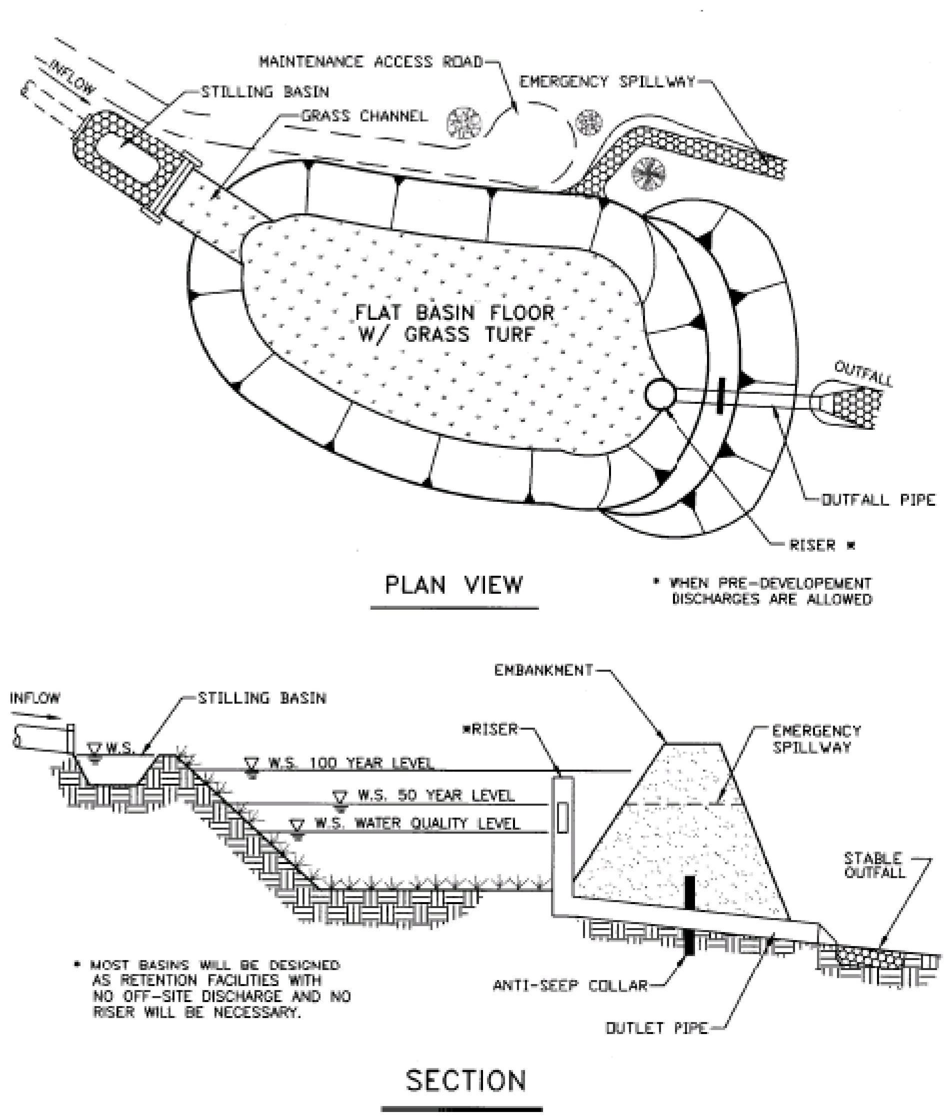


Figure 3.2 Infiltration Basin.

BMP 3.3 INFILTRATION SWALE

A. DESIGN

- Swale bottom slopes shall be between 1-4%.
- Curb cut pavement shall be installed at a maximum height of 6" above the swale if curb cuts will be used to introduce flow to the swale. Curb cuts shall be between 12-36" wide.
- A flow spreading device at the swale inlet shall be installed. Appropriate devices include shallow weirs, stilling basins, and perforated pipes. Provide a sediment clean-out area.
- Energy dissipation shall be provided at the inlet. Appropriate means are stilling basins and rip rap pads. If rip rap is used, it should be sized for the expected runoff velocity. A drainage window may be provided to direct the storm water runoff from events larger than the quantity design storm to the free draining material in the under drain. The top of the drainage window should be placed at an elevation above the water surface of the quantity design storm and should be located at the lower end of the swale.
- The swale side slopes shall be no more than 3:1.
- The swale bottom width shall be no greater than 8'.
- Swale shall be a maximum of 1.5' deep.
- The swale shall be grass-covered. Uniformly fine, close-growing, water-tolerant grasses should be used. Landscaping rock may also be used with an open trench.
- The swale under drain shall be constructed using clean 2" drain rock. The rock shall be wrapped in geotextile filter fabric, with a weight of greater than 4 ounces per square yard. The under drain will be a minimum depth of 12".
- A 6-12" layer of clean, washed sand that meets either specification: ASTM C-33 or ITD Standard 703.02, “Fine Aggregate for Concrete” shall be placed below the under drain.

B. SETBACKS AND SEPARATION DISTANCES

- Swale perimeter slope must be a minimum of 2' from the property line.
- There shall be at least 3' of separation between the bottom of the swale or under drain and the seasonal high ground water table.

C. LANDSCAPING

Vegetate swales uniformly with fine, close-growing, water-tolerant grasses that can withstand seasonally saturated soils. Swales shall not be used until the vegetation is established. The side slopes above the swale treatment area should be vegetated to prevent erosion. Additional grass or non-aggressive ground covers are appropriate.

Barrier shrubs, such as barberry, planted around the swale should be considered when there is a possibility that the public could damage the swale or hinder its function. Other plant materials are appropriate if recommended by a landscape professional.

Trees and shrubs should be planted high on the side slopes or above the water line elevation for the design storm. Avoid using bark, mulch, fertilizers, and pesticides in swale bottoms or sides. These materials tend to run off the planted area and into the swales reducing its treatment effectiveness. When storm water control and landscaping are integrated, the following standards apply:

- Up to 15% of the total area of the swale designated for storm water infiltration may be covered with ground cover plants other than grass.
- Up to 10% of the total area of the swale designated for storm water infiltration may be elevated above the bottom of the swale to allow the planting of trees and shrubs.

The decrease in swale area resulting from this action will be compensated for by infiltration of runoff that occurs during the storm. If trees and shrubs will be used, plant them on the top perimeter of swale side slopes. Minimize shading the vegetation in the swale treatment area. A spacing of at least 20' (6 meters) is appropriate for trees planted close to a swale. Avoid planting trees that would continuously shade the entire length of the swale. In addition, avoid using bark, mulch, fertilizers, and pesticides in these areas. These materials tend to run off the planted area and into the swale reducing its treatment effectiveness.

D. PRETREATMENT

To protect ground water from possible contamination, runoff cannot be infiltrated without proper pretreatment. Pretreatment shall be provided by a grass buffer strip, sediment forebay, bio-filtration swale, oil/water separator, or sediment trap.

E. OPERATION AND MAINTENANCE

Grass should be mowed to maintain an average grass height between 3"-9", depending on site characteristics. Monthly mowing is needed from May through September to maintain grass vigor. Grass clippings should be removed from the swale and composted on site or disposed of properly off site.

Sediment deposition at the head of the swale should be removed if grass growth is being inhibited for more than 10% of the swale length or if the sediment is blocking the even spreading or entry of water to the rest of the swale. Annual sediment removal and spot reseeding should be anticipated.

The swale should be regraded to produce a flat bottom width then reseeded if flow channelization or erosion has occurred. Regrading should not be required every year.

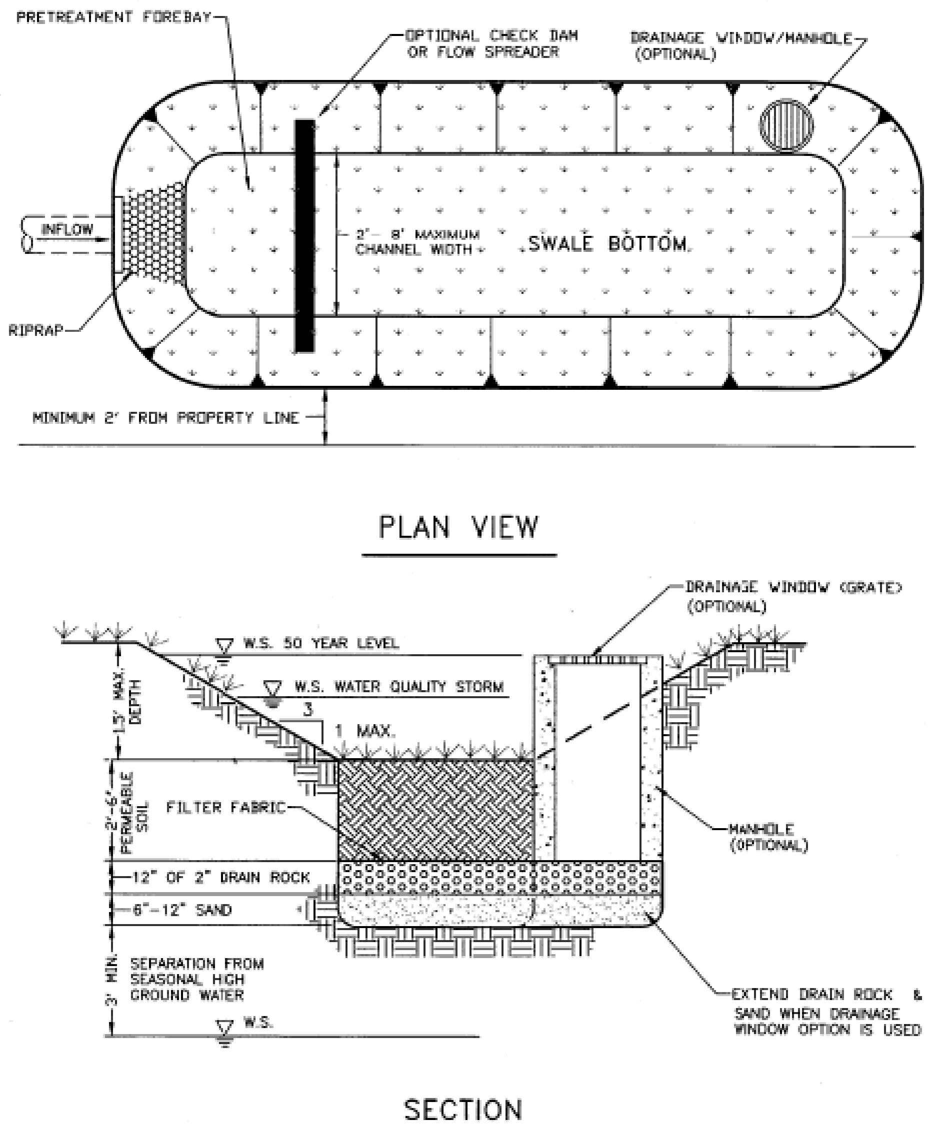


Figure 3.3 Infiltration Swale.

BMP 4: PONDS (GENERAL)

A. DEFINITIONS

A detention pond (water quantity) (Figure 4.1) is a pond designed to collect and temporarily hold surface and storm water runoff from a site and release it at a slower rate than it is collected. The water should drain within 24 hours. Detention ponds are traditionally used to mitigate downstream impacts and alleviate flooding problems. An extended detention pond (water quality) (Figure 4.2) is a pond designed to treat and release surface and storm water runoff from a site. Extended detention ponds are designed to provide water quality treatment and may be used to provide peak flow attenuation. The water is held for at least 48-72 hours to allow for treatment of pollutants by settlement, nutrient absorption, and filtering by plant materials.

B. REQUIREMENTS FOR ALL PONDS

- Design Life

  The system should be designed for at least a 50-year life.

- Location

  Ponds should not be constructed in natural streams or wetlands. Ponds should be located off-channel and should only hold storm water runoff, not natural runoff.

- Site Evaluation/Site Suitability

  Sites should be evaluated for soils, depth to bedrock, and depth to water table. Requirements will depend on pond type. Ponds may be used at sites where a receiving body or structure can accept pond discharges. Ponds designed to meet on-site detention requirements shall not be located in regulatory flood plains. Also, ponds should not be used in areas where storm water has the potential to contain soluble metals, toxic organics, or where high sediment loads may occur.

- Design

  The design of any detention pond requires consideration of several factors. Balancing the requirements is done by developing an inflow hydrograph, a depth-storage relationship, and a depth-outflow relationship. The inflow/storage/outflow relationships should be based on a storm duration that identifies a peak detention pond volume for the storm interval required. Refer to Part A, Section 3.B(6) for water quantity and quality design criteria.

The factors to be considered include:

- basin size
- minimum free board
- maximum allowable depth of temporary ponding
- recurrence interval of the storm being considered
- storm duration
- timing of the inflow
- allowable outflow rate
- the length of time water remains in the facility.

- Maximum Outflow Rate

  The maximum outflow rate shall not be more than the pre-development rate of runoff for each storm return interval. The receiving system must be shown to be capable of accommodating the pre-development flow.

- Outlets

  Outlet pipes shall be at least 12" in diameter. If riser pipes are used, they shall be 1 1 /2 times the cross sectional area of the outfall pipe. Trash racks or anti-vortex devices shall be installed. All pipe joints are to be watertight. Anti-seep cutoff walls, 8" thick, or other seepage control methods are to be installed around outlet pipes. The channel immediately below the pond outfall shall be protected against erosion and shall transition to natural drainage conditions in the shortest distance possible.

- Dam Safety Requirements

  If a pond is categorized as a dam by the State of Utah, the relevant sections of the Utah Code will apply. Contact the Utah Division of Water Rights for more information on dam safety requirements.

- Vegetative Buffers

  Vegetative buffer strips shall be established around the perimeter of the pond for erosion control and additional sediment and nutrient removal. Buffer strips should include all areas between the normal pond water surface elevation to the top of the pond embankment.

- Side Slopes/Safety

  Take all practical safety precautions. Side slopes should not exceed 4:1 (3:1, if the pond will normally remain dry).

- Soils

  A soils investigation is required on all ponds. At a minimum, it shall include information along the centerline of the proposed dam in the emergency spillway location and the planned borrow area. It should include recommendations on cutoff trenches, compaction, and any other special design requirements.

- Freeboard and Emergency Spillway

  All open surface facilities shall be designed with adequate freeboard above the maximum design water elevation. Emergency spillways are required on all ponds. The spillway shall be sized to safely pass the 100-year developed peak flow.

- Maintenance Access

  Direct access to the pond bottom, inlet sedimentation area, and control structure is required. A right-of-way maintenance easement from a road to the pond (if not accessible from the public right-of-way), shall be provided.

- Inspection

  Detention ponds should be inspected during regular semi-annual inspections to determine maintenance needs.

BMP 4.1: DETENTION PONDS

A. DEFINITION

Detention ponds are designed to detain a volume of water to attenuate peak flows. A wet pond has a permanent pool and provides temporary storage of storm water runoff. A dry detention pond does not maintain a permanent pool between storm events.

B. APPLICABILITY

Detention ponds are suitable in residential, commercial, and industrial sites.

C. POND GEOMETRY

The pond can be any shape provided that it has sufficient capacity to meet general design requirements.

D. OUTLET DESIGN

At the peak flow rate, pond volume shall be equal to the difference between pre and post-development storm volumes. The outlet structure shall be designed in accordance with the water quantity and quality requirements of Part A, Section 3.B(6). The outlet design shall incorporate a multi-stage riser that will allow water (above the permanent pool, in a wet pond) to be drained over 24 hours. The outlet shall be designed to mimic pre-development flow rates. The outlet structure shall be designed to prevent clogging and plugging.

E. CONSTRUCTION REQUIREMENTS

Detention ponds shall be excavated in a manner that will minimize disturbance and compaction of the pond. Sediment measuring devices shall be installed at opposite ends of the bottom of the basin or sediment trap to measure sediment accumulation.

F. SEDIMENT STORAGE

Ponds shall be designed to contain computed storage volume plus 15% of the computed storage volume to adequately accommodate sediment deposition.

G. FOREBAY/SEDIMENT TRAP

Each pond shall have a sediment forebay or equivalent upstream pretreatment. The forebay shall have a separate cell formed by an acceptable barrier. A fixed vertical sediment depth marker shall be installed in the forebay to measure sediment accumulation. Minimum forebay size shall be equal to 15% of the water quality treatment volume. Optimal volume should be equal to 25% of the water quality treatment volume. Forebay volume shall be in addition to permanent pool volume, where applicable, and shall be separated from permanent pool, if possible. A weir flow structure or physical separation with pipes may be utilized. A rock or an earthen berm shall be constructed with a minimum top width of 4' and side slopes no steeper than 3:1 to provide separation from the permanent pool. A drainpipe should be included in the forebay to dewater the pool area for maintenance purposes.

H. INLET PROTECTION

The inlet shall be protected against erosion or scour. Riprap or other material may be required at the inlet to provide for energy dissipation.

I. STABILIZATION

Wet detention ponds shall be stabilized with vegetation to control dust and improve pond aesthetics. A landscaping plan for a pond and surrounding area should be prepared to indicate how aquatic and terrestrial areas will be vegetatively stabilized, established, and maintained. Whenever possible, wetland plants should be used in a pond design, either along the aquatic bench or within shallow areas of the pool.

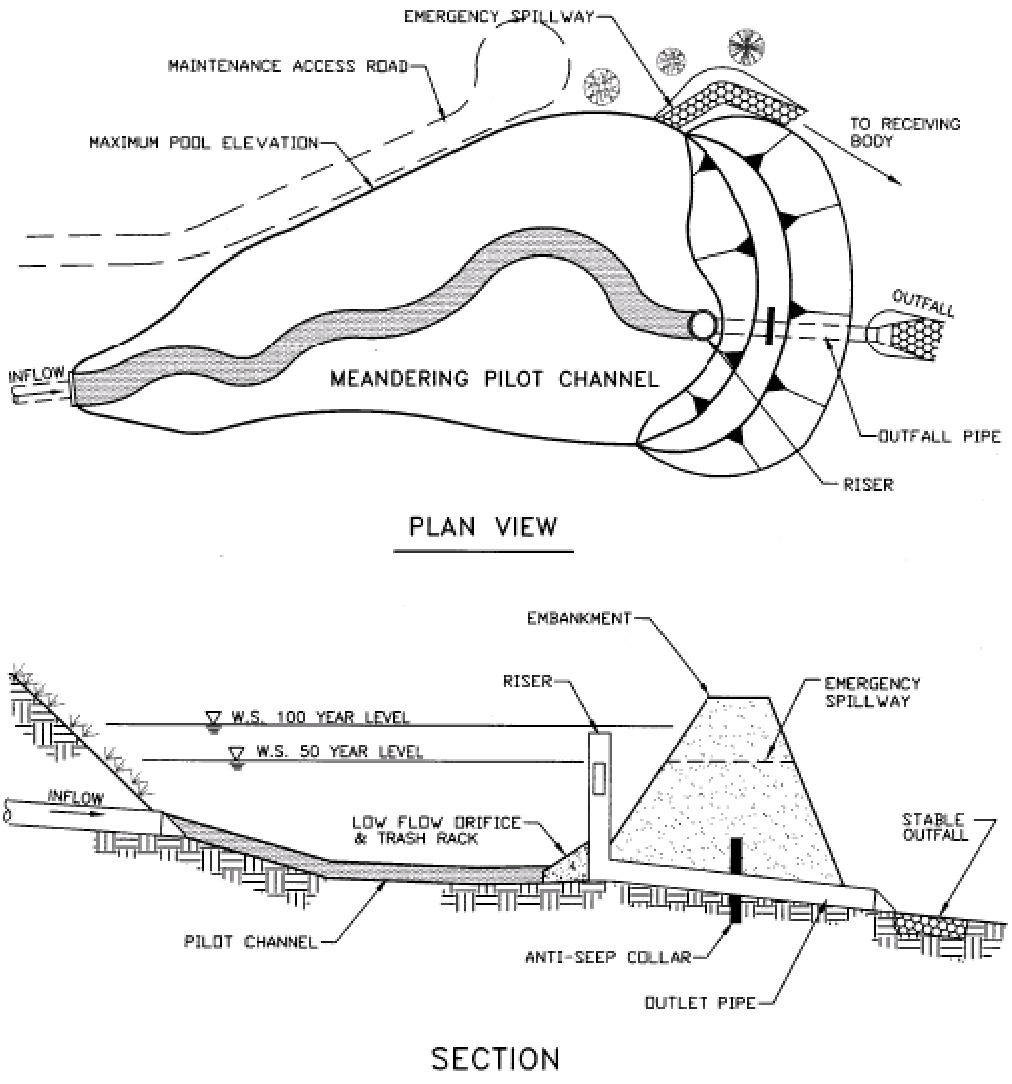


Figure 4.1 Detention Pond.

BMP 4.2: EXTENDED DETENTION PONDS

A. DEFINITION

An extended detention pond is a constructed pond designed to detain a volume of water for a minimum time to allow for the settling of particles and associated pollutants. This type of pond can also be utilized for flood control by including additional temporary storage for peak flows. A wet extended detention pond incorporates both a permanent pool and extended detention. Dry extended detention ponds do not maintain a permanent pool between storm events.

B. APPLICABILITY

Ponds should not be used where storm water has the potential to contain soluble metals or toxic organics. In addition, ponds placed in areas where high sediment loads may occur, require frequent maintenance but still may be the most cost-effective treatment method. A wet extended detention pond is suitable in residential, commercial, and industrial sites. It is appropriate in areas where nutrient loadings are expected to be high. Dry extended detention ponds do not maintain a permanent pool between storm events.

C. POND GEOMETRY

The pond shall be designed to lengthen the flow path, thereby increasing detention time and limiting peak flow rates to pre-development rates. Shallow basins with large surface areas also provide better removal efficiencies than small deep basins. The pond geometry shall meet the following criteria:

- Permanent pool depth shall not exceed 12' with an average depth between 4-6'.
- Length from inlet to outlet should be as far apart as possible.
- Length to width ratio should be approximately 3:1 and side slopes should be 4:1.

D. SIZING

Size the pool according to the design storm criteria in Part A, Section 3.B(6). The critical parameters in determining the size of the basin are the storage capacity and the maximum rate of runoff released from the basin. The design shall provide an average of 48-72 hours detention time. This design objective can be achieved by setting the maximum detention time for the greatest runoff volume at approximately 40 hours. The average detention time for very small storms should be at least 6 hours.

E. FOREBAY

Each pond shall have a sediment forebay or equivalent upstream pretreatment. The forebay shall have a separate cell formed by an acceptable barrier. A fixed vertical sediment depth marker shall be installed in the forebay to measure sediment accumulation. Minimum forebay size shall be equal to 15% of the water quality treatment volume. Optimal volume should be equal to 25% of the water quality treatment volume. Forebay volume shall be in addition to permanent pool volume, where applicable, and shall be separated from permanent pool, if possible. A weir flow structure or physical separation with pipes may be utilized. A rock or an earthen berm shall be constructed with a minimum top width of 4' and side slopes no steeper than 3:1 to provide separation from the permanent pool. A drainpipe should be included in the forebay to dewater the pool area for maintenance purposes.

F. Outlet Design for a Wet Extended Detention Pond

The outlet shall be designed to pass a flow rate necessary for extended quantity attenuation. The outlet design shall incorporate a multi-stage riser that will allow water to be drained over a minimum of 48-72 hour period depending upon the design storm.

Ponds may be constructed with safety benches. The perimeter of all deep permanent pool areas (at least 4' deep) shall be surrounded by two safety benches with a combined minimum width of 15'. The benches should be designed as follows:

- A safety bench that extends landward from the normal water level edge to the toe of the pond side slope. The maximum slope of the safety bench shall be 12%.
- An aquatic bench that extends from the normal shoreline and has a maximum depth of 18" below the normal pool water surface elevation. Pond slope between the top of the bank and bench shall not exceed 2:1.

G. Outlet Design for a Dry Extended Detention Pond

A perforated riser can be used to slowly release the water over a prolonged period. A cutoff collar should be considered for the outlet pipe to control seepage.

H. Construction Guidelines

Wet extended detention ponds should be excavated in a manner that will minimize disturbance and compaction of the pond. Sediment measuring gauges should be installed at opposite ends of the bottom of the basin to measure sediment accumulation.

I. Stabilization

A landscaping plan for a wet extended detention pond and its buffer shall be submitted to indicate how aquatic and terrestrial areas will be vegetatively stabilized and established. Whenever possible, wetland plants should be used in a pond design, either along the aquatic bench or within shallow areas of the pool. Bottom and banks of all dry extended detention ponds shall be stabilized with gravel, rock, vegetation, or other acceptable material to control dust and prevent erosion.

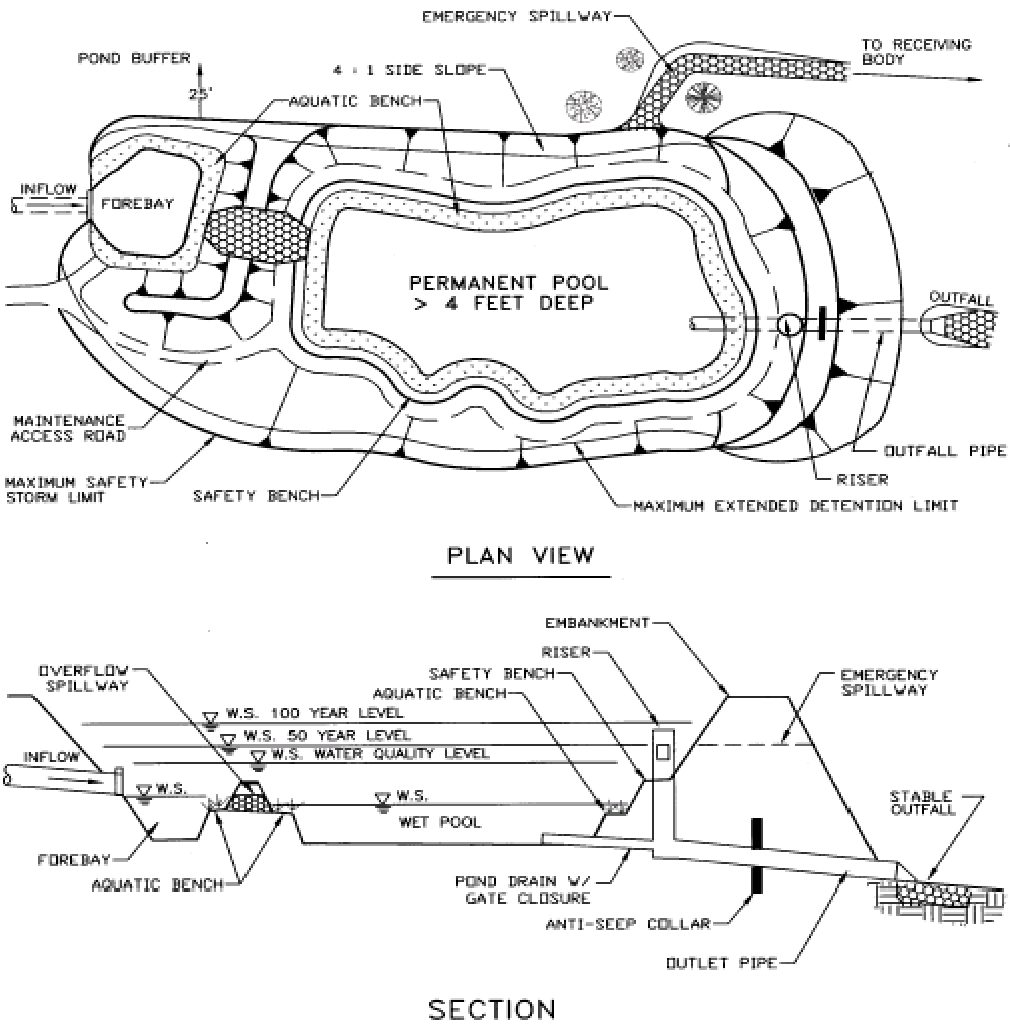


Figure 4.1 Extended Detention Pond.

BMP 5: BIOFILTRATION SYSTEMS

A. INTRODUCTION AND PURPOSE

This section includes requirements that apply to biofiltration swales (Figure 5.1) and grass buffer strips (Figure 5.2). These BMPs are pre-treatment systems that utilize plant materials for various physical and biological processes in the water quality treatment of runoff. These systems should not be used alone to treat storm water runoff. Rather, they should be used in combination with other structural and nonstructural BMPs to improve water quality.

B. PLAN SUBMITTAL REQUIREMENTS

The applicant will be required to provide a written report that includes the Plan Submittal Requirements and a Landscape Plan.

C. SIZING

Unless a bypass is included, the biofilter must be sized as both a treatment device and to pass the peak hydraulic flows. The depth of the storm water should not exceed the height of the grass.

D. LANDSCAPING

Vegetate biofilters with fine, close-growing, water-tolerant grasses that can withstand seasonally saturated soils. Biofilters shall not be used to manage storm water until the vegetation is established. The side slopes of a biofilter should be vegetated to prevent erosion. Barrier shrubs, such as barberry, planted around the biofilter should be considered when there is a high potential for people to damage the biofilter or hinder the biofilter’s function. Other grasses or non-aggressive ground covers are appropriate if recommended by a landscape professional.

If trees will be planted near the biofilter, then minimize shading the vegetation in the biofilter treatment area. A spacing of at least 20' (6 meters) is appropriate for trees planted close to a biofilter. Avoid planting trees that would continuously shade the entire length of the biofilter. In addition, avoid using bark, mulch, fertilizers, and pesticides in these areas. These materials tend to run off the planted area and into the biofilter reducing its treatment effectiveness.

E. OPERATION AND MAINTENANCE

Systems should be inspected during regular semi-annual inspections. This inspection schedule applies to all biofiltration systems unless otherwise noted.

Grass shall be mowed to maintain an average grass height between 3 -9", depending on the site situation. Monthly mowing is needed from May through September to maintain grass vigor. Grass clippings should be removed from the swale and composted on site or disposed of properly off site.

Sediment deposited at the head of the swale shall be removed if grass growth is being inhibited for more than 10% of the biofilter length or if the sediment is blocking the even spreading or entry of water to the rest of the facility. Annual sediment removal and spot reseeding should be anticipated.

If flow channelization or erosion has occurred, the facility shall be regraded, then reseeded as necessary.

Access for mowing equipment and maintenance shall be provided. Consideration should be given to providing wheel strips in the bottom of the swale if vehicular access (other than grass mowing equipment) is needed.

BMP 5.1: BIOFILTRATION SWALES

A. DESCRIPTION

Biofiltration swales are storm water runoff systems which treat and then discharge storm water runoff to another system.

B. DESIGN

- A hydraulic residence time for the storm water runoff of 9 minutes is required.
- Water velocity, as determined by Manning's "n", should not exceed 0.9 feet/second.
- The Manning's "n" for grass shall be in the range between 0.02 and 0.024.
- Swales shall be sloped as necessary to obtain the desired design velocity and residence time.
- If flow is to be introduced to the swale via curb cuts, then curb cut pavement elevation shall be no higher than 6" above swale. Curb cuts should be between 12-36" wide.
- Install a flow spreading device at the swale inlet. Appropriate devices include shallow weirs, stilling basins, and perforated pipes. Provide a sediment clean-out area. A sediment catch basin or a larger pre-settling device would control sediments at the swale inlet and allow for easy maintenance.
- Provide for energy dissipation at the inlet. Appropriate means are stilling basins and rip rap pads.
- Swale using rip rap should be sized for the expected runoff velocity.
- Swale side slopes shall be no steeper than 3:1.Swale bottom width shall be no greater than 8'.The maximum depth of flow through the biofiltration swale shall be 3.0".

C. SETBACKS AND SEPARATION DISTANCES

Perimeter slope of the swale must be a minimum of 2' from property line.

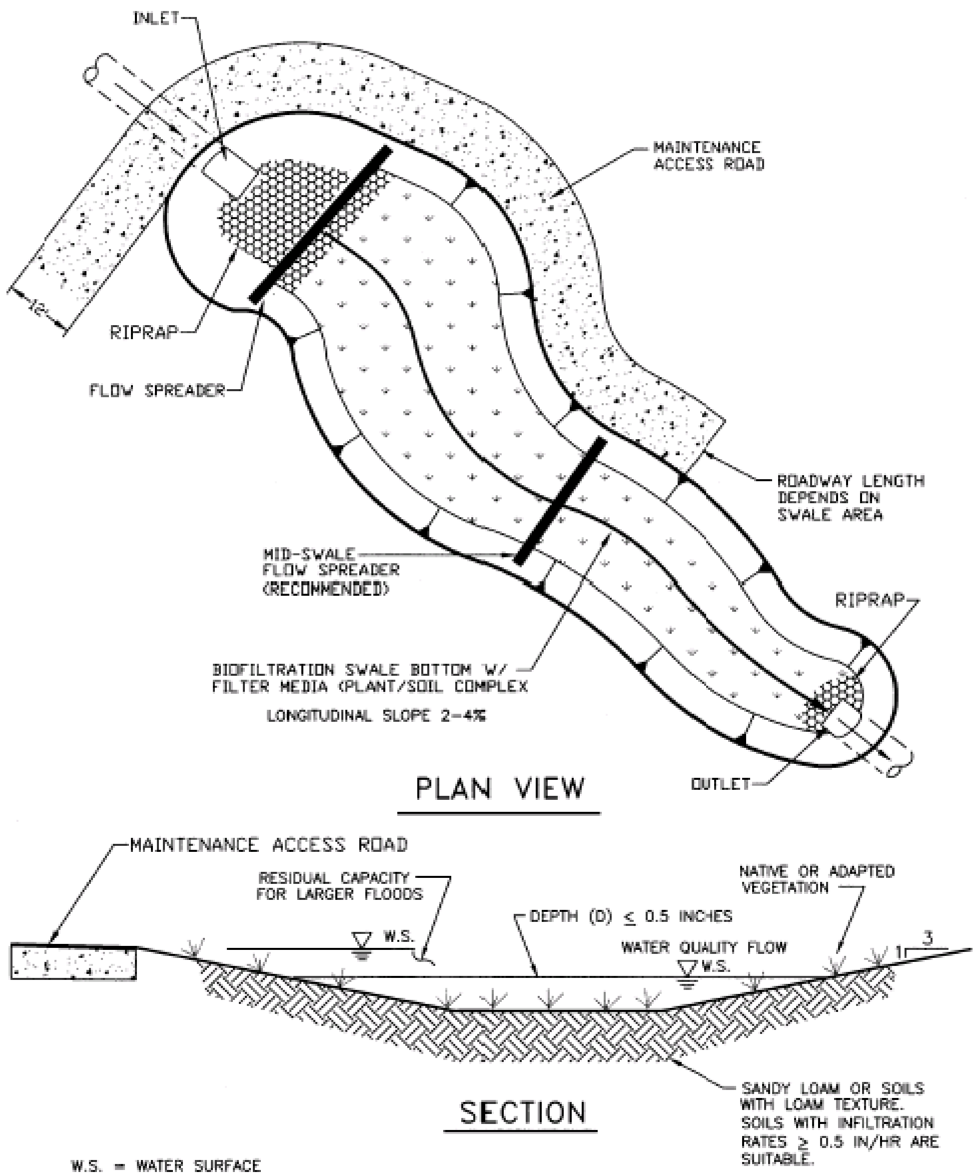


Figure 5.1 Biofiltration Swale.

BMP 5.2: GRASS BUFFER STRIPS

A. INTRODUCTION

Grass buffer strips are used as a water quality pretreatment system for smaller sites.

B. DESIGN

- The longest flow path from the area contributing sheet flow to the filter strip shall not exceed 150 feet.
- The lateral slope of the contributing drainage (parallel to the edge of pavement) shall be 2% or less.
- A hydraulic residence time of 9 minutes is required.
- A stepped series of flow spreaders installed at the head of the strip may be used to compensate for drainage areas having lateral slopes of up to 4%.
- The longitudinal slope of the contributing drainage area (parallel to the direction of flow entering the filter strip) shall be 5% or less.
- Grass buffer strips shall not be used when the contributing drainage areas has a longitudinal slopes steeper than 5% or energy dissipation and flow spreading should be provided up slope of the upper edge of the filter strip to achieve flow characteristics equivalent to those meeting the above criteria.
- The longitudinal slope of the strip (along the direction of flow) shall be between 1 - 20%.The lateral slope of the strip (parallel to the edge of pavement, perpendicular to the direction of flow) shall be less than 2 percent.
- The ground surface at the upper edge of the filter strip (adjacent to the contributing drainage area) shall be at least 1 inch lower than the edge of the impervious area contributing flows.
- Manning’s roughness coefficient (n) for flow depth calculations shall be 0.04.
- The maximum depth of flow through the filter strip for optimum water quality shall be 1.0 inch.
- The maximum allowable flow velocity for the water quality design flow (WQv) shall be 0.5 feet per second.
- Runoff entering the filter strip must not be concentrated. If the contributing drainage area is not smoothly graded to prevent concentrated flowpaths, a flow spreader shall be

installed at the edge of the pavement to uniformly distribute the flow along the entire width of the filter strip. At a minimum, a gravel flow spreader (gravel-filled trench) shall be placed between the impervious area contributing flows and the filter strip. The gravel flow spreader shall be a minimum of 6" deep and shall be 18" wide for every 50' of contributing flowpath. Where the ground surface is not level, the gravel spreader must be installed so that the bottom of the gravel trench is level.

- Energy dissipaters are needed in the filter strip if sudden slope drops occur, such as locations where flows in a filter strip pass over a rockery or retaining wall aligned perpendicular to the direction of flow. Adequate energy dissipation at the base of a drop section can be provided by a rip rap pad.

C. LANDSCAPING

Trees and shrubs should not be located within a grass filter strip.

D. MAINTENANCE

Inspections should occur semi-annually to determine maintenance needs. Access shall be provided at the upper edge of the filter strip to enable maintenance of the inflow spreader throughout the strip width and allow access for mowing equipment.

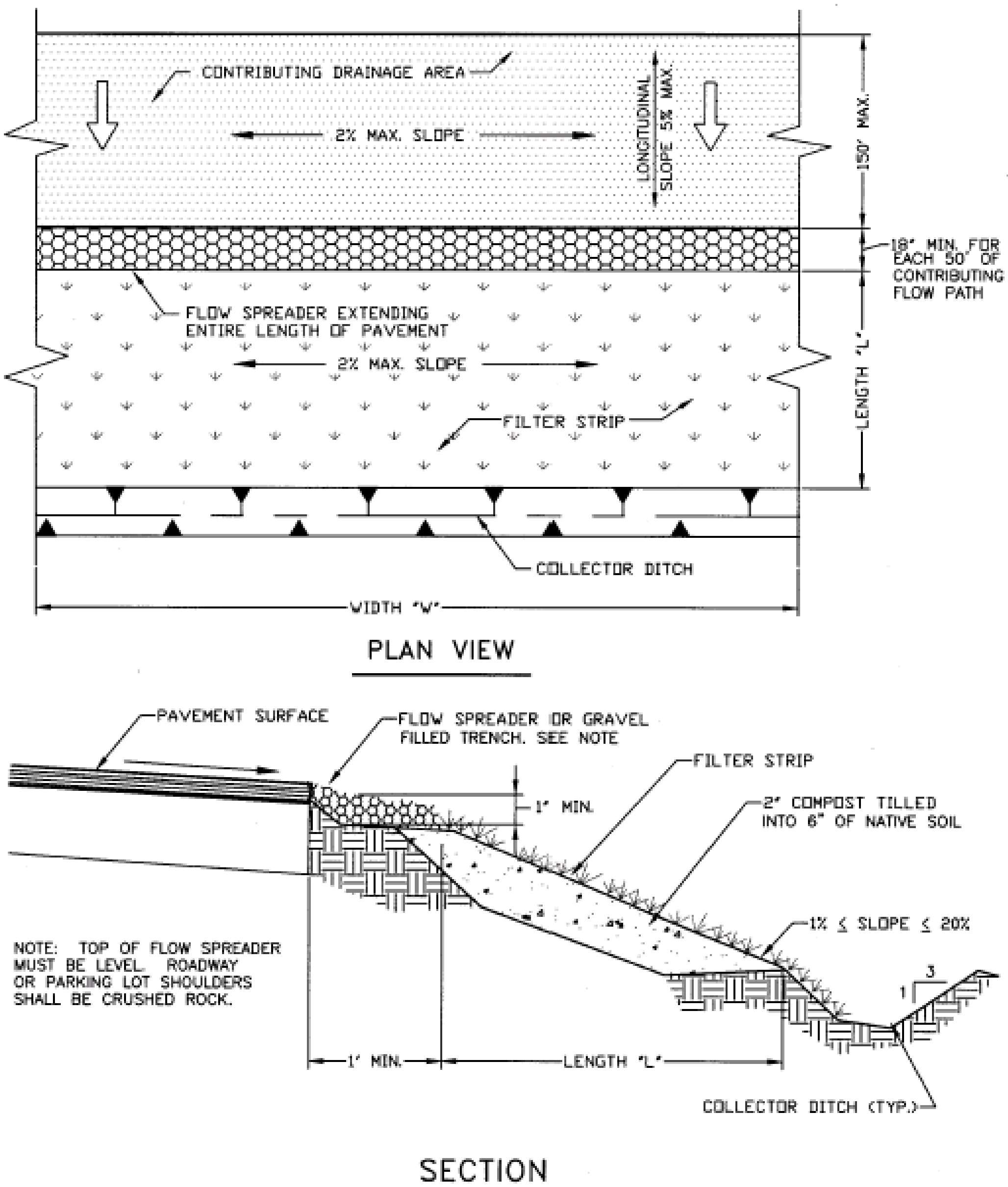


Figure 5.2 Grass Buffer Strip.

BMP 6: SAND FILTERS

A. INTRODUCTION

Sand filters consist of self-contained beds of sand either underlain with underdrains or cells and baffles with inlets/outlets. Storm water runoff is filtered through the sand, and in some designs may be subject to biological uptake. The four most commonly used sand filter systems are the Austin Sand Filter, the Delaware Sand Filter, the Trench Filter, and the Pocket Sand Filter.

- Austin Sand Filter

  The Austin sand filter (Figure 6.1), or surface sand filter, consists of a sedimentation chamber or pond followed by a surface sand filter with collector underdrains in a gravel bed. Filtered runoff is conveyed to a storm sewer or channel by gravity flow of pumping.

- Delaware Sand Filter

  The Delaware sand filter (Figure 6.2), or perimeter system, consists of parallel sedimentation and sand filter trenches connected by a series of level weir notches to assure sheet flow onto the filter. Filtered runoff is conveyed to a storm sewer by gravity flow or pumping.

- Underground Sand Filter

  The underground sand filter (Figure 6.3) is place underground but maintains essentially the same components as the Austin sand filter. The filter consists of a 3 chamber vault. A 3' deep wet sedimentation chamber is hydraulically connected by an underwater opening to provide pretreatment by trapping grit and floating organic material. The second chamber contains as 18-24" sand filter bed and an under drain system including inspection/cleanouts wells. A layer of plastic filter cloth with a gravel layer can be placed on top of the sand bed to act as a preplanned failure plane which can be replaced when the filter surface becomes clogged. The third chamber collects the flow from the under drain system and directs flow to the downstream receiving drainage system.

- Pocket Sand Filter

  The Pocket sand filter (Figure 6.4) is a simplified and low cost design suitable for smaller sites. Runoff is diverted within a catch basin. Pre-treatment is provided by a concrete flow spreader, a grass filter strip, and a plunge pool. The filter bed is a shallow basin and contains the sand filter layer. The surface of the filter bed may contain either a soil layer or grass cover crop.

B. Application and Limitations

Sand filters may be designed as trench systems to receive and treat parking lot runoff, and have been used to replace oil/water separators for pre-treatment. The storm water runoff is discharged or conveyed to another BMP for further treatment or disposal. Depending on soil types, sand filters may be designed as a stand-alone BMP to infiltrate all or a portion of treated runoff. Subsurface disposal restrictions will apply to this application. The typical drainage area to be served by a sand filter should range from 0.5 to 10 acres. Depending on design, the contributing drainage area may be up to 50 acres.

C. Sizing

Sizing should be based on anticipated sediment accumulation and maintenance. Sand filters shall be sized using the following criteria:

- The sand filter shall be sized for water quality design storm requirements if it will be used as an off-line treatment facility.
- The maximum depth of water over the sand shall be 1'.
- Calculate the sand filter surface area using Darcy’s Law or the filtration rate.
- The sand filter shall be designed to completely drain in a 24 hours or less.
- The filtration rate shall be 2" per hour.

D. Pretreatment

Sand filters should be preceded by pretreatment to allow for the settling of coarse sediment that may clog the sand filter and reduce its effectiveness. Pretreatment systems that may be used are sedimentation basins, grass buffer strips, biofiltration swales, or catch basin inserts.

E. Design

The sand bed shall include a minimum of 18" of 0.02-0.04" diameter sand or ASTM C-33 sand. If infiltration into the underlying soil is not desired, the bottom of the system shall be lined with one of the following impermeable layers:

- a minimum 12" thick layer of clay
- a concrete liner with approved sealer or epoxy coating, at least 5", reinforced with steel wire mesh (use 6 gauge or larger wire and 6" x 6" smaller mesh, or a geomembrane layer).

The bed of the filter should be composed of gravel, measuring at least 4-6"; 2" drain rock may also be used.

When sand filters are designed as off-line BMPs, they should be sized for the water quality design storm and the storm water conveyance should be fitted with flow splitters or weirs to route runoff to the sand filter. Excess runoff bypasses the sand filter and continues to another BMP for water quantity control. The inlet structure should be designed to spread the flow uniformly across the surface of the filter; use flow spreaders, weirs, or multiple orifices.

F. Design Life

Final ownership of the system may affect the design, layout and materials used in a system. The designer should specify the materials for the system and at a minimum, the system should be designed for a 50-year life.

G. Setbacks and Separation Distances

When sand filters infiltrate to the subsurface, the following requirements apply:

- Sand filters must be a minimum of 100' from public and private wells.
- There shall be a 5' vertical separation distance between the infiltration surface and bedrock.
- There shall be a 100' separation distance from surface water supplies used as drinking water and a 50' separation distance from surface water supplies not used as drinking water.
- There shall be a minimum 3' vertical separation distance from the infiltration surface and the seasonal high ground water table.

H. Maintenance

- For the first few months after construction, the sand filters should be inspected after every storm. Thereafter the sand filters should be inspected semi-annually to determine maintenance needs.
- The sand filters should be raked periodically to remove surface sediment, trash, and debris.
- Sediments shall be disposed of in accordance with local, state, and federal regulations.
- The top layer of sand should be replaced annually, or more frequently when drawdown does not occur within 36 hours after the presettling basin has emptied.

- The water level in the filter chamber should be monitored on a quarterly basis and after large storms during the first year.

- The sedimentation chamber should be pumped out or extracted when the sediment depth reaches 12".

- Oil on the surface should be removed separately and recycled. The remaining material may be removed by a vacuum pump and disposed of according to local, state, and federal regulations.

I. Maintenance Access

- Unobstructed access shall be provided over the entire sand filter by either doors or removable panels.

- Access to the sand filter should be provided for maintenance, including inlet pipe and outlet structure.

- Ladder access is required when vault height exceeds 4'. Access openings should have round solid locking lids with ½" diameter allen head screw locks.

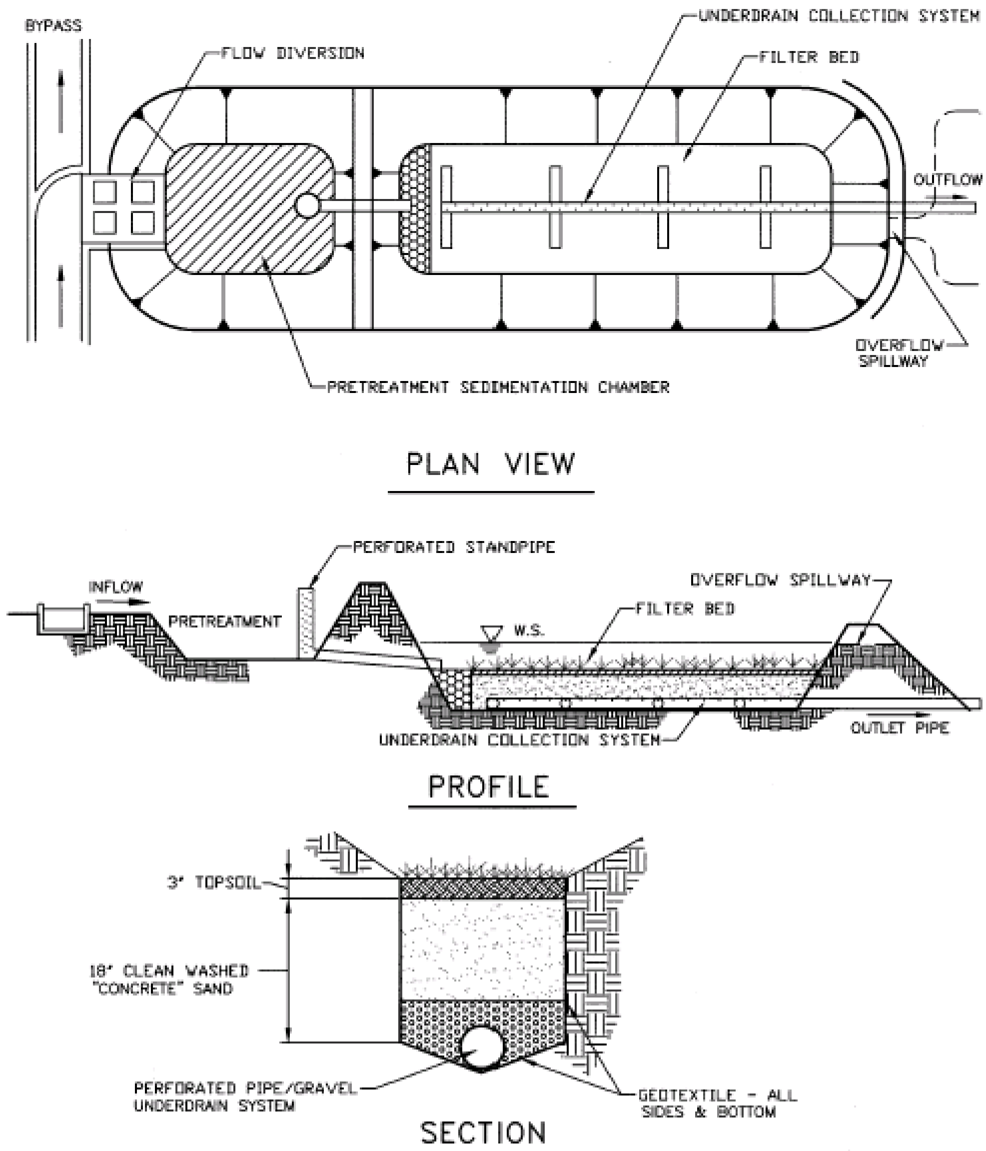


Figure 6.1 Austin Sand Filter.

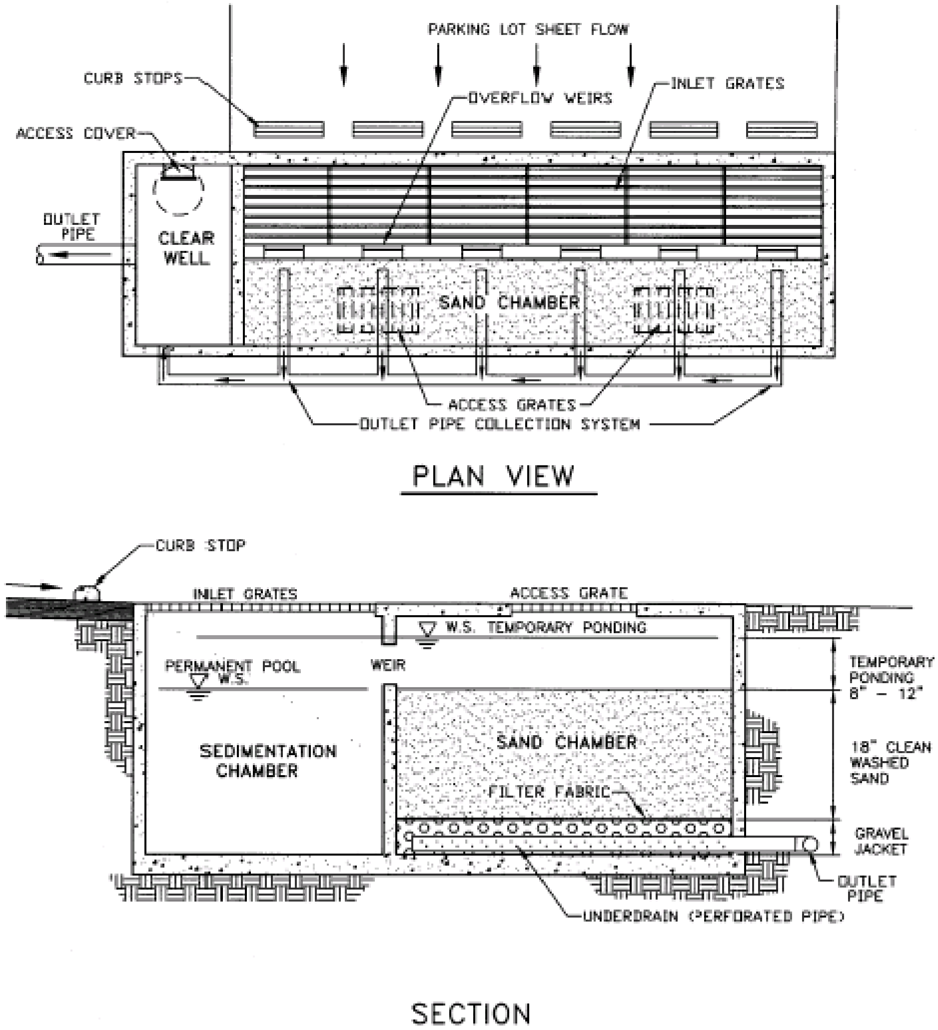


Figure 6.2 Delaware Sand Filter.

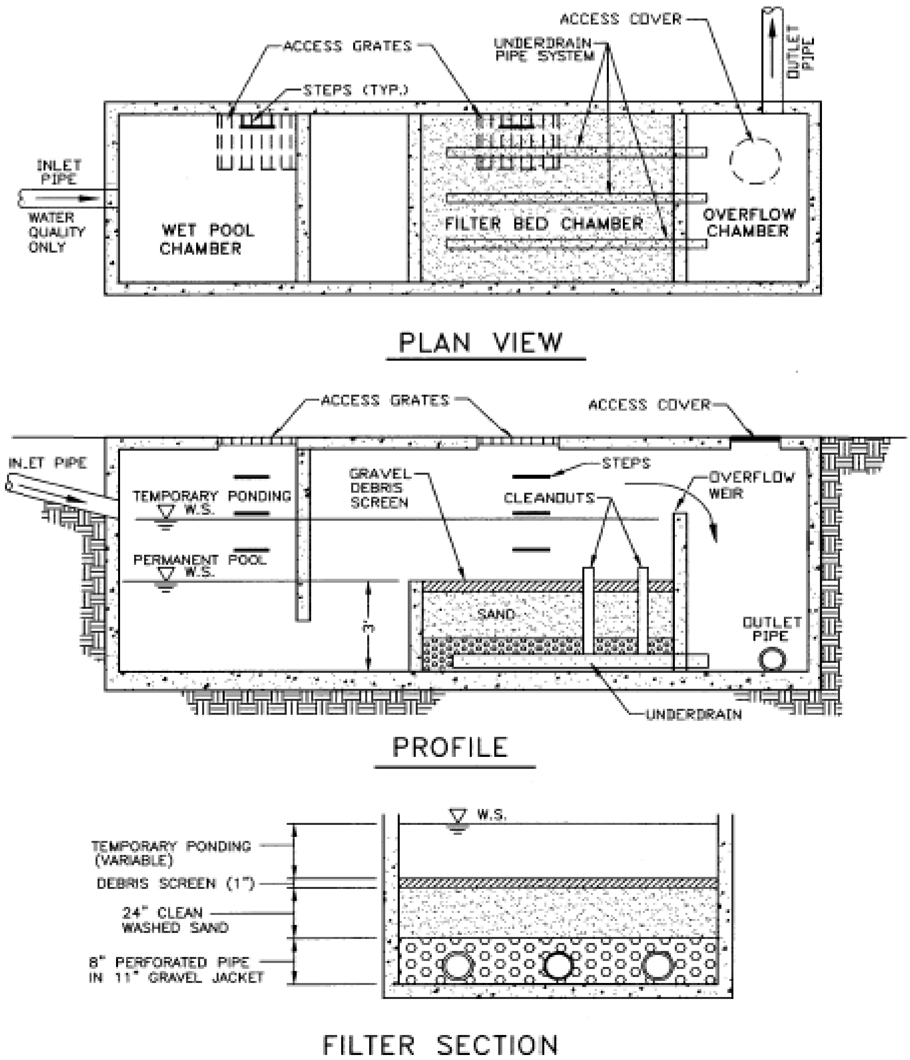


Figure 6.3 Underground Sand Filter.

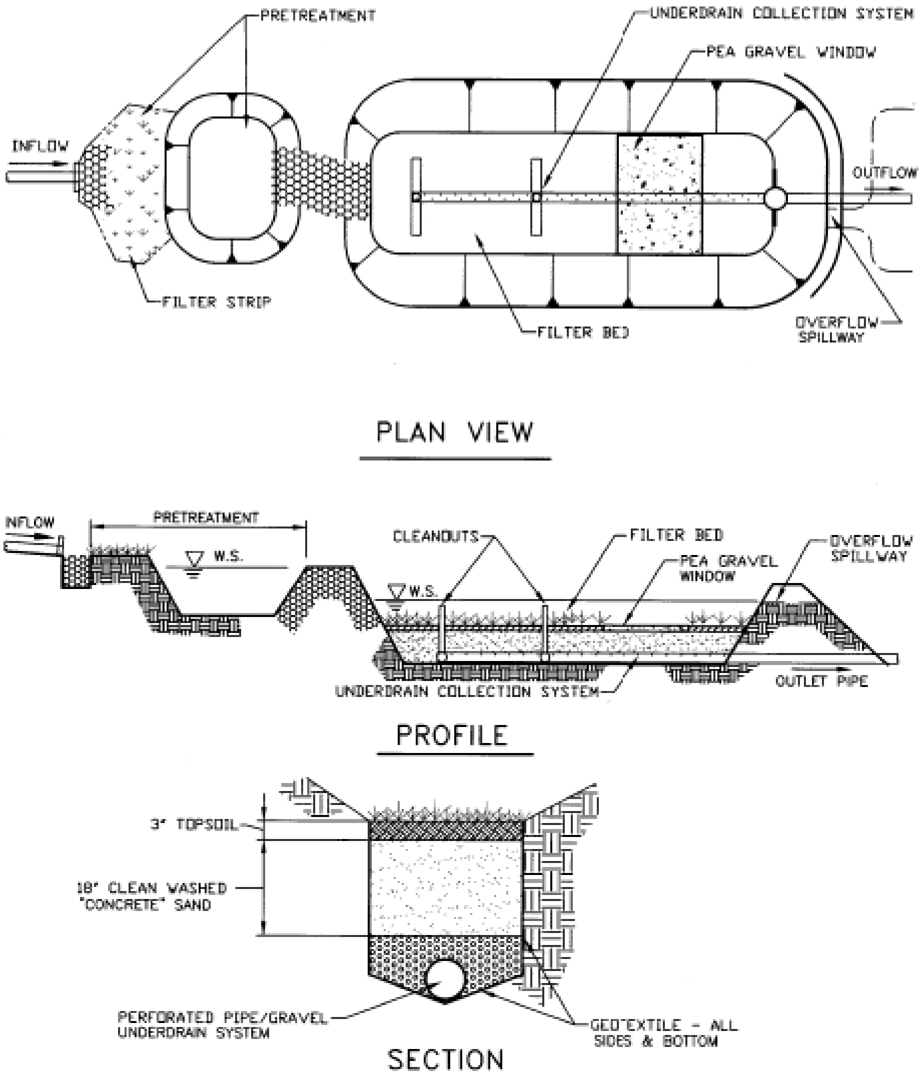


Figure 6.4 Pocket Sand Filter.

PART F: CALCULATING PEAK DISCHARGE AND VOLUME

This part describes methods for calculating pre- and post- development runoff volumes and peak discharge rates. These calculations should be performed in order to help select, size, and design stormwater BMPs to meet the peak flow rate, water quality, and groundwater recharge criteria described in Section 3.B.(6) of Part A. This Part provides steps for performing these calculations using the rational method, which is only applicable for sites 200 acres or less in size. For larger sites, areas with significant flood storage effects/features, highly complicated sites, or for BMP designs that require complete design hydrographs, calculations should be performed using the NRCS TR-55 method. A description of this method is not provided in this part; however, detailed TR-55 documentation and a free Windows-based download of the TR-55 program can be obtained on-line at:

http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/H&H_home.html

Hydrologic methods for determining runoff rate and volume other than the rational method or TR-55 may be acceptable, but the applicant must obtain prior approval from Uintah County/Vernal City/Naples City before beginning hydrologic studies and calculations using alternative methods.

CALCULATING PEAK RUNOFF

Use the rational formula:

$$Q_p = CiA$$

Q_p = peak discharge (cfs)
C = dimensionless runoff coefficient
I = rainfall intensity (in./hr) for a duration equal to the time of concentration and for the recurrence interval chosen for design
A = site area (acres)

1) **Calculate site area (A)**. This can be determined from USGS topographic maps, site surveys, and other available information.

2) **Determine the runoff coefficient "C")**. This value is obtained from the tables below, and is based on land use type (s) for developed areas, and soil hydrologic group/ slope characteristics for undeveloped areas. For areas with mixed land uses, the area should be divided into subareas with similar characteristics (A_1, A_2, etc.), and a weighted coefficient should be determined using the following formula:

$$C = [(A_1 * C_1) + (A_2 * C_2)....+(C_n * A_n)]/A$$

where C_1,C_2, etc. are the runoff coefficients for each individual subarea. Information on slope and land use can be obtained from USGS topographic maps, site surveys, air photos, and other available data. Uintah County/Vernal City/Naples City soil maps and hydrologic group information can be obtained from local Soil Conservation Districts, or on-line at:

http://soildatamart.nrcs.usda.gov/

Soil hydrologic group information can be obtained by selecting the “generate reports - water features” function at this website. The different soil hydrologic groups are defined as follows (definitions taken from USDA Technical Release-55 “Urban Hydrology for Small Watersheds, 1986):

Group A: These soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission (greater than 0.30 in/hr).

Group B: These soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr).

Group C: These soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 in/hr).

Group D: These soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr).

Table F1 Recommended Rational Method "C" Coefficients for Developed Areas.

Land Use Category	Runoff Coefficient "C"
Business	
Central business areas	0.70-0.95
Neighborhood areas	0.50-0.70
Residential	
Single-Family	0.35-0.45
Multi-family, detached	0.40-0.60
Multi-family, attached	0.60-0.75
Low Density - 0.5 acre lots or larger	0.25-0.40
Industrial and Commercial	
Light areas	0.50-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.20-0.35
Railroad yard areas	0.20-0.40
Roofs	0.90-0.95
Streets, Drives, Walks (asphalt or concrete)	0.90-0.95
Streets, Drives, Walks (brick, gravel, or disconnected pavers)	0.70-0.85

Table F2 Recommended Rational Method "C" Coefficients for Undeveloped/Pervious Areas.

	Runoff Coefficient "C" [a]			
Slope	A soils	B soils	C soils	D soils
Flat (0-2%)	0.04-0.09	0.07-0.12	0.11-0.16	0.15-0.20
Average (2-6%)	0.09-0.14	0.12-0.17	0.16-0.21	0.20-0.25
Steep (>6%)	0.13-0.18	0.18-0.24	0.23-0.31	0.28-0.38

[a]values should be selected from the high or low end of the given ranges based on the condition of ground cover/vegetation.

3) **Calculate the time of concentration (T)** to use in determining the appropriate rainfall duration and intensity to use in the rational formula. T is the time required for water to travel the longest watercourse within the drainage area (i.e., the time for water to travel from the hydrologically most remote point of the basin to the location being analyzed). T can be determined graphically using Figure F1 or calculated using the FAA formula below. For small and/or highly impervious areas with very short times of concentration, the default minimum T value to be used for design purposes is 10 minutes.

$$T= 1.8* (1.1 - C)\, D_{0.5} / S_{1/3}$$

T = time of concentration (minutes)
C = dimensionless runoff coefficient (same as used in rational formula)
D = length (in feet) of longest watercourse
S = % slope of longest watercourse

The variables D and S can be determined from USGS topographic maps, site surveys, and other available information. Care should be taken to field-verify flow path information to ensure that any existing graded swales, ditches, gutters, or other constructed drainage systems that intercept the natural contours are accounted for when determining slope and flow length for the purposes of these calculations.

For small and/or highly impervious areas with very short times of concentration, the default minimum T value to be used for design purposes is 10 minutes.

Additional information and an automated T calculator can be found on-line at:

http://www.lmnoeng.com/Hydrology/TimeConc.htm

4) **Determine the average rainfall intensity (I)**. This value should be obtained for the recurrence interval of interest and a duration equal to the time of concentration T calculated in (3) above using the NOAA Atlas 14 intensity-duration-frequency (IDF) curve for an appropriate nearby climate station. Table F3 and Figure F2 provide IDF data for the Park City climate station; additional IDF curves and tables can be obtained online at:

http://hdsc.nws.noaa.gov/hdsc/pfds/sa/ut_pfds.html

Table F3 NOAA Atlas 14 Precipitation Intensity Estimates for Station "Vernal Airport, Utah" (Station #42-9111). Values are in inches per hour.

Precipitation Intensity Estimates (in/hr)																	
ARI* (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
1	1.21	0.92	0.76	0.51	0.32	0.19	0.14	0.09	0.06	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00
2	1.56	1.19	0.98	0.66	0.41	0.24	0.18	0.11	0.07	0.04	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00
5	2.16	1.64	1.36	0.91	0.56	0.33	0.24	0.15	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00
10	2.72	2.07	1.71	1.15	0.71	0.40	0.29	0.17	0.10	0.06	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00
25	3.61	2.75	2.28	1.53	0.95	0.53	0.37	0.21	0.12	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0.00	0.00
50	4.44	3.38	2.79	1.88	1.16	0.64	0.44	0.25	0.14	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.00	0.00
100	5.40	4.11	3.40	2.29	1.42	0.78	0.53	0.29	0.16	0.10	0.05	0.03	0.02	0.01	0.01	0.01	0.00	0.00
200	6.52	4.96	4.10	2.76	1.71	0.94	0.63	0.34	0.18	0.11	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0.00
500	8.29	6.31	5.22	3.51	2.17	1.20	0.81	0.42	0.22	0.12	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0.00
1000	9.88	7.52	6.21	4.18	2.59	1.44	0.96	0.50	0.26	0.14	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0.00

5) **Calculate the peak discharge (Qp)**. For storm events with recurrence intervals more frequent than 25 years, use the following formula:

$$Q_p = (C) * (I) * (A)$$

For storm events with recurrence intervals of 25 years or greater, the runoff coefficient should be adjusted by the factor C_f because infiltration and other abstractions have a proportionally smaller effect on runoff. Values for C_f are provided in Table F4. Once the Cf is determined, peak discharge is calculated using the following formula:

$$Q_p = (C) * (C_f) * (I) * (A)$$

Q_p should be calculated for both pre- and post-development land use conditions. In order to meet the peak flow rate criteria outlined in Part A, Section 3B(6), non-structural and structural BMPs should be designed to control the post-development rate Qp to the pre-development rate. Non-structural methods that reduce the post-development runoff coefficient and lengthen the time of concentration (e.g., preservation of natural areas with type A or B soils, minimizing impervious areas, using vegetated swales instead of storm sewers, etc.) will be the most effective techniques to meet the peak flow rate criteria.

Table F4 Runoff Coefficient Adjustment Factors for Rational Method.

Recurrence Interval (years)	Adjustment Factor C_f
25	1.1
50	1.2
100	1.25

CALCULATING WATER QUALITY VOLUME

To meet the water quality and groundwater recharge criteria outlined in Part A, Section 3B(6), the runoff volume associated with a storm event of 0.41" in 1 hour must be calculated for pre- and post-development conditions.
Use the rational formula:

$$WQ_v = CitA$$

WQ_v = water quality volume (ft^3)
C = dimensionless runoff coefficient
I = rainfall intensity = 0.41"/hr = 0.034 ft/hr
t = storm duration = 1 hour
A = site area (ft^2)

$$WQ_v = C * (0.034 \text{ ft/hr}) * (1 \text{ hr}) * A = (0.034 \text{ ft}) * C * A$$

Runoff coefficient "C") values for the water quality volume calculation should be selected using the same tables and guidelines described above in the section on calculating peak runoff.

CALCULATING GROUNDWATER RECHARGE VOLUME

The criteria in Part A, Section 3B(6) require that the increase in surface runoff volume from the water quality storm (0.41" in 1 hour) is recharged into the ground rather than discharged off-site as surface runoff. This required groundwater recharge volume (GW_v) is calculated as:

$$GW_v = WQ_v \text{ (post-development)} - WQ_v \text{ (pre-development)}$$

where WQ_v is calculated as described above in the section on calculating water quality volume.

CALCULATING TSS REMOVAL RATE

Rather than requiring a calculation of the actual real-world TSS load for a site, the application of this standard has been simplified to estimate a site's annual TSS load as 1.0 (i.e., 100%) as it enters the first BMP in the system. Therefore, in addition to performing the calculations below to demonstrate that adequate BMP performance efficiency has been provided, the permittee must also demonstrate compliance by showing that:

- The treatment BMPs have been designed/sized to treat the post-development water quality volume (WQ_v), calculated as described above; and,

- The BMPs are inspected regularly and maintained as needed to perform efficiently. Information on maintenance needs for individual BMPs is included in Part E, and sample inspection forms are provided in Part G.

Steps to calculate the TSS removal rate:

1) From Table 1 in Part E, determine the required final TSS removal rate ®) based on the percent of overall site area that is impervious. Use the definition for "impervious surface" provided in Part A Section 2. For sites where newly-developed impervious areas lie within 50 feet of a live water body (perennial or intermittent stream, lake, pond, spring, or reservoir), the Table 1 sliding scale does not apply and the default 80% TSS removal standard must be met.

2) If appropriate, divide the site into individual drainage areas. It is essential that the final TSS removal rate be calculated separately for each subarea. Isolated impervious areas (e.g., disconnected rooftops) that are serviced solely by their own BMPs, such as swales or seepage beds, should be considered as separate drainage areas. Each individual drainage area must meet the TSS removal rate for the entire site, as determined in step (1).

3) For each individual drainage area, list the storm water BMPs and their order in the engineered system, beginning with the first BMP collecting storm water from the site. For example, pretreatment and conveyance BMPs will typically precede the removal BMPs. Using the values from Part E Table 2, list the estimated TSS removal rate for each BMP in the treatment system.

4) Calculate the final TSS removal rate ®) according to the following formula:

$$R = (L_1 * R_1) + (L_2 * R_2) + (L_3 * R_3) \ldots + (L_n * R_n)$$

L_1 = initial TSS load = 1.0 (i.e. 100%)
R_1 = fractional TSS removal rate for the first BMP in the system (e.g., if the removal rate listed in Part E Table 2 for BMP1 is 60%, the fractional rate R1 is 0.60)
L2 = remaining TSS load after preceding BMP = L1 - (L1 * R1)
R2 = fractional TSS removal rate for the second BMP in the system
L3 = remaining TSS load after preceding BMP = L2- (L2 * R2)
R3 = fractional TSS removal rate for the third BMP in the system
Ln = remaining TSS load after preceding BMP = $L_{(-1)} - (L_{(-1)} * R_{(-1)})$
Rn = fractional TSS removal rate of final (n_{th}) BMP in the system

As evident in the above formula, the TSS removal rates are not additive from one BMP to the next; instead, the estimated removal rates are applied consecutively as the TSS load passes through each BMP technology.

5) Check that the final removal rate ®) for each drainage area is greater than or equal to 0.80 (80%) or the applicable sliding scale standard from Part E Table 1. If R is less than the standard for any of the drainage areas, the system should be redesigned in order to meet the standards.

PART G: SAMPLE INSPECTION FORMS

SAMPLE INSPECTION FORM FOR TEMPORARY EROSION AND SEDIMENT CONTROLS

Name of Site

Inspector:_____________________________ **Date**:______________

Attendees:____

- •**Weekly Inspection** • •**Before Rain Event** • •**After Rain Event** • •**Other**

Controls: Silt Fence (SF) Straw Bale Barrier (SBB) Temporary Slope Drain (TSD) Channel Liner (CL) Stone Lined Ditch (SLD) Temporary Berm (TB) Stone Check Dam (SCD) Pipe Inlet Sediment Barrier (PISB) Sediment Trap (ST) Stone Spillway (SS)	
Station/Location	**Notes:**

General Notes / Prioritization:

- •Facility in Noncompliance
- •Facility in Compliance

Signature(s) ____

INSPECTION AND MAINTENANCE CHECKLIST FOR STRUCTURAL POST-CONSTRUCTION BMPs

UINTAH COUNTY BMP1: OIL/WATER SEPARATORS

Date: ____________ Time: ____________ Type of inspection (circle one): Semi-Annual Monthly After major storm

Site Name/Location: ____

Inspector: ____

Item Inspected: Separator Components (General)	Satisfactory yes/no	Type of Maintenance Needed if Unsatisfactory	Comments
Discharge Quality			
Inlet Pipe			
Outlet Pipe			
Trash and Debris			
Sediment			
Bypass Valve			
Oil Absorbent Pads			
Item Inspected: Vault Structure			
Ladder			
Concrete (inspect when vault cleaned)			
Maintenance hole			
Inlet grates			
Baffles			
Item Inspected: Coalescing Plates			
Sediment			
Plates			
Item Inspected: Spill Control Separators			
Tee Section			

INSPECTION AND MAINTENANCE CHECKLIST FOR STRUCTURAL POST-CONSTRUCTION BMPs

UINTAH COUNTY BMP2: CATCH BASIN INSERTS

Date: ____________ Time: ____________ Type of inspection (circle one): Semi-Annual Monthly After major storm

Site Name/Location: ____

Inspector: ____

Item Inspected: Catch Basin Insert Components	Satisfactory yes/no	Type of Maintenance Needed if Unsatisfactory	Comments
Filter Insert			
Grate Seal			
Sump			
Trash, debris, sediment, vegetation			
Pollution			
Access			

INSPECTION AND MAINTENANCE CHECKLIST FOR STRUCTURAL POST-CONSTRUCTION BMPs

UINTAH COUNTY BMP3.1: SEEPAGE BEDS (INFILTRATION TRENCH)

Date: ____________ Time: ____________ Type of inspection (circle one): Semi-Annual Monthly After major storm

Site Name/Location: ____

Inspector: ____

Item Inspected: Seepage Bed	Satisfactory yes/no	Type of Maintenance Needed if Unsatisfactory	Comments
Drain rock			
Filter fabric			
Surface Inlet (if present)			
Observation well (ponding should not be present)			
Surface (ponding should not be present)			
Surface vegetation			
Trash, sediment, debris			
Pre-treatment system (use additional checklist if appropriate, e.g. oil/water separator)			
Pollution			
Vegetated buffer strip (if present)			

INSPECTION AND MAINTENANCE CHECKLIST FOR STRUCTURAL POST-CONSTRUCTION BMPs

UINTAH COUNTY BMP3.2: INFILTRATION BASIN

Date: ____________ Time: ____________ Type of inspection (circle one): Semi-Annual Monthly After major storm

Site Name/Location: ______________________________

Inspector: ______________________________

Item Inspected: Infiltration Basin	**Satisfactory yes/no**	**Type of Maintenance Needed if Unsatisfactory**	**Comments**
Inlet channel			
Inflow			
Outlet channel			
Outfall			
Forebay/sediment trap			
Pretreatment system (use additional checklist if appropriate)			
Trash, debris, sediment			
Surface vegetation			
Emergency spillway (if present)			

INSPECTION AND MAINTENANCE CHECKLIST FOR STRUCTURAL POST-CONSTRUCTION BMPs

UINTAH COUNTY BMP3.3: INFILTRATION SWALE

Date: ____________ Time: ____________ Type of inspection (circle one): Semi-Annual Monthly After major storm

Site Name/Location: ____

Inspector: ____

Item Inspected: Infiltration Swale	**Satisfactory yes/no**	**Type of Maintenance Needed if Unsatisfactory**	**Comments**
Inflow			
Inflow energy dissipation (stilling basin, rip rap pad)			
Flow spreading device			
Sediment clean-out area			
Vegetation			
Trash, debris, sediment			

INSPECTION AND MAINTENANCE CHECKLIST FOR STRUCTURAL POST-CONSTRUCTION BMPs

UINTAH COUNTY BMP4: PONDS

Date: ____________ Time: ____________ Type of inspection (circle one): Semi-Annual Monthly After major storm

Site Name/Location: ______________________________

Inspector: ______________________________

Item Inspected: Embankment and Spillways	**Satisfactory yes/no**	**Type of Maintenance Needed if Unsatisfactory**	**Comments**
Vegetation and ground cover			
Erosion at inlets/ outlets/ side slopes			
Animal/rodent burrows			
Seeps or leaks in embankment or spillway			
Cracking, bulging, or sliding of dam			
Spillways clear of obstructions and debris			
Riser			
Pipe/ concrete/ masonry condition			
Trash rack(s) free of debris (low flow & weir)			
Orifice unobstructed by sediment/ debris			
Condition of access structures (e.g., ladders)			
Excessive sediment accumulation inside riser			
Outflow			
Evidence of slope or bank erosion			
Riprap condition			
Pipe & endwall/headwall condition			

Pond (General)			
Sedimentation level in sediment forebay			
Undesirable vegetative growth			
Sedimentation level in pond			
Evidence of pollution (oil, grease, etc.)			
Trash/ yard waste			
Graffiti			
Public safety hazards			
Noxious odors			
Noxious insects			

INSPECTION AND MAINTENANCE CHECKLIST FOR STRUCTURAL POST-CONSTRUCTION BMPs

UINTAH COUNTY BMP5: BIOFILTRATION SYSTEMS

Date: ____________ Time: ____________ Type of inspection (circle one): Semi-Annual Monthly After major storm

Site Name/Location: ____

Inspector: ____

Item Inspected: Biofiltration system components: Biofiltration swales and grass buffer strips	Satisfactory yes/no	Type of Maintenance Needed if Unsatisfactory	Comments
Discharge Quality			
Vegetation height			
Sediment			
Flow channelization/erosion			
Vegetation type			
Bare spots/need for reseeding			
Flow spreading device			
Maintenance access			
Noxious weeds			
Pollution			
Ponding			
Trash/litter			

INSPECTION AND MAINTENANCE CHECKLIST FOR STRUCTURAL POST-CONSTRUCTION BMPs

UINTAH COUNTY BMP6: SAND FILTERS

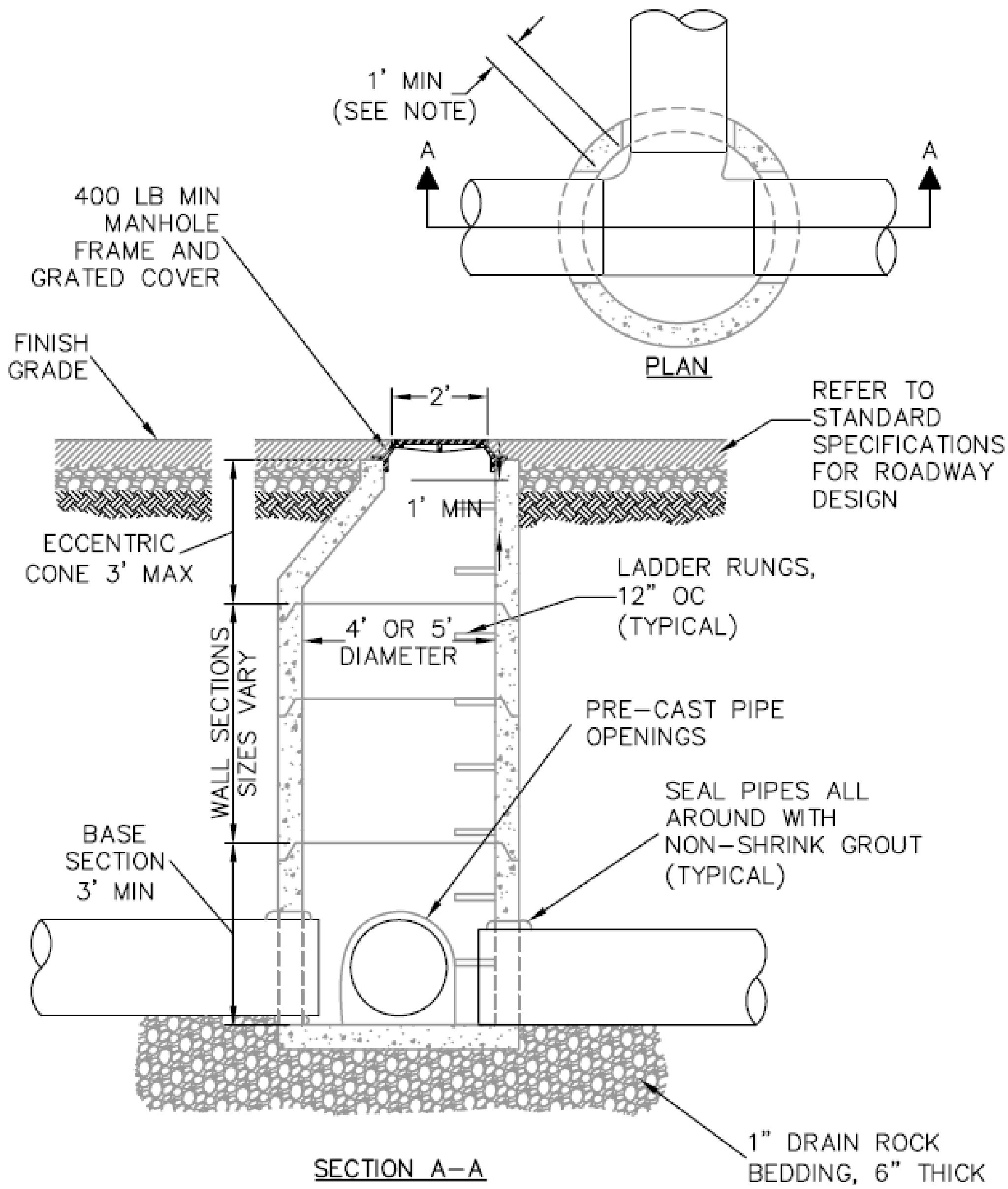
Date: ____________ Time: ____________ Type of inspection (circle one): Semi-Annual Monthly After major storm

Site Name/Location: ____

Inspector: ____

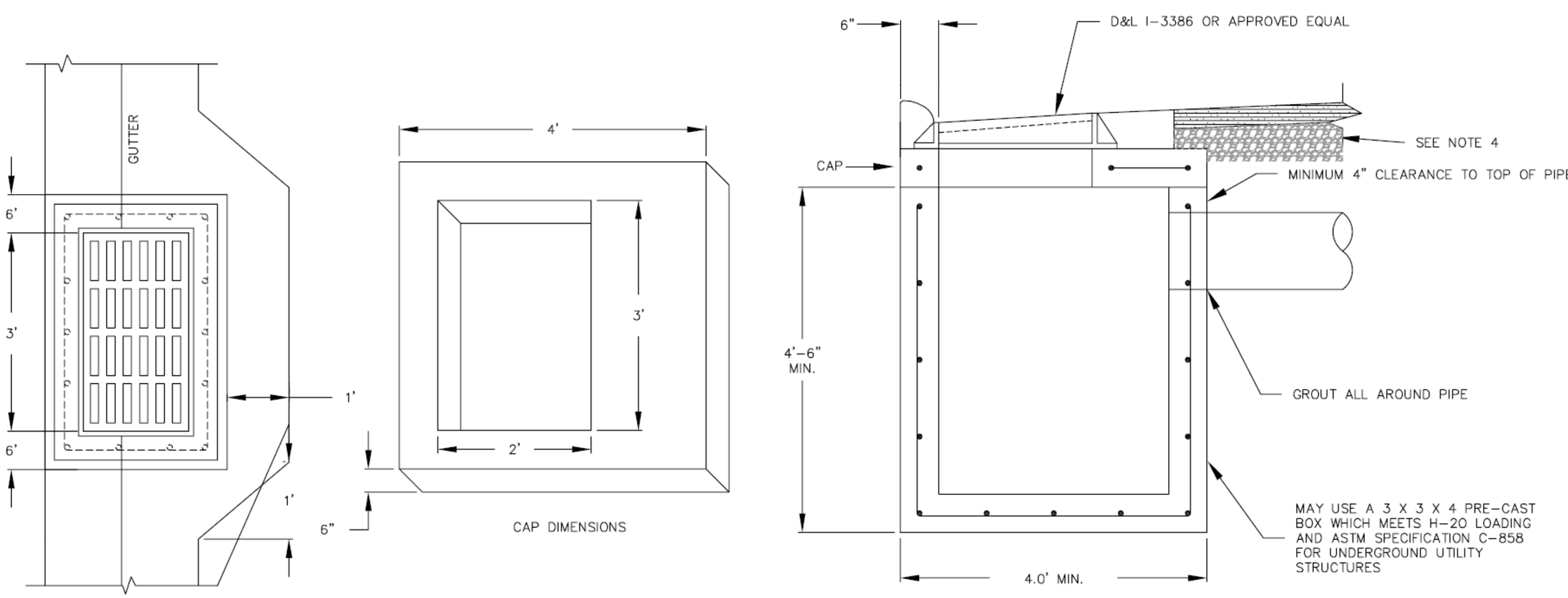
Item Inspected: Sand Filter Components (General)	Satisfactory yes/no	Type of Maintenance Needed if Unsatisfactory	Comments
Discharge Quality			
Inlet Pipe			
Outlet Pipe			
Trash and Debris			
Sediment depth			
Bypass Valve			
Filter Bed			
Sedimentation Chamber/Pond (use additional checklist if appropriate)			
Infiltration rate/ponding after 36 hours			
Oil or other pollutants			
Vegetation			

Appendix F: SAMPLE STORM WATER DESIGN DETAILS (ASSEMBLED FROM OTHER UTAH COMMUNITIES)



NOTE:
USE 5' DIA MANHOLE IF 1 FOOT MINIMUM PIPE OPENING SPACING IS NOT ACHIEVED.

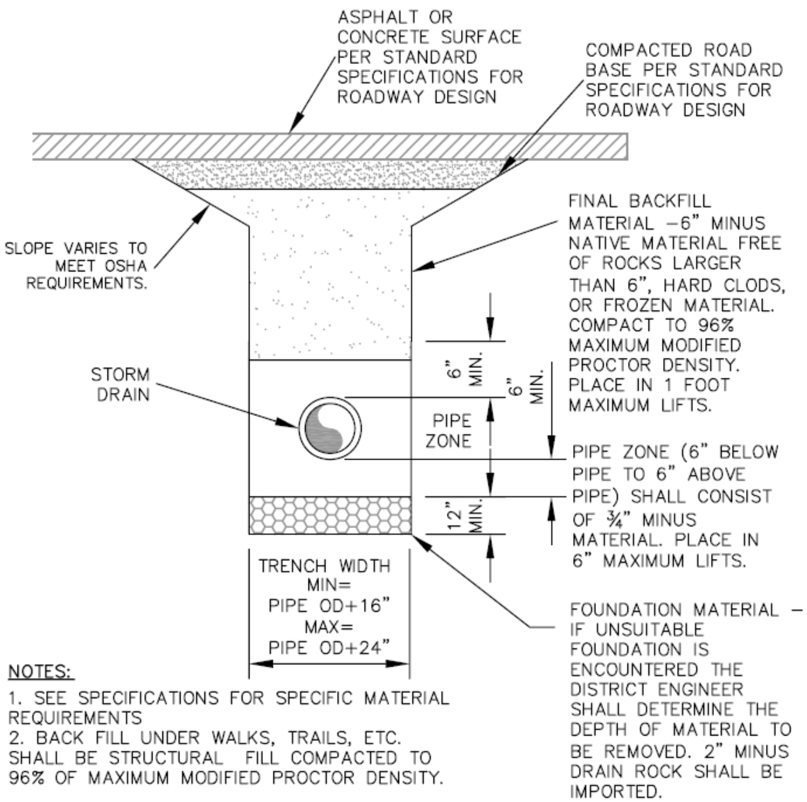
PRE-CAST STORM DRAIN MANHOLE DETAIL



NOTES:

1. ALL STORM TRANSMISSION LINES SHALL RUN THROUGH STORM MANHOLES.
2. #4 REBAR WILL BE SPACED AT MINIMUM OF 12" O.C. IN ALL DIRECTIONS IN CONCRETE.
3. ALL REBAR SHALL OVERLAP A MINIMUM OF 14".
4. REFER TO STANDARD SPECIFICATIONS FOR ROADWAY DESIGN

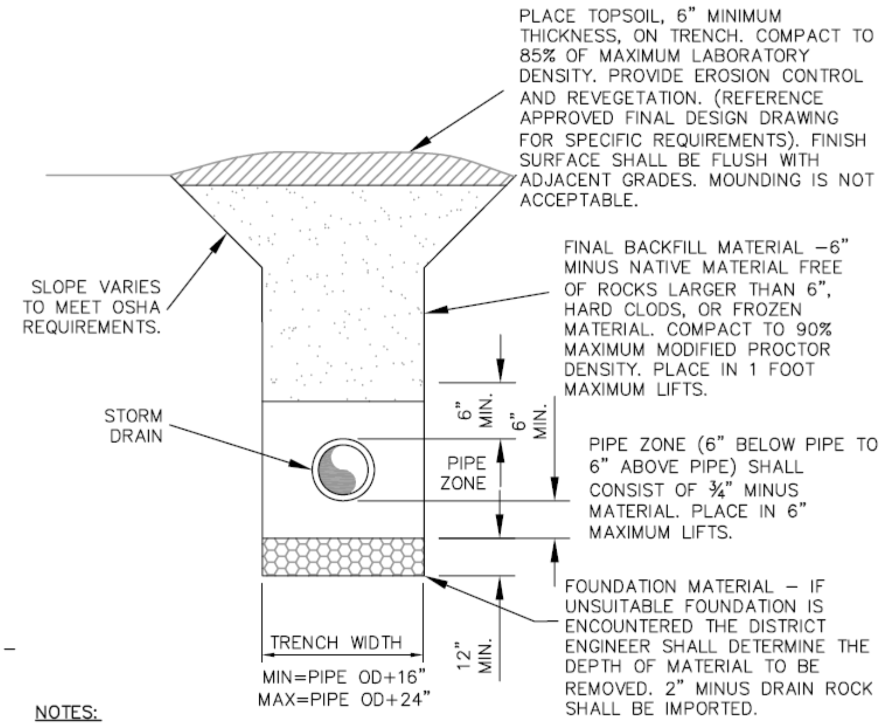
STANDARD CURB INLET BOX DETAIL



NOTES:

1. SEE SPECIFICATIONS FOR SPECIFIC MATERIAL REQUIREMENTS
2. BACK FILL UNDER WALKS, TRAILS, ETC. SHALL BE STRUCTURAL FILL COMPACTED TO 96% OF MAXIMUM MODIFIED PROCTOR DENSITY.

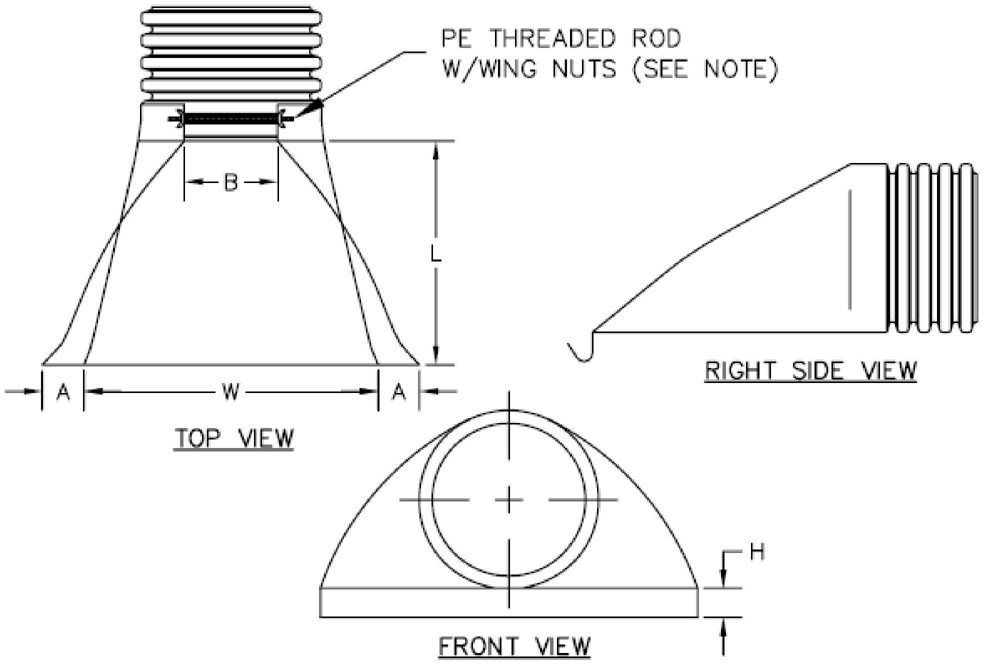
STORM DRAIN TRENCH DETAIL
IN ROADWAY



NOTES:

1. SEE SPECIFICATIONS FOR SPECIFIC MATERIAL REQUIREMENTS
2. BACK FILL UNDER WALKS, TRAILS, ETC. SHALL BE STRUCTURAL FILL COMPACTED TO 96% OF MAXIMUM MODIFIED PROCTOR DENSITY.

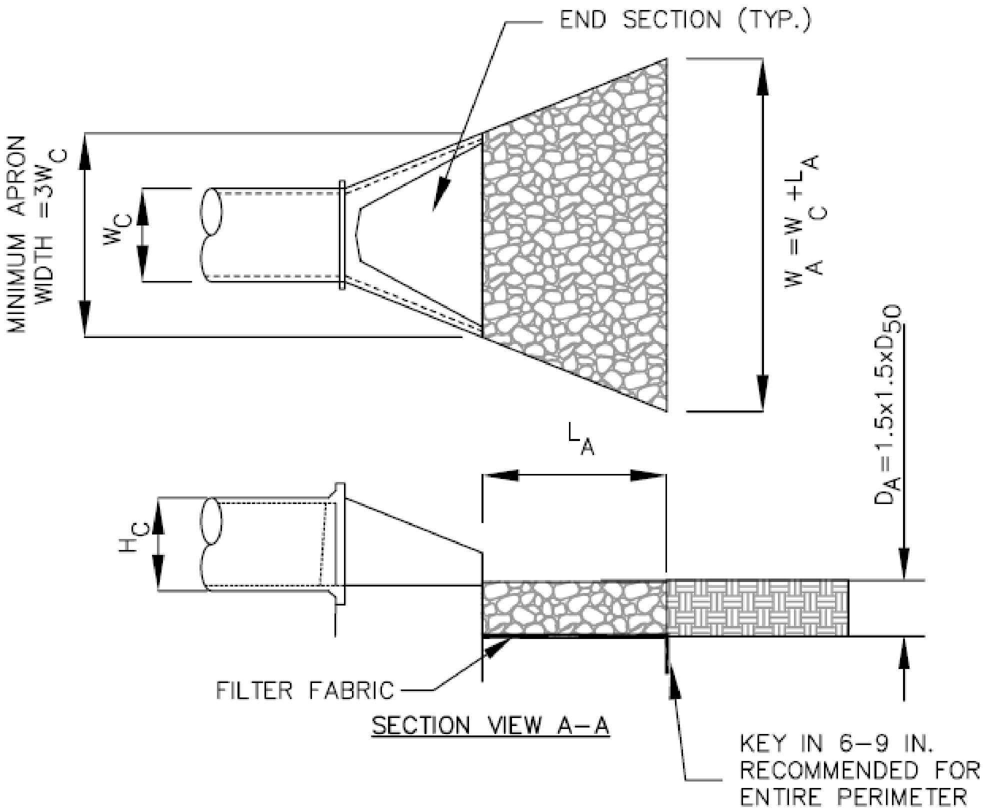
STORM DRAIN TRENCH DETAIL
NOT IN ROADWAY



PIPE SIZE	A	B (MAX.)	H	L	W
12"	6.5"	10"	6.5"	25"	29"
15"	6.5"	10"	6.5"	25"	29"
18"	7.5"	15"	6.5"	32"	35"
24"	7.5"	18"	6.5"	36"	45"
30"	10.5"	N/A	7.0"	53"	68"
36"	10.5"	N/A	7.0"	53"	68"

NOTE: 1. PE THREADED ROD W/WING NUTS PROVIDED FOR END SECTIONS 12"–24". 30" & 36" END SECTIONS TO BE WELDED TO PIPE PER MANUFACTURER'S RECOMMENDATIONS.
2. ALL DIMENSIONS ARE NOMINAL

CORRUGATED HDPE FLARED END SECTION

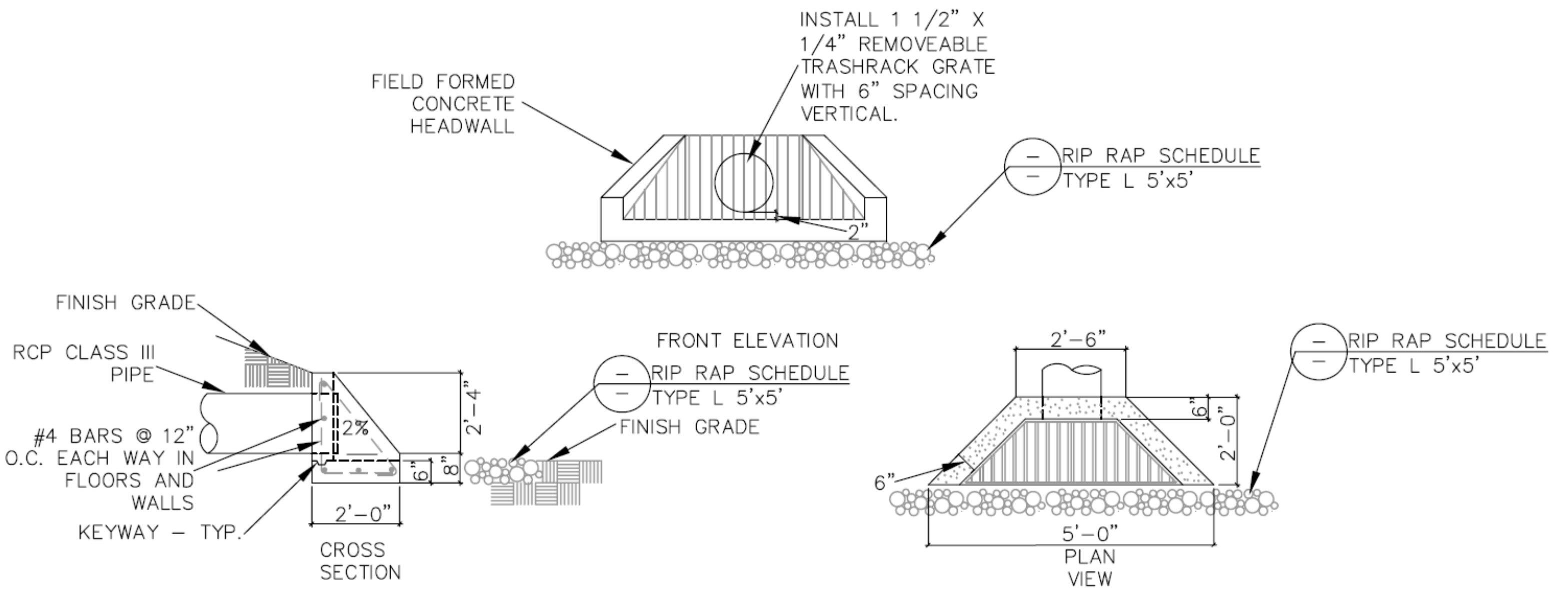


H_C = HEIGHT OF CULVERT
W_C = WIDTH OF CULVERT
L_A = LENGTH OF RIP RAP APRON
W_A = WIDTH OF RIP RAP APRON AT END
D_{50} = MEDIAN RIP RAP SIZE
$D_{MAX.}$ = MAXIMUM SIZE OF RIP RAP = 1.5 D_{50}
D_A = DEPTH OF RIP RAP APRON = 1.5 $D_{MAX.}$

RIP RAP OUTLET PROTECTION DETAIL

RIPRAP DESIGNATION BY WEIGHT	% SMALLER THAN GIVEN SIZE (INCHES)	INTERMEDIATE ROAD DIMENSIONS (INCHES)	D50	MINIMUM THICKNESS (INCHES)
TYPE L	70–100	15	6"	6"
	50–70	12		
	35–50	9		
	2–10	3		

D50 = MEAN PARTICLE SIZE



INLET STRUCTURE DETAIL